

# **FABRICATION OF MICRO AND NANOPHOTONIC DEVICES**

by

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# **FABRICATION OF MICRO AND NANOPHOTONIC DEVICES**

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## **ABSTRACT**

As the interconnect bottleneck in electronic circuits is becoming a more serious problem, optical (or photonic) interconnects are becoming a promising solution. Optical interconnects in combination with optical routing and switching components allow for a large increase in bandwidth over electrical interconnects with a decrease in power consumption. The realization of photonic interconnects in silicon provides great advantages, as much of the experience is available in silicon processing. Techniques have been borrowed from the VLSI and MEMS toolkits and many new fabrication processes and techniques have been developed for silicon photonics platforms. In order for this technology to mature to a point of widespread industrial acceptance, there is still much work that must be done in a research environment.

The work done in a silicon photonics research environment relies heavily on the use of specialized equipment for creating high precision, highly reproducible micrometer and nanometer scale features. In addition to the traditional requirements of VLSI and MEMS processing, nanophotonics has added restrictions on the quality and roughness of structures as the interactions between the light and the materials are very strong. In order to fabricate devices of the quality needed for silicon photonics research, researchers must be properly trained in fabrication techniques and how to use the fabrication equipment. The time required to completely master the operation of the fabrication can take years. However, basic tasks can be performed with a little training.

Two of the major pieces of fabrication equipment, which will be covered in this work, are an RIE-ICP system and a PECVD system. These are a Samco® RIE-200iP and Samco® PD-220N, respectively. They are two pieces of very important pieces of equipment for most researches in the nanophotonics field. The first step to mastering the use of the equipment is learning about the background of the equipment. Because of this, the theory of how each of these tools operates is covered to provide background for new users and provide information to experienced users which may help in advancing their research. Understanding how the process works is just the first step to using the equipment. The next major component step is the actual operation of the equipment. By learning the setup of the equipment and the operation of its individual components much can be learned about machine operation and device processing. This will help in making process decisions and with process troubleshooting should a problem arise. After the operation and use of the equipment is understood the preparation of samples is important. So some example fabrication processes are described to provide examples of processing techniques. These examples also show some processing recipes, which are commonly used and should be familiar to users. These topics are covered in this document. Finally, in addition to the basic theory and operation a more detailed analysis of process parameters and variables will be presented.

Along with fabrication, testing and characterization of devices is extremely important. While the types of testing and setups vary greatly, depending on the nature of the research, there are some tools which find broad use in nanophotonics research. Two of these are the spectrometer and the ellipsometer. The spectrometer allows for spectral characterization of light sources, whether this light is from testing



equipment or from a fabricated device itself. The ellipsometer is able to determine the thickness and index of thin film layers on a sample. These two pieces are extremely important when doing material level work, which helps greatly in the advancement of new materials. As with the fabrication equipment, the theory, operation, and basic use of this equipment are discussed to facilitate testing of fabricated devices.

The last important component of using fabrication equipment is proper maintenance. Without proper maintenance and servicing, the quality of results will not be repeatable. This will lead to slower research progress and more machine downtime for major repair. Because maintenance of equipment is very important and is often overlooked, it is also covered in this work. By combining good maintenance of equipment with proper use, it will lend itself to better, more reliable results in the nanophotonics research environment. This is presented throughout this work as the different components build on each other to show how they help to form a strong bond between the equipment and its users.

## **Chapter 1**

### **INTRODUCTION**

Micro and nano-photonics is a rapidly growing area of research in industry and even more so in universities. It builds on the semiconductor fabrication techniques developed throughout the years for use in electronic fabrication and Micro Electro-Mechanical Systems (MEMS). Nanophotonic fabrication takes these techniques even further in creating smaller features with tighter tolerances and better surface quality. In order to fabricate devices with the precision and quality required for nanophotonic structures, highly specialized equipment is required. This equipment performs many of the processing tasks for the user but still requires user input and knowledge of how the equipment works. Without a sound knowledge of the how the equipment works and the principles behind its operation, a researcher is no more than a technician running a process and hoping for good results. This thesis is aimed towards helping to educate new users to the point where they can become familiar with the equipment operation and theory. This is an essential first step towards becoming a knowledgeable researcher with the ability to fabricate new and exciting photonic devices.

#### **1.1 Nanofabrication Background**

As the need for faster interconnects and clock speeds push traditional metal interconnects to their limit, optical interconnects are being developed. Optical interconnects and nanophotonics in general can build a lot of the developments made

in VLSI (Very Large Scale Integration) and MEMS. However, nanophotonic devices have very specific tolerances which make processing more difficult. Features in nanophotonic devices are small and have extremely tight tolerances. As with the lumped versus distributed element argument for microwaves as the wavelength gets shorter interactions change. For optical systems this presents a whole new set of challenges with different material properties in the optical versus RF regime. Also, feature size and roughness become quite important as the features are on the scale of the wavelength and the roughness can be on the same scale or larger. Extra roughness can cause undesired scattering and render a fabricated device useless. It is because of this and the specific design criteria that processing requires such advanced equipment. This equipment is quite complex and may take years to fully understand and appreciate. Basic use of the equipment can be learned with some exposure. However, over time, increased experience and knowledge of the equipment can lead to development of even better fabrication skills and better quality devices.

## **1.2 Document Structure**

This thesis is designed to help provide some of the fundamental knowledge required to efficiently and properly use some of the equipment required for nanophotonic fabrication. Two of the most important pieces of equipment in our lab for fabrication are the Samco® RIE-200iP Fluorine ICP and Samco® PD-220N PECVD units in the cleanroom. Each of these pieces of equipment has two chapters designated to them. The ICP is discussed in Chapter 2 and Chapter 5. Chapter 2 covers the basic operation and use of the machine while Chapter 5 covers in-depth maintenance of the equipment. Chapter 3 and Chapter 6 cover the operation and maintenance of the PECVD, respectively. In addition to these two tools, Chapter 4

covers the Horiba Jobin Yvon iHR320 spectrometer and UVISEL ellipsometer. These two pieces of equipment provide measurement and characterization of processed samples.

The first chapters that cover the ICP and the PECVD provide a brief overview of the purpose of the machine and the theory of operation. This will be followed by sections describing the pre-operational check procedures and the various screens and controls of the machines. Unfortunately, due to legal considerations, the screens of the ICP and PECVD cannot be printed in this document and instead pages in their respective manuals are cited for referencing. This is then followed by the operation section, which goes through the process of editing processes on the machine along with how to operate the machine and run a full process. This is followed by a brief maintenance section as Chapter 5 and Chapter 6 contain a more in-depth maintenance write up for each of the pieces of equipment. After the maintenance, there is a more in-depth look into the theory of operation for the machine. It includes some more background on the physics and the effects of changing different parameters in the processes. More over this section also includes various references which can be used to help further one's knowledge about ICP or PECVD operation. Finally, there is a section which gives a few standard processes to run on each piece of equipment. The purpose of this section is to give some familiarity with commonly used processes and to provide a process that is easily repeatable and can be used for practice and system verification. Each recipe is listed and discussed in this section along with a walk through of sample preparation and example results for comparison and troubleshooting of process problems. A similar format is followed for both machines with minor differences based on the operation of each piece of equipment.

Along with the ICP and PECVD the iHR320 and UVISEL are covered in Chapter 4. Both of these units are located in Evans 152 and work on similar principles, which is why they are located in the same chapter. The iHR320 is covered first and the theory of operation is covered first followed by basic operation of the spectrometer. This is followed by discussions of each of the different components of the iHR320 including descriptions and any maintenance problems that may be encountered. Finally, a brief section discusses one of the external optical setups that is often used with the iHR320. After the iHR320 the UVISEL is discussed as an iHR320 is employed in this systems hardware. A brief theory of operation section is discussed followed by an operation section that walks through the procedure for taking a measurement and modeling it. Then there are several sections that discuss the hardware and the maintenance of the hardware. These include scheduled and unscheduled maintenance along with some troubleshooting tips. This chapter follows a slightly different format from the rest of the thesis but still includes important information for operation of lab equipment.

This document is structured in such a way that each subsequent section builds on the knowledge gained from reading the previous sections. So it is important to read through the sections of this document in the order they are presented, to better understand the contents and get a firm grasp of all the knowledge. At times other sections and figures will be referenced by their section name and/or number so that the reader can quickly look to that section for a refresher on the subject matter at hand or for more in-depth analysis. After this document has thoroughly been read, it should be easy to go back to a section to look up important pieces of information to help with use of the equipment. If there is a topic that is not covered in as much depth as needed

for understanding, please refer back to the first time that topic was mentioned. If it is a part of the equipment or maintenance procedure, check in the sections of similar equipment as they may contain the information that is important to you. Also, steps in recipes and sample handling procedures that are the same for different processes will be discussed in the first recipe and then difference between recipes will be discussed in the future recipes to cut down on repetition to keep the length of this document down. The point of this thesis is to provide information about the equipment and its use.

### **1.3 Assumptions**

There are several assumptions that are made in this thesis. The first and most important assumption is that the reader is fully trained in all the safety procedures of the cleanroom. Users who are not trained in all the safety procedures, including compressed gas handling, can read this document but should not try to operate any of the equipment which uses compressed gases.

In addition to safety, the users of the document are expected to understand basic cleanroom and lithography skills. For the test recipes it is assumed that the user knows how to safely and properly mix and dispose of chemicals that are used. Also, users should know how to properly spin resist on a sample and perform the full lithography process including exposure and development. Also, the SEM is needed for the analysis of the results from some of the standard processes. If a user is not trained on the SEM, then they should seek assistance from a trained user and not try to use it themselves.

At anytime while using the equipment, if the user is unsure of what to do he or she should immediately stop and contact the equipment supervisor for further

assistance to help prevent causing damage to the equipment or bodily harm to themselves and others in the surrounding area.

#### **1.4 Other Considerations**

This document is not meant to be a replacement for the equipment manual but instead an extended SOP for each piece of the discussed pieces of equipment. The steps and procedures outlined are the ones followed in the past in our lab. As times change some of the procedures and recipes may change so some of the data may become out of date. Remember the manual for each piece of equipment is a very lengthy and in-depth document providing much more information on certain topics than this document. For questions that are not answered in this document please consult the manual and/or other users.

## **Chapter 2**

### **FLOURINE ICP (SAMCO® RIE-200IP ICP)**

In the cleanroom there are two Samco® RIE-200iP systems. These are inductively couple plasma, reactive ion etching systems. One uses a chlorine gas chemistry while the other uses a fluorine gas chemistry. The chlorine system is used mainly for etching metals and III-V materials, whereas the fluorine etches group IV based materials. Most of the work done in the group is performed in silicon and uses the fluorine ICP with the exception of lithium niobate and metals, such as chrome, which are etched in the chlorine ICP. For this reason, the fluorine ICP will be discussed in this chapter. The chlorine ICP operates very similarly to the fluorine ICP. Many of the same principles apply to each. During the writing certain major differences will be pointed out. The structure of the chapter will be a brief discussion of the theory of operation followed by instructions on how to operate the machine. Then maintenance will briefly be covered, as it is covered much more in depth in Chapter 5. Finally the physics of etching will be discussed more in depth and finally test/calibration recipes will be run to give a basis for normal machine operation.

#### **2.1 Theory of Operation**

In addition to traditional wet etching, there is dry etching, which utilizes a plasma to create free radicals that enhance the chemical reactions on the surface of the sample. These dry etches can range from being completely physical as in sputtering and ion milling to completely chemical as in plasma etching. There is also a



combination of the two referred to as Reactive Ion Etching (RIE). An RIE system uses gases and a strong field to create a plasma. The plasma contains ions, radicals, and neutrals. Ions, depending on the type, give rise to physical and possibly chemical etching. Radicals on the other hand give rise to just chemical etching. The amount of etching, which is performed by each of these mechanisms, depends strongly on the process that is used.

A special type of RIE system is the Inductively Couple Plasma (ICP) system. The ICP works by applying a strong RF field (at 13.56 MHz for the RIE-200iP) which causes the gas to become ionized. The major difference between the ICP and a standard RIE is the geometry of the electrodes. In an ICP, coils are used to induce a magnetic field that induces a Lorentz force,  $F = q(\vec{v} \times \vec{B})$ , to create a longer interaction path than an RIE. In addition to the RF power which ionizes the gases, there is also a bias which is applied across the chamber. The bias is applied such that the ions and radicals are accelerated towards the sample. This will help to make the etching more effective by increasing the number of ions and radicals that come into contact with the surface of the sample. It also adds more energy to the ions thus making a physical etch more effective.

There are many different factors that affect the effectiveness and quality of etching in an ICP. Their effects can be quite complex, so they will just be briefly mentioned here. As mentioned above, there is the ICP and bias which create the plasma and direct it. The ICP power will affect how many ions are available, thus a stronger ICP means a more aggressive etch. Bias directs the ions which can make a difference in etch rate but it also affects the degree of isotropy of the etch.

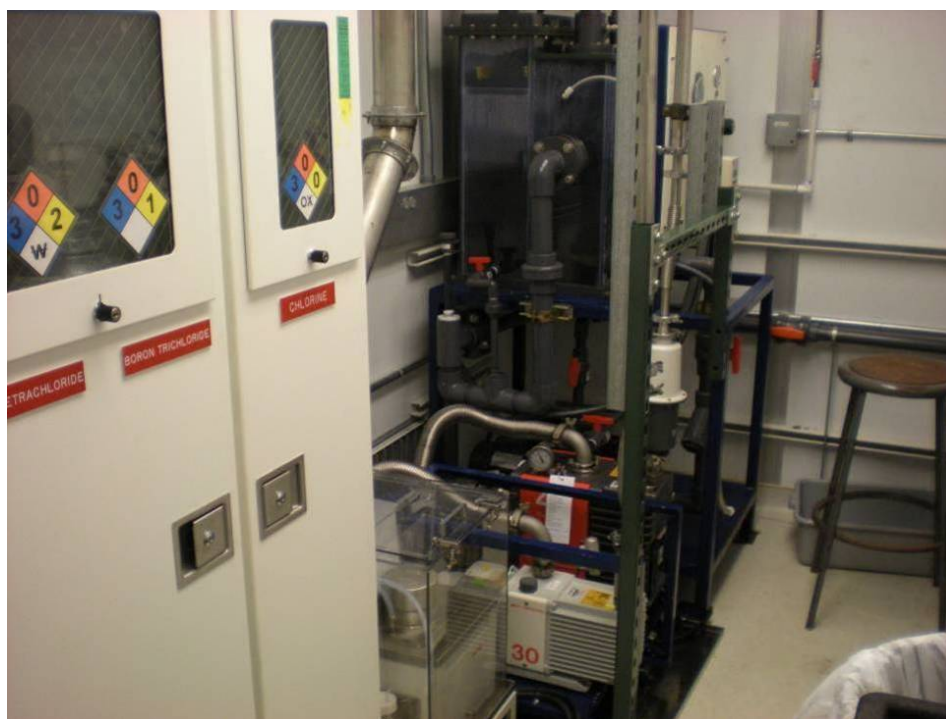
The most important component of a recipe is the gas or gases used in the process. The gases can range from oxygen and argon to chlorine and sulfur hexafluoride. Each gas has a different purpose based on its chemistry and the way it reacts with the substrate. The exact mixture and flow rate of gases is very important in processing. The last major parameter is the pressure, which affects the machines ability to strike a plasma as well as the characteristics of the etch. The theory and effects of plasma etching is discussed more in depth in Section 2.7.

## **2.2 Pre-Operational Checklist**

Before using the ICP it is important to go through the Pre-Operational check lists. The first checklist (reprinted in Figure 2.1) is located in the ICP service chase, DuPont 123. It is located in a 3-ring binder which is usually located on the cart or on the electrical conduit along the wall. It is important to actually check each of the items on the list and not just assume that everything is correct and mark it as ok. If anything is wrong on the list, immediately let the equipment supervisor of the ICP know so that the problem can be rectified as soon as possible. Each item in the checklist will now be briefly covered to provide more detail about each check. Figure 2.2 provides a snapshot of the chase for reference in this section.

<b><u>ICP Chase Preoperational Checklist</u></b>													
Date													
Time													
Check that no alarms are buzzing													
Check exhaust valves EV1, EV2, EV3, EV4 are open (vertical)													
Check that Thermo Scientific chiller is set to 15°C (near front of room, record actual temperature)													
<b>Scrubber</b>													
Check that about 0.5 of GPM fresh water is flowing													
25 PSI on pressure gauge between scrubber and wall													
Gas inlet pressure gauge >3 in differential pressure													
N <sub>2</sub> feed is about 20 L/min with pressure of 5-10 PSI (record both, flow/pressure)													
<b>For ICP being used</b>													
FI chiller - Julabo FC1200: Check that it is set to 15°C (record actual temperature)													
CI heater - Julabo 12: Check that it is set to 50°C (record actual temperature)													
<b>Two pumps per ICP</b>													
Check that the oil level is between max and min													
Check for oil discoloration													
No strange sounds coming from the pumps													
Initials of user													

**Figure 2.1 ICP chase log checklist**



**Figure 2.2** Top: ICP chase viewed from the entrance, Bottom: Chase showing the CI-ICP pumps and scrubber

The first item on the list is the alarm system. The alarm is located to the right of the door as you walk in and is a gray box containing a horn and an amber strobe. The alarm is connected to the gas sensors, scrubber, ICP, and building exhaust system. Located below the alarm box is a red emergency stop button which shuts off the hydrogen and chlorine gas cylinders and sounds the alarm. If the alarm is sounding immediately leave the room and get assistance as the problem could be serious. After checking the alarm, it is easiest to just run down the list and check each item. The first item after the alarm is the exhaust system. To check the exhaust system, verify that the ventilation valves EV1, EV2, EV3, and EV4 are all open. These valves are located on the scrubber, Cl ICP pump, Cl ICP heater box, and F ICP pump, respectively. The last generic facilities check is the ThermoFlex 1200 chiller. This chiller provides water for cooling the chamber seals and is shared between the two systems. It should be at 15°C with a pressure of 30-40 psi. To read the pressure, press the down arrow once and it will flash P1 and then the pressure. Press the down arrow again to display the current temperature. If a message such as “FLtrS” or SER is flashing you can still read the temperature and pressure, but please let the person in charge know so that this can be addressed.

The next item on the list is the scrubber, which is located in the back of the chase. The scrubber continuously circulates water as the exhaust gases from both ICP systems are pumped through it. The water reacts with the gases and creates acid and a safer gas mixture. A slight amount of fresh water is constantly added to the scrubber so that the pH of the water doesn't become too acidic as the gases pass through the system. The amount of fresh water being added to the system should be ~0.5 gpm and is read from the water flow meter on the front of the scrubber. The

level may be hard to read because of discoloration of the meter, so the easiest way to determine water flow is increase the water flow until the float is visible and then decrease it to ~0.5 gpm. Along with the fresh water, the contaminated water in the system is constantly recirculated. Proper flow should be verified by visually checking that there is a splashing of water in the tank along with checking that the pressure gauge to the right of the system reads 25 psi. The next item to check is the differential pressure, which is shown by the big magnehelic gauge. The pressure should read >3 inches of water. If the pressure is lower than 3 try flicking the gauge tubing, located behind the panel, to dislodge any water that may be stuck in the tubing. If this does not fix the problem, seek assistance from the equipment supervisor before operating the ICP. Next check the nitrogen pressure and flow. The nitrogen pressure should be between 5-10 psi and usually reads 8 psi. The nitrogen flow meter should be opened all the way and the flow should be >15 SLPM, ideally 20 SLPM. If the flow rate is too low and the pressure is  $\sim < 8$  psi you can increase the pressure slightly, which in turn also increases the flow. Be careful doing this as there could be another cause of the low flow. If all these checks pass then the scrubber should be operating normally.

The remaining checks are specific to the machine and process(es) you will be running. Check the chiller temperature and water level for the specific ICP you are using. The fluorine chuck chiller should be set to 15°C and the chlorine chuck heater should be set to 50°C. The fluorine chiller is a Julabo FC1200 and the chlorine heater is a Julabo TD12. After checking the chillers, the pumps for the unit you plan to use should be checked. There are two pumps for each machine. The smaller pump is a Fomblin® filled Edwards 28 or 30 (RP1), depending on which is currently installed, and the larger is a hydrocarbon filled Edwards 40 (RP2). The main item that has to be

checked on these units is the oil. On the Edwards 30 (or 28), the oil should be clear and should be between the maximum and minimum lines. If it looks yellowish or is less than a quarter of the way full, let the equipment supervisor know before using the equipment. For the Edwards 40, the oil can be clear or slightly yellow, however if it is brown or cloudy check before using the system. Also, make sure there is the proper amount of oil. If the oil gets too low, it can damage the pump and if there is too much oil, it can be exhausted from the pump and build up in the air ducts thus causing future problems. These are all the checks listed on the pre-op check list. However, one final check will be discussed now.

The final check is that the gases you will be using are at the proper pressures. The gases that are outside of the gas cabinet are with their target output pressure (usually 15 psi). Verify that the pressure is close to that target pressure and that the tank input side is not below 100 psi. If there is a problem with the pressure, let the equipment supervisor know. Do not try to adjust the pressure yourself as there may be another problem with the gas. For the gases in the cabinets, it may be hard to get a good reading of the pressure because of the glasses and various gauges. However, do not open the cabinets to try and read the pressures. The cabinets are there for your safety. For the fluorine ICP, the  $C_4F_8$  and  $H_2$  gases are inside a cabinet and should read ~15-20 psi.  $C_4F_8$  only has one gauge which is the output pressure gauge. For the Chlorine ICP, chlorine, boron trichloride, and silicon tetrachloride are housed in gas cabinets. Of these gases, chlorine has the most “normal” delivery system with an output pressure of 15 psi. The boron trichloride does not have a regulator but just a gauge as the tank itself is filled to a low pressure of ~5-10 psi (labeled 4.7 psi). Finally there is the silicon tetrachloride which is actually a liquid at

atmospheric pressure and room temperature. For this reason it is stored under vacuum and, like the boron trichloride, it only has a pressure gauge and no regulator.



**Figure 2.3 F-ICP inside the cleanroom**



After completion of the pre-operational check list in the chase, you can proceed into the cleanroom to the ICP (Figure 2.3) to perform the check list of the components located in the cleanroom. The first checks are generic checks dealing with both machines. The chilled water valves have to be open for the chamber seal cooling water and should always be open whether or not the ICP is in use, otherwise the system will alarm. These valves are located behind ICP on the wall and should be in open position. The next items to check are the exhaust valves EV5 and EV6 (chlorine and fluorine systems, respectively). These are not for process exhaust. They provide exhaust for the housing of the ICP which includes the gas lines. It provides ventilation in case there is a gas leak and thus both EV5 and EV6 should always be open even if the equipment is powered off. The next check, which also deals with gases, is the hydrogen and chloride switches on the wall. These are safety switches that open and close a pneumatic valve sealing off the tanks and should only be opened when these gases will be present in a process. Usually chlorine is turned on since it is used in the cleaning process while hydrogen is off as it is not used in many processes.

After these “generic” checks, the other checks are for the specific ICP, which will be used. The gases come in to each ICP on the top left side of the unit. The air pressure needs to be between 0.5 and 0.7 MPa to ensure that the pneumatic valves can operate properly and without failure. Also check that the house nitrogen is  $\geq 0.1$  MPa. This nitrogen is used for venting as opposed to the high purity nitrogen, which is used as a process gas. The last gas check is that the proper gases are turned and displayed on the left side of the screen. This has to be checked as some gases share a common inlet line. If the gas you want to use is not currently opened, do not open it. Get someone familiar with the gas changing process to help.

The load lock o-ring check should be performed when loading and unloading a wafer from the load lock and basically just makes sure that the seal is not damaged and is clear of excess particulates. The next two checks are extremely important for process integrity. The first is to check the “actual” flow rate read by the MFC. This is important as it should ideally be 0 but can drift over time, thus changing the gas ratios and severely changing a process. If there are any MFC values that are greatly off or have drifted since you last used the equipment, record them. The next check is the pressure read by DG1. DG1 is a diaphragm gauge and is used to read the process pressure during processing, and, as with the MFC values, it is very important to a process. This value should be recorded as a reference to help with troubleshooting processes and performing preventative maintenance.

The rest of the checks on the list are performed after the etch has been completed and are to have a record of what the equipment was used for to help with maintenance.

### **2.3 Description of Screens/Listing of Symbols**

Before discussing operation of the ICP, the different screens and abbreviations that will be encountered will be covered next. This is to help increase awareness about the system and provide a reference to look up terms used in the operation Section 2.4. The ICP has the Main screen, which shows the block diagram schematic of the system. Along with the Main screen, there is a set of screens that are accessed by pressing the Set button which is located in the upper left corner of the MAIN screen. These screens are Mode, Edit, Config AUTO, Config DEVICE, Config Robot, Msg Log, Data Log, and Other. These screens will not be discussed here as they are comprehensively covered in chapter 9 of the ICP Operational Manual [1] and

most of the buttons and functions on these screens will be covered in subsequent sections. The main screen will be discussed briefly to help understand the process flow. Before beginning the discussion, Table 2.1 shows abbreviations shown on the screen with a description of the abbreviations to help with understanding.

**Table 2.1** Table showing abbreviations used on ICP Main screen.

<b>Symbol/Abbreviation</b>	<b>Meaning</b>	<b>Purpose</b>
GSV1 through GSV6	Gas Safety Valve	Seals off the gas inlet from the system for safety purposes
MFC1 through MFC6	Mass Flow Controller	Controls the flow of gas during processing
GV1 through GV6	Gas Valve	Allows gas flow into the chamber
ISOV	Isolation Valve	Isolates IG and DG1 from the chamber when they are not in use
IG	Ion Gauge	High vacuum gauge for verification of pressure before processing
DG1	Diaphragm Gauge	Reads relative chamber pressure, used for process pressure measurement
DG3	Diaphragm Gauge	Chamber pressure, from atmosphere to vacuum
HV1	Helium Valve	Main Helium shutoff
PCV	Pressure Control Valve	Controls the Helium pressure during processing
DG2	Diaphragm Gauge	Helium pressure in the chuck
HV2	Helium Valve	Helium valve
HV3	Helium Valve	Helium valve used during processing
ESC	Electrostatic Chuck	Holds the wafer to the chuck during processing
RP2	Roughing Pump	Hydrocarbon roughing pump for roughing chamber and pumping down load lock
BV1	Backing Valve	Chamber backing valve between RP2 and the chamber, allowing for chamber roughing
BV3	Backing Valve	Load Lock backing valve between the Load Lock and RP2
XG	Crystal Gauge	Reads pressure of the load lock
RP1	Roughing Pump	PFPE roughing pump for backing the TMP
BV2	Backing Valve	TMP backing valve between RP1 and TMP
PV	Purge Valve	RP1 nitrogen purge, run when gases are flowed
TPV	TMP Purge Valve	Nitrogen Purge of gases in TMP. Runs when gases are flowed
TLV	TMP Leak Valve	TMP vent to atmosphere
TMP	Turbo Molecular Pump	High vacuum pump for the chamber during pumping and processing
CGV	Control Gate Valve	Seals the TMP from the chamber and actively adjusts flow to maintain chamber pressure during processing
ICP	Inductively Coupled Plasma	Power that is being applied to ICP
BIAS	Bias	Bias that is applied to chamber
LV3	Leak Valve	Load Lock slow vent valve
LV2	Leak Valve	Load Lock vent valve
LV1	Leak Valve	Main Chamber vent valve

The main screen shows everything that is going on with the system while it is in standby or running a process. It allows for monitoring and control of the system in manual and service modes. The first section of the Main screen, which will be described here, is the top bar of the figure on page 35 of the ICP manual [1]. Going from left to right, each item will be pointed out along with its purpose. First the Set button switches between the Main (current) screen and the set of screens previously discussed. BZ stop is used to silence the buzzer whenever it is going off whether it is indicating the end of a process or an error has occurred. Next to BZ stop are 3 boxes reading MODE, RCP, and Time. MODE displays the current mode whether it is AUTO, MANUAL, or SERVICE. Normally the unit is operated in AUTO mode for running recipes, however sometimes MANUAL mode can be entered for performing simple tasks. However, SERVICE mode is password protected and is only to be used for maintenance of the machine. Below mode, RCP shows the recipe that is currently running or the recipe that is currently selected on the Mode/SET screen depending if a process is running. Time, will show how much time is left in a step of a process and during a process the step number will be displayed below the time. Next are ICP and BIAS, which are the RF power for the system. One important feature of these boxes is the dotted boxes that are the setpoints and the solid boxes which are the actual read values. This is true for all the gauges/controls shown on the screen. There are two solid boxes for each ICP and BIAS which read FWD and REF under them. These are the forward and reflected power. Ideally all the power should be in the forward direction and there should be no reflected power. Matching is used to reduce the reflected power and will be discussed more in Sections 2.4.2 and 2.4.6. Finally, the last part of this section is the RUN button. This button will start running a process in

AUTO mode. While a process is running, this button will say RESET instead of RUN. Pressing RESET will stop the process and start to reset the machine to standby. After the RESET button has been pressed, it will change to STOP. Pressing STOP is supposed to allow for immediately stopping the process. However, this will not happen during normal operation because of interlock settings as stated on page 39 of [1].

The rest of the main screen displays the various controls, sensors, chambers, and connections in the system. As previously mentioned, dotted boxes are setpoints and solid boxes are read values. The solid lines show gas and/or vacuum lines throughout the system and connections are shown by a dot on the line, just like in an electrical circuit diagram. The boxes surrounded by hatch marks are different components in the system such as a valve or pump. In MANUAL and SERVICE modes, these boxes can be pressed to toggle them. When they are dark, they are closed, or off, and are open, or on, when they are highlighted. In manual mode, there are interlocks which may prevent certain operations from taking place. In addition to the hatched boxes, the values of the setpoint can be changed in manual mode. However these are changed from the manual recipe and not this screen.

For the rest of this screen, we will mainly work left to right going over the different components and their function. Remember to refer to Table 2.1 for descriptions of the abbreviations. On the very left side of the screen, the various gases available for processing are listed. Each gas first encounters a GSV (Gas Safety Valve) which is normally open during operation and can only be opened or closed from SERVICE mode. Next is the MFC (Mass Flow Controller) for each gas. These are very important for process control as they precisely control the gas flow, in sccm

(standard cubic centimeters per minute), which is important to the accuracy and repeatability of the process. These control the flow but are not good at totally preventing the flow of gas when at 0 sccm, so the GV (Gas Valve) located after the MFC takes care of this. The GV is a pneumatic gas valve which allows flow and stops it after processing, thus allowing a quick shutoff. All the gases mix in a manifold after the GV. This mixture then goes through a single line to the reaction chamber as can be seen from the screen.

Located directly above the gas inlet line to the chamber are the chamber vacuum gauges. ISOV (Isolation Valve) is an isolation valve that seals off the vacuum gauge when it is not in use to prevent damaging the gauge. The IG (Ion Gauge) is a high vacuum gauge and is used for verification of the chamber before and after processing to make sure that a satisfactory pressure has been reached. The IG has a filament which has to be turned on to get a reading. This is done by pressing the IG FIL button which is located above the IG reading. This gauge can only be used at very low vacuums so ISOV is usually closed. The next gauge, DG1 (Diaphragm Gauge), is very important as it provides the pressure reading used by the Automatic Pressure Controller (APC) to keep a constant chamber pressure during processing. It is a “relative” pressure gauge as it should ideally be 0.00 when the system is sitting at idle and under vacuum, so the zero point is at whatever the standby chamber pressure is. This ISOV is normally opened except for when the chamber is near atmospheric pressure. The last gauge is DG3 (Diaphragm Gauge) which unlike the other two does not have an isolation valve and is always open to the chamber. It reads chamber pressure all the way from atmosphere ( $\sim 10^5$  Pa) to operational vacuum. At

atmospheric pressure, the gauge will read 9999 as it is out of range, and the gauge usually does not quite read zero during normal operation.

Below the gas inlet line are the helium back pressure controls and the ESC control. During processing, helium is fed between the chuck and the back of the wafer to help provide extra cooling to the wafer. The helium enters through He and sees HV1 (Helium Valve) which is a main helium shut off valve. PCV (Pressure Control Valve) is the pressure controller for the helium back pressure. It uses the setpoint pressure in the set box as a target. The DG2 (Diaphragm Gauge) box shows the measured pressure and VPos indicates how far open the PCV is for operation. HV2 is open when the system is not flowing helium and is closed when PCV begins to flow helium. When HV2 is closed HV3 is open to allow for helium flow through PCV to the chuck to provide the cooling. Next to the He inlet is the ESC (Electrostatic Chuck) control for turning on and off the ESC. The ESC is used to hold the wafer to the chuck during processing to provide a good seal for the helium cooling and good heat conduction.

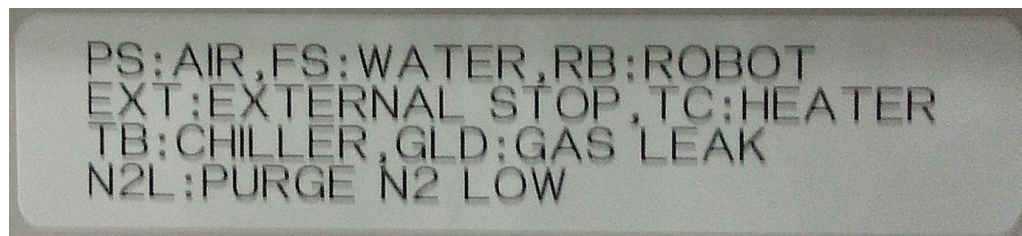
To the right of the helium is the vacuum pump section of the diagram. At the bottom are RP1 (Edwards 28 or 30) and RP2 (Edwards 40) which are the mechanical roughing pumps located in the chase. RP2 is a large hydrocarbon roughing pump which roughs the chamber and load lock. This pump is opened to the chamber (called Reactor on the display) through BV1 (Backing Valve) only when the chamber is being pumped down from atmosphere. BV3 (Backing Valve 3) is opened when the load lock is being pumped down to vacuum. The load lock pressure is displayed by XG (Crystal Gauge). VAC will be displayed above the XG once it reaches the vacuum setpoint and will read ATM once it reaches the atmosphere



setpoint. RP1 provides the backing of the TMP through BV2 which is the TMP backing valve. It is a PFPE-filled pump as it sees process gases unlike RP2. The TMP provides the high vacuum pumping of the chamber during normal/idle pumping and during processing. The TMP does not actually pump out gases but instead compresses them so that they are at a pressure that is high enough for RP1 to pump out. When gases are being pumped through the system, PV (Purge Valve) and TPV (Turbo Purge Valve) are open to allow nitrogen to help dilute the process gases. TLV (Turbo Leak Valve) is a leak valve which returns the vacuum line to near atmospheric pressure when the TMP (Turbo Molecular Pump) is turned off. The final part of the vacuum block is the VERY IMPORTANT CGV. The CGV (Control Gate Valve) is interfaced to DG1 through the APC. It controls the flow through the TMP thus changing the reactor (chamber) vacuum. The CGV has pressure and position modes, it is in position mode during standby. The position of the valve is shown to the right of the CGV and is normally at 100% to keep the chamber under vacuum. During processing, the valve position is determined by either the pressure or position setpoint in the current recipe based on which mode is selected. The M to the left of the CGV will switch the APC between pressure and position mode if the system is in manual mode. Thus, along with the MFCs and DG1, the CGV is very important for maintaining proper gas flow and chamber pressure.

The last functional section that will be discussed on this screen is the chamber section which includes the Reactor (Reaction chamber) and Load Lock Chamber (LLC). The load lock is where wafers are loaded and unloaded thus allowing the chamber (reactor) to remain under a good vacuum, keeping it clean and reducing processing time. The G between the reactor and load lock is the gate which

separates the two and is opened to load and unload wafers. This gate is critical to keeping the chamber under vacuum as it separates the chamber from atmospheric pressure when the load lock door is opened. As can be seen from the many lines on the screen, the chamber is where all the gases and vacuum lines go to do their job. In addition to the gases, the other vital ingredient for etching is a field for creating a plasma. This is provided via the ICP shown above the reactor and the Bias shown below the reactor. As mentioned earlier, the set and actual values for BIAS and ICP power are shown at the top of the screen but Load and Phase tuning % are shown in boxes above the ICP and below the BIAS buttons. Without the ICP and Bias, this unit would not have any etching capabilities. The last part of the chambers are the vent lines. LV3 (Leak Valve) and LV2 are the slow and fast vent lines for the load lock. LV3 opens first to slowly raise the pressure in the load lock and then LV2 allows for a full venting to atmosphere. Finally, LV1 is the reaction chamber vent line and is only used when the chamber has to be opened for maintenance and is used only from SERVICE mode.



**Figure 2.4** Label located below the ICP display describing each of the status indicators

This completes the different parts of the main screen that deal directly with processing and system control. At the bottom of the screen there is a STATUS section which is a panel of indicators. These give the status of the various system components, their meanings are on a label located before the screen, shown in Figure 2.4. They will briefly be covered here to better explain the causes of each error and their effects. Unlike the rest of the indicators, PS and FS are illuminated during normal operation. PS and FS are compressed air and chamber seal water (provided by the ThermoFlex 1200). If there is an error with one of these, it will blink on and off alerting the user that there is a problem. If the PS error occurs, you should check that the input compressed air pressure is at a sufficient level. If FS is tripped, make sure that both chilled water valves are open and that the chiller is running and filled with enough water.

The other indicators are off during normal operation and will flash if there is a problem. RB specifies there is a problem with the robot arm such as “overrun,” “homing error,” communication error, or any other errors as described on page 34 of [1]. GLD indicates that a gas leak has been detected. This is triggered by one of the gas detectors in the room (or chase) and should be treated in the same manner as if the clean room alarm went off for a gas leak and leave the area. The next signal is EXT which is caused by an external stop signal. This could be from many sources including, but not limited to, someone pressing the E-stop button on the wall or the scrubber stops functioning. TC indicates a heater error. For the fluorine machine, this means that the TMP heater has malfunctioned. While on the chlorine machine, it could be TMP heater or the gas line heater (chlorine, silicon tetrachloride, and boron trichloride lines are heated). The displays and controls for these heaters are located

behind the front panel (with the screen on it) of the machine and are accessed by swinging the door to the left. The temperatures can be verified but if there is a problem, get the equipment supervisor to troubleshoot the problem. Next is TB which is the chuck chilled water indicator. This is the Julabo FC1200 for the fluorine machine and Julabo TD12 for the chlorine machine. There are no valves in the lines for these units so verify that they have the proper level of liquid and flow along with maintaining temperature. Finally, N2L indicates that the N<sub>2</sub> pressure is low and the input regulator should be checked to make sure it has the proper pressure.

This finishes the controls on the main screen. Next, operation of the machine will be covered followed by maintenance and finally some example recipes and insight into etching physics.

## **2.4 Operation**

The ICP is quite a complex and powerful piece of equipment, which has many functions. Special attention has to be paid to each function of the system to be able to safely and properly operate the system.

### **2.4.1 Creating a Recipe**

Recipes are created and edited from the Edit screen (page 41 of [1]), which is accessed from the SET screen. To select a recipe, tap the RECIPE box on this screen and the box outline should become highlighted and start flashing. Now use the wheel on the front of the machine to change the recipe number, pressing the Enter button will save the selection. This operation of the wheel and Enter button are used for changing any alphanumeric box in the system. If you want to create a new recipe from scratch, scroll through the recipes until you find one where the comment box is

blank. As the system has been around for many years and has had many users there are not many unused recipes left. Also, it can be difficult to start the creation of a recipe from scratch. So the easiest way to make a recipe is find an old recipe that is no longer in use by anyone (double check this before changing any recipes) or by copying a recipe on top of an old unused recipe. Copying a recipe can be very helpful if you are making a recipe similar (or even the same) to one that exists as it will keep the values and save creation/editing time. Most recipes have the following steps: pumping out the chamber, flowing gas, applying ICP, applying BIAS, and then evacuating chamber, however certain etches, such as the time multiplexed etch (Section 2.6.3), contain more steps.

To copy a recipe, first go to the destination recipe where you want to put the copy. You can copy either a single step or an entire recipe. To copy a single step, go to the step where you want to put the copy by pressing that number in the STEP selection bar. Then go to the bottom right of the screen to the Step Copy box and click on the From box. Now scroll through the list until you get to the recipe and step you want to copy. Press Enter and then click the C to Copy that step. Now change to the next step in the current recipe and copy whichever step you want to go in there. Steps from different recipes can be copied into the current recipe. After creating the recipe, make sure to check the ESC and He pressure values. The standard ESC value is 800V and the standard He pressure is  $27 \times 10^2$  Pa. In addition to copying individual steps, an entire recipe can be copied. This is done by scrolling through the From box until you get to the recipe-All, which is located before (a left turn of the wheel) the #1 step of the recipe. Then press Enter and click C to copy the entire recipe into the current recipe. Be aware that when you do this, it will also copy the Comment. So

that will have to be changed to the proper name. To change the comment, just click on the box and use the wheel to scroll through the characters until you get the one you want. Once you get the character you want, press Enter and then it will move on to the next character. Continue until all the characters have been modified, at which time the box will no longer be highlighted. In addition to being able to copy recipes, there is also a ZERO and ZERO ALL option after recipe 101 in the copy tool. By selecting ZERO, all values in the current step are zeroed and ZERO ALL zeros everything in all steps of the recipe. ZERO ALL can be very useful if you are over writing an old program and want to completely wipe out the contents and start from scratch. Now the recipe has been created, however parameters will have to be changed. This will be discussed in Section 2.4.2 as editing of a recipe is not just done at creation time but also at other times when changes need to be made.

### **2.4.2 Editing a Recipe**

The previous Section 2.4.1 described the procedure for creating a recipe. This section will discuss the different parameters in a recipe available from the Edit screen. There are three different screens which are part of the Edit menu (page 51 of [1]). They will each be discussed in succession working from top to bottom and left to right on each screen. All boxes where alphanumeric values have to be input will be edited using the wheel and enter button.

To begin editing a recipe, go to SET and Edit to access the Edit screen. This screen displays the currently selected recipe with its parameters. To change the recipe, click on the RECIPE box and use the wheel to scroll through the recipes and Enter to select it. As mentioned in the creating a recipe section (2.4.1), the comment can be changed by clicking on the box and using the wheel to cycle characters and

pressing Enter to move to the next character in the comment. The remaining box on this line is the NEXT RECIPE box which allows you to select a recipe to be run right after the current one. You can select recipes 0-99 and also NONE if you want the processing to stop after the current recipe.

Located below this row of controls is the STEP selector. There are a maximum of 10 steps for the recipe. By clicking on a different number that step is selected. If you do not want steps to be used, then all values in that step should be zeroed out. To the right of the STEP selection is STEP SORT, labeled S, which when selected will sort the steps based on the Step Control Group instead of their step #. The step control group is located on the next line and will be discussed shortly.

The next line contains timing information. The first 3 boxes are for hours, minutes, and seconds input for the step. This is the duration of time which the step will run, if time is being used as the determining factor for ending a step, which it is by default. Located to the right of the seconds box is a button which reads EPD, End Point Detection. EPD uses an external system which uses interferometry to determine the depth etched on the sample. Selecting this will switch control over to the EPD, thus letting EDP determine the end of the current step. However, at the time of this writing, the EPD system is no longer operable. Next to EPD is the Step Control. The Step Control is a way of grouping steps together. The default is for all to be in Step Control A. By switching a step(s) to B (A-J are valid) that step will run after the steps in group A and also that step can have a different number of loops set. The number of loops is controlled by the LOOP COUNT box on the right side of this row. To run a step group of a recipe once it should be set to 1. If a recipe has a group A and group B, but you only want to run group A then set the loop count for group B to 0 so that it

isn't run. Loop counts can also be increased to more than 1 if you want the steps to run more than once. If multiple loops are set, then all the steps will run in succession and then the recipe will restart from step 1 after the last step is run.

The next section is RF Power which controls both the BIAS and ICP power. The power for these is entered in the same manner as all the other settings. To the right of these is Ramp Up/Down with a button labeled EX. This enables a ramping profile for this step. This will linearly ramp the pressure, gas flow, and RF powers from their setpoint in the previous step to their setpoint in the current step over the step time period. This can be useful if power or pressure needs to be slowly adjusted to prevent damaging the sample. Right below the RF power is the APC control section which controls the chamber pressure through feedback from DG1. There are two boxes, Pres and Pos, which provide the choice of selecting pressure or position mode. Pressure mode is on the right and is usually used for a recipe as it provides more repeatable results. The position option sets the CGV to a fixed position which can be problematic for processing as the chamber pressure can change with fluctuations in processing conditions and can cause vastly different etch results. However, position mode can be desirable for evacuating the chamber of residual gases by setting the position to 100% (full open). To switch between pressure and position, select Pres or Pos so they become highlighted. To the right of these options is Hold. Hold is an alternative to the previous two settings and will hold the CGV valve opening angle constant through the step. This can be useful for short steps which could have fast pressure changes such as applying RF power or a sudden change in the gas flow. Hold is rarely used in our recipes. For more information on hold, see page 43 of the ICP manual [1].



Below the APC control are two rows of gases. The gases can be individually modified to their desired flow rate. The range of flows is between 0.0 and the maximum for that specific gas and MFC. The maximum for each gas and MFC is listed on the Config DEVICE screen. The bottom row of the Edit screen is much like the top row in that it is the same for the entire recipe and only has to change once. The ESC is the ElectroStatic Chuck which helps to hold the carrier wafer to the chuck during processing. The standard value is 800V, in certain cases the voltage may be different but before using a different voltage please, consult the equipment supervisor. The He pressure is the back pressure for cooling the wafer. The standard is  $27 \times 10^2$  Pa and some aggressive etches use  $30 \times 10^2$  Pa, however going lower is not suggested unless there is a warranted need as it can cause the wafer to get quite hot, thus damaging resist and possibly the ICP itself. On the right side is the Step Copy section, which was discussed in Section 2.4.1. The last button is the SCREEN Next button on the bottom left of the screen. This will toggle the Edit screen to the next display which has more parameters to be edited.

The next edit screen has three options that can be edited. The first is Confirm Hi-Vac. This gives the option to evacuate the chamber to a specific value. The PECVD has a similar setting which is discussed in Section 3.4.2. The time setting is how long the chamber will be evacuated (same as the step time from the previous screen), then the system waits for the IG to reach the specified setpoint before continuing. By setting a value for this Confirm Hi-Vac, all RF power and gas flows will automatically be set to 0 in the recipe and wipe out the APC control setting as described on page 52 of [1]. This option is not usually used in our recipes as we usually just do a timed evacuation with the APC set to 100% position. The next

options are BIAS RF Pulse and the Duty Ratio for this pulse. These boxes are for setting pulse frequency (in Hz) for the RF BIAS and Duty % for the waveform. However, this functionality is not available and should not be used. Lastly, there is Dynamic Recipe Control which uses feedback from the EPD module to determine if it should jump recipes based on the readings. However, this control is also unavailable on our equipment. There is one more screen in EDIT which is obtained by pressing Next again.

This is the last screen for the EDIT menu. It once again shows the steps, loops and time settings. Below that there are two groups of options. The first is Matching Ctrl which controls the matching unit for the RF power. It has separate settings for BIAS and ICP as they will be affected by the chamber conditions differently and see different impedances. Thus, they need different matching settings. There are two buttons next to each ICP and BIAS, AUTO and PSet. AUTO means that auto matching is turned on. This is usually important to have turned on as the chamber conditions change over time and even during an etch so the tuning will have to be constantly changed to maintain the lowest reflected power possible. PSet is a button to use preset values. To use Pset, input the load (LD) and phase (PH) values for the matching networks which provides good matching in most cases. Instructions on how to get these values is discussed in the process checks Section 2.4.6. Both AUTO and Pset can be used at the same time thus allowing for a quick rough matching of the plasma followed by a fine tuning which helps provide a good, stable plasma. The last setting on this screen is EPD Control, which sends of a Sync Signal to the EPD to start it at the correct time during a recipe. When the sync signal is turned on, it communicates with the EPD hardware for film measurement. However,

since the EPD unit is down, this should be left unselected. This is the last screen. So if Next is pressed again, it returns to the initial Edit screen. The flow of the different screens is showed on page 51 of [1].

This ends the editing a recipe Section 2.4.2. Various settings may have to be changed at times other than recipe creation. If a new recipe is being created, many iterations may have to be made for calibration, or if it is an old program, changes may need to be made to modify the etch or account for system changes over time. The rest of the operation section will deal with preparing the system and sample along with loading the sample and performing the processing. After the completion of the operation section, you should have a grasp on the flow for sample processing and be able to use ICP for basic operation.

### **2.4.3 Sample/Chamber Preparation**

The first step to etching a sample is to have a patterned sample ready for etching. The sample should be properly exposed and developed thus having a patterned mask. In addition to photoresist masks, there are also chrome, oxide, and nitride masks along with other hard masking materials. The specific mask material you choose should be based on the resolution you need and the selectivity of the etch. Selectivity is how much of the silicon is etched compared to the photoresist. A high selectivity (10:1) means that etching rate of the silicon is ten times that of the mask material. If the recipe has a poor selectivity then approximately the same amount of photoresist, or more, as unmasked material is etched. This can be a problem as it means a very thick resist is needed thus giving lower resolution. If an etch has a low selectivity a hard mask may want to be used instead of a photoresist mask.

Before etching the sample, the ICP should be preconditioned. Preconditioning is performed by running the etch recipe before performing the actual etch on your sample to condition the chamber. Ideally the chamber is perfectly clean before you use it. By preconditioning it, the chamber gets acclimated to the etch gases and parameters. The precondition also gives you a chance to make sure that the process runs correctly before subjecting your sample to the recipe, which if runs incorrectly could destroy the sample. Preconditions vary based on which specific etch you are running. Examples of preconditions are given in the standard processes section (2.6) for different recipes. Some recipes which are looped such as the time multiplexed etch will be preconditioned with 15 loops while other etches, like an oxide etch may be preconditioned for 5-15 minutes depending on your specific etch time. For determination of a precondition time see the standard processes Section 2.6.

The first step to performing the precondition is to remove the cleaning wafer from the load lock. To do this, go to the Mode screen under SET (page 36 of [1]). Then, under Select AUTO Sequence, select only LLC VENT but no other options. You always have to have one of the options selected, so first select LLC VENT and then deselect the other options. After the load lock has finished venting, open and remove the cleaning wafer. It is usually placed on top of the ICP above the screen on a clean wipe. As will be mentioned many times during these procedures, check the back of the wafer for grease. The loading the sample section (2.4.4) will discuss this more and show an example of what a grease spot looks like. Next, get out a wafer for preconditioning. This can be your etch wafer or a separate precondition wafer. Check the back for grease. If it is clean, place it in the load lock. If not, refer to the Section 2.4.4 to see how to clean the wafer. Wafers should be loaded following

the procedure outline in the loading the sample section (2.4.4). Close the lid and run the precondition following the procedure outline in the running the process section (2.4.5).

#### **2.4.4 Loading a Sample**

During the precondition or after it has finished, depending on if your carrier wafer for the etch is used for the precondition, you should mount your sample to the carrier wafer. The carrier wafer is just a test grade 6" silicon wafer, which the sample is placed on so it can be loaded into the chamber for processing. The condition of the carrier wafer and mounting are very important to etch quality. If the wafer is white, dull gray, black or otherwise discolored discard it and get a new carrier wafer. If you are unsure of the location of the new carrier wafers contact the equipment supervisor. Over time wafers will get thinned and get outlines from the placement of previous samples and will have to be replaced. Samples are held onto the wafer carrier with DOW Corning High Vacuum Grease (silicone based). The vacuum grease provides an adhesive so that the sample does not move during loading, unloading, or processing and also provides a thermal path for heat dissipation during etching. The vacuum grease is used instead of another adhesive because it is made to withstand a low pressure vacuum environment without outgassing or otherwise decomposing.

To begin, get out a clean wipe to place the carrier wafer on. Before placing the wafer on the wipe, inspect the back for any residual vacuum grease. The vacuum grease can cause problems with the wafer sealing to the chuck as described in the process check and maintenance sections (2.4.6 and 2.5 respectively). Vacuum grease on a wafer will look like a dark spot on the wafer as shown in Figure 2.5. If

there is a spot, take a wipe damp with IPA and wipe the spot. It should become lighter. However it will most likely not totally clear away. Once you have made sure the wafer is clean of grease, place it on the clean wipe.



**Figure 2.5** Top left: wafer with a large amount of vacuum grease on it. Top right: wafer with grease wiped off but residue still present. Bottom: wafer with the grease residue removed with IPA.

Take your sample and carefully hold it from the edges. Get some vacuum grease with a cleanroom swab (which should be in the tube) and apply it to the back of the sample. Try to get a thin layer evenly distributed across the back of the sample.

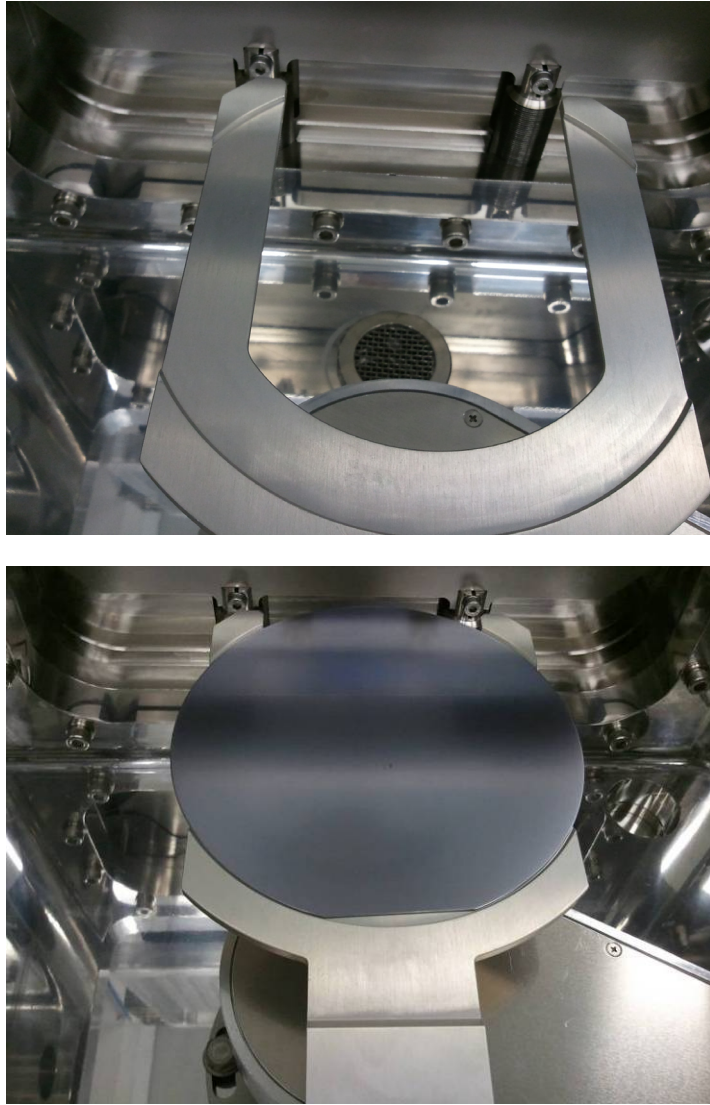
Figure 2.6 shows an example of what the grease should look like on the back of the sample. An alternative method to applying the grease is to apply it to the wafer instead of the sample. However, this doesn't give as uniform a coating and can adversely affect etch results. After applying the grease, carefully place the sample in the center of the wafer. Take a pair of tweezers (you may want to use plastic tweezers as to not scratch the resist) and use them to press on opposite corners of the sample and apply gentle pressure to the sample while twisting the sample. The twisting motion helps to prevent from applying too much force and possibly breaking the sample. Alternate between corners of the sample to make sure the sample is firmly pressed against the wafer. You should be able to look sideways at the sample and the wafer and not see a gap. Afterwards, use a razor blade to carefully scrap off any extra grease that came out when pressing down the sample. After the sample is securely mounted, apply any other samples that are ready for this process and then blow off the wafer with nitrogen.



**Figure 2.6** Sample with grease on the back of it. Notice how the grease covers the entire back of the sample. Because of this some, grease will come out from the sides when it is place on the carrier wafer but this also provides a uniform distribution under the sample.

After the wafer has been blown clean, the next step is to load the wafer into the load lock. Take out the preconditioning wafer from the chamber if it is still there. If the load lock chamber is under vacuum, vent it by choosing LLC VENT as the Auto sequence selection (for more in-depth instructions on the venting procedure see the running the process Section 2.4.5). Place the carrier wafer in the robot arm. The holder has a recessed area which slopes down to a flat wafer holding area. Place the wafer in this recess with the flat towards you for consistency. The recess is slightly larger than the wafer so gently move the wafer to make sure that it is seated in the bottom of the recess and is not sitting on the slope. Usually the wafer should sit in the middle of the recess or possibly towards the front of the recess (towards the chamber). However, this can change over time based on the current condition of the chamber and robot arm so check with a frequent user to determine if there is any special placement required for correct wafer loading. Figure 2.7 shows the robot arm without a wafer thus showing the recess and also with a wafer properly loaded. After loading the wafer, close the load lock lid. This completes the loading preparation and loading process. The next step is to run the etch recipe.





**Figure 2.7** Top: The wafer loading arm in the ICP, bottom: the loading arm with a wafer properly placed for loading into the chamber

#### **2.4.5 Running a Process**

The first step to running a recipe is to verify the recipe that you will be running. Go to the recipe and verify the times, step groups, parameter settings in all

the steps, along with the LOOP COUNT and NEXT RECIPE. These could have been accidentally changed by someone so make sure they are correctly set. A LOOP COUNT of 1 runs the recipe once, and a NEXT RECIPE of NONE will stop the process once the current recipe has ended. Make sure that the correct etch time and loop count have been set. The actual etching step is the step which has both ICP and BIAS powers set. The step with just the ICP is used to strike the plasma but not to actually performing etching. The etch step time is often changed by different users when they perform etches, so it is very important to make sure this step has the correct time. Once you have verified and/or changed your program, you can set it up to run.

Now that you have the recipe setup and wafer in the load lock chamber, go back to the Mode screen to finish setting up the AUTO Sequence to run the recipe. In the Select AUTO Sequence box, select all of the AUTO PROCESS options. In certain cases you may not want to select LLC VENT, such as if you want to inspect your sample before removal and possibly run another process on it. Remember, if you are unselecting LLC VENT from the sequence another option has to be selected first. This is because the system requires at least one of the process options to be selected at all times. Thus, select another option before trying to deselect LLC VENT. After selecting the options, click on the RECIPE box and change it to the recipe you want to run and press Enter. The recipe number and comment should match the one you want to run. After verifying everything is correct on this screen, go to the MAIN screen and verify that RCP shows the correct recipe number. Now that all the correct process information has been entered, press the RUN button to start the process. Remember that if there is an error that has to be corrected, the RESET button (RUN button after

the process has started) can be pressed, but it is best not using this and instead correctly set everything the first time.

#### **2.4.6 Process Checks**

While the process is running, there are several things that should be checked to verify that everything is correctly running. It is important to check on the loading of the wafer and starting of the process. If the wafer loads incorrectly, it could compromise the entire process run. If parameters such as gas flow, forward power, or pressure are off during processing your entire etch can be compromised. The first thing to check when the wafer is loaded is that it sits correctly in the chuck. The chuck is surrounded by a quartz ring with a recess for the wafer to sit in. However, if the wafer is not loaded correctly, it will not sit in the recess. If the wafer does not seat properly, it can cause helium to leak into the chamber which can cause improper cooling and change the gas chemistry, thus affecting the etch. So it is good idea to check the wafer by using a flashlight to look through the chamber side viewport and see if the wafer seems to be flush with the surrounding quartz. If you feel that the wafer is not properly seated you can stop the process by hitting RESET. After the reset has finished, select and run WAFER UNLOAD and LLC VENT from the AUTO Sequence screen to unload the wafer. Once the wafer is unloaded, check for any particulate or grease on the back of the wafer and try reloading the wafer. If it still looks off, find the equipment supervisor to check if it is properly seated. Another indicator of an improperly seated wafer is a high VPos for the helium flow and/or a very low helium pressure. If the VPos is above 70% or the pressure is very low, the wafer may not be sealing against the chuck properly and should be rechecked. Another cause of a bad seal is vacuum grease on the wafer, which is the reason you should

check the back of the wafer for grease each time it is loaded. The maintenance section (2.5) discusses how to remove vacuum grease from the chuck.

Along with the wafer being properly seated and the He pressure, there are some other parameters to check during processing. The first will be the gas flow for each gas. The gas flow should be close to the set value to keep the etch chemistry consistent. In addition to the gases, the chamber pressure read from DG1 should be very close to the setpoint. Depending on the type of etch and how far off the pressure is, the recipe could error out or could continue to run and give bad results. The maintenance section (2.5) also discusses some actions which can be taken to fix problems with reaching the correct pressure.

In addition to gas flow and pressure, the plasma power is another very important parameter to watch during etching. Ideally all the power should be forward power and no reflected power. In addition to looking at the screen, the plasma itself should be observed to determine if it is a good plasma. A good plasma should not flicker and should be a constant color throughout the chamber, however the color and brightness depends on the gases, pressures, and powers so each recipe will look different. Over time you will get used to how the plasma should look. For certain recipes, the matching unit may have trouble with obtaining a good match quickly and instead takes 10s of seconds to get a match. A good way to reduce this time is to get the final values and put them in as presets. To do this, run the step which is having trouble matching for an extended period of time (on a dummy wafer) and wait until there is no reflected power and record the load and phase values for both ICP and BIAS. Then input those values in the load and phase PSet values as discussed in the editing a recipe section (2.4.2). Then select both AUTO and PSet buttons next to the

load and phase values. This will start the matching unit at these preset values and should then go to auto matching which should help give a stable plasma more quickly.

In addition to these checks, always be on the look out for anything out of the ordinary such as weird noises from the machine or different indicators lit up on the display screen. If you are ever unsure of something during a process, let the equipment supervisor know in case it is a serious problem with the machine.

#### **2.4.7 Unloading a sample**

After the recipe has finished its etch, the system will beep to signify that it has completed the process and then returns to standby as it was before the process was started. At this time, you can take out the wafer and remove the sample or perform an oxygen ash. The oxygen ash is Recipe 3 and is used to remove photoresist. It is called an ash as it basically oxidizes and burns off the photoresist since it is an organic material. To run the ash, follow the same procedures as used for running this step except make sure you choose Recipe 3 and set the correct time in step 1. Recipe 3 has only a single step. Recipe 3 should have no NEXT RECIPE and only ONE LOOP. Be sure to verify this as some people may change this recipe from time to time. The time for an ash depends on which resist you used and how much resist is left on the sample after the etch. Some resists such as PMMA require a short ash, 20 seconds if you performed 6 loops of Recipe 71 which should etch 250 nm of silicon. Other resists such as AZ 5214-E and SU-8 take longer to ash. SU-8 is a particularly tough resist to ash and is often just removed with pirhana etch instead. The best way to determine an ash time if you are unsure is through trial and error. It may be time consuming to calibrate the ash time but once it is calibrated it will save you time. Start by doing a 1 minute ash (do not vent the load lock afterwards) and, based on the

a visual inspection, keep doing subsequent ashes until all the resist is removed. Doing an overly long ash can roughen the silicon surface. So try to find the minimum time required to fully remove the resist. Once all the resist is gone, you can vent the load lock chamber by only selecting LLC VENT and running the recipe. Remember that you have to select LLC VENT before deselecting the other options as you always need one option selected on the AUTO Sequence panel. Then go to the main screen and press RUN to start the load lock venting sequence. If you have completed your etch and do not wish to do an ash, then you can remove your sample. If the load lock was not vented when the process ended, then follow the same instructions just stated to vent the chamber after an ash.

Once the load lock has vented, you can remove the wafer and place it on a CLEAN wipe. Place the cleaning wafer in the load lock and close the lid. If you are done etching, it is best practice to setup and run the clean now as to not forget to run it. The cleaning recipe is Recipe 6 and is named “Hi Lo !”. More details on the cleaning recipe are discussed in the maintenance section (2.5) but the basics of running the clean will be presented here. Recipe 6 has two steps, the default cleaning time is 1 hr for step 1 and 1 hr for step 2. However, this can differ based on your specific process as discussed in the maintenance section (2.5). For now, just set the clean to 1 hr for each step (2 hours total) and then select Recipe 6 in the AUTO Sequence on the Mode screen. Select all except options except for LLC VENT from the AUTO PROCESS box. The reason for this is that after the recipe has completed, the load lock should be left under vacuum thus helping to keep a good vacuum in the reaction chamber and also helping to keep the load lock clean. After the sequence is setup, run the recipe the same way the etch recipe was started.

After the clean has been started, the next step is to remove the sample from the carrier wafer. The best way to do this is to use a pair of tweezers and a razor blade. Use the tweezers to hold the sample in place and then try to push the razor under the sample to lift it off the wafer. Once you get the sample up, take it off the wafer and use the razor to remove the extra grease from the back and set the sample aside. Repeat this procedure to remove any additional samples on the wafer. Then use the razor to scrap the grease off of the wafer. After all the grease has been removed from the wafer, take a wipe and put some IPA on it, just enough so it is wet but not dripping. Now wipe off the wafer with IPA to make sure it is clean. Try to just wipe the areas where the grease was at first so you don't accidentally spread the grease further. After the grease has been removed you can take a new wipe with IPA and clean the rest of the wafer if you wish. Check the back of the wafer for grease and if it is clean put it away, otherwise wipe it down with IPA to remove any grease residue.

The last step is to clean the back of the samples to remove the excess grease. You can use a wipe with IPA or a cleanroom swab with IPA to remove the grease. A swab is preferred sometimes as it doesn't leave lint and gives better control over which area is being cleaned. Carefully pick up the sample from the side, be sure your gloves are clean and don't touch the front of the sample! While holding the sample, wipe the excess grease residue off the back of the sample. Get a new swab/wipe with IPA and wipe again continuing until the residue level remains constant. It is important to remove as much grease as possible as it can cause problems with processing later and can also make it hard for samples to stick to certain surfaces such as carbon tape for imaging in the SEM.

In certain cases IPA will not do a good enough job removing the grease and toluene will have to be used. Toluene helps to do a better job removing the bulk of the grease residue, even if it is not visible. To remove the grease with toluene, follow the same procedure of taking the grease off with a razorblade. However, after this physical removal, wipe the sample with toluene followed by IPA to help remove as much of the residue as possible. This is important for processes where the sample has to be extremely clean.

This concludes the normal operation of the machine. Next, maintenance will briefly be covered followed by some etching physics and finally some example/calibration etches.

## **2.5 Maintenance**

Maintenance of the ICP is an involved endeavor which involves everyone from casual users to the equipment supervisor, who takes care of planned maintenance and major system repairs. This section points out little tasks that can be done during normal use of the equipment which can help keep the ICP in good operating shape. More in-depth information on scheduled and emergency maintenance can be found in Chapter 5 which is meant for the experienced user who is very familiar with the operation and workings of the ICP.

The daily maintenance of the ICP starts when you first enter the chase. By checking everything in the pre-operational checklist and reporting problems, the ICP can be kept in working order and result in fewer emergency repairs. Regular checks on the pumps, scrubber, and gases can prevent long down times when a problem does arise. Along with the pre-op checklist, there is also a log in the



cleanroom to record important equipment parameters such as the DG1 and MFC# values.

In addition to the check lists, there are some additional checks that should be performed every time you run a process. As previously mentioned, it is a good practice to watch your process as it runs to make sure there are no errors. In addition to the standby pressure of DG1, the pressure reached by DG1 during processing is important. The pressure should be very close to the setpoint. In some cases, there can be problems with the gauge, MFCs, or APC which may prevent the pressure from being reached. If the pressure is not met, there are several simple fixes that can be tried. The pressure matching problem could be a one time deal, so try and rerun the process and see if there is any difference. If the problem persists, the simplest fix for bad pressure regulation is to turn off the system and the main breaker on the back of the machine. Wait a minute and turn the machine back on. This will have the same affect as restarting a computer and sometimes fixes matching problems. If this works, it could just be that there was a glitch in the system. If there is no improvement, it could be a buildup in the chamber or TMP which can be fixed by running a TMP clean, discussed later in this section. If neither of these solutions fix the problem, it could be something more serious. Some of the more serious problems could be a leak in the chamber, pressure offset in DG1, or loss of pressure calibration in the APC. These problems are discussed in-depth in Chapter 5 as they are not simple problems to fix.

Along with checking the chamber pressure, the flows of the MFCs during processing should be checked to make sure that they meet their setpoint and return to approximately 0 after processing. The MFCs may slowly decrease back down to zero

after processing has completed while the gas reaches equilibrium inside the MFC. Zero adjustments are discussed in the Section 5.4.2. If problems with these are noticed, the sooner they are reported and corrected the better the chance of keeping the problem from becoming a major issue.

As discussed in, Sections 2.4.3 and 2.4.4, vacuum grease on the back of the wafer can cause major problems. During a process, this can be noticed by an abnormally high value for the PCV VPos and/or possibly a high pressure for DG1 (signifying extra gas in the system). If you notice grease on the back of your wafer, wipe the affected area with IPA to clean it off. If you notice a high VPos or problems with your process, there may still be vacuum grease on the chuck. The easiest way to remove the grease is take a “dummy” wafer which can be thrown away and load and unload it repeatedly. Each time it is unloaded take the wafer out and wipe the back with IPA to clean off the grease. This should clean the chuck. However if this does not work, then the chamber will have to be opened and cleaned as discussed in Section 5.6.

The last maintenance procedure, which will be discussed in this section, is cleaning recipes. There are two types of cleans for the system, High-Low (commonly written Hi-Lo) and TMP cleans. The Hi-Lo clean uses oxygen to remove buildups in the chamber from etched photoresist and polymer deposits from certain etch recipes. The Hi-Lo recipe is Recipe 6 (Hi Lo !) and should be run after every process. The first step has 100 sccm of oxygen, pressure of 5 Pa, and ICP and BIAS of 400W and 50W, respectively. The second step is the same as the first except that the pressure is 1 Pa instead of 5 Pa. These two steps help to clean the chamber from top to bottom thus conditioning it for use by the next user. The duration of the clean depends on the

specific etch chemistry, etch time, and material removed. The two steps of the etch recipe should be run for equal times and the standard clean time is 2 hours total. If you run a very short process or someone else needs the machine shortly after you, a 1 hour process (or even shorter) can be run. At the other extreme, a 3 hour clean is recommended to help clean out extra buildup from long processes. For processes that have a lot of polymer buildup or etch a large amount of material, such as a through wafer etch, a TMP clean should be run followed by a Hi-Lo clean. The TMP clean is Recipe 5. It is 3 steps which are 2 hours, 2 hours, and 1 hour, respectively. The first step flows 10 sccm of  $C_4F_8$  and 100 sccm of oxygen with a pressure of 8 Pa and ICP and BIAS of 500W and 50W. Steps 2 and 3 flow 20 sccm of argon and 100 sccm of oxygen and have the same ICP and BIAS as step one. The difference between step 2 and 3 is the pressure, like in the Hi-Lo clean the first step is at a higher pressure of 8 Pa and the second is at a pressure of 1 Pa. After this recipe completes, the TMP should be “clean” but the chamber still needs to be cleaned thus Recipe 6 is set as the NEXT RECIPE in Recipe 5. Recipe 6 should be set to run for 2-3 hours to help make sure the chamber is very clean at the end of the cleaning process. A TMP should be run before any extremely critical processes. If a TMP clean is performed, it should be recorded in the log book for the cleaning recipe so that other users are aware that more than a standard Hi-Lo was performed. A TMP clean should be run at least once a week under normal use of the machine. It is usually run last thing Friday evening so that the chamber will be in good condition for the start of the next week.

## **2.6 Standard Processes**

The ICP contains many recipes. Some are no longer used while others are quite frequently used. Listed below are some of the common etches. Their

components and purpose will be covered along with expected results from each recipe to help verify operation of the machine. Examples of good and bad etch samples will be included for reference along with steps to help correct different problems that can be seen.

### **2.6.1 Recipe 93-Silicon Dioxide Etch**

This recipe was designed for the anisotropic etching of silicon diode and silicon superlattice. It is a single loop process like Recipe 72 and gets anisotropic results like Recipe 71 but with a very different approach. This etch is a very physical etch, which is used to get a vertical sidewall in oxides. It is similar to a sputter since it is a physical etch and, because of this, can leave a rough bottom surface when it is done etching through a layer. Often times this recipe will roughen up the silicon surface, which is located below an oxide layer, once the oxide layer is completely etched away. More on these characteristics will be discussed in the etch results section (2.6.1.3). This etch is used for etching oxides and silicon nanocrystals to make structures such as those discussed in [2-11].

#### **2.6.1.1 The Etch**

Various steps of this etch will be discussed to give insight into the specifics of this etch and to give background on the general structure used for most of our etches. Table 2.2 provides the recipe for reference while reading this section and for future reference when using the ICP.

**Table 2.2** Parameters for Recipe 93-TimSLetc

Step	Gases	Pressure/Position	ICP/BIAS (W)	Time
1	--	100%	0/0	15 sec
2	2.5 sccm SF <sub>6</sub> , 2.5 sccm C <sub>4</sub> F <sub>8</sub> , 90 sccm Ar	1.5 Pa	0/0	15 sec
3	2.5 sccm SF <sub>6</sub> , 2.5 sccm C <sub>4</sub> F <sub>8</sub> , 90 sccm Ar	1.5 Pa	500/0	15 sec
4	2.5 sccm SF <sub>6</sub> , 2.5 sccm C <sub>4</sub> F <sub>8</sub> , 90 sccm Ar	1.5 Pa	500/150	Variable for etch time
5	--	100%	0/0	15 sec

The first step is a chamber evacuation step. The chamber is evacuated through the TMP by placing the CGV in position mode and opening it all the way. After the chamber has been evacuated, the second step begins by adding the gases and setting the pressure. The pressure is set in the APC and the APC works with the reading from DG1 to adjust the CGV position to reach the target pressure. This recipe is composed mainly of argon with a small amount of SF<sub>6</sub> and C<sub>4</sub>F<sub>8</sub>. The argon provides for a physical etch while the SF<sub>6</sub> and C<sub>4</sub>F<sub>8</sub> help to provide some chemical etching. SF<sub>6</sub> is usually used for etching silicon and C<sub>4</sub>F<sub>8</sub> can be used as an etchant or to deposit polymer. It will be used to deposit polymer in the time multiplexed process (Section 2.6.3). In this recipe, C<sub>4</sub>F<sub>8</sub> is used as an etchant. Whether C<sub>4</sub>F<sub>8</sub> etches or deposits depends on the etch recipe parameters. Because this recipe has a rather low content of C<sub>4</sub>F<sub>8</sub> and has other gases, it works as an etchant. However, if the C<sub>4</sub>F<sub>8</sub> content were increased, it would eventually start depositing polymer on the sample, which is undesirable. After the gas flows are set, the ICP is applied. This step allows for adjustment of reflected power and also allows the pressure to re-stabilize. The

Bias is then applied in step 4. Step 4 is the step which is the actual etch step. The time in this step is to be adjusted to meet your desired etch depth. The ICP and Bias are quite high in this recipe as it is mainly a physical etch and increasing these parameters will help to provide a physical etch. Because this etch is very physical, it is not very selective, which will be discussed in the etch results section (2.6.1.3). The last step in this recipe is just an evacuation step, like the first step, to clean out the chamber once the recipe has ended.

### **2.6.1.2 Preparation and Etching of a Test Sample**

Unlike the other etch recipes, which will be discussed, this etch test requires the PECVD to deposit a  $\text{SiO}_2$  layer for etching since it is an oxide etch. The substrate which is to be used is a <100> test grade silicon wafer prepared in the manner described in the PECVD Recipe 6 Section 3.6.2. The total deposited thickness should be about 500 nm (~7 min). Make sure to measure the thickness on the spectrometer before continuing so that you are sure of the total thickness which you will be etching. After the deposition has completed, resist can be spun on the oxide.

After taking the sample out of the PECVD, the sample should be very clean but there may be some particulate on the surface. To remove any particulate blow the sample off with nitrogen. If some of the particulate remains you can try an AMI rinse on the spinner. In some cases the particulate may be in or under the oxide and cannot be removed. Because this sample has an oxide coating, it requires an HMDS pretreat in order to promote the resists adhesion. Without the HMDS pretreat, the unexposed regions of the sample with small features will develop away. The recipe for the pretreat is Recipe 2.

Now that the sample has been treated with HMDS, it can be prepared for the application of the resist. In our case AZ 5214-E will be used. It should be noted that each resist type and thickness will affect the etch slightly. So for calibration etches, please use a resist that fits your process. With that being said, all the recipes presented here will be done using AZ 5214-E. While other resists can be used, they will not be covered here. There is no clean required after applying the HMDS. So after the pretreat has finished, put the sample on the spinner and let it cool for a few seconds. After it has cooled, dispense the resist (with a 0.2  $\mu\text{m}$  filter) and spin at 3,000 RPM for 45 seconds. After the spin has finished, bake the sample on a hot plate at 90°C for 30 sec. After the bake, the sample is ready for the actual UV lithography exposure.

Before doing the lithography, make sure that the mask has been cleaned in piranha to remove any old resist or other particulate that could cause problems with the contact. The standard 365 nm UV mirrors should be installed in the mask aligner for this exposure. The dose is 160 mJ/cm<sup>2</sup> measured at 365 nm. When performing the alignment, make sure that the waveguides are parallel with the edge of the sample. This is important so that when the sample is cleaved after etching, it will provide a nice clean cleave through the waveguides, thus allowing for imaging in the SEM. Ideally you always want to align structures with the crystal plane to make cleaving easier. After exposing the sample, it has to be developed for ~20-30 sec in AZ 327 MIF. These features are large enough that you should be able to determine when the developing is done by eye. After the developer, rinse the sample in running DI water and then blow dry with nitrogen. Inspect the sample under the microscope to make sure that it exposed and developed properly.

Before performing the etch, the chamber has to be preconditioned as discussed in Section 2.4.3. The precondition should also use a separate precondition wafer from the etch carrier wafer. This is because the precondition can roughen up the surface, which can mess up the contact between the wafer and the sample. So a separate wafer should be used. After only a few etches, the silicon may become white or dull gray as it gets roughened by the etch. This is normal and is the reason that we do not use this wafer for the sample carrier wafer. Unlike the other etches, this one is mainly a physical etch and is mainly argon, so there is not much preconditioning that has to be done of the chamber. So for this etch, we usually do a precondition that is half the length of the etch, with a minimum of 5 minutes. After the precondition you can load in the sample mounted to your wafer. For information on mounting and loading a sample, see Sections 2.4.3-2.4.4. Then perform a 3 minute and 30 second etch which should ideally remove all the oxide on the sample. The color of the oxide layer changes depending on how much resist is left. For a blue/purple or dark gray oxide color (Figure 2.8), an additional minute should remove the remaining oxide. For a thinner oxide which is a brownish gray color (Figure 2.9), there is usually 15-30 seconds of etching left. If the oxide coloration is over, most of the sample it will require 30 seconds while if it only covers part of the sample, 15 seconds should be enough.



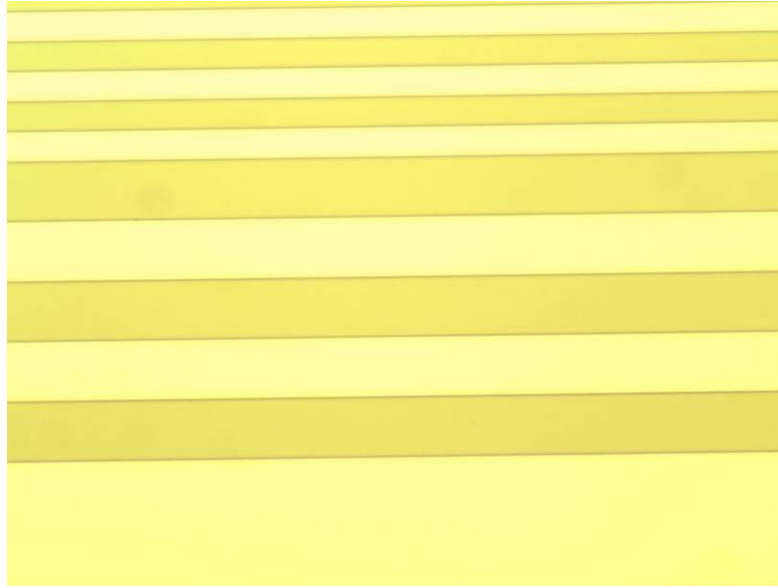
**Figure 2.8** Silicon sample with oxide remaining after etch. This color oxide layer should be removed with approximately 1 minute of etching.



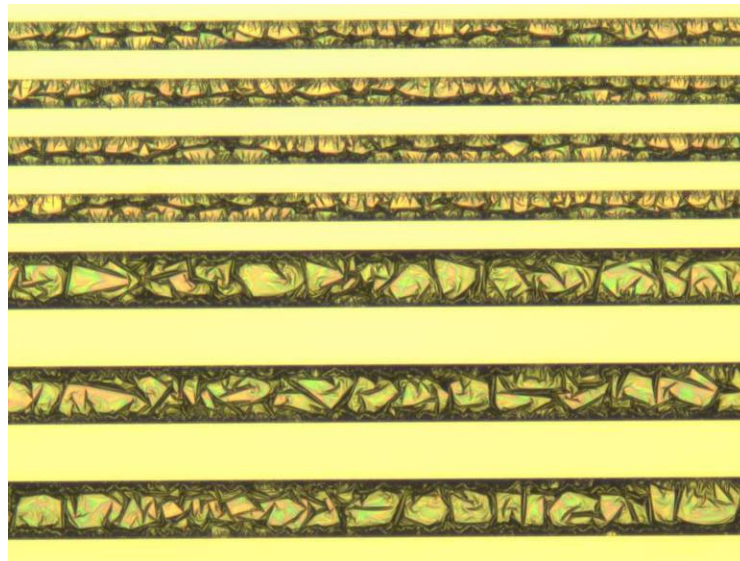


**Figure 2.9 Silicon sample with a very thin layer of oxide remaining. A 30 second etch should remove this layer of oxide.**

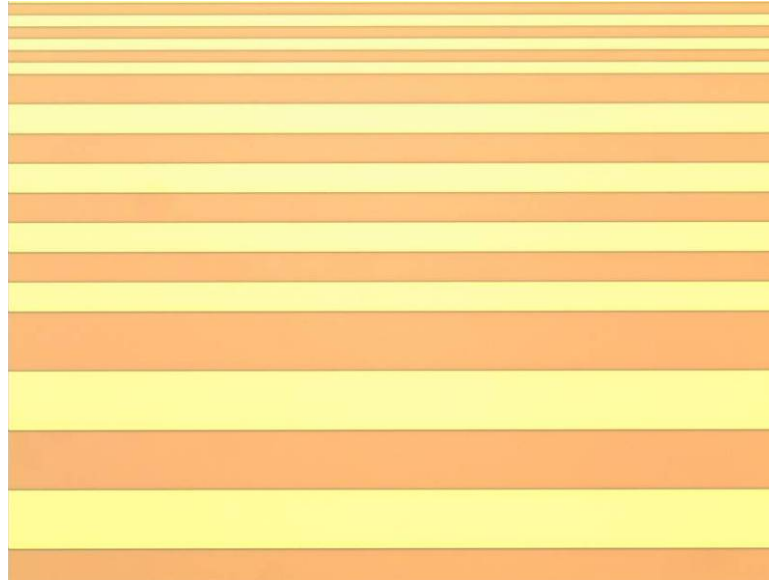
Once all the oxide is removed, it should look like bare silicon and the areas of resist should have a rainbow color because of variations in thickness. After the etch has finished, make sure that there is still resist left on the sample. It is not always easy to tell if there is resist left with the naked eye as it could have a color similar to the underlying oxide. Thus to check for resist, it is best to take the sample out of the ICP and look at it under an optical microscope. If the masked area is a dull color (often yellow/gray) or has fringes, then there is resist (Figure 2.10). If it looks colored (not necessarily the same color as the oxide started as it could have been etched), then the resist is all gone which is a problem. If there is resist left, run an oxygen plasma for 3-4 minutes. The resist should all be removed in 3 minutes but if not, then an extra minute may be required. After the ash, inspect the sample under a microscope to verify that all the masked areas are a continuous color and do not have any cracking or other artifacts to suggest resist or other damage. If additional resist still remains, the extra resist can be removed with acetone and ultrasound. This is not offered for other structures as using this can cause damage to your structure such as the undercut waveguides which will be obtained with Recipe 72. Figure 2.11 shows waveguides with resist on them that has been attacked by acetone but not totally removed. Figure 2.12 shows a picture of the etched sample with the resist removed. If the sample looks good under the microscope, then remove the sample from the carrier wafer and prepare it for analysis with the SEM.



**Figure 2.10** Sample etched with Recipe 93. The lighter regions are silicon while the darker regions are un-etched areas masked with photoresist.



**Figure 2.11** Sample from Figure 2.10 after being rinsed with acetone. The photoresist coated areas bunched up because of the acetone.



**Figure 2.12** Final structure after removal of resist in Figure 2.10 and 2.17. The orange/red areas oxide while the yellow areas are the bare silicon.

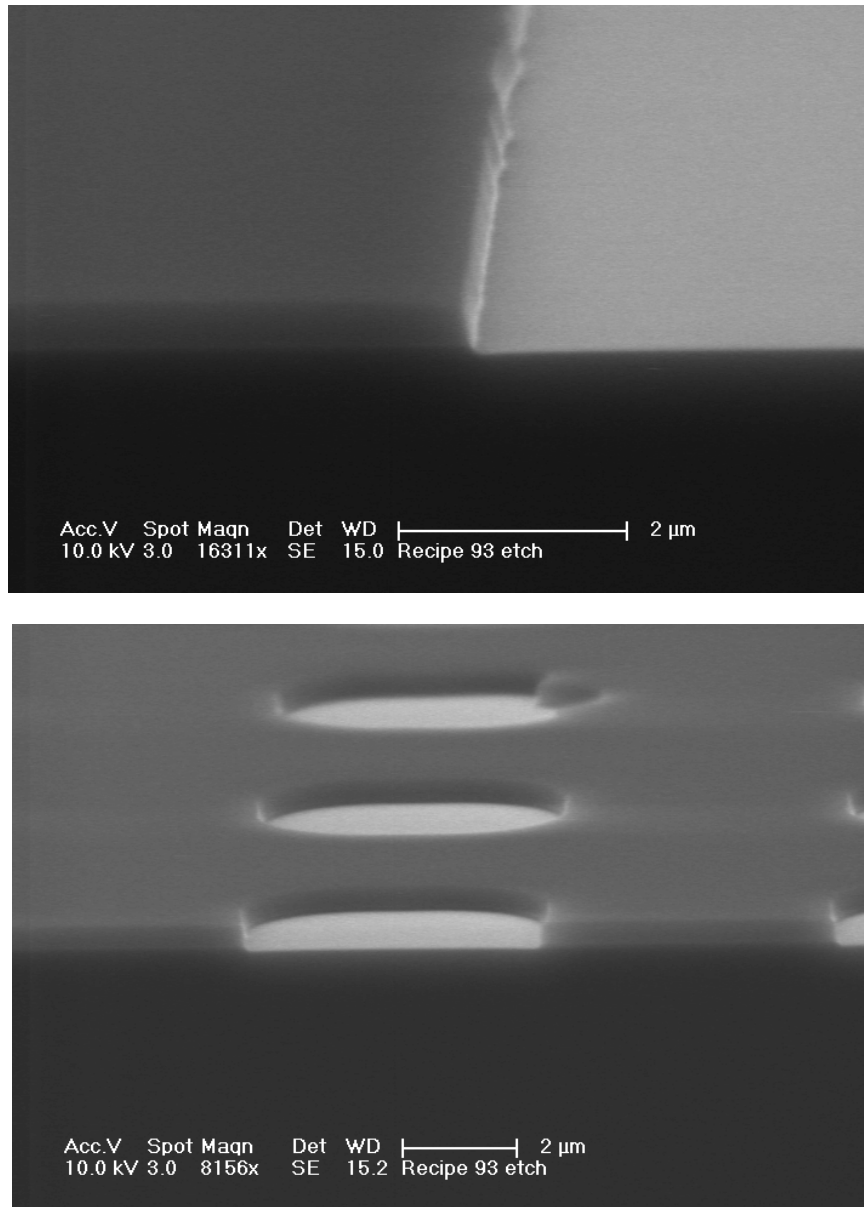
### **2.6.1.3 Etch Results**

Before looking at the sample under the SEM, it is insightful to look at it under the optical microscope in DuPont 107 (Figure 2.12). This will give you a chance to look at the features from far away and look at the colors to help determine any effects the etch may have had on the oxide. This also helps to get an idea of the shape of the structures which were etched before doing SEM imaging.

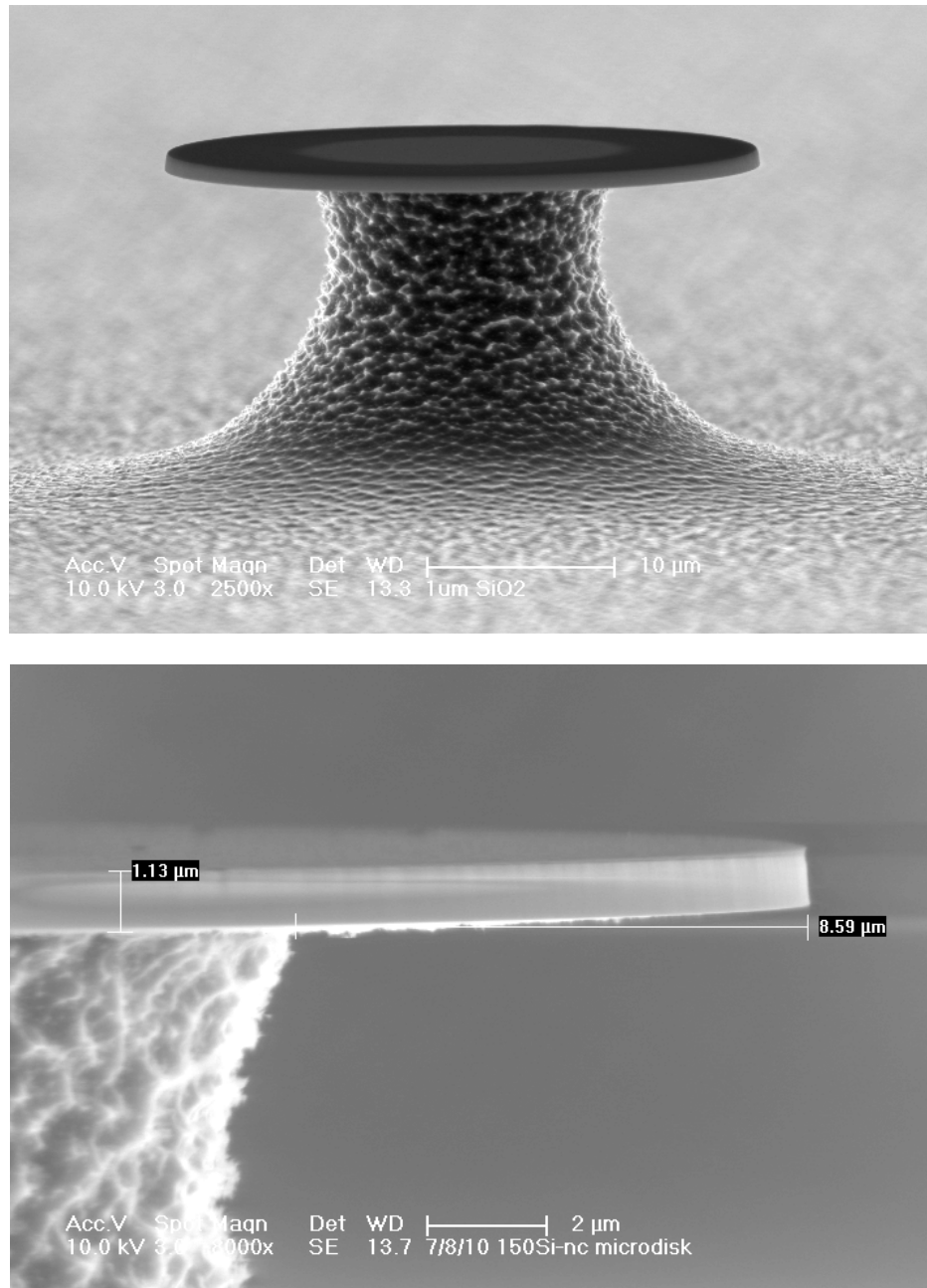
For SEM imaging, we usually try and look at a side view of the sample. Since the structures are oxide, they will charge quickly and make them difficult to view. This is another reason to start with the optical microscope. To look at the edge of the sample, cleave it near the middle of the sample and perpendicular to the guides. Then mount it to the vertical mount for the SEM. Place carbon tape across the top of the sample to help provide a ground path for electrons thus helping to reduce the

charging effects. If once you begin imaging, it is difficult to get a good picture, you can deposit 5-10 nm of gold or titanium to get a conductive layer which will help with viewing the structures.

When imaging with the SEM, the main features of interest are the undercut of the etched oxide areas and the roughness of the etched sidewalls. The roughness of the sidewall can also be caused by pattern transfer from bad lithography. Look if the roughness starts at the top of the oxide layer and continues down the entire length. If it does, then it is probably from the lithography. Whereas if it is a seemingly random pattern, it is probably roughness caused by the etch itself. Figure 2.13 shows some pictures of good sidewalls and Figure 2.14 shows some images from previously fabricated oxide microdisks.



**Figure 2.13** SEM images of the sidewalls of etched oxide structures. The large bumps in the sidewalls waveguide in the top image and back photonic crystal in the bottom image are caused by lithography and not by etch roughness.



**Figure 2.14 SEM images of microdisks with emphasis on the very vertically etched oxide disks**

Now that the good results have been discussed, there are also some things that can occur if the etch goes badly. One sign of a bad etch is missing resist. Missing resist is usually caused by an increase in the etch rate. If the etch rate is increased, there are several effects which may be noticeable. The first would be non-uniform color in the masked oxide areas when viewed with an optical microscope. This can be caused by the resist not etching uniformly thus certain areas of the oxide are etched during the etching process while other areas are still masked. Another sign of an aggressive etch would be roughening of the silicon surface when viewed in the SEM. Extra pitting in the silicon is a sign that the oxide was done being etched a while before the etch finished and thus the silicon was slowly etched afterwards. Pitting could also occur as an effect of the oxygen plasma, so another run with acetone removal instead of an oxygen plasma could be attempted. Another sign of a faster etch could be an undercutting of the oxide. These will be discussed along with some possible causes of increased etch rates.

If the only suggestion of an increased etch rate is the missing resist, then the resist itself may be suspect. Perform a test spin to check the resist thickness and make sure that it is not expired and that it had the proper bake and exposure parameters. Usually the resist is fine and it is something with the etch itself. Increased etch rates can be caused by a change in chamber pressure, gas flow, or bias power. Check that all the settings in the recipe match those listed in Section 2.6.1.1. If they do match, then check the values of these parameters while the etch is running. Along with checking while the etch is running, also check the idle values of the MFCs and DG. If the zero values are off contact the equipment supervisor about recalibrating the instruments that are off. If everything seems fine but the etch is still

very aggressive, perform a full TMP and chamber clean (Section 2.5) to help remove any contamination, which may be affecting the process.

The opposite of the resist being gone is that the oxide is quickly removed but the resist is unaffected. This can be determined if you run a shorter etch time but still have all the oxide removed. This is an indicator that the oxide itself may be bad. A good check of the oxide quality is to check the etch rate using BOE. For a 500 nm film the etch rate should be about 1 minute and 20 seconds. A faster etch rate in the BOE means the rate in the ICP will also be faster. The oxide should then be considered suspect and Section 3.6.2.3 should be reviewed for details on how to increase the oxide film quality. Finally, if you want to do a quick rate calibration without the waveguide structures, an un-patterned oxide sample can be used and the colors can be checked for determining when the etching is done. This is a useful tool when trying to determine rates if the profile of the etch is not of interest. Often times it is best to get an approximate rate using this method and then continuing on to the waveguide structures if problems are encountered with the etching process.

### **2.6.2 Recipe 72-Isotropic Silicon Etch**

Recipe 72 (steps listed in Table 2.3) has a similar structure to Recipe 93 but has different etch characteristics. It is designed to etch silicon, not silicon dioxide, and is also a fast, isotropic etch. This etch can be used when you do not care about the side walls and need to etch deep into a substrate. It also could be used to uncut and lift off small structures or isolate certain structures. An example of a structure which uses this recipe is a raised microdisk such as those fabricated in [2-11].



### 2.6.2.1 The Recipe

**Table 2.3** Parameters for Recipe 72-ELM Si!

Step	Gases	Pressure/Position	ICP/BIAS (W)	Time
1	--	100%	0/0	10 sec
2	40 sccm SF <sub>6</sub>	1 Pa	0/0	15 sec
3	40 sccm SF <sub>6</sub>	1 Pa	500/0	3 sec
4	40 sccm SF <sub>6</sub>	1 Pa	500/15	Variable for etch time
5	--	100%	0/0	10 sec

The first step of the recipe is the same as Recipe 93 and once again provides chamber evacuation by opening the CGV all the way. The second step begins by adding SF<sub>6</sub> gas and letting the flow and chamber pressure stabilize. Then the next step applies the ICP power followed by the bias in the next step. This is once again the etching step and is the step where the time is varied to get the desired etch depth. It has quite a high ICP and low bias to provide a fast etch which is mainly a chemical and not physical etch. This is in contrast to Recipe 93 which has both a high ICP and bias. Also, the lower bias helps to reduce the amount of photoresist which is etched and makes the etch more isotropic. The silicon etching power is provided by the fluorine in SF<sub>6</sub>. The final etch step is another evacuation to help clean out the chamber of extra gas and etching byproducts.

### 2.6.2.2 Preparation and Etching of a Test Sample

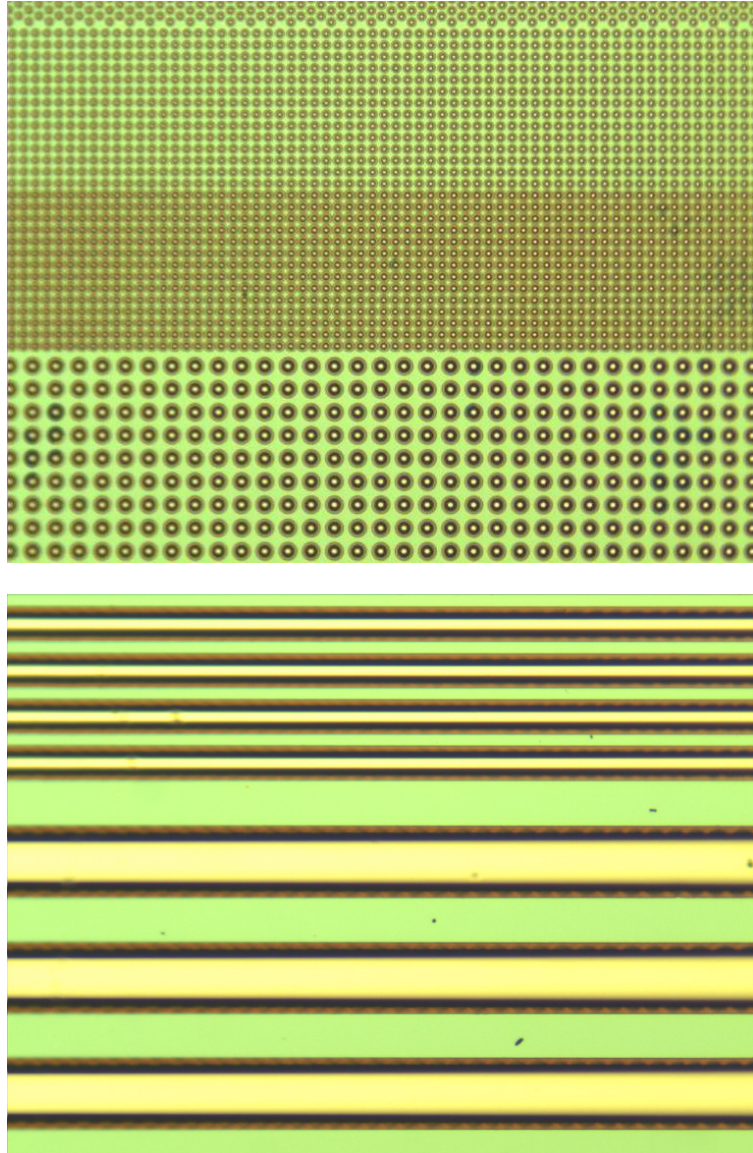
Similar to the Recipe 93 preparation, a SiO<sub>2</sub> layer has to be deposited for this test. However, unlike the oxide deposited for the Recipe 93 test, this oxide will serve as a hard mask and is not the layer of interest in this etch test. The preparation

of the sample in terms of oxide deposition and lithography is exactly the same as that used in Section 2.6.1.2 for the Recipe 93 etch. After the lithography, the oxide mask has to be etched in the same manner as in Section 2.6.1.2 including the 5 minute precondition and 3 minute and 30 second etch. A thinner oxide can be used as the etch mask. However, Section 2.6.2.3 will show what happens when a thinner oxide layer is used. This oxide etch is important as it provides a hard mask for the Recipe 72 silicon etch which is very important. After the oxide etch has finished, verify that all of the unmasked oxide has been removed. If it has not been removed, run Recipe 93 for 30 seconds at a time until the rest of the oxide is removed.

After the oxide mask has been completely etched, remove the wafer with your sample from the load lock and place the Recipe 93 precondition wafer in the load lock. The same wafer can be used for preconditioning Recipes 93 and 72. A precondition time of 15 minutes is usually plenty long for this etch. If you are doing a very short etch, you can do a precondition that is twice your etch time. Once you get to longer etches, there is no reason to go longer than 15 minutes. In our case, we will be performing a 20 minute etch so it is easiest to just do a 15 minute precondition.

After the precondition has finished, load the sample with the etched oxide mask back into the chamber. Set the etch time to 20 minutes and start the etch. Unfortunately, unlike Recipe 93, you cannot determine much about the etch characteristics with an optical microscope, except for determining that there is an undercut. In addition to the undercut, you can determine if there is still photoresist on the sample. This is very important and can be determined by looking at the sample with either the naked eye or under a microscope. The masked areas should have the color of the initial oxide and should be a constant color. See Section 2.6.1.2 for more

information on determining if there is still resist left. Figure 2.15 shows a microscope image of the etched sample with the resist removed. Notice there are three regions of different colors. The greenish areas are the areas where there is still masking oxide. The dark areas with brown fringing are areas where the silicon was undercut and there is now free standing oxide. The bright yellow-whitish areas are bare silicon that has been etched.



**Figure 2.15** Oxide coated samples etched with Recipe 72. The yellow areas are the silicon and the green areas are the masked oxide areas.

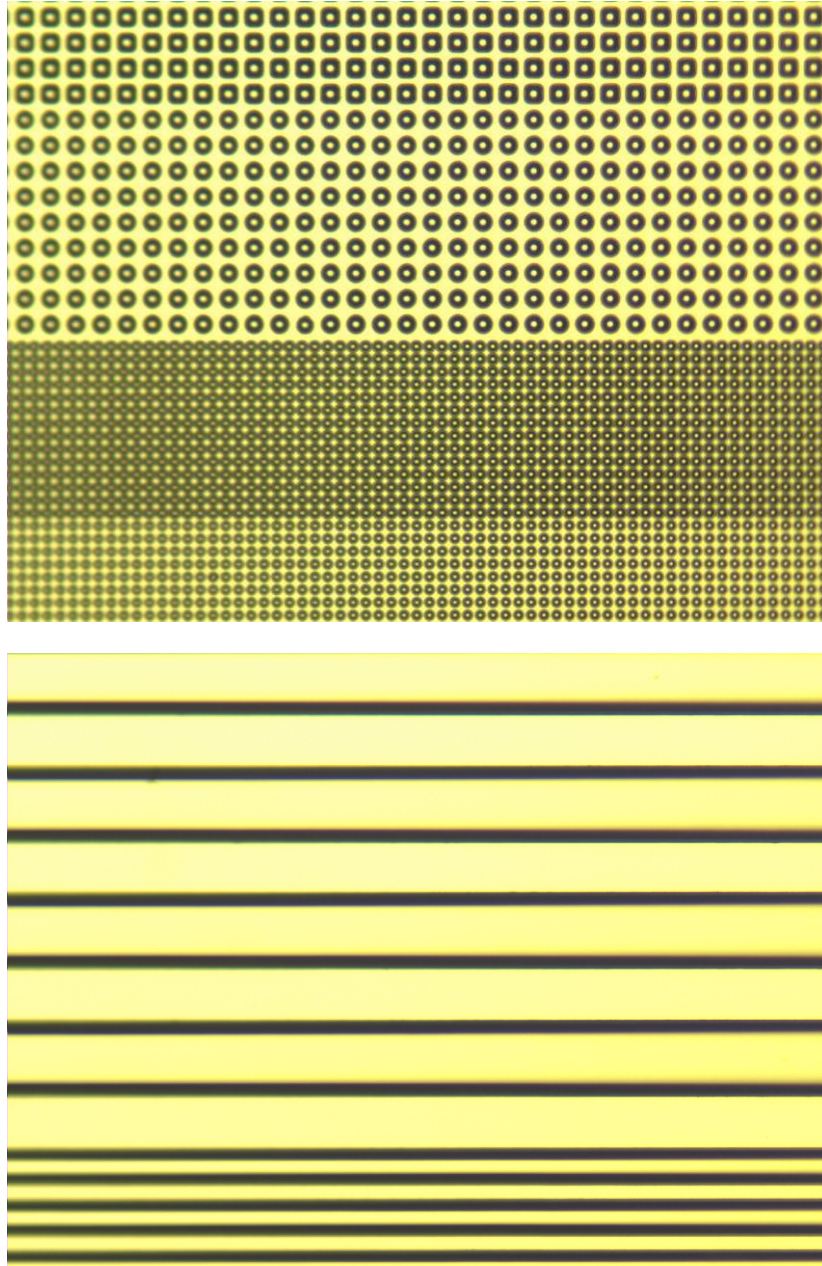
If you do not want to go through the effort of depositing and etching an oxide mask or want to see the profile of the top masked silicon surface, then this etch can be performed using just a photoresist mask. To perform lithography on this

sample, a clean must first be performed. The cleaning process involves piranha etch (3:1 sulfuric acid: hydrogen peroxide) and Buffered Oxide Etch (BOE). The process is to first immerse the wafer in the piranha for a few minutes or until the bubbles slow down. Then remove the sample and rinse it in running DI water. When removing the sample, make sure that the surface of the sample is hydrophilic. If the sample is not hydrophilic, place it back in the piranha and stir the solution to make sure the sample is sitting in well mixed solution. After doing this, whether it is hydrophilic or not, immerse it in BOE until the entire surface becomes hydrophobic. Then rinse the sample in DI water again. If the sample is not hydrophilic after the first piranha, repeat the process until you can get a good oxide to grow from the piranha, determined by being hydrophilic.

After the cleaning process, the AZ 5214-E can be spun on the sample using the same parameters as discussed in Section 2.6.1.2. No HMDS is required for this sample, so a short IPA rinse and dry may help remove any particles from the sample. If after performing the lithography, some of the features wash off the sample during the development or rinse, there may be an adhesion problem. In this case, perform an HMDS pretreat as discussed for Recipe 93 in Section 2.6.1.2.

After performing the lithography, precondition the chamber by running Recipe 72 with the same Recipe 93/72 precondition wafer. A 15 minute precondition should be long enough for this etch. For this resist masked sample, only perform a 10-15 minute etch. If the etch is too long, it will completely etch away the top of the silicon structures. After the precondition has finished, load in the mounted sample and run the recipe for the desire amount of time. After finishing the etch, it should be checked for resist. Unlike the oxide masked sample, a bare, etched sample with no

resist will look like the sample in Figure 2.16. If there is resist present, the masked areas will be a non-gray color and will possibly have swirls in the resist which make it easy to determine that there is still resist on the surface. If there is still resist remaining, there should be, it can be removed by running a 2 minute oxygen plasma. If there is still resist left, then continue running oxygen plasma in 30 second increments until it is all removed. On the other hand, if there is no resist left after the etch, then the top layer of resist has been etched. A 15 minute etch leaves a small amount of resist, so the etch time may have to be reduced to complete the etch without removing the resist. If a longer etch is required than is possible with the photoresist mask, then try a hard mask such as chrome or oxide. A chrome etch mask will not be able to maintain its shape like an oxide mask but may collapse and cause artifacts in the etch. To better determine the characteristics of an etch, the SEM should be used to obtain images of the surface. These images will be discussed in the results section (2.6.2.3).



**Figure 2.16** Silicon sample etched with Recipe 72 with no photoresist left. Notice that both the etched and un-etched areas are a similar color showing that there is no resist left. The dark lines are the undercut regions.

### 2.6.2.3 Etch Results

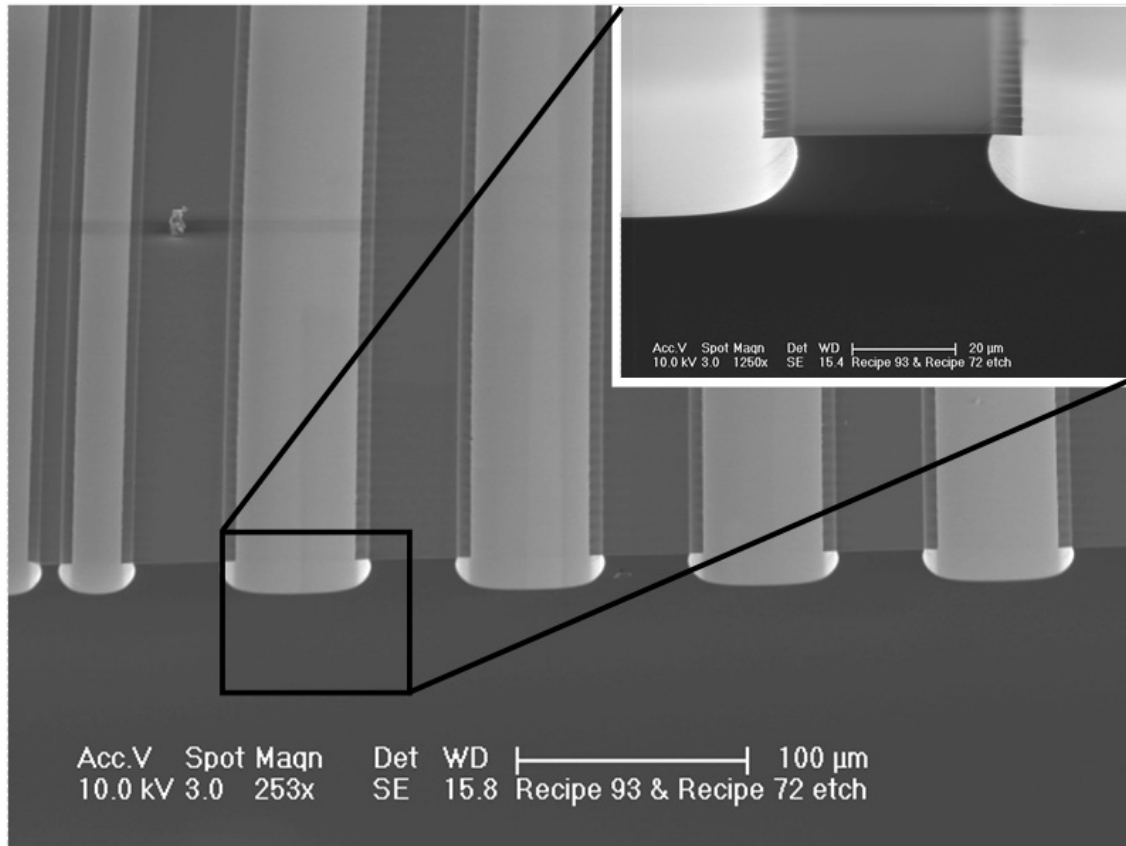
Unlike Recipe 93, it is difficult to learn much about the sample with the naked eye except for possibly the roughness of the silicon. For a rough etch, the etched areas will look hazy (gray or white) while the un-etched areas will be shiny (either the oxide color or silvery if there was no oxide mask used. Examples of etched samples with an oxide mask are shown in Figure 2.15 and examples of samples etched without an oxide mask are shown in Figure 2.16. Looking at Figure 2.15 it is easy to see the difference between the green oxide areas and the yellowish silicon areas. The darker areas are the undercut regions. Figure 2.16 is harder to determine which areas are etched but the brighter areas are un-etched and the hazy areas are etched. The undercutting of the silicon is still visible in this figure. This is because the etched regions are roughed and do not reflect the light as well. If there is no oxide mask and the un-etched areas are colored, then there is most likely still resist which was not removed, so go back and perform 30 second oxygen plasmas until the rest of the resist is removed.

To learn more about this undercutting in both the oxide masked and photoresist masked samples, they have to be examined under the SEM. To do this, cleave the samples in the same manner as was done in Section 2.6.1.3 for Recipe 93. Load the sample on the vertical sample holder so that the edge can be imaged. The edges of the waveguides are the features of interest. Along with the edges of waveguides, the circles and squares which are photonic crystals can be useful for imaging if they are cleaved through. Both Figures 2.23 and 2.24 show a zoomed out view of these regions. Both figures also have insets showing a closer view of the structures. The inset in Figure 2.17 shows a closer view of the waveguide which makes the rippling of the oxide more clearly visible. This rippling is caused due to the

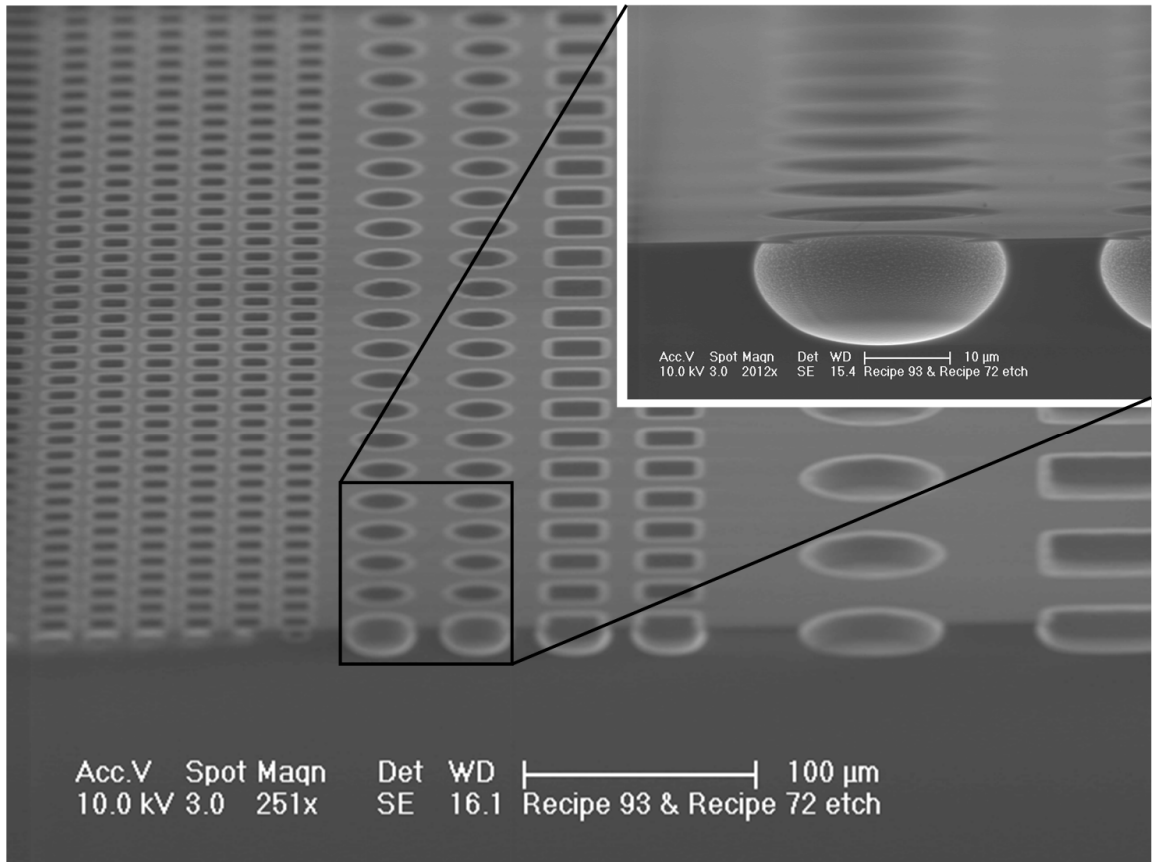


oxide being too thin. In this case only 350 nm, not the suggested 500 nm, was used and thus after the undercutting, the oxide layer began to ripple under stress. The inset in Figure 2.18 shows the undercutting of the circular opening. The etched region is rounded because of the isotropy of the etch and the shape of the masked area. This is the expected result for this etch.

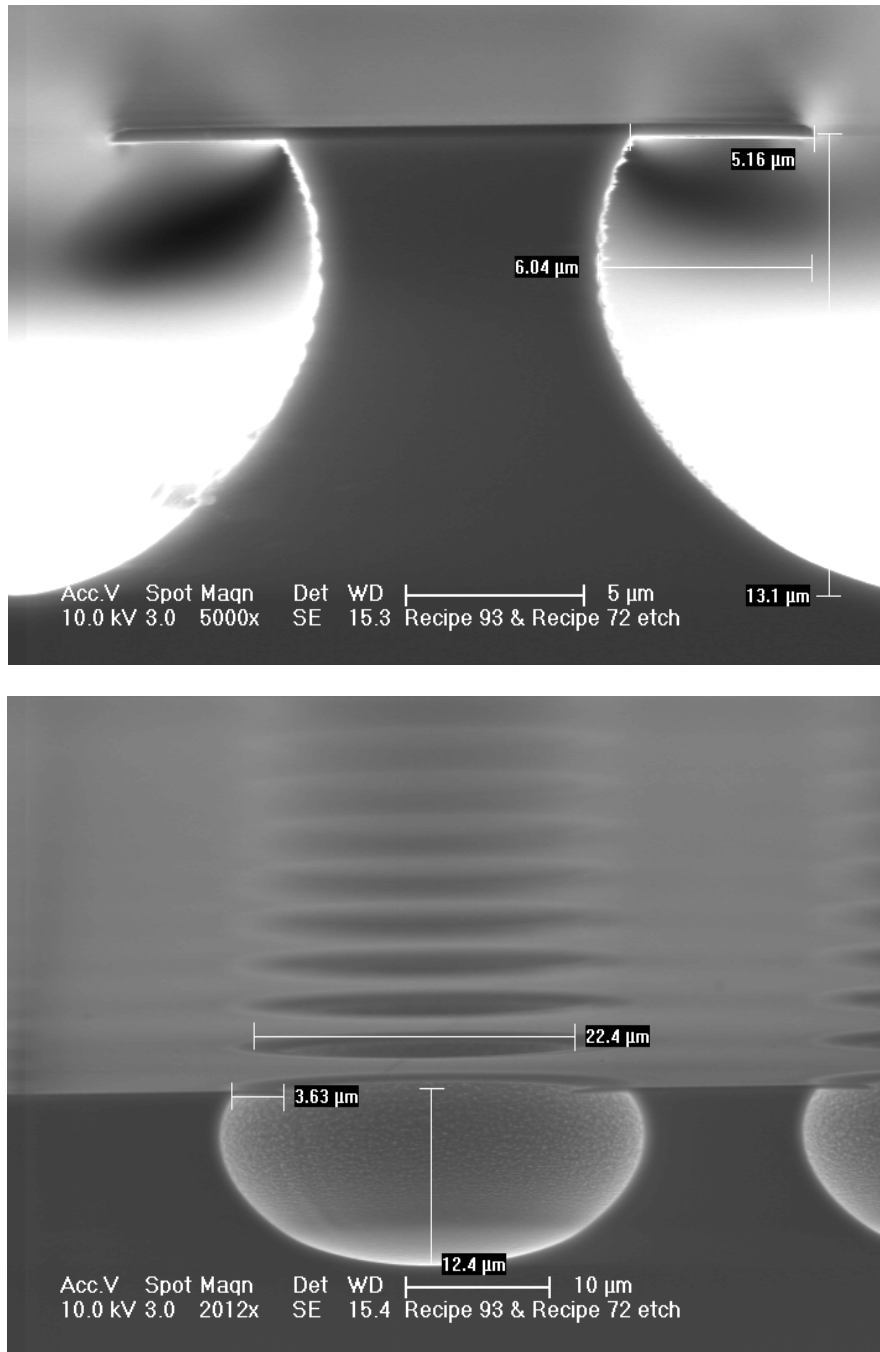
By tilting the stage less, a straight on view of the edge of the sample can be obtained as in Figure 2.19. These show measurements of the regions for rate reference. Unlike the oxide etch, these rates can change based on the mask design and exact chamber conditions. So, an etch rate is not the best determination of the condition of the system. What is important is the undercutting of the sample. As can be seen in the waveguide structure in Figure 2.19, the undercut is a little less than half the etched depth. This is normal for this etch. This biasing of the lateral to vertical etch rates is an important characteristic of the recipe. These will differ for structures such as the photonic crystals, so it has to be calibrated for other structures. Another important feature is the roughness of the silicon. From these images, it is not easy to see the silicon surface roughness. This will now be explored in context of the photoresist masked sample.



**Figure 2.17** Oxide masked waveguides. The oxide shows the initial size of the guides and shows the undercut. The inset shows the waviness of the oxide caused by a thin oxide layer and a large undercut.

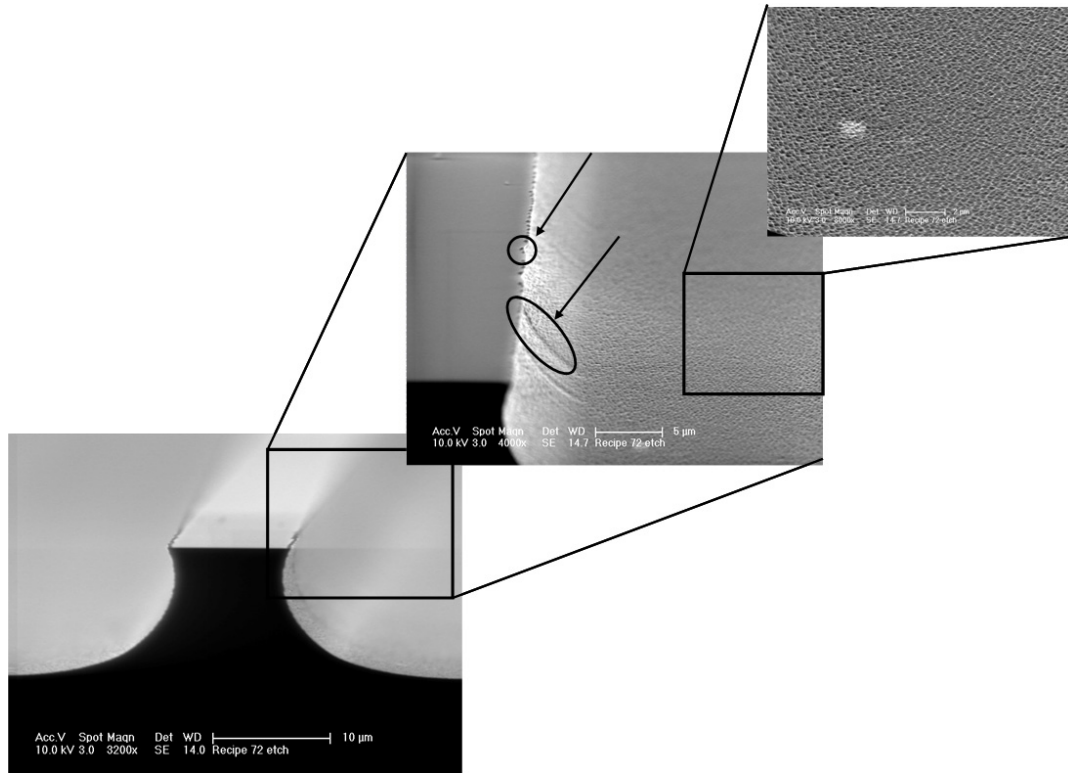


**Figure 2.18 Photonic crystal structures as etch tests. The inset shows a close up of the etched region where the undercut is more visible.**



**Figure 2.19 Measured waveguide and photonic crystals for reference of the isotropy of Recipe 72.**

In addition to imaging the oxide masked sample, the photoresist masked sample can also be imaged to gain important information about the etch. Imaging this sample can be easier as it does not have an oxide layer and thus does not suffer from charging in the same way that the oxide masked sample can. Figure 2.20 shows 3 images of the resist masked sample. The bottom image is a zoomed out view of the waveguide. The most noticeable feature is the fact that the undercut is smaller. This is because there is not a hard oxide mask as there was in the previous sample. Because of this, as the silicon under the photoresist is etched away, it cannot support its own weight and gives way. This then causes the masked area to shrink. This causes a slightly rougher surface as can be seen in the two insets. The middle inset has two features called out. These are a defect in the lithography and the resulting pattern transfer into the silicon. Thus the extra trench is caused by the lithography and not the etch roughness. The last inset shows the roughness of the sample. In general, the silicon surface is greatly roughened by this etch. The etch can be even rougher if the surface is not clean initially. In the case of Figure 2.20, some of the extra roughness is caused by the fact that a hard mask was not used. An oxide hard mask can greatly reduce the roughness as it does not degrade the same way that the resist mask does as the underlying silicon is removed.



**Figure 2.20** SEM images of an etched waveguide with just a photoresist mask. Notice the small overhang because the silicon was etched away. The first zoom shows the roughness of the waveguide edge. The circled regions are regions of lithographic roughness and the corresponding areas of transfer into the silicon. The last zoomed in feature shows the roughness of the surface.

From the previous discussion, it should be evident why an oxide mask is usually used when using Recipe 72 for etching silicon. Even with an oxide mask, there are times that the etch may not produce the results that are expected. A common problem is, having extra unwanted roughness in the silicon. If the silicon looks rougher than in Figure 2.20, there may be sample or surface contamination. Check that the sample was properly cleaned before performing the oxide deposition and/or lithography. Also, there could be contamination in the chamber that can be removed

by running a TMP clean and long Hi-Lo clean. Also, a longer precondition can help to reduce roughness in some cases. Also, a new carrier wafer may help to clean up the etch if it is getting old or is contaminated. In addition to roughness, the isotropy of the etch is important. If the isotropy is vastly different, the MFCs or DG1 may have to be re-zeroed. For fine tweaking or process control, please see Section 2.7 for more information on changing the isotropy of an etch. When editing a recipe, it is always a good idea to make a copy so that other users' processes are not affected.

### **2.6.3 Recipe 71-Time Multiplexed Anisotropic Silicon Etch**

Recipe 71 is a time multiplexed etch for the anisotropic etching of silicon. The name, time multiplexed etch, comes from the fact that it is a looped recipe instead of a continuous etch. The purpose of this etch is to get a very anisotropic etch with clean, vertical side walls. This is important for etching optical waveguides in SOI. Unlike the previous etches, this etch is performed on SOI because of its use for optical devices. Most silicon etches have some amount of isotropy, which is unwanted in the fabrication of optical devices and can cause loss. This recipe uses multiple loops of short steps to perform the etch. The recipe has both an etch and deposit step, with the deposit step being the key to the anisotropy of the etch. The etch is based off of the Bosch etch that was developed at Robert Bosch GmbH [12].

#### **2.6.3.1 The Recipe**

The steps of the time multiplexed etch will now be covered including a short explanation for the purpose of each step. Table 2.4 provides a listing of the steps and their parameters for reference.

**Table 2.4** The parameters of Recipe 71-MJZ 250S (multiple loops)

Step	Gases	Pressure/Position	ICP/BIAS (W)	Time
1	--	100%	0/0	10 sec
2	20 sccm C <sub>4</sub> F <sub>8</sub>	4 Pa	0/0	15 sec
3	20 sccm C <sub>4</sub> F <sub>8</sub>	4 Pa	450/0	3 sec
4	20 sccm C <sub>4</sub> F <sub>8</sub>	4 Pa	450/15	7 sec
5	--	100%	0/0	10 sec
6	25 sccm SF <sub>6</sub>	2 Pa	0/0	15 sec
7	25 sccm SF <sub>6</sub>	2 Pa	500/0	3 sec
8	25 sccm SF <sub>6</sub> , 5 sccm Ar	2 Pa	500/100	2 sec
9	25 sccm SF <sub>6</sub> , 12.5 sccm Ar	0.75 Pa	500/25	9 sec
10 (group B)	50 sccm O <sub>2</sub>	5 Pa	500/10	30 sec

The first step of the recipe is a chamber evacuation step. This is done by putting the CGV into position mode and opening it up all the way. As this is a multiple loop process, this runs at the beginning of each loop to ideally make sure each loop starts with similar conditions. The second step is a C<sub>4</sub>F<sub>8</sub> addition step, which allows for pressure and gas flow stabilization. The third step adds ICP power and is a short step for power and pressure stabilization. The fourth step is the first “important” step as it is the step where bias is applied and is the polymer deposition step. It might seem unusual that the deposition occurs before the etch. This is so that each etch step will have to break through the same polymer barrier to start the etch and thus keeping all the loops of the etch the same. Be sure to watch this step as sometimes it has trouble matching, which can cause a lack of polymer deposition. Unfortunately, there is not really a way to easily fix this problem mid process. However this problem can be alleviated in the future by running a longer precondition to make sure that the system is acclimated to the matching conditions.

After this deposition step, there is another evacuation step that is identical to the first step. After this step, SF<sub>6</sub> is added to the chamber and the pressure is set



just like step 2. Then the ICP power is added and allowed to stabilize. The following step adds argon and turns on the bias. The argon helps to dilute the  $\text{SF}_6$  and also provide a physical component to this step. The purpose of this step is to punch through the polymer layer and allow for the actual etch step to be more effective. After the punch through is the actual etch step for the process. The reduction of the set pressure causes the CGV to open more thus removing etch particles more efficiently and slows the etch by lessening the amount of reactants available for etching. The addition of the argon also helps to further dilute the gases and slow the etch rate. The purpose of slowing the etch is to require more loops to get to the final etch depth. This helps to remove strong scalloping from the side walls of the etch. Scalloping occurs because each etch step is itself isotropic so it etches outward before it is backfilled with polymer. By having shorter etches, the lateral etch amount between polymer depositions will be smaller and thus smaller scallops. Pictures showing the scallops are shown in the etch results section (2.6.3.3). Another parameter to take note of in this step is the bias. The bias has been lowered in step 9 to lower the physical effects of the etch and also better preserve the photoresist. This is because a higher bias makes an etch more physical and also reduces the selectivity.

This concludes all the steps in step group A for the etch. The steps listed above constitute a single loop of the etching process. The number of loops that need to be run depends on your specific substrate and etching requirements but some of these will be discussed in the etching and results sections. The final step listed in Table 2.4 is an oxygen plasma step that is in step group B. This step is the same as the Recipe 3 oxygen plasma and is duplicated here for easy access to an oxygen plasma for removing resist after the etch has finished.

### **2.6.3.2 Preparation and Etching of a Test Sample**

For this example etch, we will be using 250nm device layer SOI as it is the substrate most often used for this etch and changing the substrate can change the chamber impedance slightly thus changing the plasma and etch characteristics. The sample does not have to be very big and can be as small as 1x1 cm or up to 2x2 cm. If the sample is too large it ends up wasting material and if it is too small it will be hard to handle and suffer from plasma edge effects. As previously mentioned, this etch is normally used for etching waveguides in SOI. Because the waveguides are very small, they must be written in PMMA using e-beam lithography, which is costly and time consuming. Unless you are performing a calibration for your specific process or need features made with e-beam lithography, it is best to stick with UV lithography if possible to save time. UV lithography will be used to save time over e-beam lithography. However, it can be used if necessary. For more information on structures made using this etch and e-beam lithography, see [13-18]. The cleaning process for these wafers is the same as that used for the blank silicon wafer for Recipe 72 (Section 2.6.2.2). However, if you were choosing to use e-beam lithography, it would be required to do the piranha and BOE process twice to minimize contamination introduction into the system, which can cause major problems in the e-beam system. For the UV lithography, the standard procedure for AZ 5214-E mentioned in Section 2.6.1.2 can be used.

After it has been verified that the lithography was good, it is time to mount the sample and prepare for etching. Unlike the other etches, the etch and precondition wafer can be the same wafer. This is because the etch is not as aggressive as the others and also the wafer will have a thin coating of the polymer, which will make it more acclimated to the chamber conditions. Before mounting and

loading your sample, a chamber precondition should be performed as described in Section 2.4.3. When starting from a clean chamber 15 loops is a good precondition. However, if the etch results are not satisfactory, you can increase future preconditions to 20 loops to help provide better chamber passivation. After the precondition, you can finish mounting your sample to the carrier wafer.

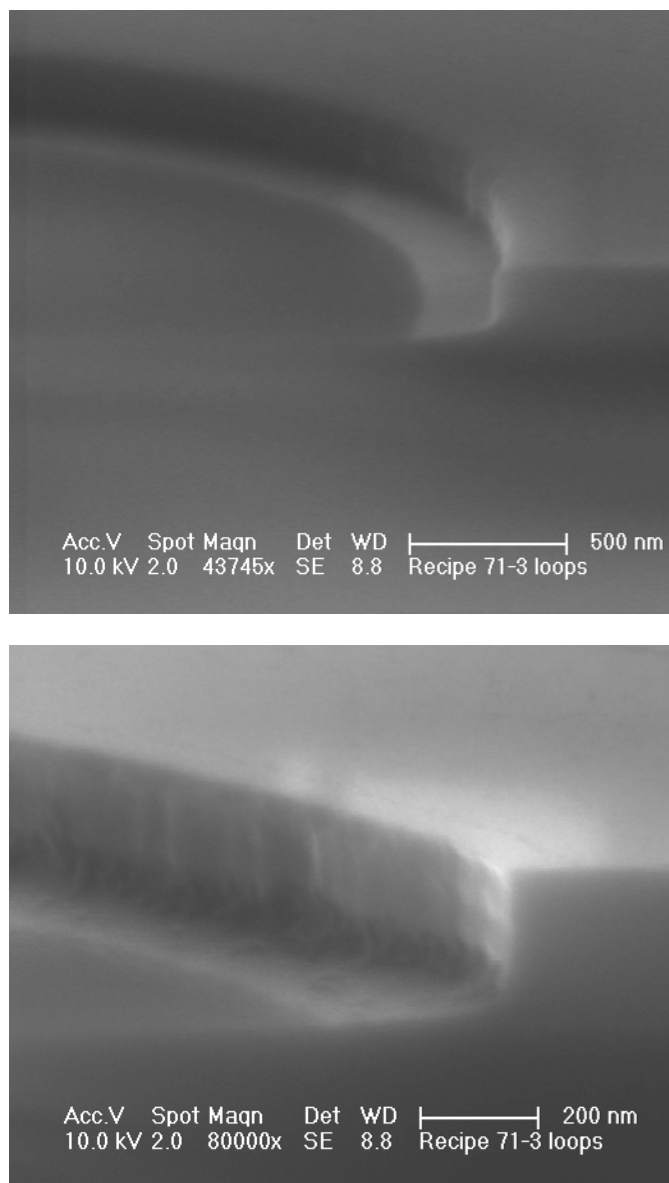
The actual etch of the sample is rather straight forward. As opposed to the other recipes, the etch time is not changed but instead the number of loops is changed. The actual etch should be completed in about 3 loops. After the 3 loops have completed, remove it from the chamber and inspect it with the visual microscope. The features on this mask are large enough that you should be able to see if the areas have cleared in the etch. Cleared areas will be a purple/gray color. This color is from the 3  $\mu\text{m}$  Buried Oxide layer (BOX) between the top silicon device layer and the bottom silicon handle. When the top silicon is removed the BOX layer is visible thus giving the purple/gray color. Areas that are un-etched will look greenish (for 250 nm Si on 3  $\mu\text{m}$  BOX) if there is silicon but no resist. If there is still resist, the color will vary based on the thickness of remaining resist. If the resist is depleted from an area during etching then that silicon area could be thinner and thus be a different color. If the sample is placed under the optical microscope, the un-etched areas will be shiny and will be a greenish/yellow color if the resist is removed. If there are areas that are unmasked but have not totally cleared, run it one loop at a time until it clears. Once the sample has been completely etched, run a 2 minute oxygen plasma. Afterwards inspect the sample to make sure that the areas with silicon are a green color by eye and look very shiny under a microscope with no traces of resist. If you are unsure, you can put the sample in acetone and then look at it under the microscope to see if the

resists cracks as discussed for Recipe 93 (Section 2.6.1.2). For these etched structures, an acetone ultrasound can be used to remove the resist. However, this is not suggested as many structures etched in this recipe are quite thin and would be destroyed by the ultrasound. After the resist is removed, the sample can be prepared for imaging and analysis.

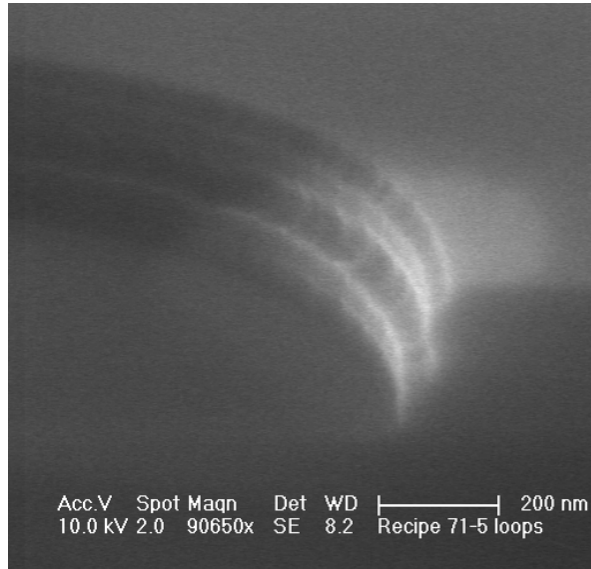
### **2.6.3.3 Etch Results**

There is not much which can be learned quantitatively from optical microscope images of these samples besides determining if resist is present or if the silicon device layer has been completely etched away. SEM images must be taken to determine the characteristics of the etch. Figure 2.21 shows an image of an etched sample. Because the device layer is insulated from the wafer back by the buried oxide layer, these samples suffer from charging in the SEM. To help mitigate this charging, carbon tape is often taped across to the front of the sample on top of some of the silicon to help give the electrons a path to ground. The structure in Figure 2.21 is a circle that has been cleaved through. The light ring on the bottom of the etched region is residual silicon that was not completely etched. To remove this layer, another loop of the recipe has to be run. The second image in Figure 2.21 shows a different view of the same structure. Upon close inspection of the sidewall, there are 3 distinct loops visible. These are the three etching loops with the bottom area being a dark gray because it has not been back filled with the deposited polymer. Figure 2.22 shows the sample after 5 loops were run. This shows more clearly the effects of the isotropy of the etch. The scalloping of the side is more evident. One reason for the extra scalloping is the etching of the photoresist around the edge of the feature. As the resist was etched, it caused the top surface of the silicon to be re-etched. Figure 2.23

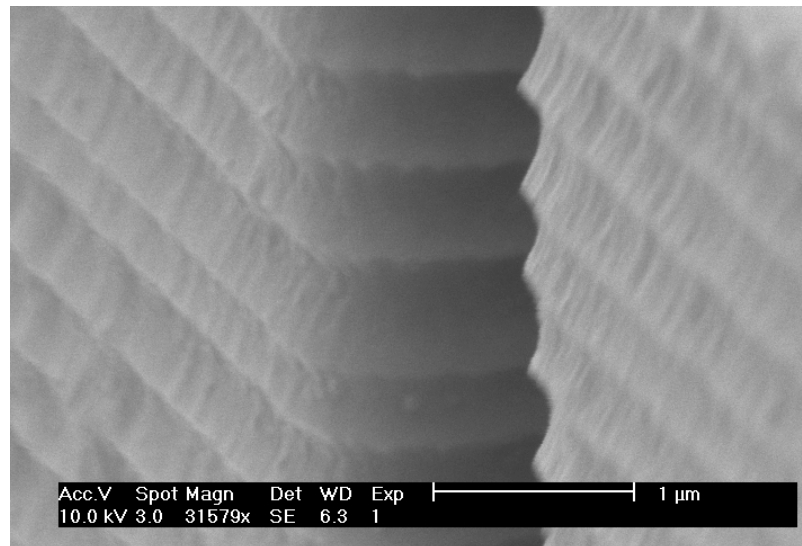
shows an image highlighting an etch with scalloped sidewalls. Based on these two etches, 4 loops should give the ideal balance of fully etching the features without eroding the photoresist. However, remember that rates can shift slightly over time and should be rechecked.



**Figure 2.21** Etch profile after 3 loops of Recipe 71. Top: Etched SOI sample with a small ring of residue along the bottom edge of the etched region. Bottom: A different view of the top structure showing that the last etch loop has not been filled in by polymer unlike the previous loops.



**Figure 2.22 Etch profile of a photonic crystal hole after 5 loops**



**Figure 2.23 Structure etched using a Bosch etch showing the scalloping that occurs from each successive etch loop. (Source: [http://en.wikipedia.org/wiki/File:Bosch\\_process\\_sidewall.jpg](http://en.wikipedia.org/wiki/File:Bosch_process_sidewall.jpg))**

The above structures are test structures using AZ 5214-E as opposed to structures written in PMMA with e-beam lithography. The e-beam lithography system will provide better resolution and cleaner structures than UV lithography. PMMA also provides good etch resistance when properly processed, thus preventing over etching as is seen in Figure 2.22. Ideally an etch should show little scalloping as is shown in Figure 2.21 and should be etched the entire way down, thus showing no residue. Unlike Recipes 93 and 72, Recipe 71 is very application specific and, for new designs and processing flows, more changes may need to be made to the recipe. Changes such as changing gas flows, pressure, and times have been made by various users over the years for specific processes. For more information on effects of changing various etch parameters, see Section 2.7. Whenever making major changes such as these to a recipe, remember to make a copy of the recipe and leave the original for other users.

## **2.7 Effects of Etch Parameters**

The exact chemistry and physics behind plasma etching is very complex and is still an area of research today. Section 2.1 briefly discussed some of the theory and ideas of plasma etching. This section will go a little more in-depth into the effects of the different parameters that can be varied. Because of the great complexity of this topic, many books, papers, and theses have been dedicated to this topic. Some examples of these are listed as references [16-28].

The RIE-ICP has a considerable advantage over a conventional RIE system in that the excitation coils are external to the chamber. This allows for them to be shielded from the gases in the chamber which can extend their lifetime. In addition to isolating the coils from the chamber, an ICP is able to excite more ions and radicals



than a standard parallel plate RIE, thus increasing the effectiveness of the etching. The RIE works by ionizing the gases that are in the chamber, thus creating a plasma composed of different components including ions and radicals. The ions are very dense and when accelerated towards the sample by the bias create a physical etch like sputtering. Radicals on the other hand react with the sample material to create a chemical etching process. A physical etch is in general more anisotropic than a chemical etch. This is because a chemical etch attacks in all directions while a physical etch just attacks in the direction of impact. This direction is usually perpendicular to the sample surface thus being more anisotropic. In addition to being more anisotropic, a physical etch affects all exposed materials and as a result is less selective than a chemical etch. There are many parameters that affect the effectiveness and properties of these two processes.

The first parameter that drastically affects the etch are the gases and their flow rates/ratio. Certain gases, such as argon, do not produce radicals and thus only lend to physical etching.  $\text{SF}_6$  on the other hand produces a radical, which lends itself to chemical etching. By creating different gas recipes, an etch can be made both physical and chemical. Also, the addition of other gases such as  $\text{H}_2$ ,  $\text{O}_2$ , or  $\text{N}_2$  can change the etch chemistry. For example, adding  $\text{H}_2$  to  $\text{SF}_6$  will change the selectivity of the etch by creating gaseous  $\text{HF}$ , which selectively etches  $\text{SiO}_2$  over  $\text{Si}$  [21, 25]. Another important example is the addition of oxygen. Adding oxygen to an etch has the effect of reducing selectivity and etching the photoresist mask more rapidly. Some specialized etches, performed at cryogenic temperatures, use oxygen to oxide the sidewalls thus allowing for a more anisotropic etch with  $\text{SF}_6$  [22, 23, 27, 28]. The gases are very important to the etch chemistry, which can be quite complex. Different

chemistries will also selectively etch certain materials in a preferential direction because of their crystalline structure.

In addition to gas flows, the chamber pressure affects the etch characteristics. The pressure affects the density of species in the chamber which in turn changes the density and mean free path between the species. This affects whether the etch is physical or chemical along with the etch rate and degree of isotropy of the etch. As the pressure decreases, there are fewer reactive species available to take part in reactive etching. Thus chemical etching processes are not as prevalent. At the same time, fewer species means that there will be fewer interactions in the chamber as an ion travels towards the sample. This will result in higher kinetic energy thus creating a more effective physical etch. A more physical etch usually results in a reduction of selectivity, which can erode a mask faster. Along with being a more physical etch, it is also more anisotropic. Physical etches are by nature anisotropic, however with the lower pressure and fewer collisions the ions will be directed more perpendicular to the sample thus being more anisotropic than if there were collisions. As the pressure increases the ions have more collisions and eventually at high enough pressures the collisions reduce the energy of the ions to the point where they cannot gain enough energy to provide a physical etch. At this point the etch becomes more chemical. Along with reducing the physical etch the chemical etch is increased by the number of reactive species available. In this regime of chemical etching an increase in pressure will increase the etch rate and also increase the isotropy of the etch.

The last major parameter which can be adjusted in the RIE 200iP system is the ICP and bias powers. The frequency is fixed at 13.56 MHz and cannot be changed. As the ICP power is increased, there is an increase in ionization of the gas

and thus the number of species in the plasma. Because of this, there are more ions and radicals to take place in etching, so the rate increases. In addition to changing the ICP power, changing the bias can affect the etch characteristics. By increasing the bias, the directionality of the species is increased. This will increase the number of ions and radicals interacting with the sample thus increasing the etch rate. The increased bias also increases the ions' energy. This extra energy allows the ions to impact the sample with more force thus increasing the etch rate. The extra physical etching along with increased directionality of the impacts makes the etch more anisotropic. At the same time, it also decreases selectivity since it is a more physical etch.

The topic of RIE processing is a vast and complicated topic. There are many more variations of parameters than discussed here. More information can be found in references [16-28] along with many other sources. Reading these resources and others can help to increase one's knowledge of ICP etching and provide the ability to modify recipes to better provide the desired results.

## **Chapter 3**

### **PECVD (SAMCO® PD-220N)**

The Samco® PD-220N is a complementary tool to the RIE-200iP. It is a Plasma Enhanced Chemical Vapor Deposition (PECVD) system. Unlike the RIE-200iP, it serves the purpose of depositing material instead of etching it. In many cases, materials that are deposited in the PD-220N will later be etched in the RIE-200iP. This chapter will discuss the PD-220N PECVD using a similar structure to the RIE-200iP. At times, discussions of certain items will be shortened as they are the same as the RIE-200iP, so refer to the appropriate section in Chapter 2 for more information.

#### **3.1 Theory of Operation**

The theory of operation of the Plasma Enhanced Chemical Vapor Deposition (PECVD) is very similar to the ICP except that it is used for depositing materials instead of etching them away. A CVD system uses reactive precursor gases and a high temperature to facilitate a reaction that causes the deposition of a film based on the precursor chemistry. The advantage of a PECVD over a standard CVD system is the lower processing temperature. This lower processing temperature is obtained by using RF power to generate a plasma thus supplying the extra energy needed. They usually run at temperatures of 200-300°C and use a RF source (13.56 MHz for the PD-220N) to generate the plasma. The gases in the chamber are able to react. An example is  $\text{SiO}_x$ , which is deposited through a mixture of  $\text{SiH}_4$  and  $\text{N}_2\text{O}$ . By

varying the ratios appropriately the x can be changed to range from SiO to SiO<sub>2</sub> and even other ratios.

The film quality and deposition rate are controlled by many different parameters, some are controllable and others uncontrollable. An important differentiation to cover is homogeneous versus heterogeneous deposition. Homogeneous deposition occurs in the chamber above the wafer and thus results in poor quality, low density, high defect films [20]. Heterogeneous on the other hand occurs on the wafer surface and produces a much higher quality film. The high reactivity of the gases makes heterogeneous deposition difficult in some situations. By having the wafer at a higher temperature than the rest of the chamber, deposition will preferentially occur on the wafer thus helping with film quality and uniformity.

In addition to homogeneous and heterogeneous deposition, there are other important characteristics of a deposition. The density of the film, stoichiometry, deposition rate, and general film quality are all very important. The gases and flow rates, RF power, temperature, and pressure all have important effects on the deposition process. A more in-depth discussion is presented in Section 3.7.

### **3.2 Pre-Operation Checklist**

The PECVD pre-operational check list (shown in Figure 3.1) is very similar to the ICP checklist except it is tailored to the facilities for the PECVD. The checklist is in the black binder located on the shelves on the right side of the PECVD chase. The chase is pictured in Figure 3.2 for reference during this section. As with the ICP, the checks should be performed each time before you use the equipment.

PECVD Pre-Operational Check List									
Date									
Upon entry, make sure that there are no alarms buzzing.									
Check that GBV1 and GBV2 (gauges above pumps) read ~2.5L/min. Record									
Ensure CSV, ESV, HPI, LPI lights are on and screen flashes 'system ready' on Silane cabinet.									
Ensure CSV, ESV, HPI, LPI lights are on and screen flashes 'system ready' on Ammonia cabinet.									
Ensure power and valve open lights are on for Nitrous Oxide cabinet.									
Check if the chiller is ON and record temp (~20°C).									
Check that the chiller is at least half way filled.									
Check the oil levels in the pumps. The levels should be above halfway between Min. and Max. levels.									
Check that the bumbox temperature is below 30°C and the flow rate is above 200 LFPM. Record them.									
Check that output pressure of gasses is ~15 PSI. The ammonia and nitrogen tanks will be higher.	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:
Check the tank pressure and make sure it is not running low. (Hexafluoroethane will always read in the zero region as it is a low pressure tank.)	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:	N2: SiH4: N2O: Ar: NH3: O2: C2F6:
Signature of Person									

**Figure 3.1 PECVD Pre-Op check list located in the chase**



**Figure 3.2** Top: Inside the PECVD chasing, viewed from the entrance, showing a gas cabinet on the left and two more on the back right. Bottom: The burn box, pumps and chiller located across from the back gas cabinets.

The first item on the list is the same as for the ICP, check that no alarms are sounding. For the PECVD there are more alarms that could be sounding. In addition to the room alarm, there are also 3 gas cabinets and the burn box, which all have alarms that are individually controlled. If you enter the room and the alarms are sounding, you should immediately leave and get someone to help with the situation unless you are familiar with the alarm silencing and resetting procedures. If there are no alarms sounding, then the next check is that GBV1 and GBV2 are flowing  $\sim 2.5$  L/min nitrogen. These are flow meters which control the nitrogen flow through the gas ballasts of the two roughing pumps and are located to the left of and just above the roughing pumps for the PECVD. The pumps are located on the back left side of the chase. If the flows are too low, they will not provide the properly flow of nitrogen to help with dilution and pumping of the gases. If they are too high, extra oil will be pushed out through the pump exhaust both wasting oil and creating a mess in the exhaust system.

After checking the gas ballasts, the gas cabinets are next on the list. The silane and ammonia tanks are located across from the pumps and are labeled thus. Looking at the display above the cabinets, verify that CSV, ESV, HPI, and LPI are all on along with the LCD reading system ready. These lights being on signify that the correct valves are open for gas delivery. If there are any alarms or red lights flashing let the equipment supervisor know so they can check the system before using the PECVD. In addition to the silane and ammonia tanks, there is also the nitrous oxide tank located next to the entrance, which has to be checked. The nitrous tank has a much smaller display panel. Once again, there should be no alarms sounding and the power and valve open lights should be illuminated. If the valve open light is off, turn



the key to purge, press station reset, and then turn the key back to normal and press station reset. This should open the valve and cause the valve open light to become illuminated.

After checking the gas cabinets, the next check is the chiller. It is located on the left side of the room against the back wall. It should read 20°C and should be about half way filled with water. To check the water level, use a flashlight to look through the side of the frosted water tank. There is a flashlight located on the metal structure above the chiller. If it is low or the chiller does not seem to be running correctly, let the equipment supervisor know. After checking the chiller, the oil level in all 3 pumps should be checked. These pumps are located to the left of the chiller. The front pump is RP2 (hydrocarbon), the back pump is RP1 (Fomblin®-PFPE), and the green pump above RP1 is the MBP. All of these pumps should be filled around half way with oil. If the oil is below quarter full or is discolored, let the equipment supervisor know before use.

After checking the pumps, the burn box, located above the pumps, needs to be checked. The burn box takes the exhaust from gas purge lines and the PECVD vacuum system and mixes it with room air. The mixture travels through a series of baffles giving it time to react and burn. At the end of the burn box, all the gases have reacted and are safe to be exhausted through the building exhaust system. The screen on the burn box displays the air flow in LFPM and temperature in degrees Celsius. The flow should be at least 200 LFPM and ideally >210 LPFM. The temperature should be <30°C and ideally around room temperature. If the air flow is low, then there may be a problem with the building exhaust so talk to the cleanroom coordinator before using the PECVD.

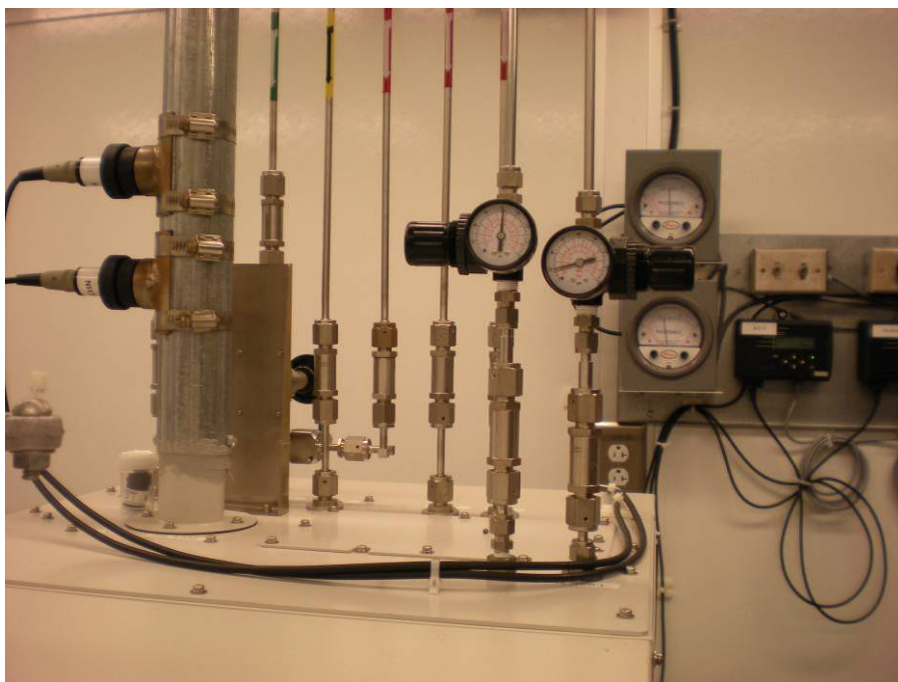
The last check can be quite time consuming, but it is a good practice that should be followed whenever using a machine. This check is checking the pressures, both input and output, of the gas cylinders. The first few times you perform these two checks it will be quite time consuming, however you do not need to give an exact reading from each gas but just an approximate reading. The importance of taking these readings is to make sure that none of the tanks are running low as some of these tanks may have a long lead time. Also, it is good to make sure that none of the output pressures are out of range. All of the gases should be around 15 psi. If the pressure is  $\pm 5$  psi it should be fine. However, if the pressure is off by more than this, let equipment supervisor know, especially if the last recorded reading was at a normal pressure. The nitrogen tank that should be used for your reading is the high purity nitrogen tank located on the wall to the right of the hexafluoroethane ( $C_2F_6$ ). The tanks inside the cabinets and next to the silane cabinet are purge tanks and are not used for processing. These are used in the automatic purging sequences of the gas lines in the gas cabinets. Also, hexafluoroethane ( $C_2F_6$ ) will always read zero on the tank side of the regulator because the input scale is very large and does not accurately show the tank pressure. After completing the chase checks, you can go into the clean room to prepare to use the PECVD.

Unlike the ICP, the PECVD does not have a check list in the clean room but just a user log. There are still a few things that should be checked before you use the PECVD. The first is to check the temperatures on the front of the PECVD and TEOS unit (shown in Figure 3.3). Behind the window in the bottom front panel of the PECVD, there are two rows of temperature controllers. The bottom row should read  $\sim 100^\circ\text{C}$  each, they can vary slightly but should be close. There is a similar window on

the TEOS unit and those displays should read 80-85°C. More information on the heaters including how to turn on the TEOS heaters, if they read around room temperature, is located in Section 6.5.



**Figure 3.3** Left: The PECVD system with the TEOS cabinet on the left. Right: a close up of the heater controllers and on switch for the TEOS cabinet.



**Figure 3.4** Top of the PECVD showing the nitrogen and compressed air regulators along with the process gas inlets

After checking the temperatures, the next check should be that the input compressed air is 0.5 MPa-0.7 MPa and nitrogen is 0.1 MPa (Figure 3.4), just like with the ICP. If these are correct, next check in the log book to see what the total deposited thickness is. If this thickness plus the thickness you plan to deposit will be over 5  $\mu\text{m}$ , a clean should be run before running your process. Cleaning procedures are covered in the maintenance Section 3.5. If the total deposition thickness is thin enough, then verify that the computer is on. If it is not, turn it on. The login is administrator and there is no password. The last check is whether  $\text{N}_2$  or Ar is currently run to MFC4. To determine this, look along the left side of the screen and see what the 4<sup>th</sup> gas is. If you are unsure about where to check, see Section 3.3 for a more in-depth explanation. If the gas is the correct gas, then you should also check

the valve on the back of the machine to verify that the correct gas is actually selected. To do this, check that the gas you are not using is closed. The valves for the gases are located on the top of the backside of the machine. If it is closed, then make sure the gas you want to use is open. Do not check that the gas is open unless you have verified that the other gas is closed or you can contaminate the gases. If the wrong gas is selected, see the maintenance section (3.5) for information on changing gases. Also, if you are unsure of how to check the gas valves, see the maintenance section (3.5) for more of a description.

The last two checks are the DG and the MFC values. Like on the ICP, you should check that the DG has a value of  $\sim 0.0$  and that all the MFC values are around 0. If DG or any of the MFC values are significantly off, let the equipment supervisor know so they can be fixed as they greatly affect your process. For more information on reading the DG and MFC actual values (not set values) see the description of screens section (3.3). After these checks have been performed and passed, the PECVD should be ready for use.

### **3.3 Description of Screens/Listing of Symbols**

Like in the preceding discussion about the ICP, the different screens for the PECVD will be listed but only the MAIN screen will be discussed in depth as the other screens are discussed in chapter 9 of the manual [29] and will be covered in subsequent sections. The first screen is the MAIN screen (page 64 of PECVD manual [29]) and shows the block diagram schematic of the system. As with the ICP, if the SET button is pressed, another set of screens is opened. The other available screens are Mode, Prog, Recipe, Config Auto, Config Device, Serv, Event Log, Data Log, and Other. Config Auto and Config Device have a + in the bottom corner of their icon

indicating that they contain multiple screens, which can be paged through by repeatedly pressing their icon. The main screen will now be discussed with Table 3.1 serving as a reference for the abbreviations on the screen.

**Table 3.1** Table showing abbreviations used on PECVD Main screen.

<b>Symbol/ Abbreviation</b>	<b>Meaning</b>	<b>Purpose</b>
GSV1-8	Gas Safety Valve	Seals off the gas inlet from the system for safety purposes
GV1-8	Gas Valve	Allows gas flow into the gas mixing manifold
MFC	Mass Flow Controller	Controls the flow of gas during processing
BPV1,2,9	Bypass Valve	Allows for quick venting of hazardous gas lines, thus bypassing the MFC. Also allows for betting line evacuation
SSV1	Safety Shut-Off Valve	Isolates the gas mixing manifold from the chamber. Opening allows gas flow into the chamber
SSV2	Safety Shut-Off Valve	Isolates the gas mixing manifold from the chamber. Opening allows gas flow into the chamber
GTA8 (GTVA8)	Gas Tank Valve	TEOS tank output (vent) valve
DG	Diaphragm Gauge	Reads relative chamber pressure, used for process pressure measurement
ISV1	Isolation Valve	Isolates DG from the chamber
GTB8 (GTVB8)	Gas Tank Valve	TEOS tank nitrogen input (dip) valve
ISV2	Isolation Valve	Isolates FRG from the chamber
GTC8 (GTVC8)	Gas Tank Valve	TEOS tank nitrogen bypass
FRG	Full Range Gauge	Full Range Gauge measuring the chamber pressure from atmosphere to high vacuum
RP2	Roughing Pump	Hydrocarbon pump for backing TMP2 and roughing the chamber
BV3	Backing Valve	Controls roughing of the chamber through RP2
BV6	Backing Valve	Backing valve for the TMP2. TMP2 is backed by RP2
TMP2	Turbo Molecular Pump	High vacuum pump for pre and post processing chamber pumping
BV2	Backing Valve	Controls the pumping of the chamber through TMP2
TPV2	Turbo Purge Valve	Provides a nitrogen purge for the turbo
TLV2	Turbo Leak Valve	Vent of turbo backing line
PLV2	Pump Leak Valve	Vents the chamber roughing line
RP1	Roughing Pump	PFPE filled pump for backing MBP
MBP	Mechanical Booster Pump	High vacuum pump for processing
BV1	Backing Valve	Seals the MBP from the chamber
CTV	Control Valve	Control valve for adjusting flow through MBP to achieve pressure
CTRL	Control	Switches the CTV from open mode to pressure control mode
PV1	Purge Valve	Provides nitrogen purge for gas dilution in RP1
PLV1	Pump Leak Valve	Vents the vacuum line between the chamber and MBP
RC	Reaction Chamber	Reaction chamber-where samples are placed and deposition occurs
RF	RF power	RF power to strike the plasma
LV1	Leak Valve	Leak valve for venting the chamber
RC Lid	Reaction Chamber Lid	Controls for opening and closing the lid of the reaction chamber

As done with the ICP, the Main screen will be discussed in functional blocks starting with the top row of the screen. On the left side of the screen is the Mode box, which indicates if the system is in Auto or Manual mode. Manual mode uses the setpoints in Recipe 101 for operation. Next to the mode box is a box containing information about the current process. The current process is displayed as follows: program\_number - order\_number / recipe\_number - current\_step (loop\_count). Below this box, the current step that is executing is displayed. This could be a system process such as RC Vacuum or the step # of a recipe. On the right side of the screen is the Time box with the solid being the actual time and the bottom dotted box being the set time. This shows the time for the current step. Unlike the ICP, this timer counts up to the total time of the process which is shown in the set box. Finally, there is the SET button to switch to the SET group of screens.

Next there is the gas group along the left side of the screen. Similarly to the ICP, the PECVD has GSV (Gas Safety Valve), MFC (Mass Flow Controller), and GV (Gas Valve) to control and turn the gas flow on and off. However, there are several important differences between the gas layouts in the two systems. One difference is the addition of BPV (Bypass Valve). These are like vent valves on the chlorine ICP, however there are no similar valves on the fluorine ICP. They are to bypass the MFC for vacuuming out the gas lines. They should not be used except for by the equipment supervisor when performing special maintenance. Another difference is that there are two gas manifolds instead of one. The top manifold contains standard process gases used for most processing while the bottom contains the cleaning gases and TEOS. One reason for the separation is that oxygen and silane cannot be in the same manifold as they react very violently. For this reason, there is



an interlock preventing SSV1 (Safety Shut-Off Valve) and SSV2 from being opened at the same time. This being said SSV1 and SSV2 are the valves that isolate the manifold from the chamber. In addition to these valves, there are GTA8 (Gas Tank Valve A), GTB8 (Gas Tank Valve B), and GTC8 (Gas Tank Valve C) on the TEOS tank. These are for operating and purging the TEOS tank and will not be discussed here.

Located below SSV2 are the two vacuum gauges. Unlike the ICP, this system only uses two gauges. The top gauge, DG (Diaphragm Gauge), performs the same function as DG1 in the ICP, which is reading the chamber pressure during processing. The DG setpoint, for use by the APC, is in the bottom dotted box and the current value is in the top box. Notice that unlike the ICP, the DG only has one decimal point. DG is isolated from the chamber by ISV1 (Isolation Valve) while ISV2 isolates FRG (Full Range Gauge) from the chamber. FRG is a full range gauge and has both a pirani and penning gauge to get the full pressure range from atmosphere to high vacuum. This gauge takes the place of DG3 and IG in the ICP and is open except during processing. Located below the FRG readout is a box that says ATM. This is the atmosphere indicator that turns on to indicate that the chamber is at atmospheric pressure after performing a vent, so that you know the RC lid can be opened.

To the right of the vacuum gauges is the vacuum system. The vacuum system in this unit is comprised of 4 pumps instead of 3 like the ICP. There are two separate vacuum systems for the PECVD. The right system is for roughing and non-process high-vacuum. RP2 is a hydrocarbon filled roughing pump that provides roughing to the chamber through BV3 (Backing Valve). RP2 also provides backing

for TMP2 (Turbo Molecular Pump) through BV6 (Backing Valve). The turbo pump is connected to the system through BV2, which will open once the chamber is roughed to get to a high vacuum. TPV2 is a turbo purge valve and is on during normal operation. TLV2 (Turbo Leak Valve) and PLV2 (Pump Leak Valve) are leak valves to bring the vacuum lines to atmosphere when the pumps are off. The left vacuum system is the process vacuum system. This line has RP1, which is a PFPE-filled pump that serves to back the Mechanical Booster Pump (MBP). There are two valves between the MBP and the chamber. The top valve, BV1, is the actual isolation valve while CTV is a control valve, controlled by the APC based on the DG pressure, which adjusts for pressure regulation like the CGV does in the ICP. CTRL switches CTV (Control Valve) between position and pressure mode in the same manner as pressing M does for the ICP. PV1 (Purge Valve) is a nitrogen purge that must be on when the MBP is running to help dilute the gases. Unlike the TMP and roughing line, this is the line that is open during processing so it sees all the gases. The last item in the vacuum system is PLV1 (Pump Leak Valve), which is another leak valve for when the pumps are turned off.

Above the vacuum block are the chamber and lid controls. The chamber, labeled RC (Reaction Chamber), shows the setpoint and actual temperature of the lower substrate heater. During most processing, this temperature rises to 300°C. To the left of the temperature boxes is a button labeled Heat that enables and disables the heaters. The heaters should always be enabled whether they are set to room temperature or processing temperature. Above the reactor is the SV, set value, forward and reflected RF power. As with the ICP, ideally all the power should be forward and there should be no reflected power. To the right of these is the RF button

for turning on and off the RF power. Unlike the ICP, there is no BIAS so the RF power is all controlled through this one button. Between RF and LV1 is a Front Cover indicator. Below Front Cover is a box that says CL. This is the indicator for the front door of the PECVD. When the door is closed, it is highlighted and it is no longer highlighted when the door is opened. To the right of this is LV1 (Leak Valve) that is the chamber vent valve. Unlike the ICP, there is no load lock so this is the vent valve used when venting the chamber before and after processing. Finally there is the RC Lid box that controls the reaction chamber lid. The RC must be at atmospheric pressure in order to open the chamber. Sometimes the Open and Clos (for Close) buttons need to be held momentarily to get them to register and open/close the lid.

The final section on the main screen is located at the bottom of the screen. This box contains some buttons that were located along the top of the ICP screen. The first button in the top left corner of this box, labeled BZ, is the buzzer stop button. BZ stop will stop the buzzer for process ending and for alarms. If an alarm sounds, it has to be reset by going to SET>Event Log (page 60 of [29]) and then clicking on Reset in the bottom right corner of the screen. Data Log should automatically turn on during processing to log the process data but can also be pressed to turn on during manual operation and standby to monitor the system. The Abort Cond button has no function except in interlock cancel mode. Finally, there are the Auto Operation buttons of Run and Abort. Unlike the ICP, this unit has separate buttons. Run will start running all the recipes in the selected program and Abort will stop the process and begin returning the system to standby.

### **3.4 Operation**

Operation of the PECVD is very similar to the ICP with a few differences that will be pointed out before operation is covered. The first and most notable difference is the input method. Unlike the ICP, the PECVD does not have a wheel for input but instead has a number bar or keyboard that appears at the bottom of the screen for data entry. Whenever you click on a box to change the data, hit CLR before entering any new data to prevent misentry. If CLR is not pressed first, the new entry may be appended to the old data depending on the specific values that are entered. After entering the data, press ENT to accept the changes. The second difference is the way that a recipe is run. Unlike the ICP, the PECVD has programs, which are a group of recipes. A program is run instead of a recipe and inside each program individual recipes can be selected for execution in different orders. These differences will be elaborated on more in the following sections.

#### **3.4.1 Creating a Recipe**

Similar to the ICP, the PECVD also has recipes that are run except these recipes are for depositing films instead of etching them. To access the recipes, go to the Recipe screen (page 42 of [29]) from the SET screen. Like the ICP, you can try to find a blank recipe or overwrite an existing recipe. To scroll through the recipes, click on the Recipe box and then use the arrows in the bottom right of the screen to scroll through the recipes. When you get to the recipe you want to edit, click the Recipe box again. Steps of a recipe are scrolled through in the same manner by clicking on the Step box. To change the comment/name of the recipe, click on the comment box and then click CLR and enter the characters you want. By pressing Keyboard Change, you can switch between alpha and numeric keyboards. Press ENT once you have

entered the comment you want. After creating the recipe, you can start editing the recipe or copy steps from another recipe.

Copying a recipe is not as easy in the ICP. An entire recipe cannot be copied, only individual steps from a recipe. In order to paste a step, a step already has to exist in the recipe. A recipe starts with one step. To add another step before the current step, press the Add button under the Current bracket in the first row under the Recipe #. Next to this is also a button to delete the current step (Del) and a button to add a step after the current step. To delete a step, the Del button has to be held down for a least half a second. In order to copy a step, you have to go to the recipe and step that you want to copy. Then click copy, located to the right of Add, Del. Then navigate back to the recipe and step in which you want to paste a step and click Pst to paste the step. This is time consuming and may not be the best for copying an entire recipe but can be very helpful in copying steps in the same recipe when making a new recipe. For example, if you are creating a recipe you will probably want to build on the previous step keeping the same temperature, gas flow, and pressure so copying the previous step and pasting it may help save time.

### **3.4.2 Editing a Recipe**

Editing a recipe on the PECVD has a similar procedure as the ICP but different parameters and a different screen layout. There is only one screen for parameter entry instead of 3 and entries are made with an onscreen keyboard instead of a wheel. To discuss editing a recipe, we will start at the top of the screen and work down moving left to right doing the bottom left panel first, followed by the bottom right panel.

The top row of the recipe editing panel has the recipe number and comment boxes. The comment is basically the name of the recipe and can be changed by clicking on the box. This will bring up a keyboard to change the name. The arrows, DEL, BS, and CLR can be used to delete individual characters or the entire comment. To the left of comment is Count that gives the loop count for the recipe, for a normal recipe this is 1. Next Recipe is the recipe number that will be run after the current one is finished. Unlike the ICP, the next recipe should be set to 0 if you do not want a recipe to run after the recipe finishes. These settings apply to all steps in the recipe whereas the other settings only apply to a single step.

The next line shows the recipe number, which can be clicked on to scroll through the steps in a recipe. Normally when a new recipe is created it has one step. Located on the right side of the screen are Del, Add, Copy, and Pst that are for deleting, adding, copying, and pasting steps in the recipe as discussed in the creating a recipe section (3.4.1). Copy and paste is extremely helpful for copying and pasting consecutive steps so that steps can build on setting from the previous step such as temperature, gas flow, and pressure. This can help to significantly reduce the time for creating or editing a recipe.

On the left side of the screen is the Set Value box. This contains the temperature, gases, pressure, and RF power settings. The top box is the setpoint for the chamber heater in degrees Celsius. Below these are located the 8 MFC controls. There are only 7 which you can choose from. Also, note that C<sub>2</sub>F<sub>6</sub>, O<sub>2</sub>, and TEOS cannot flow at the same time as any of the other gases because they are on a different gas manifold. The gases are set by clicking on each individual gas and entering the value you want. When changing a value from a non-zero value, the CLR button

should be pressed first to clear the entry so that when the new value is entered it is correctly entered, as the system appends digits to the end of numbers in some cases. After the MFC, there is the APC that is the target pressure for chamber during processing. It is controlled through the value read from DG during processing. The RF power box is the RF power in watts that will be applied to the chamber to strike and maintain plasma for deposition. The data for these two are entered the same way as the other boxes. Unlike the ICP, the PECVD does not have matching parameters on the PECVD itself but on a computer located next to the PECVD. These are all the settings in the Set Value box.

The right box is the time schedule box. It includes confirmation settings and a time for the step. The first three options are confirmation options. By entering a value and selecting the Conf button to the left of the box, the timer for the recipe will not start until all of the selected criteria have been met. The first is the temperature for the chamber and is usually chosen as a setting for the first step of the process to make sure it is up to temperature. The second is the DG pressure, which is helpful in making sure the chamber is purged of process gas before continuing to the next step. The third is the FRG confirm that confirms the overall chamber pressure. These confirms are used before starting a process. They verify that the chamber is at a designated base pressure while maintaining a specific temperature. After a process they are used to pump the chamber back down to the initial base pressure. This verifies that all the residual gas is properly evacuated. The last box is the time box showing H:M:S. If there are no confirm settings, then this is the timer for the step. If there are confirmations, then the timer will start after all the confirms are met.

These are all the settings that are on the recipe editor page. Through the right combination of the different parameters, you can change and create the recipe you need. Existing recipes are good references for creating and editing recipes.

### **3.4.3 Creating/Editing a Program**

An additional level of hierarchy not on the ICP is the program. Programs contain multiple recipes in a specified order and are selected for execution on the Mode screen. In addition to having to create a recipe to run a process, a program has to be created to contain that recipe. Programs are accessed from the Prog screen (page 38 of [29]). Once on the Prog screen, you can scroll through programs by clicking on the program box and using the arrow keys. When you get to the program you want, click on the box again. There are only 40 programs so it may be hard to find an empty program. When creating a new program, you may have to overwrite a program that is no longer used. To change the program name, click on comment, press CLR, and then enter your new name followed by ENT. After creating a program, the order/contents have to be selected. These are recipes/operations that are to be run in the order you select. When a program is run the selected orders are run in order. An order is selected by pressing the Exec button to the right of each order so it becomes highlighted. Pressing it again will deselect it.

To change the recipe selected for an order, press on the content box and then use the arrows to scroll through the recipes and other operations to the desired one. The first order of every program should be System Start (ORG). This will initialize the system to the proper state to start running a program. After this, you can add other recipes. Recipes can be added multiple times, so that multilayer structures can be made using a single program run. In the order box there are two numbers. The



small number is the order number and the big number is the step number in the program. The order # does not change but the program step # changes based on how many orders have contents. Blank boxes will be the same step number as the previous order. Other recipes/operations that should be added to a program are RC Vent, RC Vacuum, and System Shutdown. These should be put at the end of the program as they are often run after the normal recipe finishes. RC Vent is needed to open the chamber to add or take out samples and RC Vacuum to place the chamber under vacuum after processing is completed.

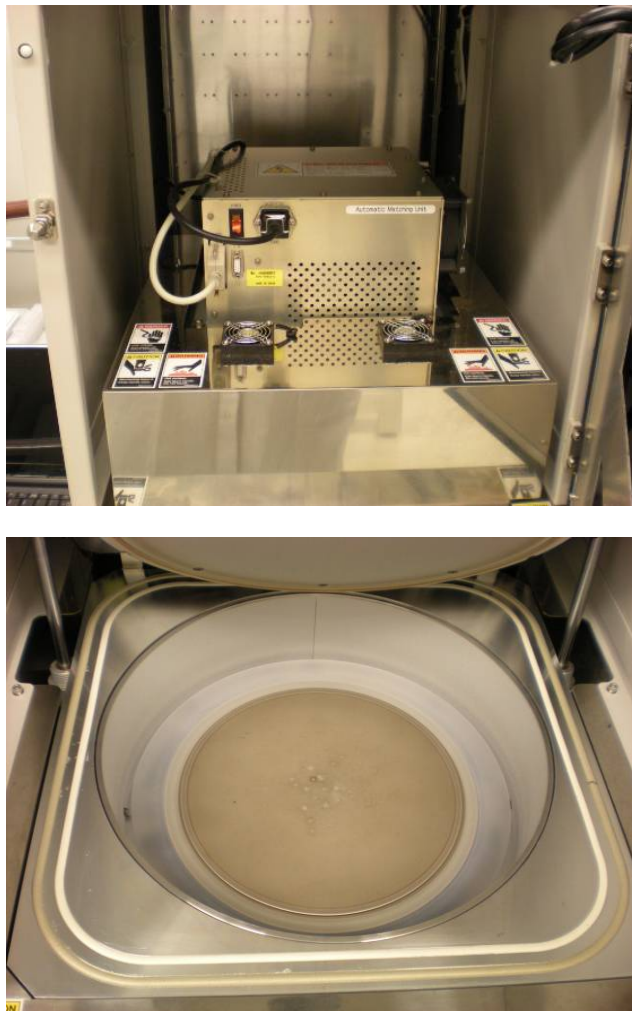
#### **3.4.4 Sample Preparation**

Sample prep for the PECVD is quite different from the ICP. Instead of etching a material, the system deposits a new material. Along with the deposition, the sample is also heated to quite a high temperature, which is the opposite of the fluorine ICP which cools the substrate for processing. For this reason the sample should be very clean and contain NO photoresist or vacuum grease. Photoresist could reflow or decompose thus contaminating the chamber for future users. Having photoresist on the sample also would not help with performing lift off as the resist would not lift off after the high temperature processing. It is recommended that a piranha clean be performed to prepare your sample for PECVD deposition. This will remove any organics which could be on the surface that could contaminate your film or the chamber. Also, after the piranha etch, it may be advised to do a short BOE dip. The use of BOE depends on your substrate type and previous processing but with silicon it is advised, if possible, to help remove any native oxides along with any oxides grown by the piranha clean. This will help give a cleaner surface for the film to grow on. Besides having a clean sample, there are not really any other preparation steps

required for the PECVD. Unlike the ICP, there is no required carrier wafer, though one can be used as long as NO vacuum grease or other bonding medium is used.

### **3.4.5 Loading a Sample**

To load a sample, the chamber has to be vented. To vent the chamber, first go to the SET screen and then to the Prog screen. Choose the program you wish to use and then select only System Start (ORG) and RC Vent to run. Then go to the Mode screen and click on the Program box and chose the program that you want to run. Then go back to the Main screen and press Run. If you are unsure about this process, see Section 3.4.6 on running a program for more in-depth coverage of running a program. After the chamber is vented, open the RC lid by pressing and holding Open until the Clos button is no longer highlighted. After the chamber opens, you can open the front cover. Figure 3.5 shows the inside of the PECVD with the front cover open with both the RC lid open (right) and closed (left). Carefully place your samples on the center of the sample pedestal, keeping them close to the center. If you have multiple samples, keep them spaced far enough so that edge effects will not affect neighboring samples and keep them from the edge of the holder, where the quartz begins. After placing your samples, close the front cover and press Clos under the RC Lid until Open is no long highlighted. After this, it is time to run your program.



**Figure 3.5** Left: the top of the chamber lid with the front door of the PECVD open. The matching unit is the box located in the middle of the lid. Right: the inside of the chamber showing the two seals along with sample holder and outer quartz ring.

In certain cases when you want to make sure the chamber is in good condition for your deposition, you may want to perform a test run like the chamber pre-treat on the ICP. To do this, you will run your program with your program selected BEFORE placing your samples in the chamber. Normally a 5 minute pre-

treat is enough to help improve the film quality. It will help to make sure that the chamber is coated in the same material you will be depositing along with purging out some of the old gas from the system and heating up the chamber to remove contamination. This will help create a better quality film and will decrease etch rates as will be discussed in Section 2.6. After this program has finished, you can load your samples in the manner previously described. Doing a pre-condition is not required but can help passivate the chamber and help to flush old gases out of the lines. So it is advised if the system has not been used in several days or you are the first deposition since the weekend.

#### **3.4.6 Running a Program**

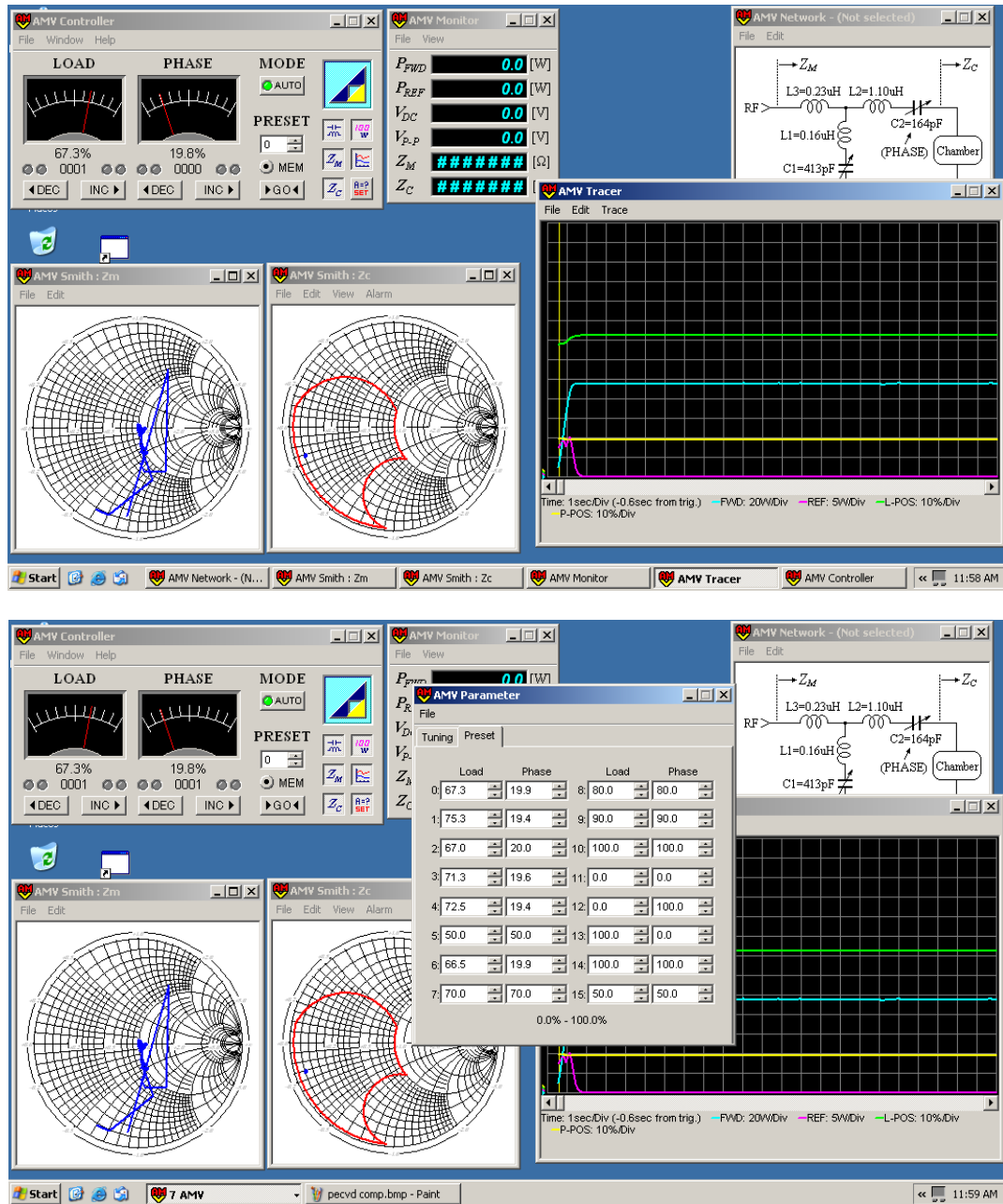
Running a process in the PECVD is similar to the ICP except that you run a program instead of individual recipes. The program contains the listing of recipes and you select which recipes you want to execute in order and then run the program.

The first step to running a program is to make sure each individual recipe has the proper settings and times. Go to the recipe(s) you want to run and verify the gas flows, temperature, pressures, and RF power. Also, be sure that the steps are the correct time. The most important step to have the time correctly set is the deposition step. The deposition step is the one with RF power enabled. As multiple people may use this recipe, the deposition time can change each time you go to use the recipe, so you should always make sure this time is correctly set. In addition to the time, make sure you have the correct loops set in the Count box, 1 means it will run the recipe only once. Also, the Next Recipe box should read 0 if you do not want any recipe to run next, unlike the ICP, which reads NONE when you are not running a next recipe.

After making sure that the recipe is correctly setup, it is time to edit the program from the Prog screen. Find the program you want and then select System Start (ORG) and any other recipes you wish to run. Make sure that the recipes are in the correct order and all other recipes are unselected. Do not select RC Vacuum **before** your recipe starts or it will cause an error when it tries to run your recipe. The reason for this error is after the system finishes RC Vacuum, it leaves BV2 open so that the TMP is pumping the chamber. However, when a recipe starts, the system expects BV2 to be closed and thus gives the error BV2 not closed. If you plan to be at the PECVD when it finishes the recipe, select RC Vent as the last step. Otherwise select RC Vacuum as the last step to keep the chamber under a good vacuum once the process finishes. If you do not select RC Vent or RC Vacuum, the chamber will sit under vacuum but no vacuum pump will be actively pumping the chamber, so its pressure will slowly increase.

Once the program is setup, go to the Mode screen (page 35 of[29]) and look under the Program (for Automatic Operation) section for the Program that is set to run. Click on the program box and use the arrows to select the program that you want to run. After you have selected the program, you want to make sure that Control Mode is Auto mode. To begin running the program, go to the Main screen and verify that both the RC lid and Front cover are closed. Then click Run to start running the program. It should begin by going to System Start and then displaying the program and order at the top of the display along with the recipe in that order. Under this bar, it will say Process Start before the actual recipe begins. During this step, the chamber is being pumped down to  $5\text{E-}3$  Pa, which is the vacuum required to start a recipe. Once that pressure is reached, step 1 of the first recipe will begin.

Step 1 of the program usually verifies the temperature and pressure for the recipe, where the temperature is usually 300°C. It takes about 25 minutes for the PECVD to heat up to 300°C from room temperature. During this time, you should make sure the laptop on the cart to the left of the PECVD is on and that the AMV program is running. The AMV program provides an interface with the matching unit for the RF power. Instead of setting parameters in the program like is done in the ICP matching, parameters are set in this program. If the program is not open, open the AMV shortcut on the desktop. This should open a screen similar to the top image in Figure 3.6. The computer is connected to the controller through a USB to serial converter and a 9 to 25 pin serial converter. Normally when using this program, the matching parameters are set to Preset 0 and Auto Mode should be turned on. If you have another preset loaded, you can change to the Preset value and click >GO< to change the settings. A listing of the various parameters for presets can be viewed by clicking on the button that says “A=? SET” or by going to Window>Parameter Window (bottom image Figure 3.6). Finally, the last part of this program which has to be set to run the process is the Tracer. If there is a trace currently running, click File>Stop Trace to stop the trace. If the trace is stopped, you can either click File>Clear Trace and then File>Start Trace or just click File>Start Trace directly. It will say waiting for trigger and will start tracing the FWD and REF powers along with the matching loads once the RF power is applied.



**Figure 3.6** Screen of the PECVD matching computer. The bottom image shows the screen with the Tuning and Preset Parameters window open.

At this point you can leave and come back when the program is done running. If this is the first time you are running this process, you will want to wait around in case there are problems with matching and other parameters. If you do leave, you can see the AMV trace afterwards to verify how the process ran.

### **3.4.7 Process Checks**

While running a process, there are several things that should be checked, especially if it is a new program or if it has had problems running recently. The process checks for the PECVD are similar to that of the ICP with several differences, but the idea is still the same.

The first and easiest parameter to check is the temperature. The temperature should remain within a few degrees of the setpoint and not fluctuate too much during processing. In addition to temperature, the gas flows through the MFCs should be very close to their set values. As with the ICP if there are problems with the MFC maintaining proper flow, they may need to be re-zeroed or there may be a problem with the input gas itself. If there is a problem with the flow rate, let the equipment supervisor know so that it can be investigated. In addition to the MFC flows, the pressure should be checked. If there is a problem with the pressure being maintained, it could be a problem with the CTV, MBP, RP1, or the APC. Problems regulating pressure could be a one time deal or could signify a problem with the system, such as the DG in the APC needing to be re-zeroed. The PECVD usually has fewer pressure problems than the ICP does. However, if the pressure has problems matching multiple times, try shutting down the system and restarting it to reset the APC. If the problem recurs many times, it could be a problem with the APC EPROM.



See the ICP maintenance Chapter 5 for more information on the reprogramming the APC as they use a similar unit for both machines.

The plasma is extremely important to a good deposition. The easiest way to determine if there is a plasma is a visual inspection. There is a viewport on the front of the PECVD to look into the chamber. This will allow you to see the plasma and determine if it is a good plasma or not. If it is a steady plasma with consistent color, it is probably good. You should become familiar with the color of the plasma for your process as a change in color can indicate a change in pressure or gas chemistry. In addition to visually inspecting the plasma, the forward and reflected power can be read from their indicators on the main screen. These are rough values however and the computer screen gives better forward and reverse measurements in some cases. These values can also be obtained from the computer.

The forward and reflected powers are indicated on the numeric display as well as on the graph on the computer. In some cases when there is a lot of reflected power, the matching unit may take a while to find a good match. In cases like this, you may need to change to manual mode to get a good match. To change to manual mode, click on the Auto button so the green light turns off. Then use the Inc and Dec buttons to change the % for the load and phase tuning elements to lower the reflected power. Whether you get the recipe to match in automatic or manual mode, you can write down the parameters to input for use next time. To save the parameters to use again, open the parameter window as discussed in the running a program section (3.4.6). Then choose an unused program to enter your values, most of the recipes are not used. Then the next time you run your program, set it to Auto mode but change

your Preset to the program you just made and press >GO<. This should help fix the matching problems you may have with a program.

If during processing there are any problems with the system or you need to stop the program, press the Abort button. The Abort button will stop the process and start resetting the system to standby.

### **3.4.8 Unloading a Sample**

After the program has finished running, you can prepare to take your sample out of the chamber. If you selected RC Vent in your program, the chamber should be at atmospheric pressure. This can be verified by looking under FRG and seeing whether ATM is illuminated. If the chamber is still under vacuum, edit the program so that only System Start (ORG) and RC Vent are selected to run and then run the program. The current process should say RC Vent after it starts. Wait for it to finish. Once the chamber is at atmospheric pressure, click and hold the RC Lid Open button until Clos is no longer illuminated. After it starts to open, you can open the front cover. Be careful as the chamber still may still be quite hot. You can now remove your samples using metal tweezers. If for some reason you want to use plastic tweezers, carbon tipped tweezers, or coated tweezers or you need your sample to cool down, leave the chamber under vacuum until it has reached a suitable temperature. Never use plastic tweezers above 200°C and make sure that they are able to withstand the temperature before using them to remove a sample.

To unload the sample with metal tweezers, it is best to have two pairs. The first pair is to hold the sample still and then use the second pair to pick up the sample from the opposite side. The point of this is to keep the sample from sliding and to keep from scraping your tweezers across the platform as they can scratch it,

which can cause imperfections in the plasma and depositions. If the sample is hot, set it on a glass slide or a wipe until it cools. Placing it in a plastic box may cause the sample to melt the box, thus getting the sample stuck to the case. After all of the samples are removed, close the front cover and press CLOS to close the RC lid. If the deposited thickness warrants a cleaning, see the maintenance section (3.5) for more information on how to run the clean. If a clean is not needed, then edit your program to just perform System Start (ORG) and RC Vacuum. Run the program and verify that it starts the RC Vacuum properly before leaving. After the RC Vacuum has started, the system should be good to leave as it will pump down and return to its normal standby state.

### **3.5 Maintenance**

Maintenance of the PECVD starts when you enter the chase to complete the pre-op checklist. Even though the equipment supervisor of the PECVD periodically checks the facilities, it is everyone's responsibility to make sure the PECVD runs smoothly. The pre-checks in the cleanroom also make sure that nothing is wrong with the PECVD and help ensure it is working correctly. Checking that the DG and MFC values are properly zeroed is extremely important to recipe integrity. The further they drift, the more off a recipe can get and then when they are re-zeroed large process variations can be seen. So the sooner a drift is noticed and fixed, the fewer process variations there will be. Zeroing of the DG and MFCs is discussed in Section 6.4.3.

Along with the pre-operation checks, system checks are important to the maintenance. As discussed in the process checks section (3.4.7), there are checks on the MFC, DG, heaters, and RF power during processing, which are very important to

perform. By checking these during processing, you are not only checking on your process but helping to diagnose problems with the system before they become major problems and cause machine downtime.

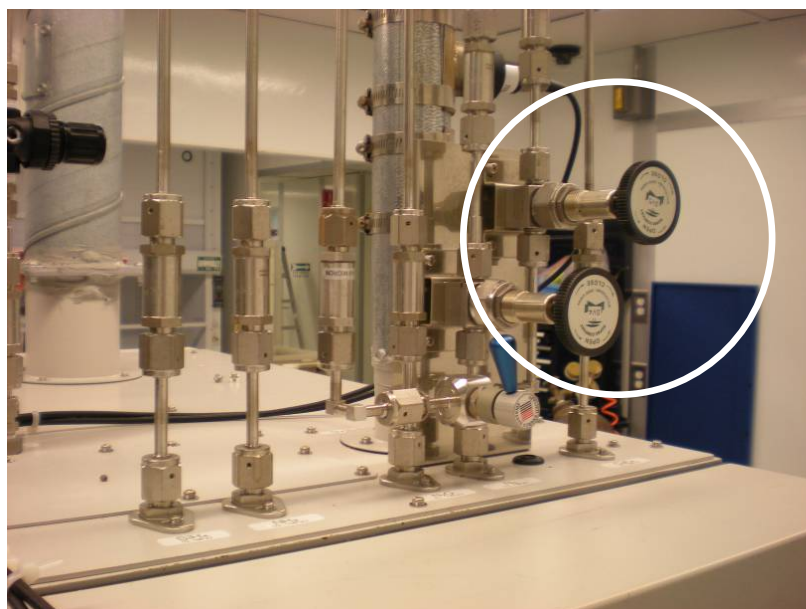
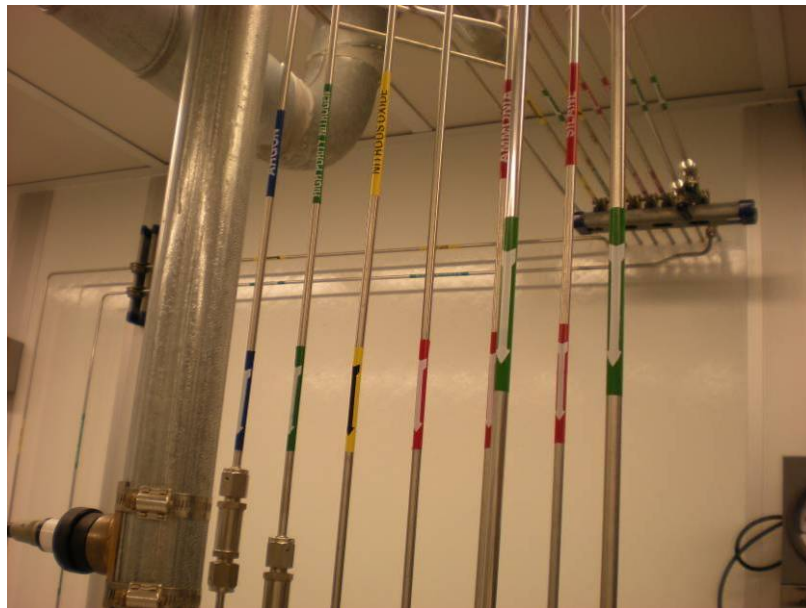
In addition to these checks, there are a few other items, which will help with clean running of the machine. Inside the chamber, there is a quartz ring surrounding the sample stage (Figure 3.7). This ring, at times, gets extra deposition built up on it and this build up can wipe or flake off. From time to time, check this quartz ring by carefully wiping it with a clean dry wipe and noticing if any particles wipe off. If there are particles that wipe off, carefully wipe the ring with a wipe that is damp with IPA to help collect the dust and keep it from re-depositing in the chamber. Only do this if the chamber is room temperature as you do not want the IPA to boil. Also, if you notice the quartz ring severely flaking or chipping, let the equipment supervisor know so that they can look at it and determine if it has to be replaced.



**Figure 3.7** Close up of the quartz ring and sample holder inside the PECVD chamber

In addition to wiping out the chamber, there is also a chamber clean that has to be run periodically. This chamber clean removes build up from depositions and helps to keep the chamber from flaking with thick layers. This clean should be run whenever the total deposited thickness since the last clean nears 5  $\mu\text{m}$  or you have a delicate process, which you want to perform. The clean is Recipe 2 followed by Recipe 4. Recipe 2 is a  $\text{C}_2\text{F}_6$  and  $\text{O}_2$  clean that etches away the various deposited layers. The clean should be run for approximately twice the total deposition time. This should be enough to clean off all deposits whether they are silicon, oxides, nitrides, or a combination of films. After the initial clean is run, there is also Recipe 4, which is an oxygen clean. The oxygen clean helps to make the chamber very clean for

the next process run by removing any water vapor or organics that happen to be in the chamber. The oxygen clean should run for 30 minutes no matter what the length of the chamber clean. Program 1 contains these recipes; however you can also add these to your program for easy cleaning. After a clean is performed, the chamber should be pumped under vacuum using RC Vacuum instead of venting it. This allows for extra particulate removal and helps to keep the chamber clean. Finally, after a chamber clean, the chamber walls have to be passivated. This passivation helps to cover the alumina parts and provides a coating so that future depositions are more uniform and reproducible. The material of the passivation is not important but it is easiest to just run whatever recipe you plan to run next as the passivation layer. Ideally the passivation should be run after the oxygen clean before the chamber has been vented to provide a clean deposition and the thickness should be at least 500 nm but may be thicker, which will give better uniformity.



**Figure 3.8** Top: The gases going into the PECVD showing the labels. Bottom: The gases going into the PECVD showing their inlet connections and the valves for MFC4 (circled).

As discussed in the pre-operational section (3.2), you should check if argon or nitrogen is connected to MFC4 before running a process that uses those gases. The valves to switch between these gases are located on the top of the back side of the PECVD (Figure 3.8) and are labeled such. There is one inlet into the system that comes from 3 separate lines which join together. Each of the 3 lines has a valve to control which of the 3 lines is selected. The valve that goes to the line with a red and white label should be left closed at all times since that line is no longer in use. If the wrong gas is selected, then the gases will have to be switched. The gas has to be both physically switched through the valves and also switched in the software to get the correct flow through the MFC. The instructions on how to do this are located in the front pocket of the log book but are reprinted here for reference and will be commented on.



1. Close the open input valve to the manifold (N<sub>2</sub> or Ar)
2. Go into manual mode
3. In Recipe 101 (manual), set the gas flow rate to the full scale value (see step 14) and make sure all others are 0 zero
4. Ensure the BV2 and BV3 are closed
5. Make sure MBP and RP1 are on
6. Ensure ISV2 is closed
7. Open PV1, ISV1, CTV, and BV1
8. Open SSV1
9. Open GV4
10. After flow drops to zero, wait until DG drops close to 0 and wait about 30 more seconds. Then close GV4 and SSV1
11. Close BV1
12. In Recipe 101, set the gas flow rate to 0
13. Open valve to manifold for desired gas
14. Change gas parameters in the Configure Device screen
  - a. NOTE: Full Scale N<sub>2</sub> – 1000 sccm  
Full Scale Ar – 1410 sccm
15. In Recipe 101, set the gas flow rate to 100 sccm
16. Open SSV1 and GV4.
17. Wait for the flow to settle around 100 sccm and then close GV4
18. Wait for DG to drop to close to 0 and wait 15 more seconds
19. Close SSV1
20. Switch to Automatic Mode and run System Start (ORG)

The first step makes sure that the valve for the gas that is currently in use is closed. You have to switch to manual mode so that you can manually control the pumps and valves to evacuate the gas line. The 3<sup>rd</sup> step just sets the MFC so it will quickly pump down the line when it is opened. Step 4 makes sure that both the TMP and RP2 are sealed off from the chamber and step 5 makes sure that the MBP and RP1 are ready to pump the gases (RP1 has to be on before MBP can be turned on). Step 6 isolates FRG from the chamber while step 7 opens up DG and the MBP to the chamber. Step 8 and 9 open up the manifold and gas valve so that the gas can be evacuated through the chamber. After the chamber has pressure has dropped to about

0 and flow through the MFC has dropped to about 0, the line is sufficiently evacuated and can be closed. Step 11 closes BV1 to isolate the MBP from the chamber; however CTV is left open since it is left open even when the MBP is turned off. The MFC is then set to 0 as there will be a rush of gas when the valve is opened in step 13. After the gas has been opened, the gas has to be input into the Configure Devices screen so that the MFC has the proper calibration data to get the correct flow rate. The screen has a display problem, so the gas will include extra characters such as SPECAR or BiAr (it is really from B<sub>2</sub>H<sub>6</sub> but the 2 is cut off) may be visible when looking at Ar. To clear this, select the gas and then go to a different screen and come back, the display should be normal. After setting the gas, steps 15 and 16 are to run some gas through the system to make sure it is flowing correctly in the lines so that it will provide good flow during processing. Next 18 and 19 are to evacuate the manifold to prepare for processing. Finally, step 20 will return the PECVD to normal standby status so that processing can be carried out as normal.

In addition to these maintenance items, Chapter 6 includes additional maintenance tasks that are to be performed on a regular basis and also includes information on certain emergency maintenance tasks. If more information is needed on any of the maintenance discussed here, see Chapter 5 and the Samco® Operation Manual [29].

### **3.6 Standard Processes**

#### **3.6.1 Recipe 5-Silicon Nitride**

Recipe 5 is used for silicon nitride deposition. The silicon nitride deposited by this recipe can be used as a hard mask for etches, for passivation, or for

optical films such as in an anti-reflective coating. Unlike the other recipes that will be discussed, which use argon, this recipe uses N<sub>2</sub>. The reason for using nitrogen instead of argon will be discussed in the deposition section (3.6.1.2). Optical properties and thickness calibrations will be discussed in the results. Table 3.2 shows the recipe steps that will be discussed below along with calibration of depositions and a summary of the results.

### 3.6.1.1 The Deposition

**Table 3.2** Recipe 5- Silicon Nitride deposition recipe

Step	Gases	Pressure (Pa)	RF (W)	Temperature (°C)	Confirms	Time
1	--	--	0	300	Heater= $\pm 5^{\circ}\text{C}$ , FRG $\leq 5\text{e-}3$ Pa	10 sec
2	300 sccm N <sub>2</sub>	137 Pa	0	300		45 sec
3	300 sccm N <sub>2</sub> , 10 sccm SiH <sub>4</sub> , 6 sccm NH <sub>3</sub>	137 Pa	0	300		45 sec
4	301 sccm N <sub>2</sub> , 10 sccm SiH <sub>4</sub> , 6 sccm NH <sub>3</sub>	137 Pa	100	300		variable
5	--	--	0	300	DG $\leq 0.3$ Pa	1 min
6	--	--	0	300	FRG $\leq 5\text{e-}3$ Pa	10 sec

The steps of a deposition in the PECVD follow a similar structure to that of the ICP. The major differences are the settings and ranges of values used. The first step in this recipe pumps down the chamber using the TMP and also turns on the heaters for the chamber. This step waits until the chamber reaches 300°C ( $\pm 5^{\circ}\text{C}$ ) and attains a pressure of  $\leq 5\text{e-}3$  Pa on the FRG. After this is attained, the system actually

starts the 10 second count. If during the count one of the confirms is broken, it will stop and wait until both confirms are met again to begin counting. The TMP is the vacuum pump used in this step as it provides the pumping capability required to get the chamber down to the high vac required before the process starts. This can also be determined by noting that FRG and not DG is used for this step. The FRG is used when the roughing pump or TMP is open to the chamber while DG is used when the MBP is being used. The ISV for the FRG is closed when the MBP is on to isolate it from the chamber.

The second step switches from using TMP to pump the chamber to using the MBP for pumping the chamber. This is determined by DG being set to 137 Pa. Also, N<sub>2</sub> is flowed into the chamber during this step. The MBP and not TMP has to be used whenever the chamber has gas flowing through it (this is automatically taken care of by the system when running an automatic recipe). Thus the 2<sup>nd</sup> step sets the pressure by using the APC to adjust the CTV and starts the flow of nitrogen into the chamber. The 3<sup>rd</sup> step is similar to the second step but has the addition of silane and ammonia to the chamber. The nitrogen and ammonia provide the nitrogen for the silicon nitride while the silane provides the silicon. Step 4 is the actual deposition step. Unlike the ICP, there is only RF power, not a separate ICP and Bias. Thus there is no presoak step. Once the plasma is struck, the deposition starts, so the time of this step is changed to allow for different film thicknesses. Sometimes the recipe can have trouble striking a plasma and some tips for getting around this are discussed in the deposition section (3.6.1.2).

After the deposition is completed, there are two remaining steps. The first of these confirms  $DG \leq 0.3$  Pa, which means the chamber and gas manifold are

pumped down through the MBP until this pressure is met. The purpose of this step is to make sure that the chamber is evacuated of any reactive species. The next step confirms  $FRG \leq 5 \times 10^{-3}$  Pa, which means the chamber is being pumped by the TMP instead of the MBP. This will return the chamber back to the initial base pressure used to start the deposition process. These two steps together serve the same purpose as the 100% CGV in the last step on most ICP etches. After the recipe finishes, the next order in the program is run or the system returns to idle if there is no other order selected.

### **3.6.1.2 Preparation and Deposition of a Sample**

The preparation for deposition tests in the PECVD is much shorter and easier than the preparation for the ICP etch tests. The reason is that there is no patterning needed for the tests of these samples. In fact, samples coated with resist cannot be used in the PECVD chamber because of the high temperature, thus there is no way to do lift off with deposited materials. Instead, a clean piece of test grade silicon is all that is needed for the deposition. For this simple deposition, the silicon substrate should just be clean of particulates and the native oxide. To do this, perform a short BOE dip and DI rinse on the sample. However, a more thorough clean, such as that used for the etch tests, can be used if wanted.

Before you start to prepare your sample, there are two important things that you should do with the PECVD. The first is to check that MFC4 is set to N<sub>2</sub> and that nitrogen and not argon is actually open to the gas inlet (see Section 3.5 for instructions on checking the gas and changing it if needed). After the gas has been verified, you should run a precondition of 5 minutes. This will help to clean out the gas lines and give better film quality. It will take about 30 minutes to run since it has

to heat up the chamber. However, you can put RC Vent at the end of the program so that the sample can be placed in the chamber as soon as the precondition is done. Another purpose of the precondition is to make sure the chamber is hot when the sample is placed in it. This will cut down on the heating time for the actual run and also will help to eliminate chamber contamination.

After the precondition has finished and the sample has been cleaned and prepped, the sample can be loaded into the chamber (see Section 3.4 for more information on the operation of the PECVD and sample loading procedures). After loading the sample, set the time for step 4 of Recipe 5 to 5 minutes. Then run a program consisting of System Start (ORG) and Recipe 5. It can be followed by an RC Vent if you will be around when the process finishes.

Start running the program and make sure that the computer is set to record the plasma characteristics and is set to auto mode (see Section 3.4.6). At times, there can be trouble getting a plasma to strike. If there are problems getting the plasma to strike, you can run either Recipe 26 (O<sub>2</sub> Preclean) or Recipe 28 (N<sub>2</sub> Preclean) before Recipe 5 to help with plasma striking. Only a minute or less of these recipes is needed as they are just to help remove extra water vapor from the chamber and make matching easier for the recipe. An O<sub>2</sub> clean will also help to remove organics from the chamber but may also grow a thin oxide layer ( $\sim < 2$  nm) on your sample, so the N<sub>2</sub> plasma may want to be used. A preclean plasma is not required for every process, but these may prove useful in the case there is a problem striking plasma or the sample needs to be cleaned before processing. These are not needed but just suggested for future runs using Recipe 5 on an actual sample. After the process has finished, remove your sample and place the chamber back under vacuum. Make sure to take

note of the RF power traces on the computer. The deposition results section (3.6.1.3) will discuss measurements that can be taken on this sample to determine the characteristics of the deposited film.

### **3.6.1.3 Deposition Results**

After the sample has gone through the deposition, there are several tests that can be performed to check on the film and state of the PECVD. These tests measure the thickness, index, and reproducibility of the deposition.

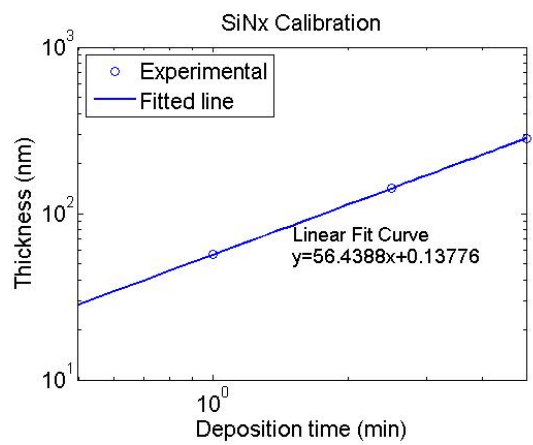
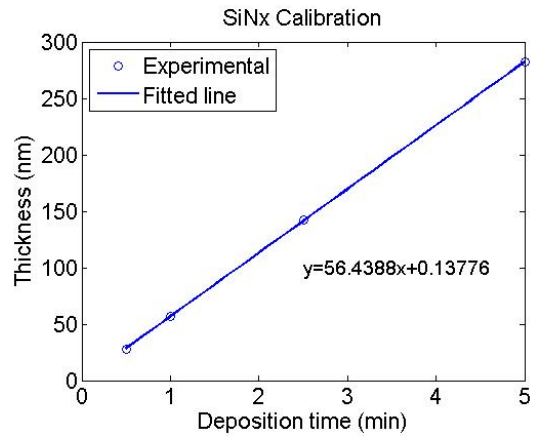
The thickness measurements are done in the cleanroom using the spectrometer and with the ellipsometer in Evans 152. The easiest measurement to take first is the thickness measurement with the spectrometer in the cleanroom. This is a very quick and easy measurement to take. Turn on the spectrometer and open the software. Set the dark and experimental references with a piece of blank silicon. Then switch to reflectance mode and choose Si3N4.nk as your film file. Take a measurement from 300-1100 nm and set the upper and lower bounds to 500 and 50, respectively. Make sure that the spectrometer is set to Match Spectrum Mode under the Options menu. Get a reading of the film and make sure that the Fit Quality box is not red. For a 5 minute deposition, this thickness should be  $290 \pm 10$  nm. If the thickness is thinner, check that the plasma matched in the correct amount of time. In addition, the gas flows or pressure could be off and need to be recalibrated.

Along with the clean room spectrometer, the ellipsometer in Evans 152 can be used to get thickness measurements. Ideally the measurements from both tools should be close but they can vary some. For information on using the ellipsometer, see Chapter 4. Using the ellipsometer can be very important if the spectrometer gives a thickness that is not what you expected. The ellipsometer can also determine the

index of a film, which can be important for optical applications. There is a saved model, PECVD SiNx 5min cal, which should be used to model the film. It will also output a graph of the index versus wavelength so that the value for the index can quickly be checked. Ideally the index for silicon nitride should be 1.92-1.93. It can be lower if the film is less dense than usual. The easiest way to try and fix this is to run a longer pre-treat before running your etch. If this does not help, you can have the equipment supervisor purge the gas lines to make sure that all of the old gas from the lines is removed and fresh gas is used in the deposition. If these do not help to produce a better film, then the gas flows or pressure may have to be recalibrated.

At times it is important to have a more thorough calibration for a deposition. To do this, run some additional deposition at times such as 1 min and 2.5 minutes. Do measurements on these samples as was done before. Be sure to include times that give thicknesses around your target thickness so that you have a better set of data to base your times on. After the data is collected, plot it in Matlab and fit a linear curve to it as shown in Figure 3.9. The code used to generate this plot is in Appendix B. The data in Figure 3.9 is from when the PECVD had just undergone preventative maintenance in December 2010. The fitted value for the data provides a good rate to use for calibration as it helps to remove some of the error that can occur in a single run. A table of values from when this thesis was written is shown in Figure 3.10. As can be seen, the rates can drift over time, so calibrations need to be done for sensitive depositions and they also help to provide a check on the condition of the machine.





Time (min)	Deposition Thickness (nm)
0.5	28
1	56.5
2.5	142
5	283.5
fitted per min	56.5 nm/min

**Figure 3.9** Calibration data for Recipe 5 after the preventative maintenance in December 2010

Time (min)	Deposition Thickness (nm)
1	52.7
2.5	138
5	300
fitted per min	62 nm/min

**Figure 3.10 Calibration for Recipe 5-October 2011**

### **3.6.2 Recipe 6-Silicon Oxide**

Recipe 6 is used for the deposition of silicon oxide or silicon dioxide. The exact stoichiometry can change over time due to drifts in the system but the recipe ideally deposits  $\text{SiO}_2$ . This recipe has a similar structure to Recipe 5 but uses different gases and settings for the deposition as shown in Table 3.3. The oxide deposited can be used to provide an etch mask, diffusion barrier, electrical isolation, passivation, cladding, or other structures for optical operation. This is the most used recipe in the PECVD and thus is very important to become familiar with.

**Table 3.3** Recipe 6- Silicon Dioxide deposition recipe

Step	Gases	Pressure (Pa)	RF (W)	Temperature (°C)	Confirms	Time
1	--	--	0	300	Heater= $\pm 5^{\circ}\text{C}$ , FRG $\leq 5\text{e-}3$ Pa	10 sec
2	120 sccm $\text{N}_2\text{O}$	67 Pa	0	300		1 min
3	120 sccm $\text{N}_2\text{O}$ , 6 sccm $\text{SiH}_4$	67 Pa	0	300		1 min
4	120 sccm $\text{N}_2\text{O}$ , 6 sccm $\text{SiH}_4$	67 Pa	50	300		variable
5	--	--	0	300	DG $\leq 0.3$ Pa	1 min
6	--	--	0	300	FRG $\leq 5\text{e-}3$ Pa	10 sec

### 3.6.2.1 The Deposition

This recipe follows the same flow as Recipe 5 with just changes in the gases and parameters, so the differences will be pointed out in this section and a more in-depth coverage of the various steps can be found in the Recipe 5-silicon nitride section (3.6.1). The first step is the same as Recipe 5 and just provides heating and chamber evacuation. The second step once again sets the pressure and the gas flow. This time the gas pressure is lower (67 Pa) than the silicon nitride etch and the gas is  $\text{N}_2\text{O}$  instead of  $\text{N}_2$ . The lower pressure is a characteristic of the recipe, but it also makes the plasma a little harder to strike at times but a lower pressure also provides a better film quality. The range in which the pressure affects the film quality without changing the chemistry of the deposition depends on the specific gas chemistry of each deposition recipe. The third step introduces silane to the gas flow. The reason the  $\text{N}_2\text{O}$  is used instead of  $\text{N}_2$  and  $\text{NH}_3$  is that this recipe creates an oxide and not a nitride, so oxygen and not nitrogen is required. Using pure oxygen is not allowed for this process as silane is pyrophoric and would spontaneously combust when it came in contact with the oxygen, which is why the oxygen cannot be used. The oxygen is

actually on the second gas manifold, which prevents it from being used at the same time as silane. For this reason,  $\text{N}_2\text{O}$  is used. Step 3 then adds silane.

Once the gases have had time to flow through the system, the deposition begins in step four with the application of the RF power. As with silicon nitride, it is the time of this step that actually determines final deposited thickness. At times, this step can have problems matching and it will take ~15 seconds for the plasma to start. Solutions to this problem are discussed in the deposition section (3.6.2.2). After this step, the next two steps are the same two post process evacuation steps as Recipe 5.

### **3.6.2.2 Preparation and Deposition of a Sample**

The procedure for running Recipe 6 is very similar to Recipe 5. Once again the sample is just a piece of test grade silicon with the native oxide removed with a BOE dip and DI rinse. Unlike Recipe 5, you do not need to verify the gas on MFC4 since only silane and nitrous oxide are used for this recipe. Like the other recipes, you should run a 5 minute precondition to help prepare the sample for your deposition. After the sample has been prepped, place it in the chamber and close the lid. For this recipe, set step 4 of Recipe 6 to be 5 minutes. Then set the program to include System Start (ORG) and Recipe 6. Once again, RC Vent can be included if you will be there when the process is finished. Set the computer to auto mode and make sure to start the trace. As with Recipe 5, sometimes it has trouble with getting a good match the first time. For this recipe, you can either choose Recipe 26 ( $\text{O}_2$  Preclean) or Recipe 27 ( $\text{N}_2\text{O}$  Preclean) as the preclean plasma. One minute of either recipe will be sufficient. The  $\text{N}_2\text{O}$  clean works similar to the  $\text{O}_2$  clean as it is also an oxidizer and will oxidize the silicon slightly but should be less than the  $\text{O}_2$  clean oxidation. After the recipe has finished, remove the sample and place the chamber

under vacuum again. The next section will discuss results and other possible problems that may be encountered.

### **3.6.2.3 Deposition Results**

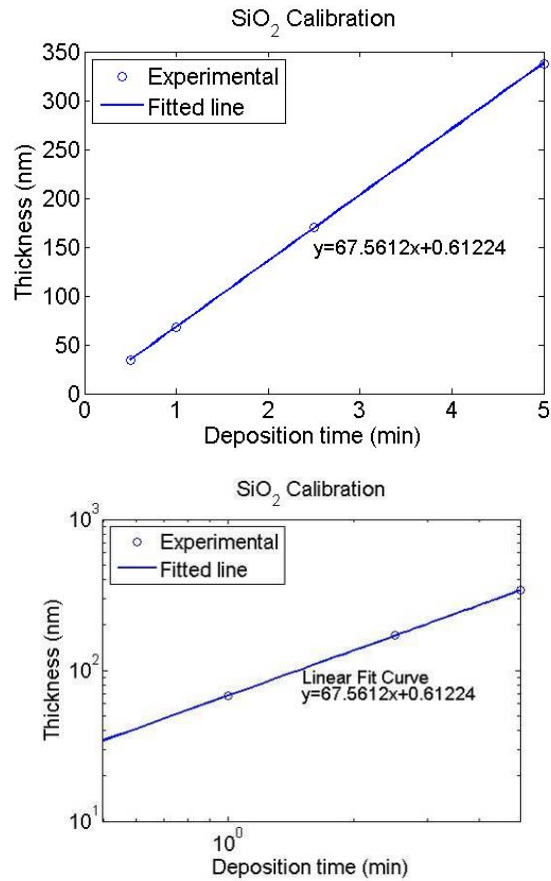
After the deposition has finished, there are several tests that can be performed to check the results. These are the same tests as for the nitride deposition with the addition of an etch test. The etch test is an easy and extremely insightful test of the film quality.

The procedure for measuring the film thickness is the same as was done in Section 3.6.1.3 for the silicon nitride. The only differences are the film layer to choose and the expected thickness. For the film, choose SiO2\_(CVD).nk for the film and take the measurement. The measure should be about  $350 \pm 10$  nm for the 5 minute deposition. A quick color check should show that the film is a blue or blue-green color depending on the lighting and exact thickness (use regular light not the lithography room light). Additional measurements can be taken on the ellipsometer and should yield similar results. The model to use for getting a thickness of this film is PECVD SiO2 (silane)-2 5min cal. This model also outputs the index that should be around 1.44-1.45. Once again, if the index is lower, it could be an airy film. The same procedures for trying to adjust density and film thickness problems apply to Recipe 6 as it did for Recipe 5.

Another test for Recipe 6, which was not discussed for Recipe 5, is an etch test. An etch can be performed using either BOE or Recipe 93 on the fluorine ICP. Only the BOE etch will be discussed here as the ICP would introduce other variations and this etching process is discussed in Section 2.6.1. To perform this test, dip the sample in BOE and begin timing the etch. To determine when the etch has

finished, inspect the sample by carefully pulling it out of the BOE to see if it is hydrophobic yet and then immediately put it back in the BOE. You should check the sample about every 10 seconds, specifically around the periods of time when you expect the sample to be done etching. When the sample becomes hydrophobic, the oxide layer has been removed. A good film will etch in about 40 seconds whereas a bad film will etch in about 20 seconds. To increase the etch time, try doing a longer precondition and/or cleaning out the gas lines. Also, make sure that the PECVD chamber has not been vented long and the chamber is hot when you put the sample in to help limit contamination, which may degrade the film quality.

Lastly, like with Recipe 5, a more in-depth calibration can be run to check the state of the machine and/or to help calibrate a sensitive process. The calibration process is the same as in Section 3.6.1.3. Take measurements at important thicknesses near your target thickness and then take measurements, plot, and fit the data. Figure 3.11 shows the data after preventative maintenance and Figure 3.12 shows a slight drift over time. It is important to use the fitted rate for your deposition rate as it gives a better rate than choosing a single point. Using the above test, a lot can be learned about a film and the state of the PECVD and can help to troubleshoot if a problem were to arise.



Time (min)	Deposition Thickness (nm)
0.5	35
1	68
2.5	170
5	338
fitted per min	68 nm/min

**Figure 3.11 Calibration data for Recipe 6 after preventative maintenance in December 2010**

Time (min)	Deposition Thickness (nm)
1	72
2.5	177
5	360
7	490
fitted per min	70 nm/min

**Figure 3.12 Calibration data for Recipe 6 October 2011**

### **3.6.3 Recipe 37, 39, 41-Silicon Superlattice**

Recipes 37, 39, and 41 together form the process that is used for silicon superlattice deposition (Table 3.4). The deposition produces a periodic structure of silicon and silicon dioxide layers that form the superlattice. When the superlattice is annealed at high temperature, it will form silicon nanocrystals that will emit light when excited [30-39]. This light emission can be used to verify that the superlattice was properly deposited in the PECVD. These specific properties will be discussed more in the following sections.



**Table 3.4** Recipes 39, 37, 42-Silicon Superlattice deposition recipe (Rcp 39-Pre, Rcp 37-Dep, Rcp 42-Post)

Step	Gases	Pressure (Pa)	RF (W)	Temperature (°C)	Confirms	Time
1	--	--	0	300	Heater= $\pm 5^{\circ}\text{C}$ , FRG= $\leq 5\text{e-}3$ Pa	10 sec
Next Recipe: 37						
1	1 sccm SiH <sub>4</sub> , 20 sccm N <sub>2</sub> O	67 Pa	0	300		1 min
2	2 sccm SiH <sub>4</sub> , 20 sccm N <sub>2</sub> O	67 Pa	30	300		variable (10-24 sec)
3	--	--	0	300	DG= $\leq 0.3$ Pa	30 sec
4	4.5 sccm SiH <sub>4</sub> , 52 sccm Ar	67 Pa	0	300		1 min
5	4.5 sccm SiH <sub>4</sub> , 52 sccm Ar	67 Pa	30	300		variable (3-5 sec)
6	--	--	0	300	DG= $\leq 0.3$ Pa	30 sec
<b>MULTILOOP</b>						
Next Recipe: 42						
1	--	--	0	300	FRG= $\leq 5\text{e-}3$ Pa	10 sec

### 3.6.3.1 The Deposition

The deposition of silicon superlattice is broken into 3 separate recipes. The bulk of the process is in Recipe 37, which is the actual deposition recipe, which will be looped many times to get as many layers of superlattice as is required.

The first recipe is Recipe 39, which is only a single step. This single step is the normal first step in most recipes such as Recipes 5 and 6 to get the chamber conditions ready for deposition by setting the temperature and pressure. After Recipe 39 finishes, it goes on to Recipe 37, which is the important recipe. Unlike Recipes 5 and 6, the gases are added in a single step for this recipe to help cut down on processing times. So the first step of this recipe sets both the pressure and gas flows.

These are the gases for an oxide deposition. Notice however that the gases are  $1/6^{\text{th}}$  the values they were in Recipe 6. This is to slow down the deposition rate. Recipe 38-Slow SiO<sub>2</sub> Silane (or Recipe 61-Slow SiO<sub>2</sub> 2 which is modified to help with matching) uses these values and can be used for doing calibrations of oxide layer thicknesses. After the gases and pressure are set, the plasma is turned on for a short period of time for the deposition. This provides a short oxide deposition and thus gives thin layers of oxide in the superlattice structure. After this step,  $DG \leq 0.3$  Pa is confirmed to make sure that the chamber and gas manifold are evacuated. Next in step 4, silane and argon are used for creating the silicon layer. Argon is used instead of nitrogen since using nitrogen gas would create a non-stoichiometric silicon nitride film and argon is used just to dilute the silane gas and is not incorporated into the silicon film itself. Recipe 35- Slow a-Si is a stand alone recipe for calibrating the silicon layer thickness. The actual deposition occurs in step 5 once the RF power is applied. The silicon layers are very thin compared to the oxide layers ( $\sim < 1$  nm) and thus the deposition times are very short. After step 5, the chamber is evacuated again to prepare the chamber for another loop. The number of loops will vary based on how thick you need your superlattice stack and the application of the film. At times, the first loop will fail to deposit correctly and it will take until the second step to get good depositions of both the silicon and the oxide layers. This should not be of concern unless you need to have an exact number of layers or are depositing very few layers. Ways to help fix this problem will be discussed in the deposition results section (3.6.3.3).

After Recipe 37 completes all the loops, Recipe 42 is the next recipe that runs. This recipe once again only has one step and provides post process evacuation

through the TMP. After this step has completed, the superlattice deposition has completed and the PECVD will run the next order in the program or return to its idle state.

### **3.6.3.2 Preparation and Deposition of a Sample**

The superlattice recipe is a specialized recipe used for the creation of silicon nanocrystals for light emission. The full process for these samples is longer than the other deposition tests. This is because they require a post deposition anneal to precipitate the nanocrystals. There are two separate types of samples that can be made with this type of process, PL samples and EL samples. The difference between these two is the substrate and the total number of layers deposited. The EL samples are deposited on highly doped p-type wafers (0.01-0.02  $\Omega\text{cm}$ ) and PL samples are deposited on test grade silicon. The reason for the highly doped silicon is that it has to provide conductivity for the sample for current transfer. Also, EL samples usually have a thinner film in order to lower the required pumping voltage. The PL sample deposition process will be discussed here.

Similar to Recipe 5, MFC4 must be checked before starting this process. However, for this recipe, MFC4 should be set to Ar and should be connected to argon instead of nitrogen as was discussed in the previous section (3.6.3.1). To switch the gases, see Section 3.5. After verifying the gases, a precondition should be run. This time the precondition should be 5 minutes of Recipe 6. This is because a majority of the superlattice deposition is oxide and this recipe is more commonly used than the a-Si recipe, so it is easiest to use it for the pre-treat. While the precondition is running, the samples can be prepared.

As with Recipe 5 and 6, the native oxide has to be removed from the silicon before placing it in the chamber. After placing the sample in the chamber, the times for steps 2 (SiO<sub>2</sub> deposition) and 5 (a-Si deposition) in Recipe 37 have to be set. The times can vary between 10-24 seconds for step 2 and 3-5 seconds for step 5. For this test, we will use 14 and 4 seconds for our deposition times. Also, there should be 30 loops for Recipe 37. This will give enough loops to get a considerable amount of PL but not so many layers that it wastes time and gas. Make sure that Recipe 39 is followed by Recipe 37, which is then followed by Recipe 42. After this, set the program to run System Startup (ORG) and Recipe 39 (37 and 42 will follow after). As you will probably not be around for the end of this process, it is best to not include RC Vent in the program order. Ideally RC Vacuum should be selected after Recipe 39 so that the chamber is actively pumped by the TMP after processing has finished.

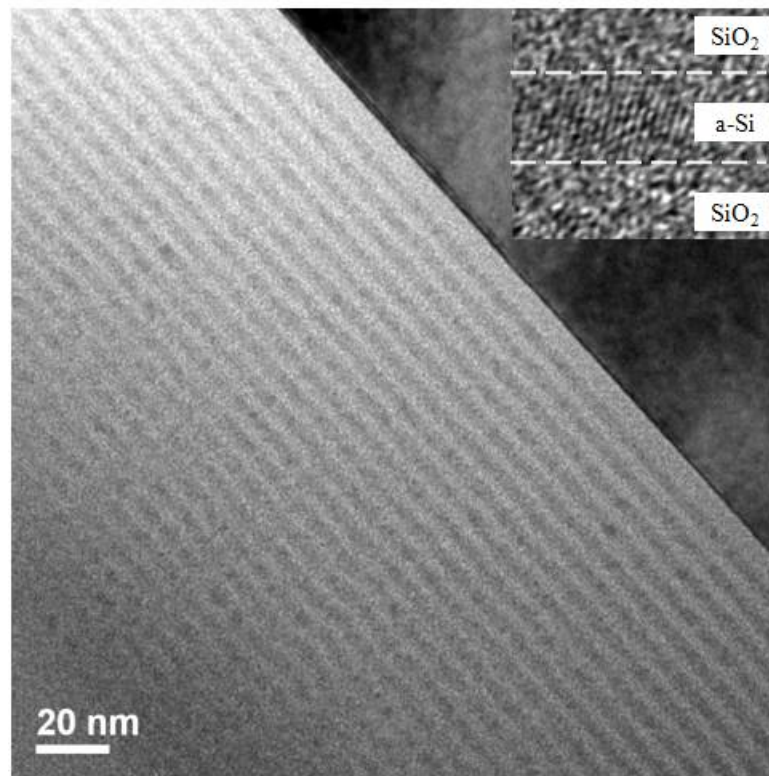
To begin the deposition, start the trace on the computer and start the program running. Try to be around for the first loop as often times it does not match because of the short deposition time. This is nothing to worry about and is normal. If you want to have exactly 30 loops, you can set 31 loops and check if the first loop runs or not and adjust from there. After the deposition has finished, remove the sample from the PECVD. The next step is to perform an anneal in the Mellen furnace by the clean room window. The anneal should be performed in the boat with the sample facing sideways so the air flow down the furnace tube goes across the front and back of the sample. The temperature should be set to 1100°C even though the furnace may max out around 1070°C or so. This is fine. The nitrogen flow should be set to 2 L/min. The sample should be placed in the center of the furnace and annealed for 1 hour. Placing the sample into the furnace and removal of the sample should be

slow. The sample should be let to sit for 5 minutes at the mouth of the furnace to allow for a gradual temperature change. After the anneal is completed, the sample processing is done. The deposition results section (3.6.3.3) will discuss the testing procedure along with the effects of varying the oxide and silicon layer thicknesses.

### **3.6.3.3 Deposition Results**

Unlike the nitride and oxide depositions, testing of the resultant superlattice films is quite different. As it is composed of many layers, it is very hard to measure the thickness of the individual layers. It is easier to get information about them using PL or EL testing along with TEM imaging.

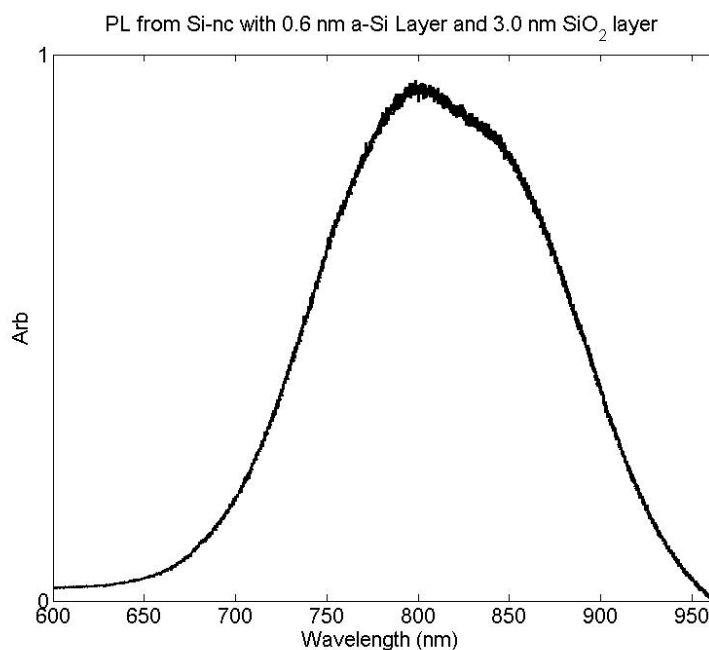
When the silicon superlattice is annealed, the a-Si layers will form silicon nanocrystals. These nanocrystals, through quantum confinement, will emit light when they are excited either electrically (EL) or optically (PL). These effects are well documents in the literature [30-39]. To get insight into the basic structure of the deposited and annealed film, it has to be analyzed through TEM. This is a very time consuming process and was originally performed by Tim Creazzo when he was creating this recipe for use in the PECVD. Figure 3.13 shows a TEM picture he took with the inset showing a single nanocrystal. The nanocrystal is characterized by the slanted grainy pattern. This is because of the crystallinity of that area. TEM imaging is good for looking at the structure but not good for getting the properties of the bulk film. This is best done through optical characterization.



**Figure 3.13** TEM picture of a superlattice film (Credit: Tim Creazzo).

PL and EL testing are very powerful tools for testing silicon superlattice films. EL takes more processing and is less reliable than PL testing, so it will not be discussed here but more information on EL testing can be found in [3, 35, 39]. PL testing should be performed with the 532 nm laser on the free space collection setup of the spectrometer in Evans 152. When the silicon superlattice film with nanocrystals is hit with the 532 nm light, the nanocrystals are excited and because of their close proximity they have a pseudo band gap. This band gap causes them to emit light of a certain wavelength based on the size of the nanocrystals and thus the a-Si layer. There is a sample on top of the spectrometer labeled as a calibration sample with a 14 second oxide, and a 4 second silicon deposition. These are the same times as the sample

prepared in the previous section (3.6.3.2) and this will be used for comparison. Obtain a plot similar to that in Figure 3.14 using the laser at max power and the 950 gr/mm grating. For information on running the spectrometer and collecting data, please see Chapter 4. Make sure that neither signal is clipped when taking a measurement and use the same settings for each measurement.



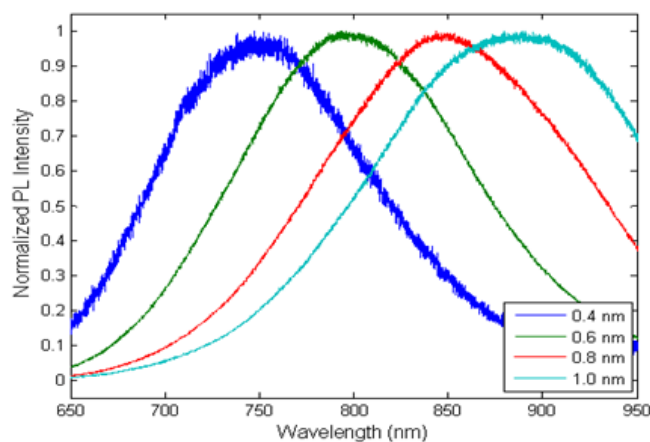
**Figure 3.14** Plot of PL from a nanocrystal film made 14 second SiO<sub>2</sub> layers and 4 second a-Si layers

If the two plots are not the same, there are various possibilities for the differences. Figure 3.15-3.22 will be helpful in discussing the properties of the films and the effects of various changes in the films. Figure 3.15 shows the effects of changing the silicon (a-Si) layer thickness. As the layer thickness is increased, the

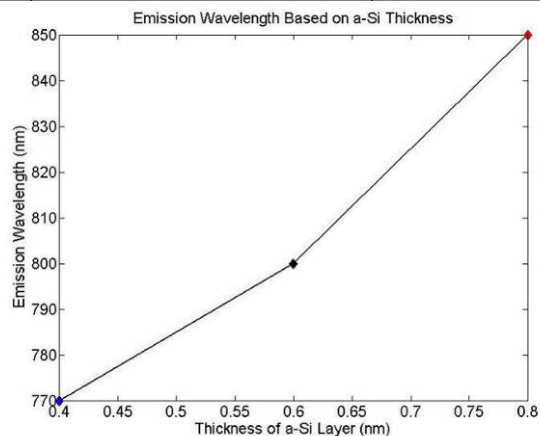
nanocrystal size increases. As the size increases, they cannot be as close together and thus they do not undergo as strong quantum confinement. This means they have a smaller (lower energy) band gap and emit at longer wavelengths. So if the peak is shifted in wavelength between the reference and test sample, try changing the silicon layer thickness to adjust the position of the peak.

Figures 3.21 and 3.22 show the effects of the oxide thickness layer. As seen in the first figure in 3.21, the oxide layer thickness has no noticeable effect on the emission wavelength. Thus a shift in emission wavelength would be from the a-Si layer and not the oxide layer. The second plot shows the trend for PL emission versus oxide layer thickness. As the oxide layer is increased, the PL intensity increases until it begins to level off around 5 nm of oxide. The deposition rates can change over time so it may be important to check the peak intensity. If there is a shift in intensity, try changing the oxide layer thickness in the direction needed to achieve a reasonable match. Figure 3.17 shows a series of plots for silicon layers of 0.4 nm, 0.6 nm, and 0.8 nm and demonstrates the increase in PL intensity with increased oxide layer thickness.



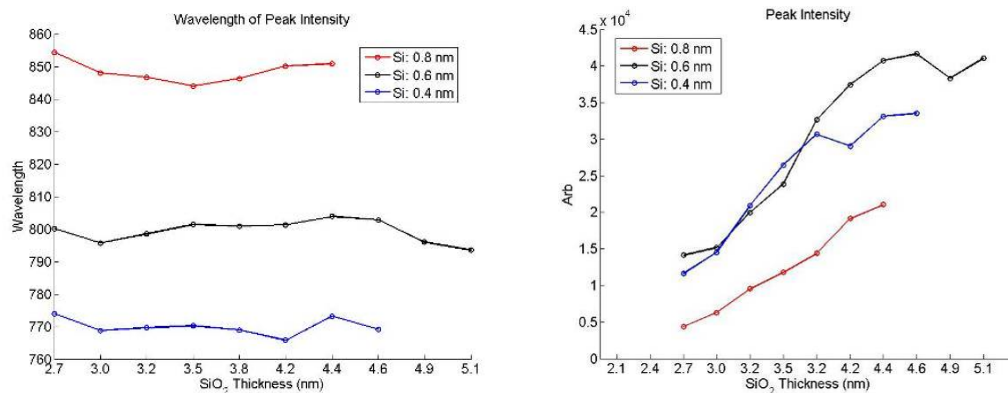


Time (sec)	Deposition Thickness (nm)	Emission Wavelength (nm)
2	0.4	750 nm
3	0.6	800 nm
4	0.8	850 nm
5	1	880 nm



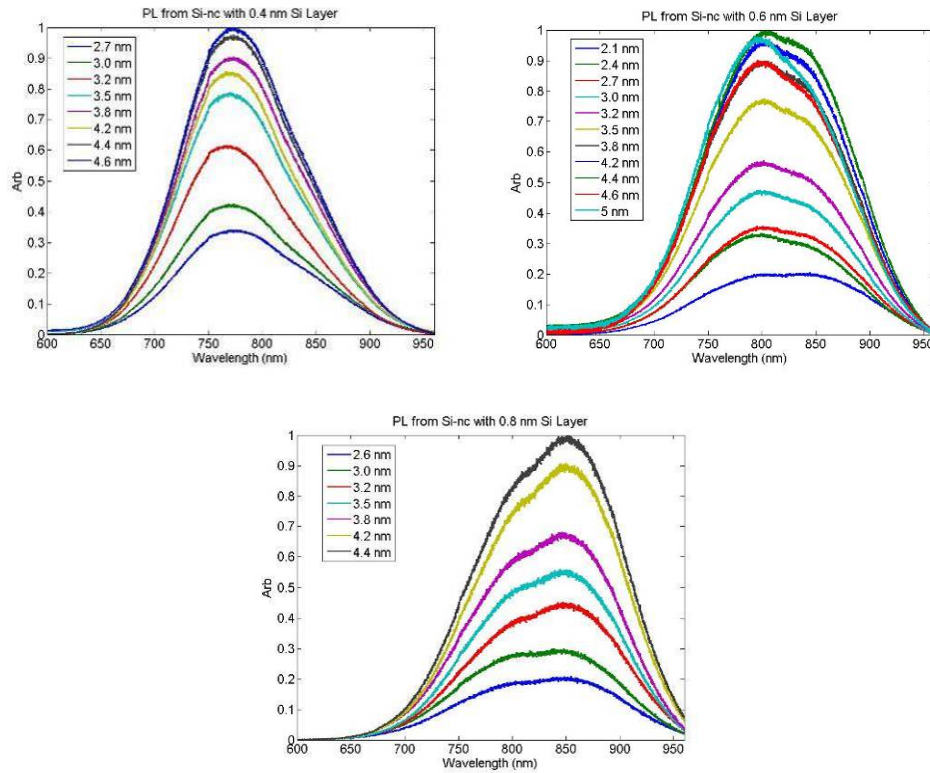
Time (sec)	Deposition Thickness (nm)	Emission Wavelength (nm)
3	0.4	770 nm
4	0.6	800 nm
5	0.8	850 nm

**Figure 3.15** Plots showing the effects of varying the oxide layer thickness. The top plot shows the shift in the peak wavelength as the lay thickness is increased (Credit: Tim Creazzo). The table shows the time to thickness correlation for this calibration. The second plot shows same data after the December 2010 recalibration. The bottom table shows the times of deposition corresponding to each thickness based on the recalibration.



Time (sec)	Deposition Thickness (nm)
10	2.693
12	2.965
14	3.215
16	3.54
18	3.767
20	4.189
22	4.378
24	4.628
26	4.998
28	5.1
30	5.474

**Figure 3.16** The effects of varying oxide thickness. The top plots show that as the oxide layer thickness is increased the peak wavelength remains constant (left) while the output intensity increases (right). The table shows the relationship between deposition times and oxide thickness for this calibration.



**Figure 3.17** Plots of PL with varied oxide layer thickness. From top to bottom and left to right a-Si thickness 0.4 nm, 0.6 nm, and 0.8 nm.

If problems do occur with trying to get the spectrum to match the reference by making changes based on the provide information, the layer thicknesses may need to be recalibrated. This is quite a tedious process. Please see [3, 35, 39] for more information on the calibration process. For the oxide calibration, Recipe 38 should be used. If there are problems getting a quick match, Recipe 61 can be used to help get a faster match. For the a-Si layer, Recipe 35 should be used and should be deposited on a quartz or fused silica wafer and capped with 20 nm oxide. A thicker oxide layer can be used if it is difficult to get a good match with the ellipsometer. As this is quite a time consuming process, hopefully it will not have to be performed.

### **3.7 Deposition Physics**

Section 3.1 briefly discussed the theory behind PECVD operation and mentioned some of the important characteristics and parameters of a deposition. PECVD deposition has the major advantage over traditional CVD that it can occur at a much lower temperature. The increased temperature in a CVD system is used to provide the necessary energy to get the system above the activation energy that is required for film formation. The exact energy required depends on the gases used and the chamber condition. The more energy that is supplied to the system, the better the film quality will be. So a higher temperature helps to create a better film [21, 22].

Temperature, RF power, and gas flows are all very closely related in a PECVD system and their effects on the process depend on one another. The temperature not only determines the film quality but also makes some determination of the deposition rate. At lower temperatures, the reaction is slow because of the lower available energy and film quality is poorer. This regime of deposition is called surface reaction limited. As the temperature increases, there is an Arrhenius relationship between the temperature and deposition rate. This means that there is an exponential rate increase with temperature. However, this will only increase until the point at which mass transport is the limiting step. This means that the reaction is at the point where the available reactants (and thus gas flows) limit the reaction rate [22]. Increasing the RF power will also cause an increase in the deposition rate. This comes with the serious drawback of creating a lower density film with more defects. As the RF power is increased, it will eventually reach a point where it no longer increases the rate because the reaction is being limited by the gas flow [21]. In the PECVD, the temperature is usually a value that does not provide much of a change in deposition rate but helps to provide a better quality film. The RF power should usually be set to a

value that works with the gas flows to provide a good deposition rate and high quality film. As the deposition rate of  $\text{SiO}_2$  is increased, the density decreases, thus increasing the etch rate and lowering the index [21, 40]. For a-Si, there is a similar trend in that the density decreases which results in a lower conductivity [41].

The process pressure also has a very large effect on the deposition. The underlying effect of changing the pressure is changing the gas concentration in the chamber. As the pressure decreases, the amount of gas and thus reactants in the chamber decreases. This has an effect on the film quality, gap fill efficiency, and deposition rate. At lower pressures, deposition rate is surface reaction limited [20]. In addition to affecting the rate, the film quality is also affected by the pressure. At lower pressures, the mean free path between reactants is increased. This results in fewer homogeneous reactions and more heterogeneous reactions, thus providing a better quality, denser film. This is a desired result, but lowering the pressure has some drawbacks. By lowering the pressure, the gap fill effectiveness is decreased. This is because there is less of a driving force to cause the reactants to go into the gaps and fill effectively. In general, PECVD provides an adequate gap fill but will often pinch off the gap for small gaps or high aspect ratio [20, 21]. The fill can be improved slightly by increasing the pressure. Another method for getting better gap fill is through high density plasma deposition systems. These systems use the addition of a bias electrode to cause a combination of physical sputtering and deposition. The physical sputtering reopens gaps that pinch off and cause re-deposition on the sidewalls, resulting in better fill [20, 21, 42].

This section covered some more in-depth concepts about PECVD processing. The full process is very complicated and there is more theory than that

discussed here. Along with using these trends to achieve better films, there are physical limitations on processing ability. One such limitation is the ability to strike plasma at low pressures. Plasmas are easier to strike at sub-atmospheric pressure, however if the pressure is too low, then there are not enough species available to facilitate a plasma. In some cases, a plasma may need to be started at higher pressure and then decreased in pressure to get the desired film characteristics. This is just one of many considerations that have to be considered in PECVD process development. As with RIE-ICP technology, there are many papers, theses, and books devoted to this topic which should be reviewed for more information [20-24, 40-42].

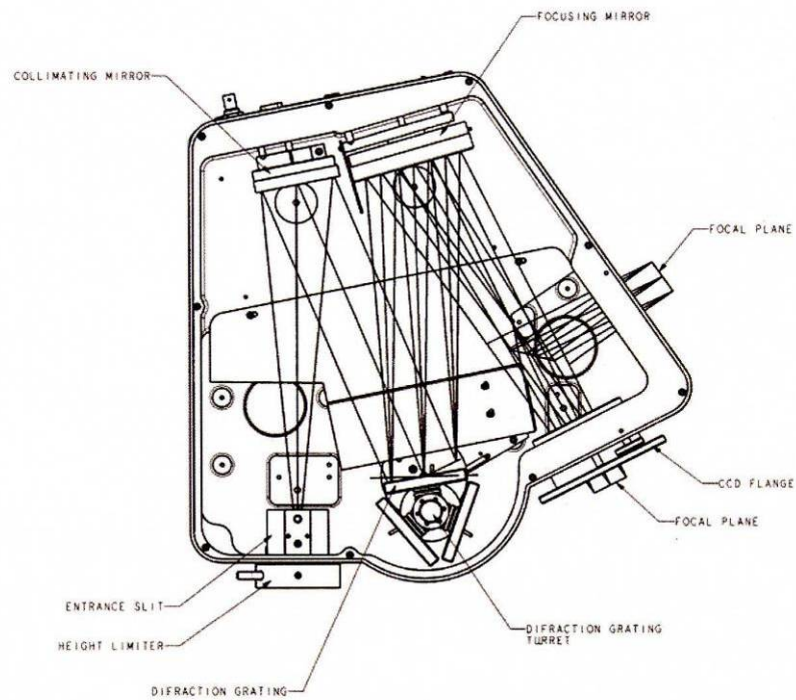
## **Chapter 4**

### **HORIBA IHR320 AND UVISEL**

In addition to being able to complete material and device processing, an effective photonics research must be able to test the fabricated devices. A spectrometer is very important for the testing and characterization of optical emitters. It allows for the measurement and quantification of optical emission from materials and characterization of light sources. In addition to a spectrometer, an ellipsometer is useful in determining the characteristics of a sample. It uses polarized light and a spectrometer to determine important information about thin films such as thickness and refractive index. These two pieces of equipment will be discussed in this chapter including theory, use, and maintenance.

#### **4.1 Spectrometer: Theory of Operation**

A spectrometer is an optical system that is used for measuring the spectrum of an input light source. It can be used for measuring reflectance, transmittance, or luminescence of a sample as well as the spectral characteristics of an illumination source. A spectrometer has relatively few parts compared to other pieces of lab equipment. The main components are the slits (for the entrances and exits), mirrors, grating(s), and detector(s). The grating and detector are the most important parts of the system as they perform most of the important tasks in the operation of the system.



**Figure 4.1** Schematic of the iHR320 showing the path of the light entering through the front entrance and leaving the front exit. (Source: Horiba Jobin Yvon iHR320 Manual [43] p. 39. Reprinted with permission, Appendix A)

The best way to discuss the operation of the system is to follow the path that the light takes as it travels from the slit to detector (shown in Figure 4.1). The light enters the spectrometer through a slit and hits a mirror. The mirror is a focusing mirror with its focal point being in the slit so that it ideally produces collimated light. This collimated light then intersects the grating. This spreads the light in the first diffraction order ( $m=1$  in equation 4.1) so that it travels out at different angles ( $\theta_m$  in equation 4.1) depending on the wavelength ( $\lambda$ ), grating period ( $\Lambda$ ), and incident angle ( $\theta_i$ ). For a fixed  $\theta_i$ ,  $m$ , and  $\Lambda$ , the incoming beam is diffracted at an angle, which changes with  $\lambda$ . This means that a single beam of light will be separated out into the



different spectral content. As the grating is rotated,  $\theta_i$  changes, the angle  $\theta_m$  will change for the entire beam. This change allows for a different range of the diffracted spectrum to be measured by the detector. After the grating, there is another mirror that focuses the light onto the detector. So as the grating is rotated there is a different wavelength which makes it onto the detector face. Some detectors are a single pixel while others are arrays which allow for faster collection of a broad spectrum.

The wavelength resolution, the minimum separation between wavelengths which can be determined, is determined by a few characteristics of the system. These are the pixel size, grating period (grooves/mm), and the entrance/exit slit opening. The slit is the first part of the system that determines the resolution of the system. The larger the slit, the more light that enters the system. However it also gives a lower resolution. As the slit is reduced, there is less light getting through and also a decrease in the bandwidth of the light getting through. The chart on page 39 [43] (recreated as Table 4.1) shows the resolution that can be achieved for a given groove density based on a 12  $\mu\text{m}$  slit opening and 26  $\mu\text{m}$  pixel size. The higher the groove density a grating (grooves/mm) has, the higher the resolution that can be achieved by that grating. This is seen in the grating equation,

$$\sin(\theta_m) - \sin(\theta_i) = m \frac{\lambda}{\Lambda} \quad (4.1)$$

where the output angle ( $\theta_m$ ) is inversely proportional to the grating period or spacing ( $\Lambda$ ). The other terms in the equation are  $\theta_i$  the incident angle,  $\lambda$  the wavelength, and  $m$  the diffraction order. For normal operation of the spectrometer,  $m=1$  is used. As the groove density increases, the grating period (spacing between grooves) decreases. Since  $\theta_m$  is inversely proportional to the grating period, an increase in the period means that the wavelengths in a given light source will be spread at a wider angle.

This wider angle means that the wavelengths will be more widely spaced on the detector and thus can be more easily discerned. So decreasing the slit size or increasing the groove density will help increase your measurement resolution. Finally, the resolution is ultimately determined by the detector pixel size. This is because the resolution is determined by how much the wavelengths are spread across the detector. Smaller pixels allow for a smaller difference in wavelength to be detected. So the resolution is determined by the grating and detector, which is fixed for the spectrometer and the slit opening, which is controlled by the user.

**Table 4.1 Gratings and their resolving powers.** Shows the linear dispersion and the attainable resolution for a 26  $\mu\text{m}$  pixel if the grating and pixel size are the limiting factors.

Groove Density (gr/mm)	Typical Linear Dispersion (nm/mm)	Typical Array Resolution (nm)	Typical Spectral Coverage (nm)	Scan Range (nm)
2400	1.17	<0.075	31	0-750
1800	1.57	<0.1	41	0-1000
1200	2.35	<0.15	62	0-1500
900	7.00	<0.2	83	0-2000
600	4.70	<0.3	124	0-3000
300	9.4	<0.6	248	0-6000
150	18.8	<1.2	496	0-12000

Source: Horiba Jobin Yvon iHR320 Manual [43] p. 39

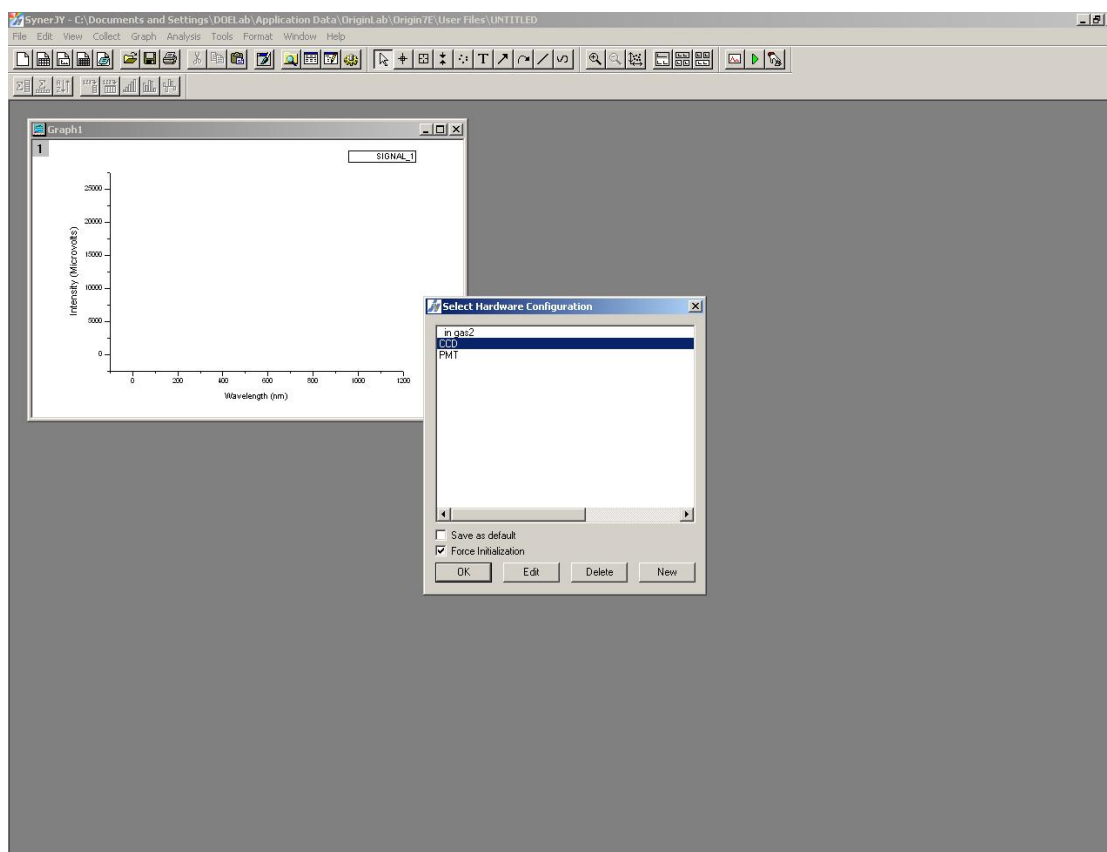
This is a general overview of spectrometer systems. Next specifics about the iHR320 in our lab will be discussed.

## **4.2 iHR320**

### **4.2.1 Computer Operation/Maintenance**

#### **4.2.1.1 Normal Setup and Scans**

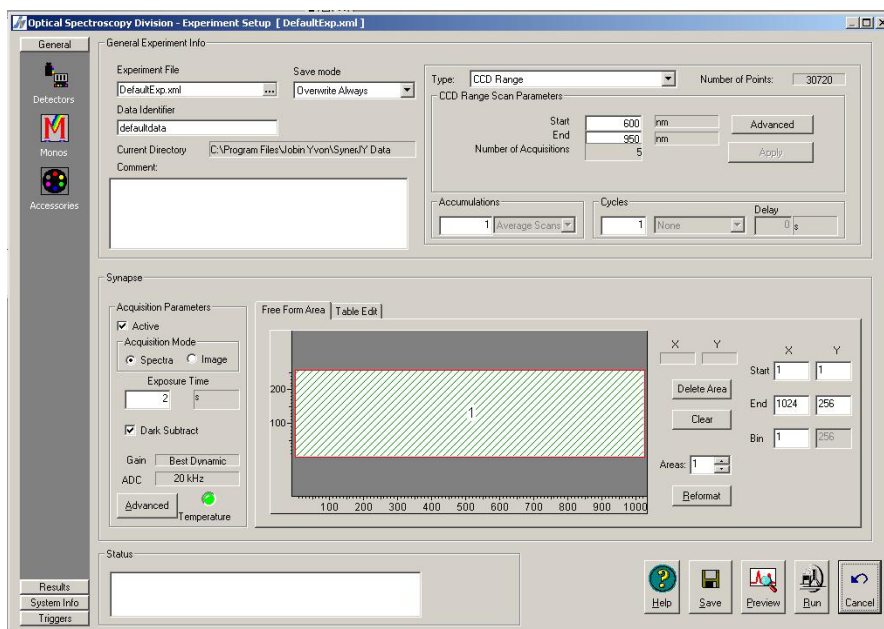
To begin a scan, you need to open the SynerJY software. Next click on the Collect menu and choose Experiment Setup. This will bring up a dialog box with different detectors (Figure 4.2). Choose either CCD or InGaAs (shown as “in gas2”) depending on which detector you will be using. Then click the check box for force initialization and click OK. This will begin the initialization process for the spectrometer and detectors. If any part should fail, it will display an error. If there is an error, close the software and repeat. If there is still an error, close the software, shut off the computer and the spectrometer and restart both. If the error continues and deals with a detector, please see Section 4.2.3 for more information about the detectors.



**Figure 4.2 Hardware selection window showing the different available detectors.**

After initialization, the experiment setup window will appear (Figure 4.3). Before describing this screen, one important note about this screen that should be remembered is do not click the “X” or cancel. There is a software glitch that will prevent you from taking further scans if the setup screen is cancelled. The first screen that appears in the experiment setup window is the Detectors tab. It provides settings for choosing the detector that will be used as well as setting parameters for the detectors. The top right panel lets you choose between the CCD and InGaAs detector. For CCD, there is both range and position; range is usually chosen as it allows the

scan to cover a large wavelength range. To choose the InGaAs detector, you choose the Wavelength option and then select the IHR320 InGaAs detector. For the InGaAs, you specify both start and stop wavelengths along with a step size between acquisitions. For the CCD, you specify a range of wavelengths and it automatically determines the spacing. If you are using the CCD range and the number of acquisitions is greater than one, you should use autogluing. To turn on auto gluing, click on the advanced button and check auto glue. The overlap amount should be 10. For general scans, the number of accumulations and cycles should be set to 1.

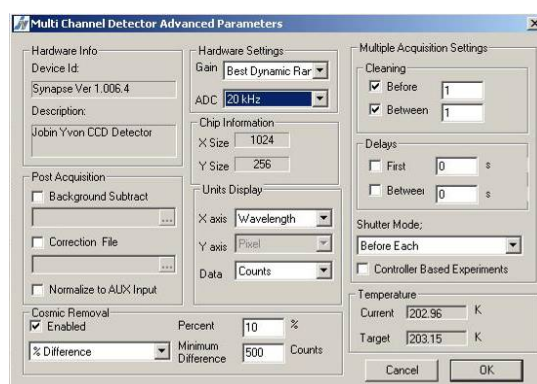


**Figure 4.3** Experiment setup window with the detector selection in the top right, CCD binning in the bottom right, and Acquisition Parameters in the bottom left.

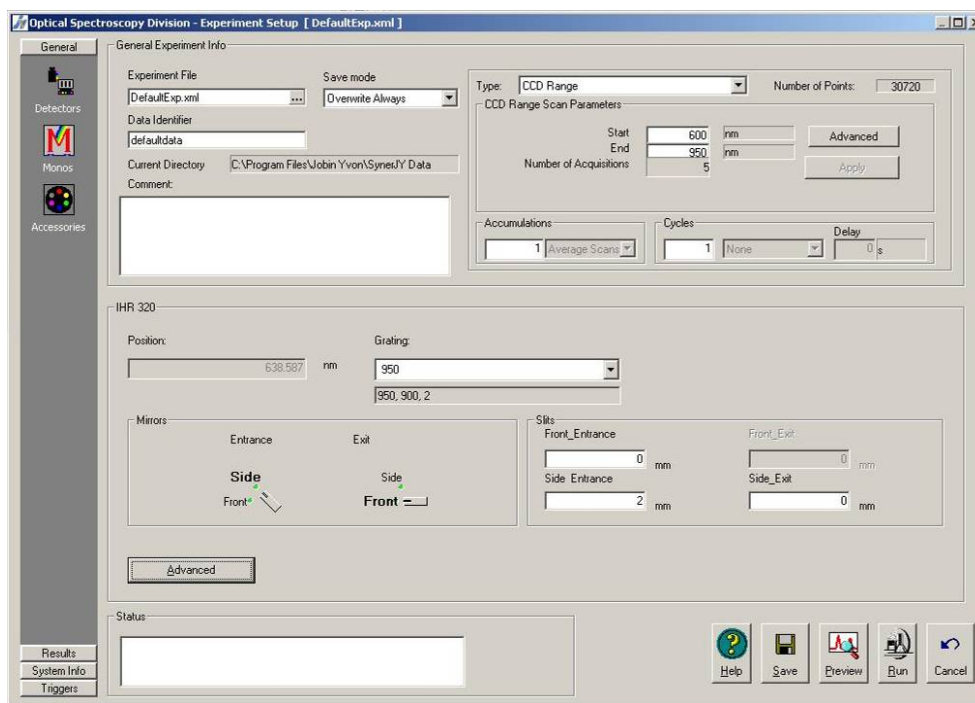
The bottom panel of this screen varies based on whether the CCD (Synapse) or InGaAs detector is selected. If you have only initialized the CCD, it will probably just show a single panel saying Synapse. If the InGaAs detector has been initialized, then it will display two tabs, which read Synapse and SpectrAcq2. The SpectrAcq2 is the InGaAs detector settings. The only setting that has to be changed for the InGaAs is the integration time. This integration time does not increase the acquired signal (which is not the case for the CCD) but helps to remove noise from the signal. The high voltage should be turned off and set to zero. The CCD has a few more settings which will be discussed.

The Synapse panel has an Acquisition Parameters section and a section for detector array setup. The detector array setup should not be touched unless you have a specific reason to redo the binning or other characteristics of the detector, which will not be discussed here. The Acquisition Parameters section provides the necessary controls for making further adjustments to the CCD acquisition. The Acquisition Mode should be set to Spectra for normal operation, which provides a graph of intensity versus wavelength. Image mode, which provides a color map, will be discussed in Section 4.2.1.3. The exposure time is similar to the integration time for the InGaAs detector as it helps to remove noise from the signal. However, for the CCD the longer the integration time, the stronger the signal you get. So a longer exposure time helps to remove noise but also can peg your intensity at its upper bound (~64,000 counts) requiring adjustment of the slits on the Monos tab. Next there is the dark subtract check box. This box should always be checked as it removes the background signal that the detector sees when the slit is closed, thus not allowing in ambient light. For normal operation, the gain and ADC settings should be Best

Dynamic and 20 kHz, respectively. These settings can be adjusted by clicking on the advanced button, thus opening the window shown in Figure 4.4, but normally do not need to be changed. The last part of this panel that should be noted is the Temperature light. This light indicates if the CCD has been cooled to operational temperature. If the light is not lit, see Section 4.2.3.1 on the CCD detector for more information.



**Figure 4.4** Advanced settings under Acquisition Parameters section



**Figure 4.5 Monos tab from which gratings, entrances and exits, and slits are controlled**

After making adjustments on the Detectors tab, switch to the Monos tab, Figure 4.5, for selecting the gratings and slit settings. The top half of this screen is the same as the Detectors tab. The bottom panel reads IHR 320 and gives selections for the grating, entrances and exits, and slit openings. The gratings are chosen by their groove density. Then the box below the drop down menu should display the groove density, blazed wavelength, and location in the turret. Once you have selected your grating, you should choose your entrances and exits. They are discussed more in depth in the entrance and exits Section 4.2.4 but will be briefly covered here. The front entrance is from the fiber port, the side entrance is from the free space collection, the front exit is the CCD detector, and the side exit is the InGaAs detector. Finally the



slit opening needs to be set for the different entrances and exits. The front exit (CCD) is the only one that does not have an adjustable slit and is not selectable. The slits are variable between 0.08 mm (80  $\mu$ m) and 2 mm. The wider the slit, the more light that will be let in and thus the larger the signal. However this also hurts the resolution. This is seen in the following table. Table 4.2 shows that as the slit gets narrower, your bandpass becomes narrower thus resulting in better resolution. The band pass is determined by multiplying the linear dispersion (nm/mm) and the slit width (entrance or exit, whichever is larger). The resolution is limited by either this band pass or by the detector pixel size and groove density depending on the relationship between the two. So based on the resolution and collected intensity required for a scan, the slit and exposure/integration time can be adjusted as required to achieve the results you want.

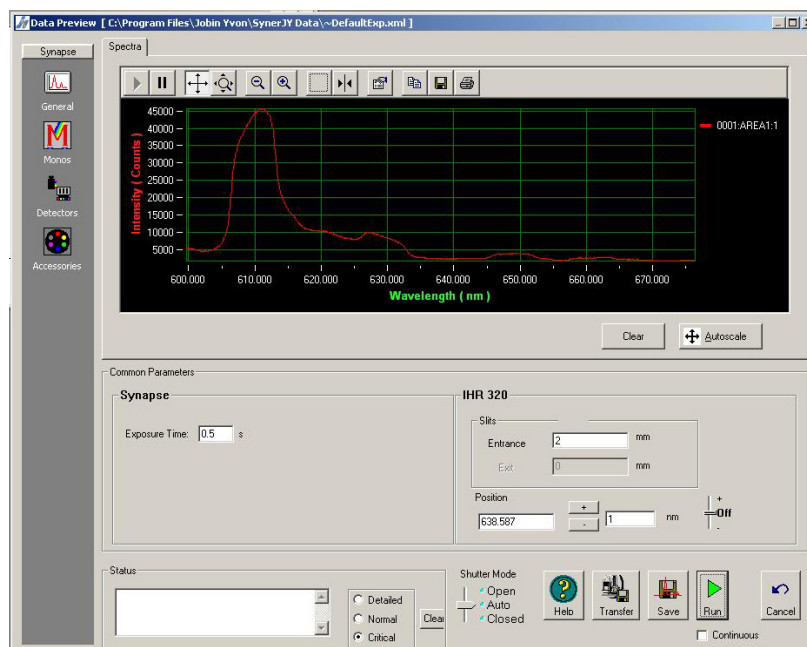
**Table 4.2 Slit Width vs. Bandpass.** Theoretical limits of resolution based on the slit width being the limiting factor.

Slit Width	Bandpass (nm)-limited by slit width
80 $\mu$ m	0.188
0.1 mm	0.235
0.2 mm	0.470
0.5mm	1.175
1.0 mm	2.35
2.0 mm	4.7
4.0 mm	9.4

Source: Horiba Jobin Yvon iHR320 Manual [43] p. 40

After you have finished adjusting the settings, you can test clicking on preview. This will allow you to check your settings at a specific wavelength to determine if you need to make any adjustments. If the CCD is being used, then you

will get a full spectral scan around the specified wavelength as shown in Figure 4.6. To run it continuously, check the Continuous check box below the Run button. If this is the InGaAs detector, it will take a scan just at the specified wavelength and it will instead display the relative intensity versus time, where time just relates to the number of scans taken. The CCD will have intensity in counts whereas the InGaAs will be in mV. By selecting various tabs, all the settings from the previous screen can be modified here. After you have finished, click Cancel to return to the configuration screen or click Transfer to transfer your settings to the previous screen. The Save button will save the current settings so that they will remain as the default until a new set is saved. This does not have to be done to run a scan. At this point, click the Run button and run the actual scan and the data will be displayed after the scan is complete.

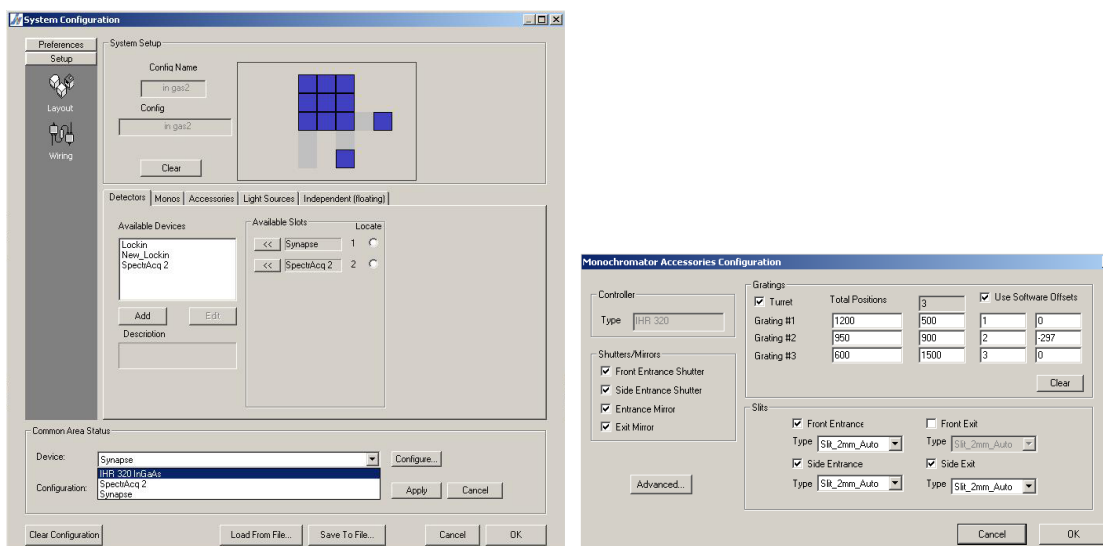


**Figure 4.6** Preview window showing a spectrum taken with the Synapse CCD detector

#### 4.2.1.2 Software Calibration and Setup

At times, certain accessories need to be reconfigured or calibrated. This section will discuss some of the various software tools that are available for configuration and calibration of the hardware. Configuration tools in the SynerJY software, as well as some stand alone programs from Horiba which are located on the desktop, will be used. First SynerJY configuration will be discussed. The first of these is the detector configuration obtained by choosing Edit from the Hardware Configuration screen you get when you first try to open Experiment Setup. This will open a screen that controls which devices are used for each detector configuration. It allows you to change which devices are used for a specific detector configuration and to make changes.

Under the “in gas2” configuration, the listed devices should be Synapse, SpectrAcq2, and IHR 320 InGaAs (Figure 4.7). Even though the Synapse is not used for the InGaAs detection, it is still required for some hardware configurations. By clicking on Configure more advanced options can be obtained. If IHR is chosen, the slit and grating options are changed by clicking on the Accessory Config button. It will open the window shown in Figure 4.7 (right). This provides the ability to turn on and off slits and mirrors. It also provides information on the gratings and their offsets. These offsets are used if the Use Software Offsets check box is selected (it should be). These are important for fine adjustments of the gratings so that the wavelength calibrations are correct. Software wavelength calibration will be discussed later. The last setup for the InGaAs is the SpectrAcq2, which is the data acquisition link to the computer. The settings should never have to be adjusted but it provides settings such as the GPIB address in the case that the GPIB address (it should be 3) were to get changed.



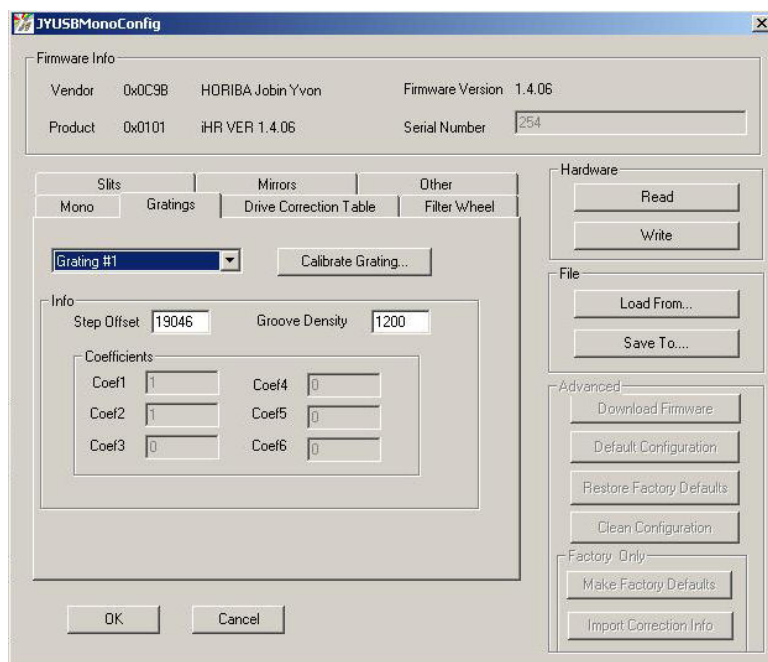
**Figure 4.7** Left: Configuration screen obtained by clicking edit on the hardware selection screen. Right: Accessory configuration screen with the software grating offsets.

The CCD configuration is very similar except that there is no SpectrAcq2 and the spectrometer is referred to as IHR320. The options are the same as they were for the “in gas2,” however some of the values such as the software offsets may be different. These settings will not have an effect on the other detectors configurations as they are all stored independently.

The simplest type of calibration to perform is a software calibration, which is preformed from the preview screen. The Calibration button allows you to change the wavelength which you are actually looking at in relationship to what the scan says. Calibrations should be done in CCD position or Wavelength modes as in these modes the spectrometer is aware of the exact wavelength it should be measuring unlike CCD range mode. This can be done by either using a laser source or a known line of a fluorescent light. When performing a calibration, the slit should be as small

as possible while still achieving a good SNR. This will provide the best resolution and give you the most accurate peak readings. To make adjustments to the calibration, either view the signal in preview mode or after taking a scan. Determine the wavelength at which the peak of your signal occurs and then go to preview mode. Make sure you are at the same position as the peak was observed in the previous measurement. Then click on Calibrate and input the wavelength at which the observed peak should occur at. After accepting the calibration, you need to reinitialize the hardware to make sure that all the settings were correctly applied. If the calibration does seem to take effect, toggle the power on the detector and restart SynerJY to see if it helps to causes the calibration to take effect.

In addition to the SynerJY software, there are several other software tools for configuration and calibration of the system. The first one, JYUSBSpectrometerConfig (or JYUSBMonoConfig), is shown in Figure 4.8. This gives similar options to the previously discussed configuration utility for the IHR320 but deals with the hardware/firmware settings. The settings used in this program are stored in the actual spectrometer hardware and not the software, so care should be taken when adjusting them. The tabs provide information on the different pieces of hardware in the spectrometer. The gratings tab provides a separate offset from the software offset seen in the SynerJY software. This offset should not be changed unless instructed by Horiba. The offset can be changed via the Calibrate Grating button but as mentioned this should not be done unless specifically instructed to do so.



**Figure 4.8 JYUSBMonoConfig software main screen**

Another software tool is HJYSpectrometerControl. This provides another way to control the spectrometer in addition to the SynerJY software. It allows for control of the spectrometer and accessories such as changing gratings, opening and closing slits and adjusting slit opening. It also allows for initialization of hardware. This software should not have to be used much on this system because the SynerJY can be used for this. However, it can be used if the SynerJY software malfunctions or you need extra control. In contrast, the UVISEL system can use this program to provide a method to interface with the spectrometer which usually is not available.

The final piece of software is SynapseOffsetAdjust. This is a simple DOS program that has the purpose of correcting the stored dark subtract offset values. Over time the dark subtract value can shift or become corrupted. There are two main symptoms of this. The first is that the signal reads very high with dark subtract on the

shutter closed and height limiters closed (see Section 4.2.4 for more information on the height limiter). To keep the shutter closed during a reading, slide the shutter slider on the preview window from auto to closed. The second symptom would be a zero signal appearing with increased integration time. This happens because dark subtract data for that section of wavelength is incorrect and causes the recorded signal to peg about the maximum. Both of these should be able to be corrected by this software. To run the software, close the height adjustments on the slits and make sure that the shutter is closed. Then run the software, choose the detector that is having the problem and follow the prompts. After the software has finished, close it and shut down the computer, spectrometer, and detector. Restart them and try doing a scan with the height limiter closed and make sure that it reads around zero signal. If this does not fix the problem try running the software again. If the problem persists, contact Horiba for more assistance.

This concludes the discussion of the software tools that are readily available for use and testing of the spectrometer. Other utilities may be available from Horiba if they are needed. Also, the spectrometer manual has more information on using the software which may be helpful during use or troubleshooting of the system.

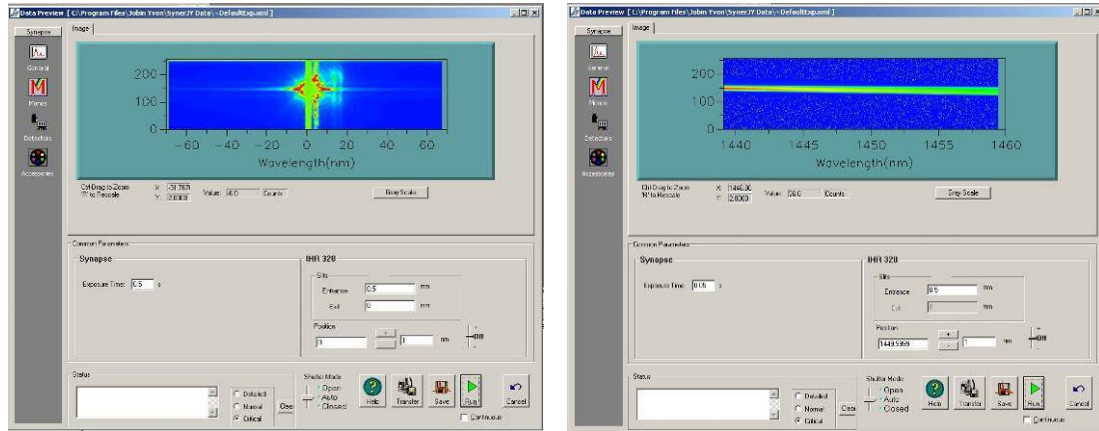
#### **4.2.1.3 Image Scan**

In order to do get more information from certain scans or to help in system troubleshooting, an image scan may be performed. This provides a mapping of the relative intensity across the CCD detector face. Figure 4.9 provides an example of an image scan. The scan shows intensity in a color map. The pixels in the vertical direction show the light incident along the height of the detector and pixels along the horizontal direction show the intensity at different wavelengths. So along the



horizontal direction, the image provides the same information as a normal scan. It shows a mapping of intensity versus the wavelength.

To perform an image scan, first open up the experiment setup window. Select CCD position instead of CCD range for this scan. If you have CCD range selected and then try to click on the Image Scan radio button, it will not be selected and will instead become grayed out. Select the specific wavelength you want to have at the center of your scan. Also, for an image scan, the ADC settings under the Advanced options for Acquisition Parameters have to be changed from 20 kHz to 1 MHz. After these changes have been made, an image scan can be acquired in preview mode as shown in Figure 4.9. The colors should cover the entire height of the image. The height of the acquired signal can be adjusted by the height limiter (Section 4.2.4). This will change the image and it will now only have a horizontal slit of intensity across the image. This is very useful for troubleshooting alignment of the detectors and gratings and can also help to make an image easier to view by removing extra color, which may be confusing. Finally, if the position selected for your scan is 0, then the grating is turned so that it is at normal incidence and acts like a mirror as shown in Figure 4.9 (left). This can be used to image your source and entrance slit, which can be very useful for troubleshooting grating problems and detector alignment. Besides these differences, an image scan can be taken just as if you were taking a regular spectra scan.



**Figure 4.9 Left: image scan at 0 nm. Right: image scan showing a spectrum**

## 4.2.2 Gratings

The iHR320 has 3 different gratings. Each grating serves a different purpose for scanning. The two important specifications given for the gratings in the iHR320 are the groove density and the blaze. The groove density, given in grooves/mm, is the inverse of the grating period. The density is related to the dispersion of the incident light as shown in Table 4.1. As the groove density increases, the dispersion increases. Thus the light is spread further and allows for a better resolution. The blaze is the wavelength at which the grating works most efficiently. A grating works most efficiently from  $2/3$  of the blaze wavelength to twice the blaze wavelength. The gratings are changed from the Monos tab as discussed earlier. Our system has three gratings that are 1200 gr/mm blazed for 500 nm, 950 gr/mm blazed for 900 nm, and 600 gr/mm blazed for 1500 nm. By switching between these gratings, scans can be taken over a very large range of wavelengths with varied resolution.

Normally the gratings operate without any maintenance. The gratings can be changed and after they are changed, adjustments to the grating data under the configuration have to be made. Also, a calibration would have to be performed on the grating to get the wavelength alignment correct. Gratings also have to be correctly mounted so they are not at an angle, which can throw off the wavelength calibration. Determination of grating tilt can be determined by taking image scans and determining if there is a noticeable slope in the acquired image with the height limiter closed. For more assistance on this sort of determination, please contact Horiba.

### **4.2.3 Detectors**

The iHR320 in our lab is configured with two detectors, a silicon CCD array and a single pixel InGaAs detector. These will be discussed further below.

#### **4.2.3.1 Silicon CCD**

The first detector is the Synapse silicon CCD detector. It is located on the front exit of the iHR320 spectrometer (shown in Figure 4.10). It is a 1024x256 TEC cooled silicon detector array. It is interfaced to the computer via a USB port and receives power from the power supply through the round connector. It also has a coaxial cable that provides signaling to the spectrometer to open and close the shower. The power supply sits on the shelf above the optics bench and is connected to the detector through a proprietary cable and connector. When the power supply is turned on, it supplies power to the detector head and the power LED turns illuminates on both the detector and power supply units. The detector head has another light on the back that is for the temperature status. The detector head is cooled to 203 K by an internal thermoelectric cooler. The light will be yellow if it has not yet reached

temperature and green if the temperature is ok for use. The actual temperature can be seen by clicking on the Advanced button in the Acquisition Parameters panel of the experiment setup window. The connector for CCD is the USB connection to the computer. This is the interface between the detector and the computer.



**Figure 4.10 Back of the CCD showing the connections**

#### **4.2.3.1.1 Installation/Removal**

The CCD detector is connected to a flange on the front exit (Figure 4.11). It is connected with 3 screws and nuts. To remove the CCD turn off and unplug the power, trigger cable, and USB and then take out the three screws. They can be difficult to work with because of their position, so be patient. The flange on the CCD and the metal plate with a rectangular window are not meant to be removed. There is

a case for the detector located under the optics bench, which includes a dust cap for covering the detector head to protect it. Any time you have to transport or ship the detector it should be done in that box.



**Figure 4.11 Mounting flange for connecting the CCD to the spectrometer. The circled item is a tilt adjustment screw.**

To reinstall, just follow the removal steps in reverse. Just make sure that the three screws go into the three grooved sections on the CCD mounting plate, not the 3 small stationary holes. Once the detector has been mounted, connect the USB, trigger, and power cable. Once power is applied, it should turn on and the temperature light should be yellow until it has cooled to the proper operating temperature. In the next section (4.2.3.1.2), the rotation and tilt adjustments of the detector will be discussed.

#### **4.2.3.1.2 Alignment/Calibration**

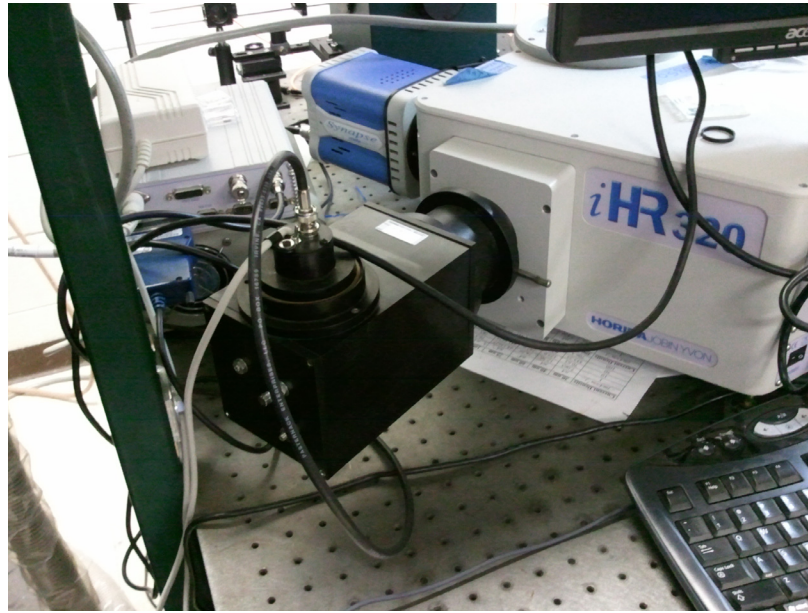
After installation of the CCD, it has to be aligned to get accurate readings. The first adjustment is in the rotation of the detector. This is why the detector mounting bracket has grooves, so that adjustments can be made to get the detector rotation correct. One rough method to get it aligned is to use a 2D bubble level and compare the leveling of the top of the spectrometer to the detector and make adjustments until they match. This is a rough method and should be performed first. Another method that can be performed is to use the image scan at 0 nm position. Close down the height limiter and use a very small slit size. Adjust the integration time so that you can clearly see the vertical bar and it is not overpowered by the source image. Take a scan and then make adjustments until the line is vertical thus indicating that the detector is aligned to the incoming light source.

After the rotation alignment is performed, the tilt has to be adjusted. The tilt is controlled through a screw on the mounting bracket, circled in Figure 4.11, and there is a locking screw on the spectrometer unit that has to be adjusted in order for the tilt to be adjusted. More information on performing the tilt alignment through peak narrowing is in the Synapse CCD Detection System manual on pages 22-24. Another method is to turn off dark subtract and run a preview scan with the shutter closed. It should register between 1000-2000 counts if it is properly aligned. If the tilt alignment is off, then the signal intensity will be lower and peaks may not be as narrow but the wavelength calibration should still be correct. If the wavelength calibration seems off after installing the CCD unit, perform a software alignment as discussed in Section 4.2.1.2.

#### **4.2.3.2 InGaAs**

The InGaAs detector is located on the side exit (pictured in Figure 4.12) and is composed of two separate parts. The first part is the mount and focusing setup, which is part number 1427B and the second is the detector, DSS-IGA020TC. The specifications about both of these pieces are located in the binder for the spectrometer behind the purple tab.

The top of the detector has 3 important features. The first is the BNC connector, which will be discussed again later when talking about the computer interface. This BNC is the voltage output from the detector, which connects to the acquisition system. Another connection is the white cable coming out of the top of the detector with a DB-9 connector on the other end. The DB-9 connector provides power and connects to the little red and black box above the spectrometer. Power is provided for both the detector and the TEC cooling, which is discussed in the cooler section (4.2.3.2.1). Finally, the last component on the top of the detector is the gain switch. The switch is normally flipped away from the power cord, which puts the detector in high gain mode. Flipping the switch in the opposite direction will put the detector and amplifier into low gain mode. A schematic and pin out of the power connector are in the spectrometer binder behind the purple tab.



**Figure 4.12 InGaAs detector in its mount connected to the side exit of the spectrometer. Visible to the right of the connection, the height adjustment is visible. The white box behind the detector head is the SpectrAcq2 converter box.**

The InGaAs detector sits in the 1427B housing and is connected to the side exit. The housing provides the seating and alignment of the detector. Besides adjustment screws for alignment, there is also a slit height adjustment on the 1427B. The slit adjustment is controlled with the metal pin that sticks out from the mount near the spectrometer. This slit height adjustment is fully open when the pin is pulled out and closed when it is pushed in. Remember that like the two input slits, there is also the slit width, which is controlled from the computer. The most important part of the housing is the alignment and focusing. These are both covered extensively in the spectrometer binder and should be reference in the case that the alignment ever needs to be changed or verified.



#### **4.2.3.2.1 Cooler**

Similar to the Silicon CCD, there is a thermoelectric cooler for this unit. The control for this unit is the PS/TC-1, which is the red and black box located on the shelf above the spectrometer. It connects to the InGaAs detector through a DB-9 connector, which is hardwired to the InGaAs detector. In addition to cooling power, the DB-9 connector also supplies power to the detector for normal operation. The controller should be set to  $-30^{\circ}\text{C}$  and have a current draw of around 0.6 A DC during normal operation. There are 3 lights on the front panel. The big red light on the right side is the power light. The other two lights are the green and red status lights above the temperature knob. When the green light is lit it, indicates that the proper temperature has been reached for operation.

#### **4.2.3.2.2 Computer Interface**

Similar to the Synapse, the physical connection to the computer for the InGaAs detector is through the USB. However, the electrical setup is much more complicated. The output from the InGaAs detector is taken via a coax cable and connects to the voltage input on the SpectrAcq2. The SpectrAcq2 acts as an A/D converter and outputs the signal from the InGaAs in terms of mV. The SpectrAcq2 outputs via GPIB that is interfaced to the computer via a USB-GPIB converter. The address of the SpectrAcq2 is usually 3 but can be verified from the NI Measurement & Automation software. The SpectrAcq2 should not have any maintenance as long as it works well. At times it may lose communication and need to have the power cycled to regain proper communication with the computer.

#### **4.2.3.2.3 Troubleshooting**

The InGaAs detector does not require much maintenance as long as the cooler maintains the proper temperature. However, at times you may not get a signal when trying to take a reading. There are several reasons this could be happening. The first step to solving the problem is to restart SynerJY and reinitialize the InGaAs detector. Make sure that the correct settings such as slits, detectors, and exits are selected. If there is still no detected signal, try shining an illumination source near the selected entrance and see if there is any signal. If there is no still no signal, shine a light on the top of the InGaAs detector around the edge where the detector and housing meet. This will determine if there is something wrong in the path of the light to the detector. If light does go through, systematically check each component along the way such as the slits (both on the computer and the manual adjustment), gratings, and entrances. If there is still no light, shut off the spectrometer and computer and then turn on the spectrometer followed by the computer. After this, retry the software. If there is still no signal but a signal gets through the top of the detector housing, you might need to change detectors or open the spectrometer to trace out the problem.

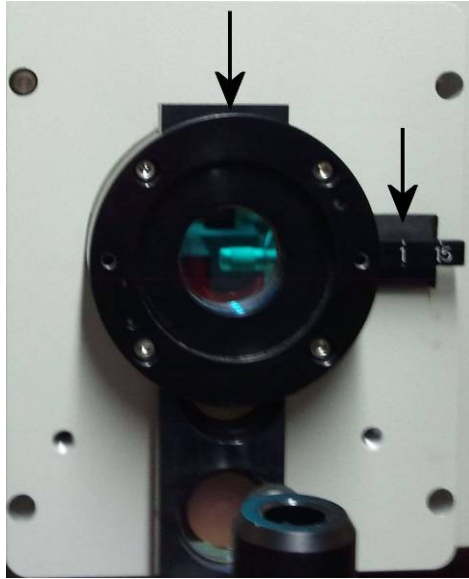
In the case that light does not go through the top of the detector. the problem is probably somewhere along the electrical chain to the computer. Try turning off the SpectrAcq2 and closing SynerJY. Then turn on the SpectrAcq2 and verify that the device can be seen by the computer and that it can be communicated with from the Measurement & Automation software. If you cannot communicate with the SpectrAcq2, make sure the GPIB is connected correctly and restart both the computer and the SpectrAcq2. If you can communicate through Measurement & Automation but not from SynerJY, check the communication settings under the “in

gas2” detector. If you still are experiencing difficulty, you may need to contact Horiba for more assistance.

For more information on the detectors, please see the specific manuals located in the spectrometer binder or contact Horiba for more assistance.

#### **4.2.4 Entrances and Exits**

As mentioned earlier, the spectrometer has 2 entrances and 2 exits. The side entrance is used for collecting free space light. This entrance is usually used with the PL/EL setup, which will be discussed more in the next Section 4.2.5. The notable features of the entrance are the slit, shutter, height limiter, and filters. The slits are adjustable from 2mm to 80  $\mu\text{m}$  through the SynerJY software. The shutter is used for blocking out incoming light and gating of the signal and is controlled through SynerJY and is usually toggled automatically by the computer. The two parts that are physically adjusted by the user are the height limiter and the filters (Figure 4.13). The filters are in a sliding bar, which clicks into place for each filter. The center position is left empty so there is no filtering. The top is usually a 532 nm line filter for removing the pump laser from the input signal and the bottom one is interchanged. The height limiter is a sliding piece that has marking sticking out of the right side of the entrance. It has adjustments of 15, 1, and S which represent the different positions of the height limiter, from full open to fully closed. This has uses for dark subtract calibration and image scans as previously mentioned.



**Figure 4.13 Free space collection entrance showing the height adjustment to the right of the filter bar.**

The front entrance is similar to the side entrance except for it has a 220F fiber port adapter, which allows for fiber instead of free space collection. The filter bar and height limiter work the same as on the side entrance. The fiber adapter can be opened by rotating the top thus revealing the optics rails and lenses. These lenses are for properly collimating and focusing the beam.

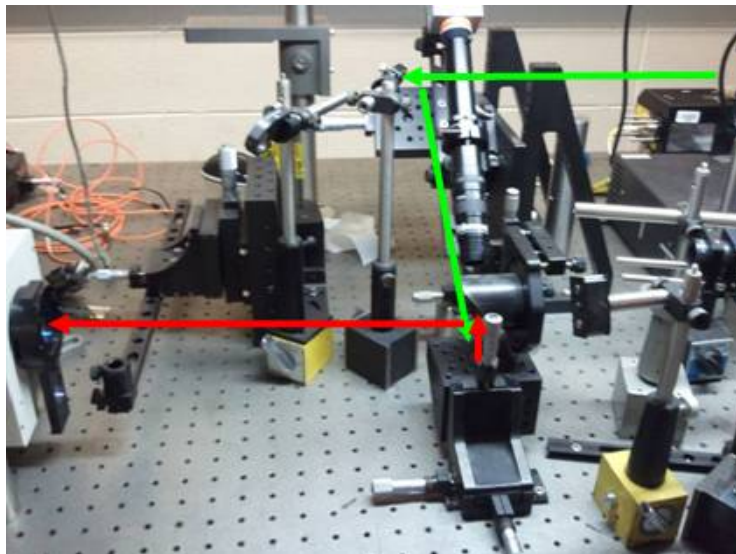
Next there are the two exits. The first exit that will be discussed is the front exit, which goes to the CCD detector. This exit is extremely simple and has no slit or other adjustments. The side exit, which goes to the InGaAs detector, has a slit adjustment controlled by SynerJY, however the height limiter is part of the detector mounting, not the exit itself, as discussed in the InGaAs detector section (4.2.3.2).

For both entrances and exits, the light is directed correctly by the use of mirrors. The side entrance and side exit are used by having internal mirrors swing

into position to direct the light into the path that is taken if both front entrance and exit were used. The mirrors automatically move when entrances and exits are changed in the software. If there were ever to be a problem with them, the top of the spectrometer can be removed to reveal the mirrors for further troubleshooting.

#### **4.2.5 External Optics**

The spectrometer is often used with external optics used for excitation of samples and/or collection of light. The specific external optical setup varies for each test but the main optical setup is the PL/EL collection setup, which couples to the free space entrance (side entrance) on the spectrometer. This is the setup used for testing nanocrystals as discussed in Section 3.6.3.3. This illumination and collection setup is shown in Figure 4.14. The illumination is provided by a 532 nm laser which is redirected towards the sample through the use of a adjustable tilt mirror. The beam then hits the sample causing photoluminescence. This emission is collected by the parabolic mirror directly above the sample. The focal point of the parabolic mirror should be at the entrance slit to the spectrometer. This is because, as previously discussed, the first mirror in the spectrometer has its focal point at the entrance slit. The path of the illumination and collected luminescence is show with the green and red arrows in Figure 4.14.



**Figure 4.14 Free space EL/PL collection setup for the spectrometer**

There are two alignments that have to be done with this setup. The first alignment is a painstaking alignment and should ideally only have to ever be performed once on the system. This is the alignment of the parabolic mirror and the sample stage. This alignment is done to make sure that the light of the parabolic mirror is focused correctly on the slit. The parabolic mirror has x-y-z and 2 tilt adjustments. By using these, the mirror should be aligned. First it should be aligned by eye to make sure that it is about centered on the entrance to the spectrometer. This will be fine tuned later. Connect a fiber coupled laser to the fiber port in the bottom of the sample stage and place an aperture over the opening. Then, using a small piece of paper or business card, you can view the spot right in front of the slit. You do not want it to be in focus on this card as that means it will be slightly out of focus when it is at the entrance. So put the spot in focus on the card and then move the focal point back towards the entrance until you feel it has moved enough. After this, the height

and lateral adjustment should be made. To perform these, first get them roughly aligned and then use the spectrometer to take measurements of the light source. Start with the slit all the way open and height limiter all the way open. Slowly close down the slit and make adjustments to maximize the input light at each slit size until you have closed the slit all the way to 0.08 mm. This will guarantee that the light is aligned to the slit laterally. Next close down the height adjustment one setting to make sure that the beam is hitting the middle of the entrance. After these alignments are completed the collection mirror is aligned.

The second alignment, which should be performed every time you use the setup, is the laser mirror alignment. To do this, set a piece of Si-nc on the sample stage and turn on the laser. Then carefully make adjustments to the mirror to try and maximize the signal. We are doing this because at times the mirror can get bumped and thus you are not getting the optimum collection of signal. After completing this, the free space collection setup is ready for use.

The previously discussed setup is the most commonly used setup; however it is not the only setup that can be used for free space collection. Depending on your excitation and collection needs, other setups can also be used instead of this setup.

### **4.3 UVISEL**

The UVISEL system is an ellipsometric system for determining the characteristics of a sample with various films. This system uses an iHR320 spectrometer in performing its measurements, which is why it is included in the same chapter as the iHR320 spectrometer. In addition to the spectrometer, it has a light

source, polarizer head, and analyzer/collection head. These will be discussed more in the following sections.

#### **4.3.1 Theory of Operation**

Unlike the other equipment discussed so far, the theory for operation of the ellipsometer will not be discussed. This is because there are training files located in the SE training folder on the desktop of the measurement computer, which is discussed in Section 4.3.3. Along with this, the *Handbook of Ellipsometry* [44] is a good source for the theory of how the ellipsometer works.

#### **4.3.2 Operation**

The UVISEL system contains 4 main pieces of hardware. These are the sample stage, server computer, control computer, and spectrometer. Only the sample stage and control computer will be discussed in this section as the server computer and spectrometer are usually abstracted away from the user during normal operation. These other pieces of hardware will be discussed more in-depth in later sections including some troubleshooting and maintenance issues associated with them.

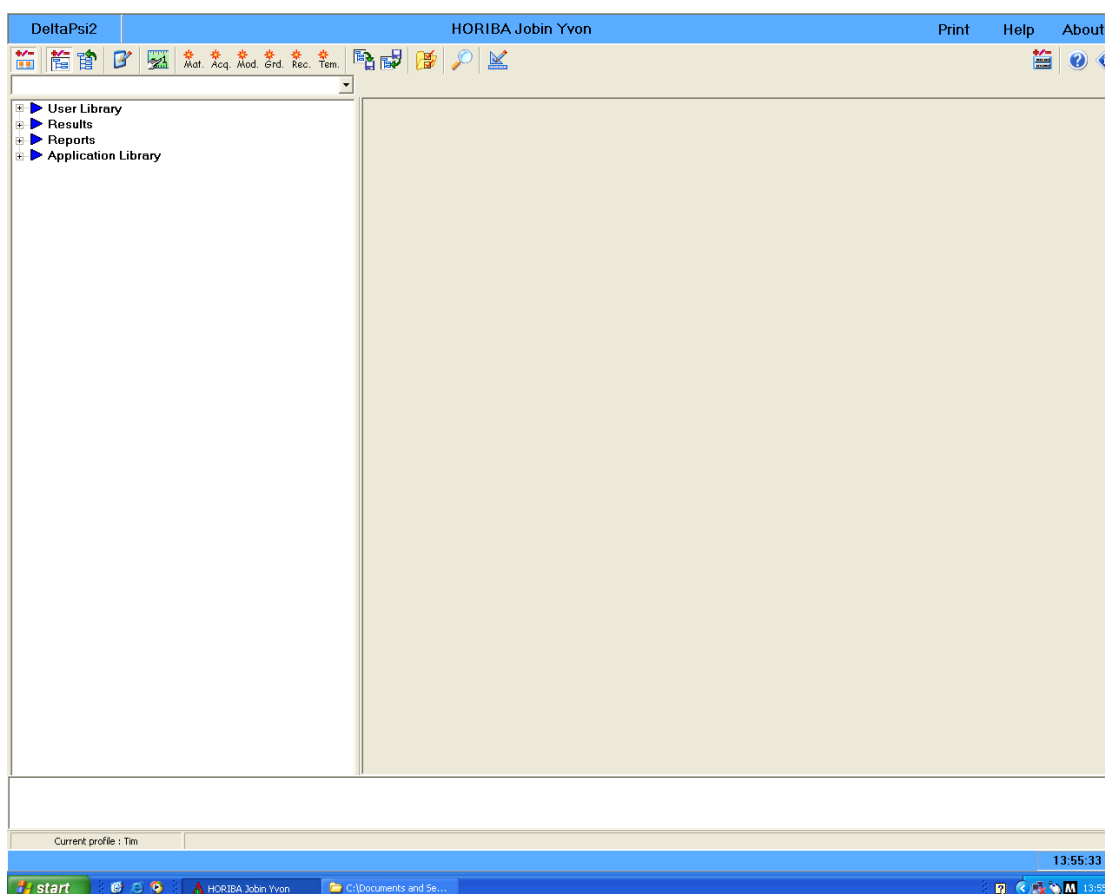
##### **4.3.2.1 Sample Setup and Data Acquisition**

This section will go through the process for aligning the sample and using the Delta Psi software for collecting data. For this section, it will be assumed that the system is on and working correctly. If a problem is encountered, please consult the appropriate Section 4.3.3-4.3.6 to help rectify the problem.

The first step to using the spectrometer is to turn on the light source located in the main ctrl-unit. The switch is the big green button on the left side of the front of the unit. It should become illuminated once it is flipped indicating that the



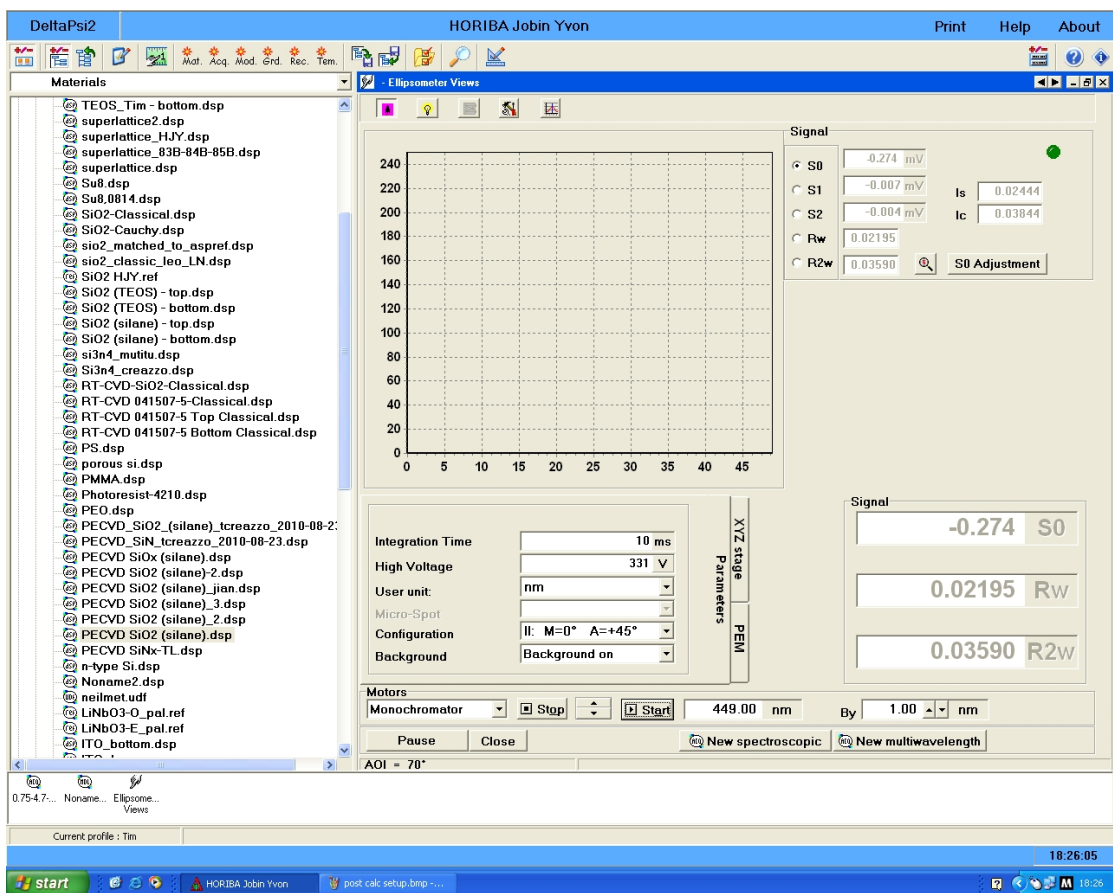
light has been turned on. After this, turn your attention to the computer. The DeltaPsi2 software should be opened and look similar to Figure 4.15. If it is not already open, open it from the icon located on the desktop.



**Figure 4.15 Main screen of the DeltaPsi2 software when it is first opened**

After the software has been opened, place your sample on the center of the sample stage (see Figure 4.32 for a picture). There is a hole in the center that is a vacuum port, which can be turned on by turning on the vacuum switch on the top of

the unit. Turning on the vacuum port is not required. After placing your sample, click on the 5<sup>th</sup> icon from the left which shows a ruler with a finger. This will bring up the ellipsometer views screen (Figure 4.16), which displays the measured intensity. This turns on the beam so you can see where it is hitting your sample. If you receive an error, see Section 4.3.3 for more information on how to correct these errors. Using a piece of paper or other material, make sure that the light is hitting your sample where you want and adjust the sample placement if necessary. Next, turn on the light using the light switch on the top of the unit next to the vacuum switch. Then look in the eyepiece that is located above the sample. It has two crosses that are 45° to each other. Using the knobs on the bottom of the sample stage, move the crosses so that their centers overlap. After you are done with the adjustment, turn off the light and turn your attention back to the computer screen. At the bottom of the screen it displays the wavelength in nm. Change this to 450 nm and click start. If you hear a click but do not hear a motor turn on, enter 449 nm and click start again. You should hear a motor moving, which is the monochromator being adjusted. There should be a red signal going across the graph now. If there is not see, Section 4.3.3 for information on troubleshooting this problem. Use the micrometer on the front of the sample stage to maximize the signal. If signal goes off the screen, press S0 Adjustment to bring it back into range. After you have finished maximizing the signal press the S0 Adjustment button again. After the alignment has finished, click Close on the bottom of this screen.



**Figure 4.16 Ellipsometer views screen that is used for aligning the sample for measurement**

Now that the sample is properly aligned, it is time to take a measurement. The measurement routines are accessed by clicking on User Library→Acquisition Routines on the left side of the screen. The routines that we usually use are ones given in eV. The 0.75-4.7 eV range provides the most flexibility and provides the most information. However, this takes more time and will error out for materials that are lossy in certain energy ranges. The next part of the scan name is the step size. The step size is used based on the film thickness. For thicker films, there will be more

fringes so a finer scan will be required. In general, you can always run a finer scan than is required; it will just take longer to get data. If a course scan is run and the data is jumpy, then a finer scan should be run. To run a scan double, click on it to open the window shown in Figure 4.17. Click the Run button to bring up the screen in Figure 4.18, which is a screen to enter scan information. Enter a folder name in the Lot name box. If the folder does not exist, it will create one for you. Then enter the sample name you want it to be called and click ok to begin the scan. After the scan finishes, the data can be analyzed, which is discussed in the next section (4.3.2.2).

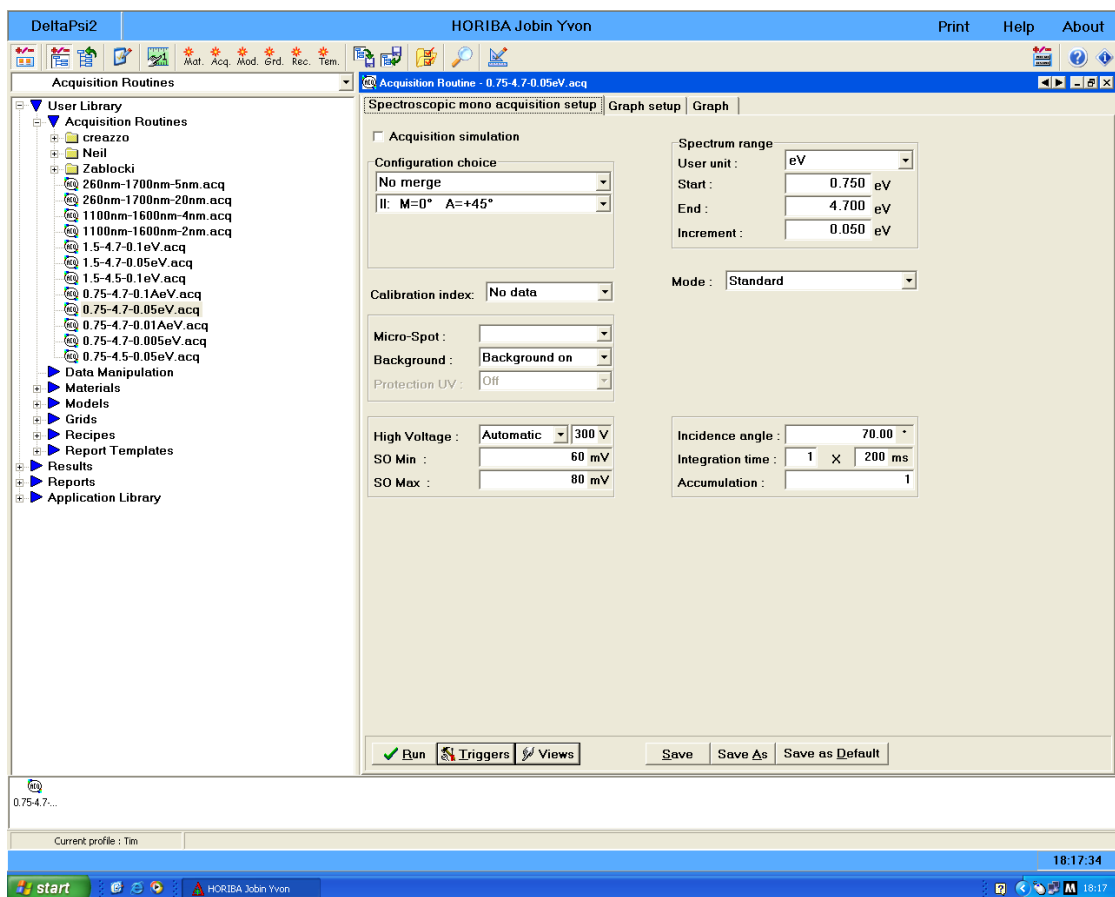
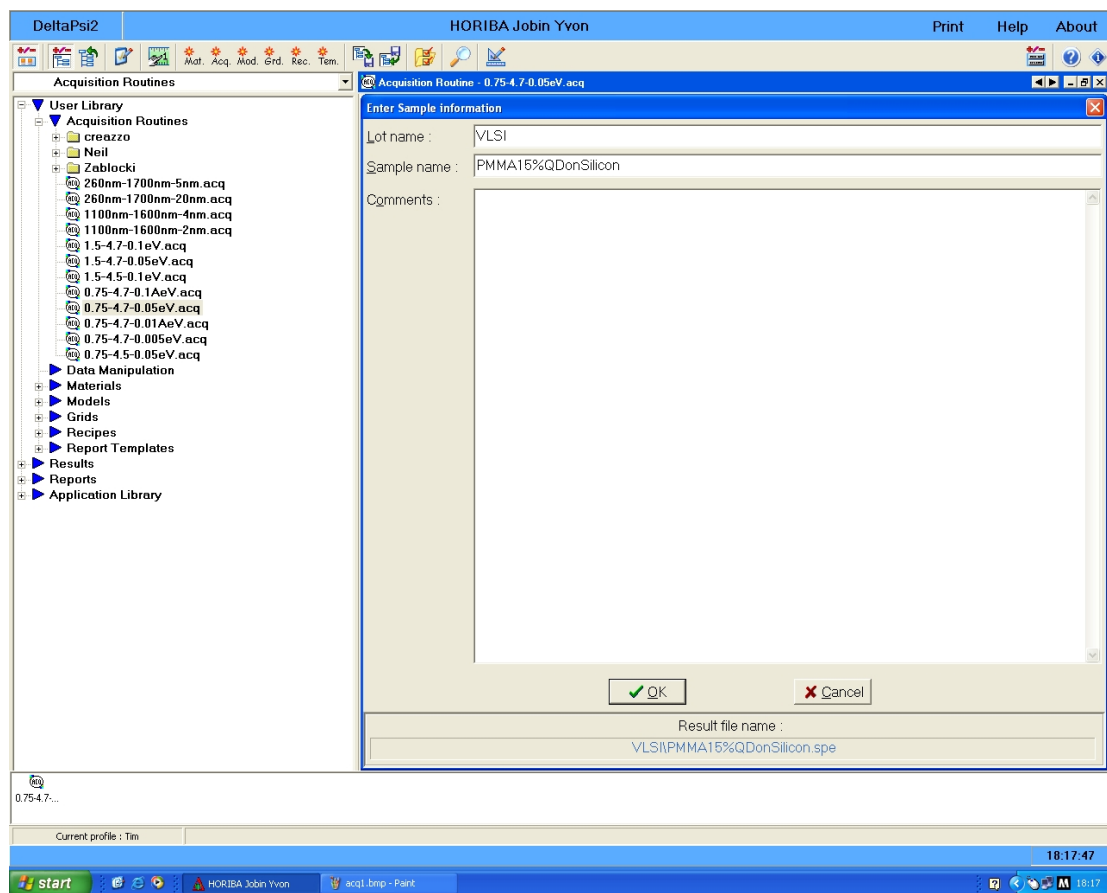


Figure 4.17 Acquisition routine screen showing the scan range options



**Figure 4.18 Acquisition routine sample information screen for entering information for saving the acquired data.**

#### **4.3.2.2 Sample Measurement and Modeling**

Now that the data has been collected from the sample, a model has to be created to extract the information of interest. To create a new model, click on the button at the top of the screen labeled Mod. This will bring up a box for selecting the type of model to create. Select spectroscopic model to bring up a new model such as that shown in Figure 4.19. To create the structure, different films have to be dragged over to the bottom section of the screen where there is the purple bar. This purple bar

is the sample substrate layer. To add a material for the substrate layer, the material file has to be found in the folders in the left pane and then dragged to the substrate layer. For example, to make a silicon substrate the file is Csi\_uv.ref. This means a crystalline silicon material that contains UV data. The .ref file extension means it is a reference files and the material properties cannot be changed as opposed to a .dsp file, which is a dispersion material file. The Csi\_uv.ref file is located in Application Library →Materials. This contains a large library of materials supplied with the system. Additional materials made by other users can be found in User Library→Materials. After the addition of the silicon layer, the window should look like Figure 4.20. To add an additional layer, find the file you want and drag it to the area above the silicon. This will add the additional layer on top of the silicon substrate as shown in Figure 4.21. This can be repeated to add additional layers. If a layer is dropped on top of an existing layer, then it forms a composite layer in which the percentage of each material in the composition can be adjusted. After the materials have been added to the model, it has to be configured for fitting.

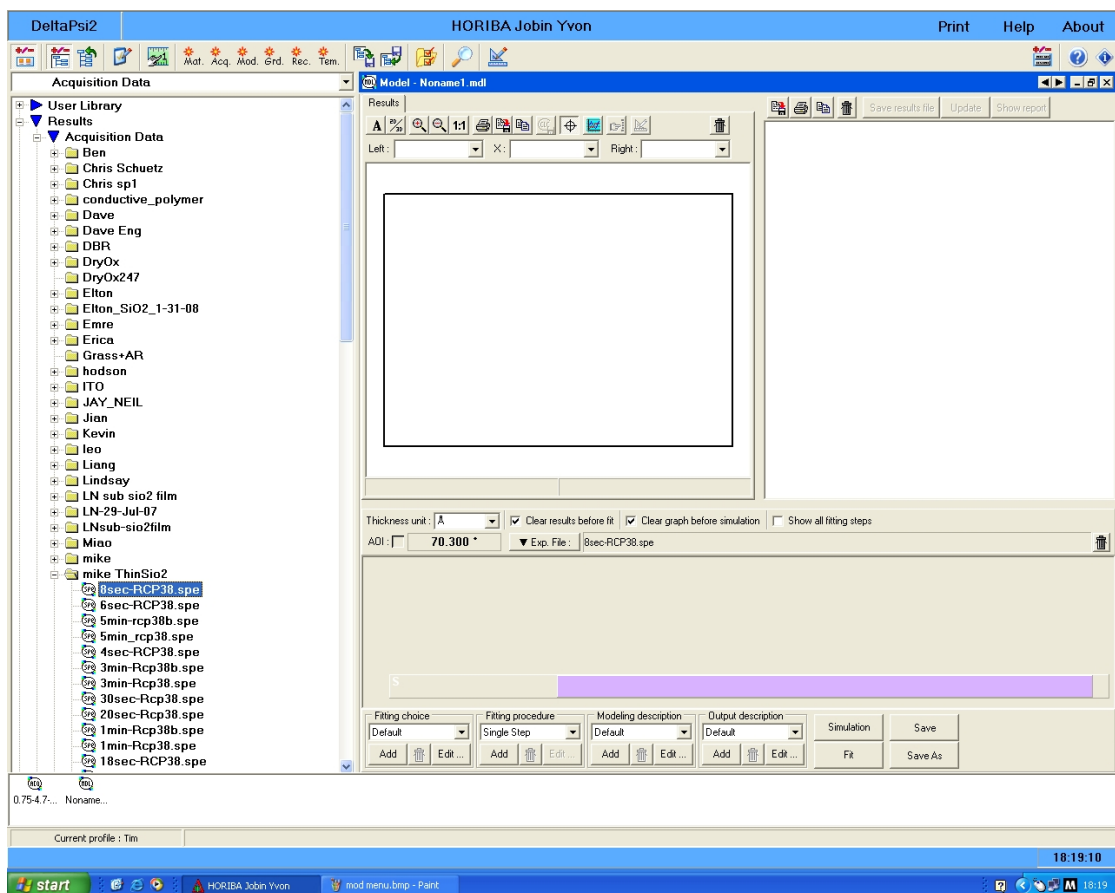
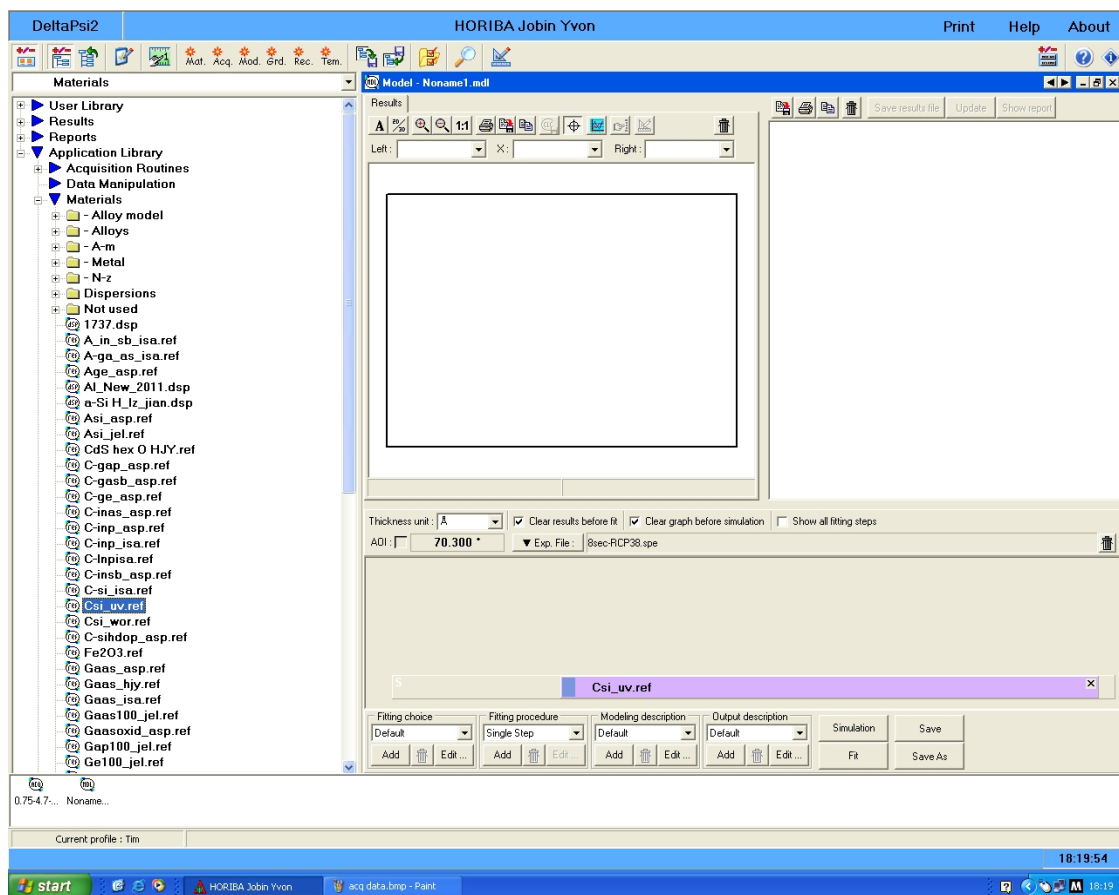
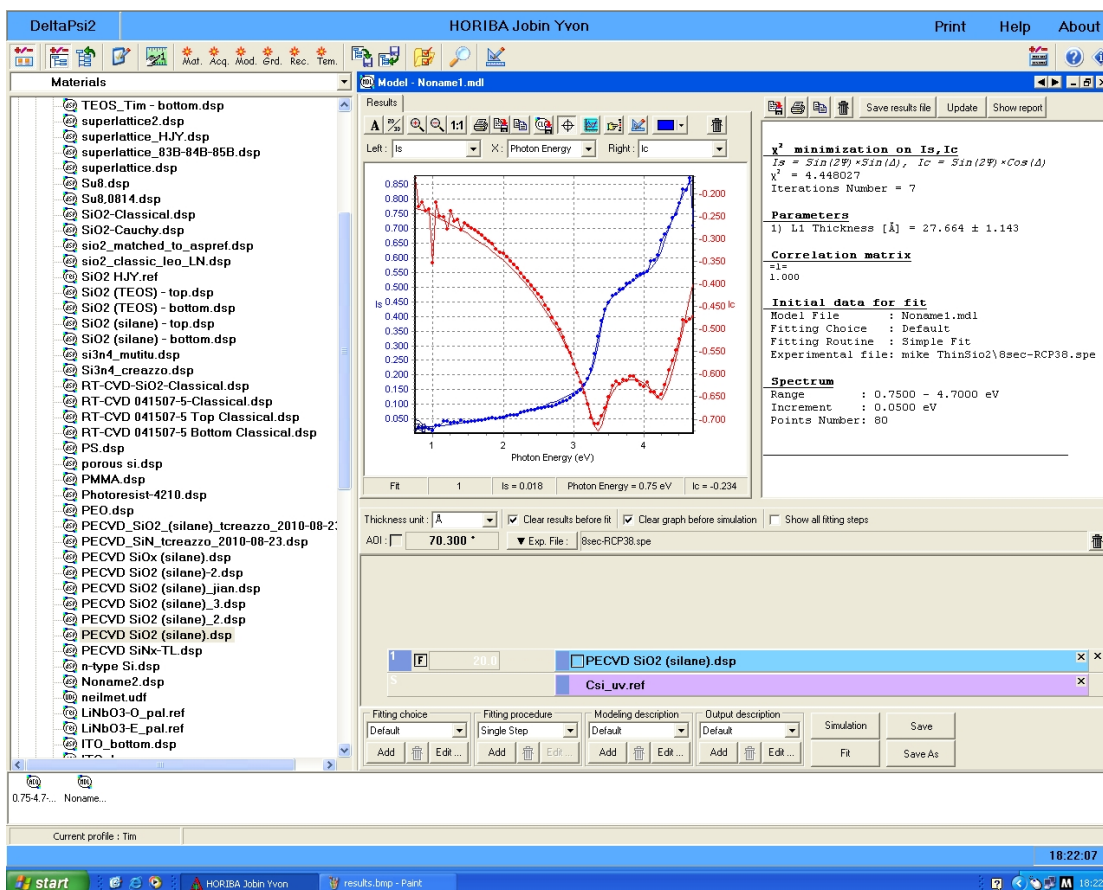


Figure 4.19 Spectroscopic model with no layers added





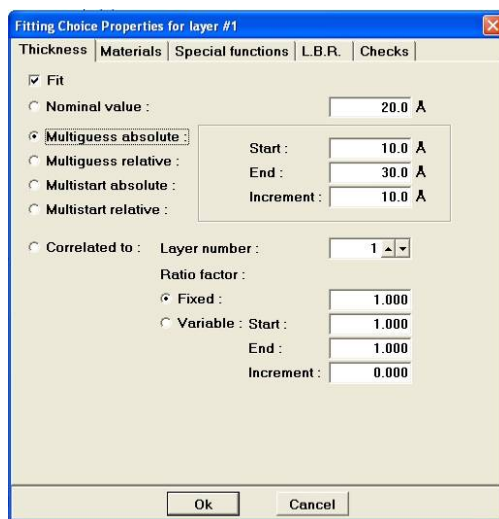
**Figure 4.20** Spectroscopic model with silicon selected as the substrate (purple box)



**Figure 4.21** Model consisting of a silicon substrate and a PECVD oxide layer. The plot shows the measured data as points and the fitted data as the solid line. The right panel shows the results of the model fitting.

After the layers have been selected for the model, the fitting parameters have to be selected. The first parameter is the thickness of each layer except for the substrate which does not have a thickness parameter. These thicknesses can be set manually or can be fitted by the computer models. Even if the computer model is used to determine the thickness, an initial guess is still required to allow for the model to have a starting point. To select a layer for thickness fitting, click on the box just to the right of the layer number on the left side of a layer. The box should toggle from

being empty to saying “F” and will become blank again if clicked again. To the right of this box is the thickness initial guess box. Clicking on this box will bring up another window shown in Figure 4.22. This window provides various options for choosing the initial guess for the layer thickness.



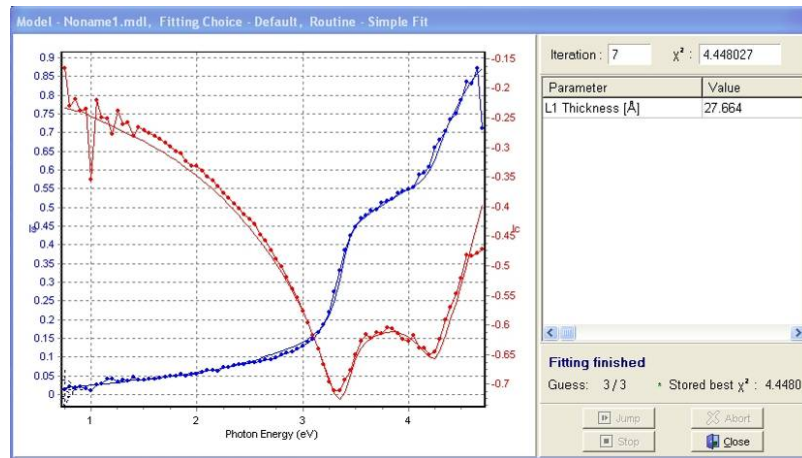
**Figure 4.22 Model fitting properties window showing the options for setting initial value of film thickness**

The window that is opened by clicking on the initial guess box allows for selecting the method for choosing the initial guess(es) and inputting the data. The default method is the nominal value method. In this case the expected value of the thickness should be entered and then the fitting will proceed from there. Another option that is often chosen is the multiguess absolute option. This option takes a start and end value for the guess range and an increment value that determines the step size used between guesses. This method is useful when you are unsure of the starting

thickness but have a range of possible values. After setting the initial guess, values click OK to accept.

Now that the modeling has been setup, a data file (or experiment file as they call it) has to be selected for fitting. To do this, go to Results→Acquisition Data. Then find the file that you want and drag it over the model and drop it in the box to the right of “Exp. File”. This should load the data file into the model thus completing it and making it able to be used. Now that the model is complete, click the Simulate button to run a fit with the given initial guess. This will give you an idea of how close your guess is to the actual value. You can change your guess if you would like or click Fit to run the fitting program. If an error box pops up about the spectral ranges not matching, click OK. This error can be removed by changing the range of energies used for material fitting. To change this range, click Edit under the model description section. Then click the radio button next to user defined spectrum and input the start and end values specified in the error message. Also specify the increment value to be the same as the step size in your data file. The experiment file limited option does the same things as user defined except it takes the increment value from the data file instead of using a user inputted value. After setting this range, the error should be removed and this technique can be used later to remove regions of your data that are not accurately fit by your model to increase the model accuracy. During fitting the screen in Figure 4.23 will be displayed and it will show the fitted results after the fitting process has finished. If nominal value is chosen, it will run and try to fit the curve and then stop. If multiguess is selected, it will run a fitting at various initial guesses and then chose the one with the lowest  $\chi^2$  value. A lower  $\chi^2$  value indicates a better correlation between the fitted data and the measured data. A value of less than

10 is considered good but a value of more than 10 is acceptable if the curves seem to be matched to a given trend.



**Figure 4.23** Results window with the measured and fitted data shown on the left. The right side shows the estimated thickness for the layer in angstroms. This window will also contain other fitted parameters if there are multiple layers or fitted material properties. Above this area is the  $\chi^2$  value that describes the fit quality.

In some cases, a high  $\chi^2$  value will be because of a bad initial guess. If your initial guess is a nominal value, try changing the value to the fitted layer thickness. This is one of the uses of the multiguess. By choosing multiguess, it will start at multiple nominal values, thus increasing the accuracy of the fitting. It will take more time to run but will often times provide better results than choosing a single nominal value. Another method used to help improve fitting is adding a roughness layer. A roughness layer is a layer located above your, which is composed of the current layer material and void.dsp. To make this layer, drag another layer of your current top layer above your current layer to add it to a new layer. Then drag a void

material on top of this new top layer. This will merge the two into a single layer that is 50% of each material. This is a roughness layer and helps to provide a better fit for some materials. The last part to making the roughness layer is setting it to fit the layer thickness as was done for the previous layer. Set it to a nominal value of 5 angstroms. Ideally the roughness is 0 but this small value will help with fitting. After adding the roughness layer, try rerunning the model to see if the fit improves at all. If the fit still is not improved the material file you are using may not be a good match and should either be changed or the material parameters of the material may need to be fit.

At times the fitting of the model may be unsatisfactory or information about the material properties besides thickness may need to be extracted. In order to help with these, the model should be changed to not just try and fit the material thickness but also the material parameters. To do this click on the little box located to the left of the description of a material in the model. This box should be similar to the box clicked to turn on fitting of a material layer. Clicking on this box will open one of the two windows show in Figure 4.24. Usually the first window is opened but it can depend on the exact material parameters and the model. Usually all the material parameters on this Sub formula page are selected. For more advanced fitting and data analysis, an experienced user may change their selections and change values on the parameters tab. After selecting the values to be fit, click Close. The box that was clicked to open the dispersion parameter window should now display an “F” indicating that it will be fit. To turn off fitting, simply click this box again to remove the “F”.

Now that the dispersion parameters have been set to fit, they will automatically be fit when the fit button is clicked. The fitting will now take longer

that there are more parameters and iterations required to fit the required data. Once the fitting has finished, the parameters will be displayed on the right side of the results window along with the summary report if this window is closed. It is important to check to make sure that the fit values for the material make physical sense. An example of a nonphysical value would be a negative  $\epsilon_{\infty}$ . If this happens, try changing the material initial guess thickness or turn off the High Frequency parameter option in the sub formula page of the material fitting parameters window.

Dispersion Fit Parameters

Dispersion file name: superlattice2.dsp

Dispersion formula name: Classical

Parameters Sub-formula

☒ High Frequency

$$\epsilon_{\infty}$$

☒ Single Oscillator

$$\frac{(\epsilon_s - \epsilon_{\infty}) \omega_t^2}{\omega_t^2 - \omega^2 + i \Gamma_0 \omega}$$

☒ Drude Model

$$\frac{\omega_p^2}{-\omega^2 + i \Gamma_D \omega}$$

☒ Double Oscillator

$$\sum_{j=1}^2 \frac{f_j \omega_{0j}^2}{\omega_{0j}^2 - \omega^2 + i \gamma_j \omega}$$

☒  $\Gamma_0 \neq 0$

☒  $\gamma_1 \neq 0$

☒  $\gamma_2 \neq 0$

Close

Dispersion Fit Parameters

Dispersion file name: superlattice2.dsp

Dispersion formula name: Classical

Parameters Sub-formula

Nominal Check: ☒ Absolute ☐ Relative

	Fit	Value	Min	Max	Internal	Output
$\epsilon_{\infty}$	<input checked="" type="checkbox"/>	1.0000000	0.0000000	0.0000000	<input type="checkbox"/>	<input type="checkbox"/>
$\epsilon_s$	<input checked="" type="checkbox"/>	2.5000000	0.0000000	0.0000000	<input type="checkbox"/>	<input type="checkbox"/>
$\omega_t$	<input checked="" type="checkbox"/>	12.0000000	0.0000000	0.0000000	<input type="checkbox"/>	<input type="checkbox"/>
$\omega_p$	<input checked="" type="checkbox"/>	0.0000000	0.0000000	0.0000000	<input type="checkbox"/>	<input type="checkbox"/>
$\Gamma_0$	<input checked="" type="checkbox"/>	5.0000000	0.0000000	0.0000000	<input type="checkbox"/>	<input type="checkbox"/>
$\Gamma_D$	<input checked="" type="checkbox"/>	0.0000000	0.0000000	0.0000000	<input type="checkbox"/>	<input type="checkbox"/>
$f_1$	<input checked="" type="checkbox"/>	0.0000000	0.0000000	0.0000000	<input type="checkbox"/>	<input type="checkbox"/>
$\omega_{01}$	<input checked="" type="checkbox"/>	0.0000000	0.0000000	0.0000000	<input type="checkbox"/>	<input type="checkbox"/>
$\gamma_1$	<input checked="" type="checkbox"/>	0.0000000	0.0000000	0.0000000	<input type="checkbox"/>	<input type="checkbox"/>
$f_2$	<input checked="" type="checkbox"/>	0.0000000	0.0000000	0.0000000	<input type="checkbox"/>	<input type="checkbox"/>
$\omega_{02}$	<input checked="" type="checkbox"/>	0.0000000	0.0000000	0.0000000	<input type="checkbox"/>	<input type="checkbox"/>
$\gamma_2$	<input checked="" type="checkbox"/>	0.0000000	0.0000000	0.0000000	<input type="checkbox"/>	<input type="checkbox"/>

Fitting mode for  $\epsilon_{\omega}$ :

☒ Nominal value

☐ Multiguess absolute:

☐ Multiguess relative:

☐ Multistart absolute:

☐ Multistart relative:

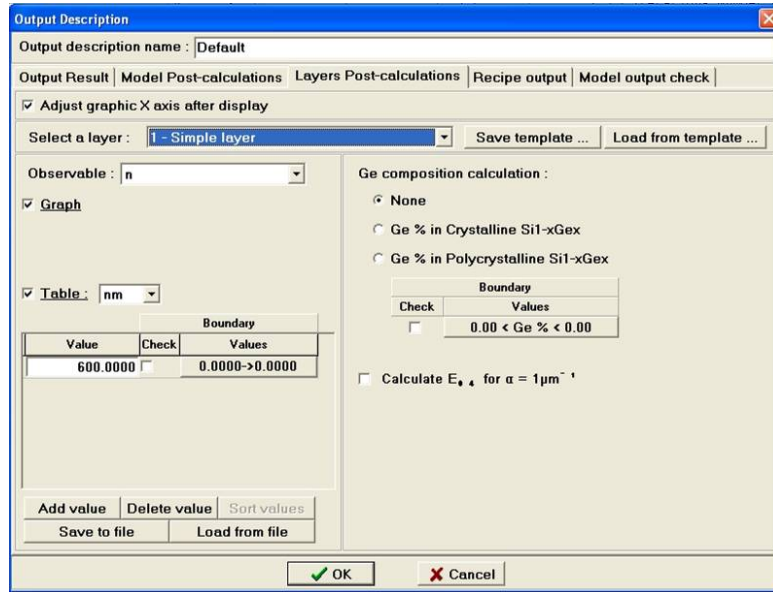
Close

**Figure 4.24** Dispersion Fit parameters window that allows for the selection of which parameters will be fit. The top window is the one usually shown but the bottom provides more flexibility and setting the parameters.

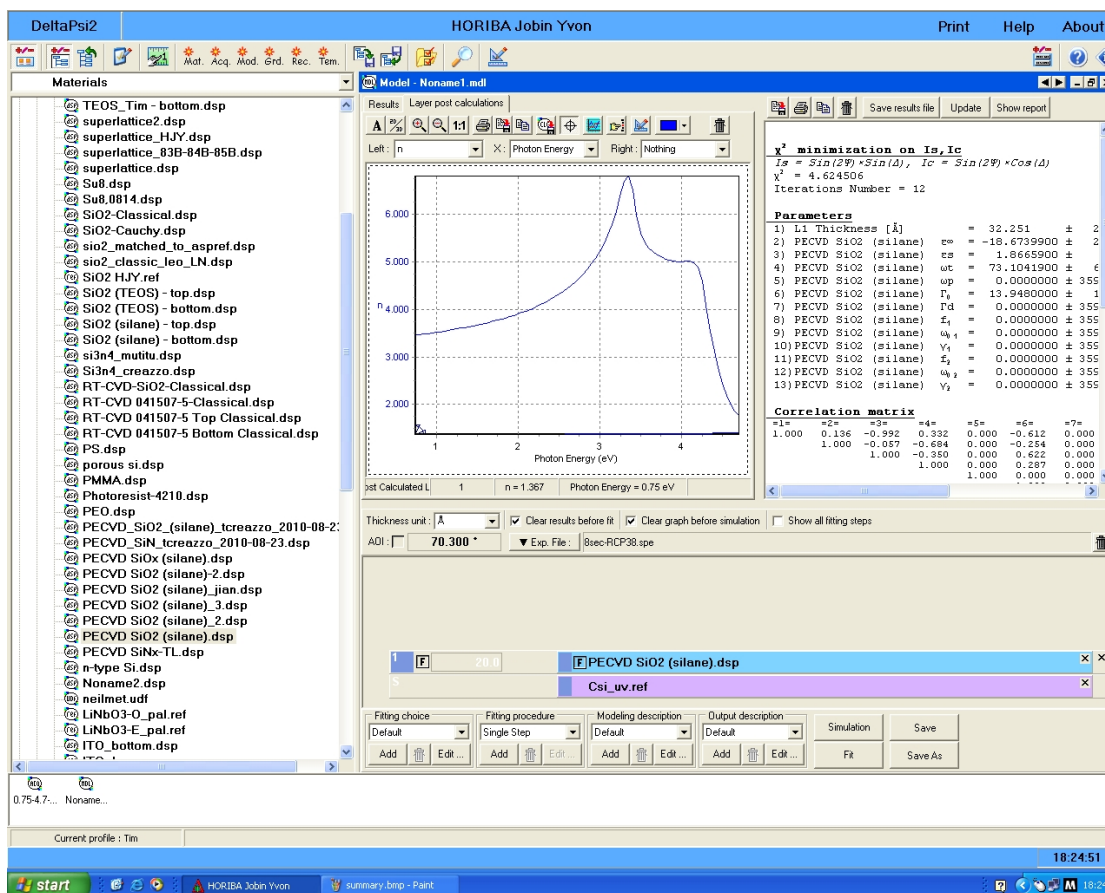
Another advantage of using parameter fitting for materials is the ability to gain extra information about a film such as the index. To get access to this data, click on edit under output description. This will bring up the box in Figure 4.25. Go to the



layer post calculations tab to select which material parameters will be output after the fitting is complete. Next, to select a layer, click the drop down box and select the layer you want information about. After this, select the observable you want outputted and choose either a graph or a table for displaying the data. Selecting a graph adds a post layer calculation tab in the results as show in Figure 4.26 that provides a graph of this data. The axis can be changed from eV to wavelength to make the plot more readable. In addition to the graph, a table can also be generated to give discrete values. To add a value for which data will be extracted, click on the Add value button at the bottom left corner and then input the wavelength or energy of interest. Multiple values can be entered and this data will appear at the bottom of the output report, which appears to the right of the graph. This can be very useful for determining the optical properties of materials and determining the quality of a deposited film.



**Figure 4.25** Post processing output description window. The Layer Post-calculations tab is open. This tab allows for choosing which fit material parameters will be output.



**Figure 4.26** Results for a fitted material showing a layer post calculation plot of the refractive index of the fitted oxide layer.

After a model is used, it can be saved for future use or discarded. To save the model, click the Save As button next to the fit button. After initially saving the model, clicking the Save button will save the changes. The models are saved in User Library→Models. To recall a model for later use, simply locate the file and double click to open it. You can then change the data file specified and use it to fit your new data as you would any other model.

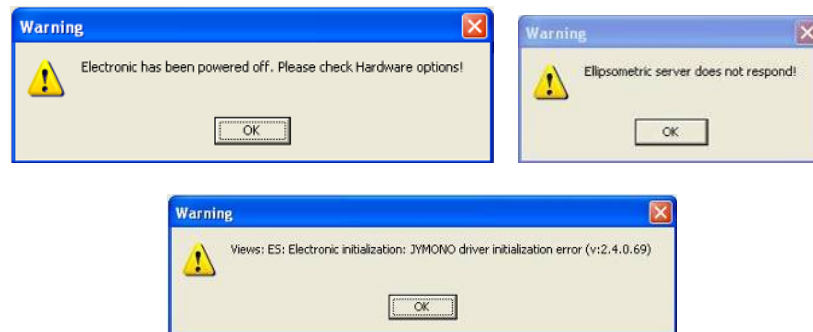
This is the basic operation of the ellipsometer. More information can be found in the references specified in Section 4.3.1, theory of operation. Also, more experienced users may be consulted for additional help in using the ellipsometer most effectively.

### **4.3.3 Measurement Computer**

The UVISEL system has two computers that are used for operation of the system. The black Dell computer is used for taking measurements and modeling samples. Along with the measurement software, this computer also contains the training material. The training material is located in the SE training folder as pdf files, which contain information about how an ellipsometer works and how to use the system. Inside that folder there is a Technical notes folder, which contains technical notes on different types of material models and how to find parameters to help create new material models. Besides the training, it also has the Delta Psi software, which is used for actual control of the UVISEL system including the spectrometer. This software is extremely important and is normally the source of required troubleshooting on this computer.

Aside from hardware and operating system issues which can arise, the majority of problems come from within the Delta Psi software. Most normal problems such as the software freezing or not responding well can simply be fixed by restarting the program. Since there is no “X” to close the software you either have to close it from the task bar or with Alt+F4. Another common problem that occurs with the software is the loss of communication with the ellipsometric server thus causing one or more of the errors seen in Figure 4.27. Depending on the severity of the communication problem, there are several steps that may need to be taken. The first is

to close the Delta Psi software. Afterwards you need to correctly shutdown and restart the ellipsometric server as discussed in the server section (4.3.4). After the server has correctly restarted, restart Delta Psi also. If this does not fix the problem, both computers will have to be restarted. Consult the server section (4.3.4) for how to correctly shut down the server computer. When restarting the computers, make sure that the server computer is up and that the ellipsometric server has finished the initialization before turning on the control computer. This is necessary to help regain the communication. If there is still a problem, shut down the computer and turn off the UPS power. Wait a few minutes and then turn the power back on and start up the computers as before. If the problem persists, contact Horiba. Besides this major problem, the control computer usually does not require any maintenance and runs well if it is properly used.

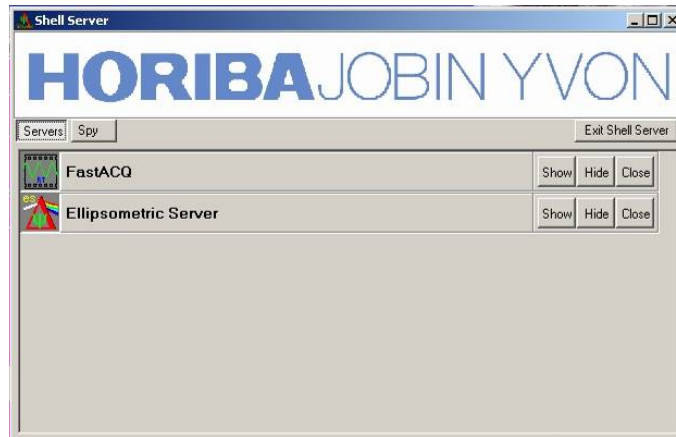


**Figure 4.27** Three different error messages that can be caused by a communication error between the two computers.

#### **4.3.4 Server Computer**

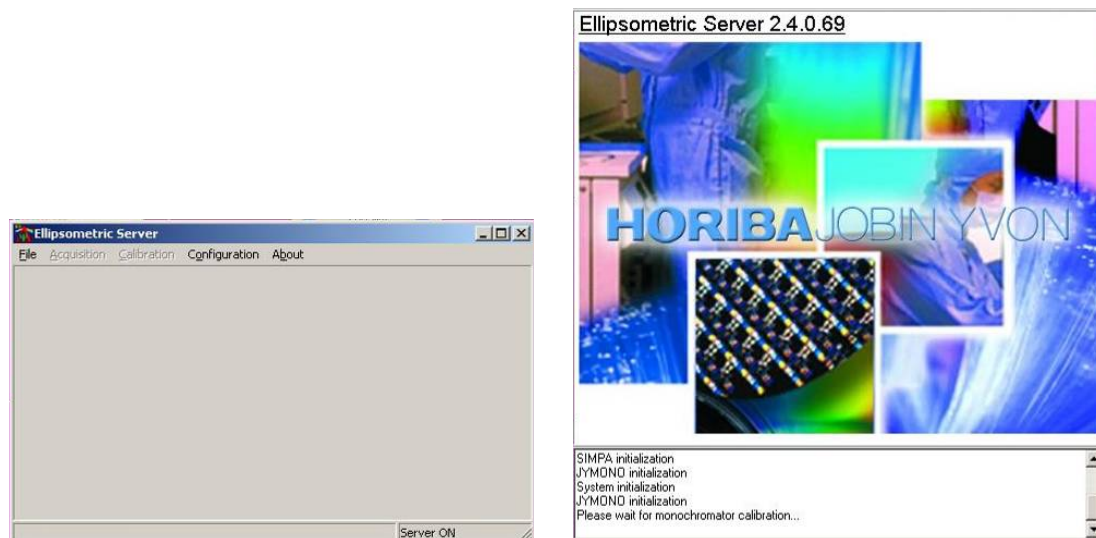
Located in the main ctrl-unit is the ellipsometer server computer. This computer controls the data acquisition from the detectors, the light source, optics, and the iHR320 spectrometer. Usually this computer runs without problem and only needs to be interfaced with when rebooting the system or troubleshooting problems such as the communication problem seen in the Section 4.3.3 about the measurement computer. The different software tools available will be discussed followed by troubleshooting and maintenance procedures.

The server computer has two servers running. They are FastACQ and the Ellipsometric Server. They are both controlled by the Shell server. The shell server icon is the red triangular icon in the system tray. It starts up when the computer is started and automatically opens the FastACQ and Ellipsometric server. The shell server window is shown in Figure 4.28 and allows individual servers to be shown, hidden, or closed. The shell server has to be opened at all times in order for the system to be running, even though it might not always be visible. The servers have to be shut down in a specific order which is discussed later in this section.



**Figure 4.28 Shell Server showing the two running servers**

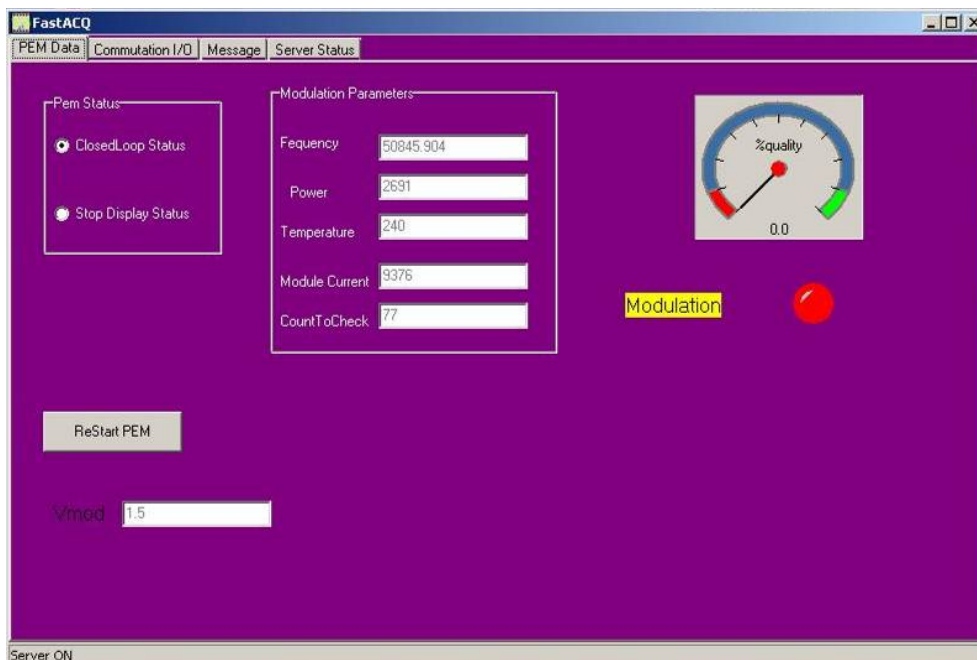
The Ellipsometric server controls the interfacing and control of the ellipsometer. As can be seen in Figure 4.29, the server window does not have many options. The server is mainly noticed during initialization when the shell server is restarted. This initialization, shown in Figure 4.29, shows step by step the different components being setup and tested in the system. This screen allows operation to be verified and will at times produce errors that will indicate problems with the spectrometer. One such problem, with the exit mirror, will be discussed in the mirror homing error section (4.3.6.2). The server can also recall the last spectroscopic scan taken from the file menu and a configuration screen under the configuration menu. The configuration should never have to be changed. If it does, Horiba should be consulted before making any changes.



**Figure 4.29 Left: The Ellipsometric Server, Right: Ellipsometric server initialization screen**

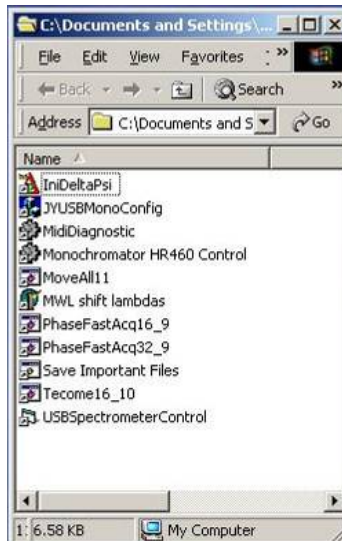
The FastACQ server deals with the data acquisition and the recording of the input signal. The main item of importance on the main screen is the % quality indicator dial on the right side of the screen along with the Modulation indicator. These are visible in Figure 4.30 where the system is not operating thus there is no modulation. If it were operating properly, the quality would be in the green region and the Modulation light would be green. This main screen also has a ReStart PEM button that should be pressed if the % quality indicator drops low or if there is a problem with acquiring a signal in the Delta Psi software. The other useful tab in the FastACQ server is the Communication I/O tab. This gives the status of different pieces of hardware in the setup which allows for quick checks of operation and troubleshooting. Normally this server, like the ellipsometric server, will run without any user intervention.





**Figure 4.30 FastACQ server window showing the % quality indicator and Modulation indicator on the right side**

Along with the servers, the server computer also contains some extra utilities. They are located in the Ellipsometer Tools folder on the desktop and are shown in Figure 4.31. The main utils of interest are JYUSBMonoConfig and. These are both discussed in the software calibration and setup section (4.2.1.2) from the iHR320 spectrometer. The USBspectrometerControl software is especially useful as it provides an interface to control the spectrometer. Unlike the luminescence spectrometer, SynerJY is not used so this is the only link to directly control the spectrometer. This can be used for testing of the system and troubleshooting as will be seen when the mirror homing error is discussed.



**Figure 4.31 Ellipsometer Tools folder showing the different utilities available.**

As previously mentioned, at times the servers have to be shutdown and restarted. If they are not properly shutdown they may not function properly when restarted. The proper way to shut them down is to close each individual server from the shell server. The shell server is opened by right clicking on the system tray icon and then selecting show shell server to show the shell server. Then each server can be closed from this screen by clicking on their respective close buttons. Afterwards you can click on the exit shell server button or right click on the icon again a click exit. If the servers aren't individually closed, the shell server should automatically shut down each server if you click exit but it is good practice to individually close them first. You should not click the "X" to close the servers as they will not shut down properly. After shutting down the servers you can shutdown or restart the computer if needed. To restart the server without restarting the computer simply open the shell server again and the servers should automatically reinitialize.

### **4.3.5 Hardware**

#### **4.3.5.1 Main Unit**

The main unit for the ellipsometer is labeled ctrl-unit. It contains the server computer, illumination source, and acquisition hardware. Usually the only interaction with this unit is to turn on the server computer, if it happens to be off, and to turn on and off the light. During normal operation only the light switch has to be touched. Maintenance of the server computer was previously discussed and the illumination source and bulb replace are discussed in the following sections.

#### **4.3.5.2 Illumination Source**

The ellipsometer illumination source is housed inside the main computer unit and is routed to the sample test setup via fiber. The source is a 75W xenon bulb (Hamamatsu L2174-01 (fused silica) or L2194-01 (ozone free silica)) that is housed behind the panel labeled “75 W Light Source.” This is a xenon arc bulb and is very expensive so the light is usually only turned on during use of the equipment and then turned off. It is turned on and off via the illuminated green button to the left of the light housing. The light from the bulb is then focused onto the face of fiber at the front of this panel. This fiber then goes to the excitation head and polarizer on the sample setup. The excitation head, shown in Figure 4.32, provides the illumination for the sample. On the right side of the head there is a little black disk with a silver dot on it that the fiber plugs into. This adjusts the spot size of the illumination on the sample to one of three sizes. With the dot rotated away from the user, it gives the largest spot and towards the user gives the smallest. Usually the largest spot is used for getting the best signal but a small spot can be used if a small region on a sample needs to be measured.



**Figure 4.32 Ellipsometer sample stage setup: on the right is the excitation head, in the center is the sample stage and alignment scope, and the left is the detection head.**

#### **4.3.5.2.1 Bulb Replacement**

The bulb in the system does not have to be replaced often but it still does happen. As mentioned before, the bulb is a Hamamatsu L2174-01 xenon arc lamp (the L2194-01 can also be used and should not cause any difference in the operation of the equipment). It is a very high intensity bulb and as with all high intensity bulbs should be handled with great care. Gloves should be worn and you should not touch the glass at all as this can still leave oils, which can cause catastrophic failure when the bulb is at high temperature. To replace the bulb, make sure that all of the equipment is powered off. This is important because the lamps use a very high voltage to start up and even though the switch may be off, it is still best to make sure the system has no power. To access the bulb, the front panel in front of the bulb has to

be removed. Remove the fiber and carefully set it aside so that nothing touches the tip. Next loosen the 4 thumb screws. They are spring loaded and will pop out when loosened but will not completely come out of the panel. Once the screws are loosened you can carefully pull the panel out. It is a tight fit so it will take quite a bit of effort and wiggling to get it out. Once the panel is open, it will reveal the bulb. Take note of the orientation of the bulb before removing it so that the new bulb is correctly installed.

To remove the bulb, loosen the screw that is clamping the bottom base of the bulb and the 3 screws holding the top spring contacts, shown in Figure 4.33. After the screws have been removed, rotate the bulb and top contacts and remove them from the housing. Now that the bulb and top contact have been removed loosen, the screw that holds the top of the bulb and remove the bulb. Next, carefully install the new bulb; be sure not to touch the glass! After the top contact is inserted (the metal should say top), align the slit in the spring contact so that it is perpendicular to the screw. Tighten the screw to hold the top contact tightly. Now place the bulb into the base and tighten all the screws. Now that the bulb has been replaced you can put the housing back into the main unit. Replacing it can be just as difficult if not more difficult than removing it, thus it will take quite a bit of force. Once the bulb assembly is mostly reinstalled, use a screw driver to try and get each of the 4 screws to catch and then alternate tightening the screws to pull the unit back into full engagement.



**Figure 4.33** Left: the bulb in the assembly with the spring contacts on top. Right: the removed bulb with the spring contacts installed on the top of the bulb.

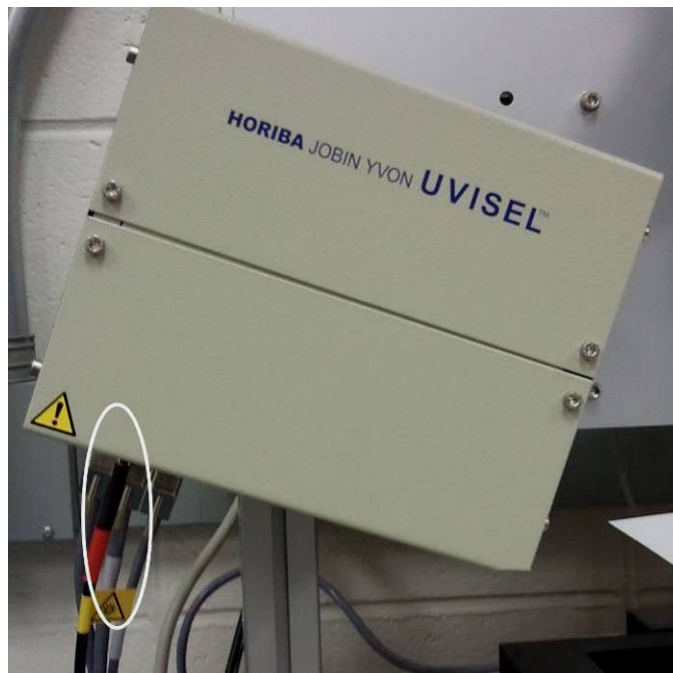
#### **4.3.5.3 Collection Optics**

After the light is incident on the sample it reflects and is collected by the collection optics opposite of the source. During normal use the sample is leveled and the height is adjusted to get the highest signal. These adjustments help optimize the light collected by the collection housing. It has a slit at the entrance and then the light is directed through a series of mirrors to redirect the light onto the collection fiber that goes to the spectrometer. There is a dial located on the left side of the collection unit which rotates the final mirror, which focuses the light on the fiber. The dial normally is rotated all the way to the right (front of the unit) which should focus the light onto the fiber when everything is properly aligned.

##### **4.3.5.3.1 Collection Fiber Alignment**

After reinitializing the ellipsometric server there can be some problems with collecting light. This is because the collection fiber has been moved. The fiber is connected to a motor, which moves the fiber and it moves the fiber out of the path

of the light. To correct this gently grab where the fiber connects to the detection head and slide it to the left (Figure 4.34). It should slide easily with little to no resistance. If it doesn't move freely try to see if it shifts to the right at all. If you can't get the fiber to move at all and you are still not collecting any light then there may be an alignment problem elsewhere in the system which will be addressed next.



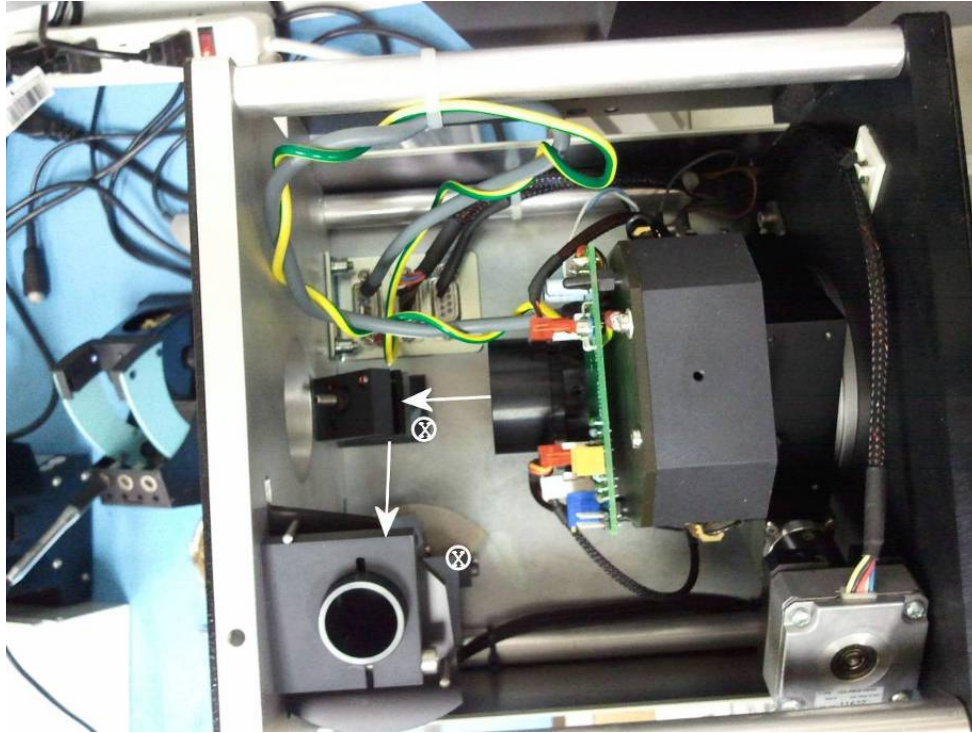
**Figure 4.34** Detection head with the collection fiber circled. This is where the fiber is to be gripped to move it for realignment.

#### **4.3.5.3.2 Collection Optic Alignment**

If adjusting the fiber does not fix the collection problem, you will have to trace out the problem. The first step is to make sure the reflected light is near the

center of the collector opening (use a piece of paper or the like to see the spot location). If it is not in the center, adjust the sample height to try and get the light as close to the center as possible. If this does not fix the problem the unit will have to be opened. The top is removed by removing the two screws on the front and pulling the top off. This will reveal the series of mirrors, which the light hits to get redirected to the fiber as shown in Figure 4.35. Trace out the path of the light and make sure they you can see the entire spot as you go from mirror to mirror making sure that none of it is clipped. If it makes it through the system and to the fiber but there is still no or low signal, try adjusting the dial on the left side of the collector to redirect the light into the fiber. If this corrects the problem, see if you can return the dial to its original position and carefully move the fiber so it is correctly aligned with the light. If this is not possible, change the dial and close the unit, remember that the next time the system is reinitialized, the fiber may sit in a different place and the dial will have to be adjust back to its original location.





**Figure 4.35** Inside the detection head. The arrows show the path of the light as it comes into the detection head. It bounces off two stationary mirrors before hitting the adjustable mirror connected to the back wheel and finally hitting the fiber.

If after tracing out the light you still get no signal, try restarting the systems, as discussed in the server computer section (4.3.4). If there is still no luck, make sure that there is light leaving the collection fiber and going into the spectrometer. If there is, then there are several possible problems with the spectrometer that could be causing these problems. These will briefly be discussed in the next section (4.3.6).

#### **4.3.6 Spectrometer**

The spectrometer used in the UVISEL is the same model as the PL spectrometer. This spectrometer allows for the relative intensity of the probe light to be measured across a large spectrum thus allowing for fitting of material parameters and thickness. There are several differences between the two systems.

##### **4.3.6.1 Differences from Spectroscopic iHR320**

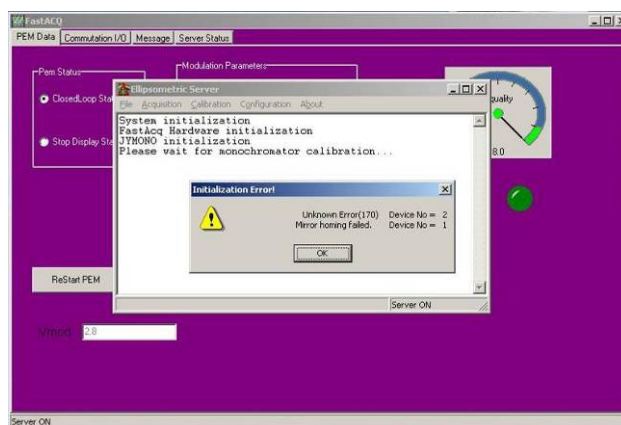
The first difference is this system has different gratings from the system used for the PL/EL measurements. The gratings in this system cover a much large spectrum than the gratings in the other spectrometer. The gratings are 1200 gr/mm blazed for 330nm (listed as 190-900 nm on the label), 600 gr/mm blazed for 750 nm, and 300 gr/mm blazed for 2000 nm. These cover the entire range used for taking scan measurements of a film. In addition to the gratings being different, this system also has vastly different detectors. The detectors are an “IR” detector connected to the side exit and a “UV” detector connected to the front exit. The input fiber goes into the front entrance. The side entrance, which is the free space entrance on the PL setup, is sealed off as it is not used in this system.

Besides the hardware differences, the other major difference between the two systems is the computer interface. On the spectrometer the user has direction control through the SynerJY software. However on the UVISEL, the user uses Delta Psi which communicates with the ellipsometric server. It is the server that then communicates with and controls the spectrometer. This means that the scan type, slits, gratings and other settings are not adjustable during operation of the system. In the case that there is a problem and direct control over the spectrometer is required;

there are several pieces of software that can be used. They are located in the Ellipsometer tools folder on the server computer.

#### 4.3.6.2 Mirror Homing Error

At times the spectrometer can have a problem with the exit mirror which causes an error during server initialization as shown in Figure 4.36. This occurs when the spectrometer tries to move the output mirror but it times out. This time out occurs because the mirror does not hit a limit switch indicating that the mirror is in position. The temporary fix is to carefully open the top of the spectrometer and reach your hand in and push the limit switch until it clicks. If needed, pull the unit out slightly to be able to reach the limit switch.



**Figure 4.36 Mirror homing error caused by a limit switch error**

To fix the problem more permanently, you need to carefully take the spectrometer off the shelf to access the inside of the system more easily. Make sure that everything has been powered off before disconnecting sensors and the

spectrometer. Once things have been disassembled individual components can be powered up as needed. To fix the limit switch problem, the switch has to be slightly bent to guarantee that it engages when the mirror is swung into position. In order to get to both limit switches, the spectrometer will have to be hooked up to the computer and the USBSpectrometerControl software can be used to move the mirror between the two positions, thus allowing both switches to be adjusted if needed. This movement of the mirrors will also help to verify that it is correctly contacting the switches. After the adjustment has been made put the system back together and restart all the hardware. The initialization process should go more smoothly now.

## **Chapter 5**

### **ICP MAINTENANCE**

Chapter 2 covered basic use and maintenance of the RIE-200iP ICP. The maintenance of this tool is much more complicated than was covered in Section 2.5. In addition to the actual tool itself there are many other utilities such as vacuum pumps, water chillers, compressed gases, and the scrubber, which are needed for the ICP to operate. This chapter covers many of these topics more in-depth to discuss preventative and emergency maintenance. Much more information can be found in the Samco® RIE-200iP manual [1] or in manuals from the manufacturer of the component of interest. As one becomes more familiar with the ICP, performing maintenance will be easier and more efficient. Appendix C lists contact information of several people at Samco® who can provide additional help with ICP operation and maintenance problems.

#### **5.1 Pumps**

One of the major parts of an ICP system are the vacuum pumps. There are three pumps associated with our system. There are two mechanic roughing pumps and a Turbo Molecular Pump (TMP). The two mechanical pumps are an Edwards E2M40 and E2M30-PFPE. These pumps are sealed oil rotary vane pumps. They require more maintenance than the TMP usually. The mechanical pumps share much as the same maintenance with just a difference in parts, so they will be discussed together and differences will be pointed out.

The two mechanical pumps are located in the ICP chase. There are two pumps for each fluorine and chlorine ICP systems and the maintenance on each is the same. Users should be aware that the contaminants in the oils of these pumps may be toxic, so take precautions when handling used oils. The E2M40 uses what is commonly referred to as hydrocarbon oil, more specifically it is TKO-19, TKO-119, or some other variation that includes 19 or 119 in the name. This pump is used for very rough pumping of the reaction chamber along with pumping down the load lock. It only pumps down the chamber after the chamber has been vented to the atmosphere. Because of this, the pump never seems process gases and thus it can use the hydrocarbon oil. The E2M30 is used as a backing pump for the TMP and thus it sees all the process gases. This pump uses PFPE or Fomblin® oil (Y-LVAC 06/6). It is a fluorinated oil and can withstand the various process gases which are pumped through it. Next the different parts of the pump that require maintenance will be discussed.

The oil in the pumps should be replaced at least every 6 months to help prevent a buildup of contamination and solids, which could damage the pump. However, every time the ICP is used, the oil levels in each pump should be checked. If the levels are low, you should look for leaks in the system, which can be a sign that the pumps need to be repaired, in which case see the rebuilding section (5.1.4). Usually if the oil is low, it has been exhausted through the outlet into the mist filter, which is perfectly normal. However, if this occurs very frequently, then the gas ballast flow should be decreased, see the gas ballast section (5.1.3).

It is easiest to replace the oil when it is hot as it will flow out of the pump more easily. When actually replacing the oil, the pumps **must** be turned off. It is best to totally turn off the ICP and make sure no one turns it on until you are done

changing the oil. To change the oil, first get a container to collect the oil. You may want to use a shallow bowl-shaped container that can fit under the drain and then be emptied into a bigger waste bottle. On the E2M30, there is a small gray stopper that you have to remove to drain the oil out. The E2M40 has a larger quarter turn valve on the side and should have a hose attached. To help the oil drain, open the oil inlet on the top of the pump. Once you are done draining, replace the oil drain plug. For the E2M30, fill it with Fomblin® and for the E2M40, use the hydrocarbon oil. In both cases, fill the view port about  $\frac{3}{4}$  of the way. If you over fill, it you should drain it slightly or else the oil will end up saturating the mist filter and it will have to be replaced sooner. After the oil has been added, seal the oil inlet and clean up. Make sure that the used Fomblin® and hydrocarbon oils are in different containers and that they are properly marked with a waste label.

#### **5.1.1 Oil Mist Filter**

The oil mist filters are located in the metal housing on the gas exhaust. Their purpose is to trap and absorb oil so that it does not condense in the exhaust lines, which can be quite hazardous. They should be inspected and usually replaced every time you change the oil. Once again, you should have the pumps and ICP turned off before replacing these parts. On the E2M30, the filter is in a small, metal housing with part number OME 25 C/H and the small mist filter element is part AV-066800 from Kurt J. Lesker. Remove this part from the line and set the o-rings and clamps aside. Carefully unscrew the 4 screws and take off the top of the filter housing. Be careful as there is a spring holding a plastic top against the mist filter. Carefully remove and dispose of the filter, it may fall apart when removing it from the housing, so make sure to get out all of the pieces and then wipe the housing out with a dry

wipe. Afterwards replace with a new filter and reassemble the same way it was when you took it apart and place onto the system as before. For the E2M40, you have a larger filter (AV-068443) in housing OME 40S. The same ideas apply except this time, there are more screws and they are located in different locations and the filter is different. The filters and housings are shown below in Figure 5.1.



**Figure 5.1 Left: Oil mist filters for the OME 25 C/H and OME 40 S respectively, Middle: OME 25 C/H, Right: OME 40 S**

### **5.1.2 Oil Filter (E2M40 only)**

Along with replacing the oil and mist filter, the E2M40 also has an oil filter (like a car) that should be replaced each time you replace the oil. The oil filter is a white canister located on the back of the pump next to the ballast controls (Figure 5.2). To remove it, first drain the oil from the system and then, using a strap wrench or equivalent, loosen the oil filter to the point where it can be loosened by hand. Place



a container under the filter as it is filled with oil that will drip out. There is a lip on the pump to collect and redirect this flow but it most likely will not do a very good job and the oil gets everywhere. So be prepared to have to clean up quite a mess. After you have completed the removal, wipe up any excess oil from the pump and oil housing. Get a new filter. It should be ready for immediate installation. However, ensure that the gasket on the oil filter is properly seated before installation. To install the filter, tighten by hand and then tighten an extra  $\frac{1}{4}$  turn using the wrench. Afterwards you can refill the pump with new oil.



**Figure 5.2** Back of the E2M40 showing the oil filter (left) and gas ballast inlet and valve (right)



**Figure 5.3** Top of E2M30 (RP1) showing the gas ballast inlet (left) and the ballast adjustment valve (right)

### **5.1.3 Gas Ballasts**

The gas ballast mixes nitrogen with the pumped gases to help dilute them as they are exhausted. The inlet is located on different places on the E2M40 and E2M30 as shown in Figures 5.2 and 5.3. The lines are nitrogen lines with a 208V solenoid that opens once the pumps are up to speed. The line connects to the pump through a 1/4" British Standard Pipe (BSP) threaded adapter. All the pumps should already have them installed. If a new one is needed, you can order the parts from an online supplier (such as McMaster Carr) and make them in the machine shop and have them welded in the engineering machine shop (this has been done before).

The gas ballast flow is controlled through two different valves. The first of these is a valve on a flowmeter located on the back of the pump enclosure frame. The second is a ballast valve located on the pump itself. The locations on the two,

pumps are shown in Figures 5.2 and 5.3. Figure 5.4 shows the flowmeters located on the back of the pump enclosure. The left two are the flowmeters for the ballasts of RP2 and RP1 respectively. The right most flowmeter is for the gas purge of RP1. During normal operation, the ballast flowmeters should have 1-1.5 L/min N<sub>2</sub>. If there is no flow, verify that the ballast valve on the top of the effected pump has been opened a few turns. After verifying that the pump ballast valve is open, readjust the flowmeter. The purge flowmeter should read 0 L/min when the system is sitting idle. The purge only turns on during processing and should read ~7.5 L/min N<sub>2</sub> when it is turned on. As long as the ballast and purge flows are correctly set they should require no maintenance.



**Figure 5.4** Gas ballast flow meters: Left to right these are the RP2 ballast, RP1 ballast, and Purge for RP1 (PV).

#### **5.1.4 Rebuilding**

Often times the pumps for the ICPs get worn out and need to be rebuilt. Talk to the cleanroom coordinator about getting these rebuilt by VPX. They have done rebuilds for us in the past and are very trustworthy. We own an extra E2M40 and an E2M28 which can be switched out when the current pumps are sent out for repair. When connecting these pumps make sure that the phases are wired correctly. Also, before connecting the inputs and output, turn the ICP on in manual mode and verify that the flow and exhaust are correct. Also, verify that the rotation of the motor is correct. This is done by turning the pump on and off and watching the motor rotate through the vents on the housing. They should turn in the direction of the arrow on the motor housing. If they do not, check that the phases are connected correctly and consult Kjeld if you still cannot get it working correctly.

#### **5.1.5 TMP**

The TMP is the main pump that gets the chamber down to ultimate pressure. It does not actually pump the gases but compresses them. It is basically a jet engine and has many fins that rotate and compress the gases so they are brought to a higher pressure that can then be pumped out by the roughing pump (referred to as a backing pump when discussing a TMP). Our TMP is manufactured by Osaka vacuum. It spins at 32,000 RPM and is magnetically levitated so that it has no oil or bearings. The only maintenance that it requires is a TMP clean, which is done by running the appropriate program on the ICP. On the CI-ICP this is included in the standard cleaning process and on the F-ICP, it is Recipe 5, which should be followed by a standard Hi-Lo clean. If damage or excess wear occurs to the TMP, it will have to be

repair/replaced. In the case that this were to happen, contact Samco® for assistance on how to get the TMP serviced.

#### **5.1.6 Pump Conclusion**

This basically concludes the section on pumps. If more information is needed, please consult the manuals that are located in the binders for the ICP. If they are not located in there, you should be able to find the manuals from Edwards online.

### **5.2 Chillers**

There are three water circulation units that provide heating/cooling to the two ICPs. There are the ThermoFlex1400 and Julabo FC1200, which are chiller units, along with the Julabo TD12, which is a heater unit. The ThermoFlex1400 provides service to both ICPs while the FC1200 only provides cooling to the F-ICP and the Julabo TD12 to the CI-ICP only (shown in Figure 5.5).



**Figure 5.5 Left: Julabo FC1200- fluorine ICP chuck chiller, middle: ThermoFlex 1200- seal chiller for both ICPs, right: Julabo TD12- chuck heater for chlorine ICP**

### **5.2.1 Julabo FC1200**

The Julabo chiller is located on the left side of the gas cabinet for the F-ICP. It runs at 15°C and cools the substrate chuck for the F-ICP. Its purpose is to cool the chuck and the sample. If the sample gets too hot, the etch and resist will be adversely affected. There is a cable coming out the front of the unit. This is the

interlock for the ICP. If it is disconnected or the chiller is off, the ICP will alarm and not allow an etch to take place.

To keep the unit running properly, the coolant level should be kept between  $\frac{1}{2}$  and  $\frac{3}{4}$  full. It uses a 1:1 DI water:glycol mixture. If the level drops, you should be able to add DI since, like your radiator in a car, the glycol should not evaporate. However, if the level seems to be dropping rapidly, check for a leak in the system before adding more water. To add more water, pull out the metal spout that is located on the front, under the front cover as shown in Figure 5.6. To drain the coolant, locate the hose that goes to the bottom of the heat exchanger. Make sure that the valve at the other end is closed and disconnect the hose from the bottom of the radiator. Then place it in a container into which it can drain. You might have to pick the unit off the floor and place it on a slightly elevated surface so that it will drain better (be careful as the unit is heavy and has short hoses running to the ICP). With the unit off, open the valve and let it drain. After the draining has slowed, you can turn on the pump and it will pump out the coolant faster. Afterwards replace the hose and close the valve. Then add the new coolant mixture.



**Figure 5.6** Front of the FC1200 chiller with front cover removed. From left to right: fill spout, interlock wire, drain hose and valve, and water level indicator.

### 5.2.2 Thermo Fisher ThermoFlex1400

The ThermoFlex 1400 chiller services both ICP systems. It cools the seals of the chamber to 15°C (some people may call it the RF chiller but it does not actually cool the RF unit). It also uses a 1:1 mixture and should be filled in much the same way as the Julabo chiller. To drain the coolant, there is a plug on the back left of the system which is removed and allows the coolant to be drained. When draining the unit, make sure that the power is turned off. To add coolant, unscrew the cap on the front and add the coolant. You have to be careful with draining and filling this unit as there are a lot of pipes between it and the machine that can make draining and filling very difficult. Be sure when refilling that the unit has enough water to run correctly but not too much as to overflow the reservoir if it is shut off. If no water drains, or if you want to drain the entire system see the instruction manual for more in-depth



instruction. This may be trial and error for adding coolant slowly. The valves on the input and output of the chiller (located on the wall) can be turned off so that only a small amount of water is drained from the chiller and not the entire system.

Along with maintaining the cooling water, there is also a water filter on this unit that requires some maintenance. It is located under the cap on the front of the machine. To access it, unscrew the cap and then pull the blue plastic casing off. This should reveal the filter and high water shutoff switch. If water hits the shutoff switch, the unit will error out and will not start again until it has dried out. The filter will collect algae so it has to be removed sometimes and rinsed with DI water. Once it is rinsed, it can be placed back into the system. The unit may have to be powered down and valves closed so you do not accidentally trip the water sensor. REMEMBER, this water contains glycol so use gloves when handling the filter. Along with the water filter, there is an air filter on the front of the machine, which can be removed and cleaned if it builds up extra dust and particulates. Also, the unit display will sometimes flash FLtrS. This indicates that the air and/or water filter needs to be cleaned or replaced. Ideally you will want to clean the filters when this happens, but you can also stop the alarm by pressing enter. This will cause the display to stop flashing FLtrS and go back to displaying the current temperature.

The two filters that need cleaning periodically are the air filter on the front of the unit and the water filter in the top compartment under the funnel through which water is added. The air filter is located on the bottom front of the unit and is removed by simply pulling off the bluish plastic grating. Then take the grate to another room to vacuum it off or take it outside to the dumpster to pull off the dust if large amounts have accumulated. After cleaning, place it in the front of the unit again.

The water filter is a little more difficult to remove and clean. The water filter is located under the cap and water funnel assembly on the front left side of the unit. To remove them, lift up on them to remove the funnel, thus revealing the filter. Remember that this water contains ethylene glycol so you should always use gloves when handling the water. To remove the water filter, carefully pull it out of the water. You may have to tilt the filter some to remove it from the water. Be careful to not hit the water level float on the left side of the tank or it will shut off the water and cause the ICP to also shut off. So before trying to remove the water filter, make sure that no one is running a process in the ICP. Also, you can shut off the entire chiller unit if you do not want to have water flowing through the filter as you remove it but this will definitely trigger the ICPs to error out.

Once the filter is removed, take it in the clean room and rinse it off with IPA and DI water. You will want to scrub it against itself to help remove some of the buildups. After you have rinsed with and scrubbed with the IPA, make sure to thoroughly rinse it with DI water to remove any IPA residue and to help remove more build up from the filter. Once the filter has been rinsed with DI water, put it back into the chiller. Be careful when you put it in that you do not build up an air bubble under the air filter or it will give a false reading on the water gauge on the front of the unit. After installing the filter, make sure that the water is flowing through it correctly and close the unit. If you have not already done so, press enter to cause the display to stop flashing FLtrS.

### **5.2.3 Julabo Heater**

The Julabo TD12 unit is a heater for the chuck of the CI-ICP. It heats the chuck to 50°C and instead of using an DI:Glycol mixture, it uses a silicone oil for heat

transfer. For more information on servicing of this equipment, contact Leo as he does most of the maintenance for the CI-ICP.

### **5.3 Scrubber**

After the process gases leave the pumps, they must be neutralized in such as way to prevent them from being released into the atmosphere. This is the job of the scrubber. The gases are pumped into the top, front inlet at which point they are mixed with nitrogen gas to further dilute them. They then travel through several chambers of water. In each of the chambers they are sprayed with water from nozzles. They then travel through some plastic mesh (a demister) before exiting through the system exhaust. During normal operation, the front panel of the scrubber is the only part that needs to be adjusted. The front panel (Figure 5.7) shows the fresh water flow, differential pressure, N<sub>2</sub> pressure, and N<sub>2</sub> flow. The scrubber has a pump that circulates water and pumps it back out through the shower heads at the top of the chamber. To tell if the flow is adequate, inspect that the shower heads are spraying and that the water pressure on the gauge to the right of the tank reads about 25 psi. In addition to recirculating the water already in the tank, there is also fresh water continuously added to the tank to help dilute the water contamination, thus continuously flushing water as fresh water is added. The fresh water should be just barely flowing through the flow meter (~.5 GPM) which can be hard to see as the flow meter gets very dirty over time. The nitrogen pressure should be ~8 PSI and the flow should be ~15-20 LPM, not the 12 LPM is states on the label. The differential pressure should read 3 inches of water. If it does not, try flicking the tubing that goes between the tank and the gauge as sometimes water gets trapped and causes a false reading.



**Figure 5.7** Front panel of the ICP scrubber: 1 differential pressure gauge, 2 nitrogen pressure gauge, 3 nitrogen flow meter, 4 freshwater flow meter, 5 power switch.

Over time the scrubber tank builds up quite a bit of dirt and has to be cleaned. The frequency of cleaning has varied over time but it should be cleaned about once a year. Before cleaning the scrubber, make sure that both ICPs are off and locked out so that no one can start them up as this can cause a potentially deadly

situation. After all the equipment is shut off, the water flow and pump of the scrubber have to be shut off and the tank has to be drained. To begin this, turn the water flow all the way off using the flow meter and then close the valve on the wall to the right of the scrubber. Next, turn off the pump by pushing the red button on the front of the machine. Next, you have to isolate the pump by closing the inlet and outlet valves that are located under and on the left side of the machine. After closing them, you can open the small drain valve on the rear, left side of the unit shown in Figure 5.8. At this time, the water should start draining. Once it has completely drained, close the exhaust valve by rotating it until it is perpendicular to the duct. Close off the nitrogen flow by adjusting the flow meter but not the pressure gauge. At this time the scrubber is totally off and can be cleaned out.



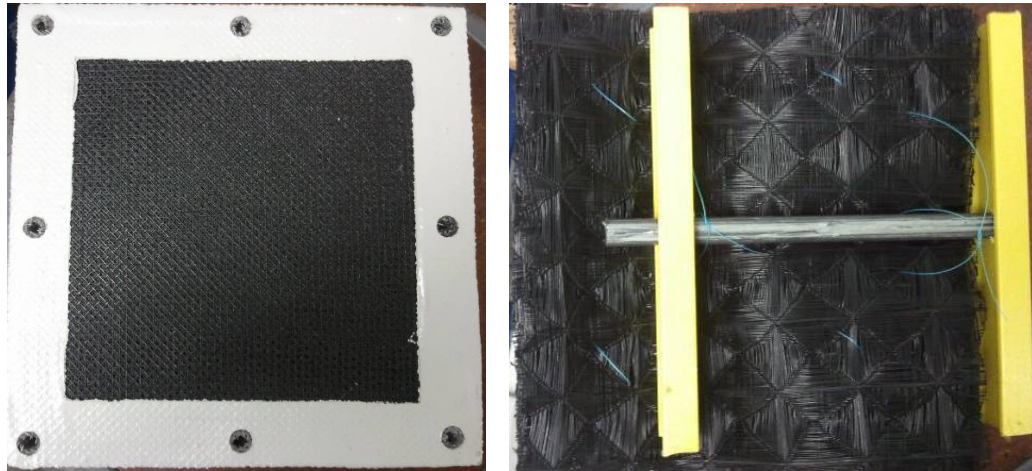
**Figure 5.8** Side view of the scrubber. On the left is the red drain valve and on the right is the drain pipe that allows for continuous draining of water during operation.

There are 5 main parts that are removed during cleaning, the gas inlet port, exhaust duct, water sprayer head pipes, shower heads (3 of them), and the top back panel of the scrubber. The order used in the past for disassembling the scrubber will be used here but other methods may be possible and work better for you. First, the pipes for the spray heads were removed. These pipes are all one piece, which are welded together. To remove it, carefully unscrew the connections to the shower heads (be careful as one front shower head has a flexible tubing inlet, not a hard pipe). The last part of this assembly to remove is the inlet flange. To remove it, you have to take off the metal u-bracket so that you can access all the bolts. Once you remove the bolts and the flange you can remove the tubing assembly. Be careful not to lose or damage the seal in the flange. After this part has been removed, you can remove the spray heads for inspection. All of the shower heads can be removed in the same manner which will now be outlined. To remove one, take out the 4 bolts and carefully use a flat head screw driver to pry them from the corner. Do NOT try to use the inlet pipe to pry, it will break! Once you have the head off, inspect it to make sure there is not any excess build up or corrosion. Clean off any build up and replace it if there is severe corrosion. However, we have a limited quantity of heads left so be judicial when replacing them. After they are inspected, you can replace them and screw them back down. As long as the old sealing tape is not too badly damaged, it can be reused. Otherwise replace it with new tape.

The next piece to remove is the gas inlet connection. This is removed by taking out the bolts and taking out the nitrogen line from the quick disconnect port. To remove the pipe section, you have to have a second person push up on the metal inlet pipe and then carefully take out the pipe and set it aside. Be sure not to lose the

seal. Next, the exhaust section can be removed. Unscrew the angled metal section at each end (make sure that the valve is closed first!) and remove this metal section. This leaves just the back cover to be removed. This piece is easy but time consuming to remove because it has many bolts holding it down. Remove all the bolts and be sure not to lose them. Along with the bolts around the edge, there are 3 bolts in the center, which divide two sections which have to be removed before the top can be removed. After the bolts are out, carefully use a flat head screw driver to pry at the corners and edges to remove the top, do not apply too much pressure as you could crack the top. At this point, the scrubber tank is completely disassembled.

Now that the scrubber is open, it is time for the dirty part of the cleaning to begin. You will want to put on a Tyvek® frock, safety glasses, and gloves at minimum. At first it is easiest to remove the two black plastic mesh elements (Figure 5.9) and rinse them out with water (tap or DI). When removing the right element be careful to not break the screws as they are easily broken and are hard to replace. As long as the elements are still black or slightly gray they can be reused. If they are becoming brittle or are gray/white, replace them, but as with the shower heads, we do not have many of these elements left for replacement. Set these aside for reinstalling after you are done cleaning.



**Figure 5.9 Demister elements from the scrubber**

The bottom of the tank contains a mixture of water and oil along with some solid particulates. The easiest way to clean it out is to get the wet dry vac and prepare it for wet use (clean out the contents and remove the air filter). You can use it to vacuum out the water through both the front small gas inlet along with any of the sections in the back of the scrubber. Once the water is vacuumed, you will see the dirt and the oil on the bottom. Before wiping out the inside, you want to remove as much oil as possible. To remove more oil, turn on the water, on the wall, and open up the water inlet into the pump (the valve which normally drains the tank into the pump). Then turn on the water flow (using the flowmeter) and water should begin to flow into the tank. Do not open the pump outlet as this will spray water out the top and do not turn on the pump with the outlet closed or you will “dead head” the pump which can severely damage it. As the tank fills with water, vacuum up the top surface of the water to remove the oil from the surface of the water. Be sure to vacuum from multiple areas and sections of the tank to get as much oil out as possible. After you



have vacuumed most of the oil, shut off the water and vacuum out the rest of the water. Now you can carefully reach into the tank and wipe out the oil and solids from the bottom of the tank. Also, clean out the small gas inlet section of the scrubber and make sure to wipe the top of the pump inlet pipe in that section. It can be difficult to get your arm into that section, so do not force your arm and get it stuck. Continue wiping out the bottom of the tank until it is as clean as you can reasonably get it.

The last part that should be cleaned is the water flow meter. To clean this, make sure the water is turned off and take the top metal plug out. Then using a brush or wipe and screw driver, carefully clean out the flow meter the best you can. Most likely you will not be able to get it perfectly clean. It is not necessary to get them perfectly clean.

Now that everything is clean, replace the filter elements and begin reassembling the unit in the reverse order you took it apart. When reattaching the exhaust duct, you may have to try the bolts and washers in different spots on the top flange as they only fit together one way. Also, if the seals leak, either get new sealing putty or apply a layer of silicone sealant around the cracks. For the front gas inlet, the holes do not line up perfectly so you just have to carefully fidget around to get everything lined up. This is the reason that the top flange of that piece is cracked, so be careful to not crack more as you reconnect piece. When replacing the pieces make sure that the seals are in good condition and tighten the bolts sufficiently but do not over tighten them to the point where you can actually crack the enclosure. Once everything is together, make sure that everything looks good and there are no extra pieces. Now open the exhaust and make sure that you do not hear too much howling

noise. If you hear a lot of howling noise, try to find the leak and tighten the bolts or apply more sealant.

After everything is together, you can start refilling the system. The first step is to close the drain valve at the bottom of the tank but do NOT close the drain valve on the wall, that must remain open at all times. Next open the water and fill the tank the same way you did while cleaning the tank. After the water is about half way to the normal value, you can open the pump outlet and then start up the pump. At first, the pump may make some noise as it gets air out of the system. After about 30 seconds it should sound normal. Verify that there are no leaks and that the shower heads are working correctly. Once the water has reached its normal level, turn the water flow back down to ~0.5 GPM. Turn the nitrogen flow back up and verify that the differential pressure gauge is reading correctly. At this point, if everything seems to be working well, you can turn the machines back on.

#### **5.4 Gases**

At the heart of the ICP's processing ability are the gases that provide the reactive species. The gases used for the F-ICP are: hydrogen, oxygen, argon, helium, sulfur hexafluoride ( $\text{SF}_6$ ), octafluorocyclobutane ( $\text{C}_4\text{F}_8$ ) and for the Cl-ICP: oxygen, argon, Halocarbon 14 (tetrafluoromethane,  $\text{CF}_4$ ), chlorine, boron trichloride, and silicon tetrachloride. The more dangerous or toxic gases such as hydrogen,  $\text{C}_4\text{F}_8$ , chlorine, boron trichloride, and silicon tetrachloride are housed in gas cabinets. These gas cabinets have no controls on them; later in Chapter 6, the gas cabinets for PECVD will be discussed and they have controls for flow and purging. The gas pressures should be checked each time you go to use the machine. Each regulator should have a label listing the desired output pressure. Notice that the silicon tetrachloride is

actually under vacuum so the pressure is negative on the gauge (below atmosphere). The other maintenance is changing gases if they are empty, zeroing the Mass Flow Controllers (MFC), and replacement/calibration of gas safety sensors.

#### **5.4.1 Operation and Cylinder Replacement**

The ICP also has several controls for the gases. These include GSV, GV, and MFC. The GSV are gas safety valves and isolate the machine from the input gas line. These are controlled from service mode. The MFC are the controllers that determine and control how much gas is flowing into the chamber during processing. GV are the actual gas valves that turn on the flow of the gas to the chamber. It is very important that these do not leak as they can cause major process problems. A leak can be noticed by seeing an increase in chamber pressure when there are no gases open or by seeing a non-zero value in the MFC that goes away when the GSV is closed showing that flow has stopped because all of the gas is gone. On the CI-ICP there is also VV which is a bypass Vent Valve for venting the Chlorine compounds straight to the TMP and scrubber. A venting procedure, which uses the vent valves, is discussed on page 93-94 of the ICP manual [1]. However, it is not recommended to use these for doing the initial vent because of the warning on page 94 but to use these valves to get a better vacuum on the gas line.

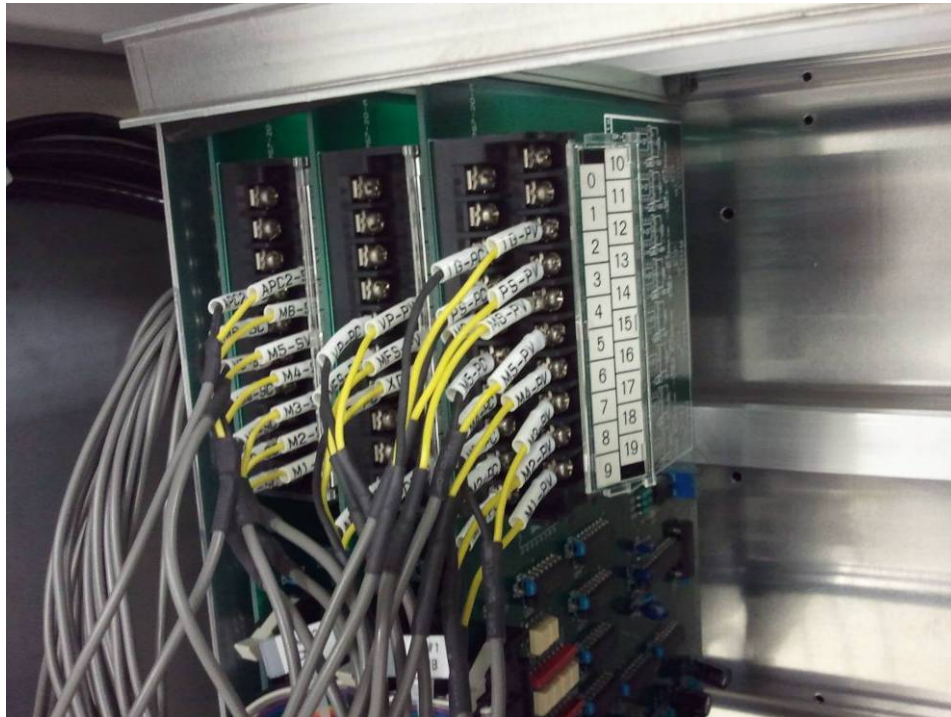
Changing gases correctly is very important to the purity of process gases and the safety of the user. The first step is to close the valve on the gas cylinder itself. If the tank is not totally empty, take note of the output pressure on the regulator so you can set the new tank to the same value. Once this is closed, go into the clean room and use the ICP to pump out the line. This is done by going into manual mode and setting the gas flow in the manual recipe to the maximum value of that MFC. You

may also want to flow some nitrogen at the same time to help dilute the gas flow. To begin actually flowing the gases, first make sure ISOV for the IG is closed and the ISOV for DG1 is open. Then open CGV to 100% and turn on TPV and PV, which further dilute the gases. Then you can open the GV that corresponds to the gas you need to flow (ISOV, GV, and CGV will be discussed more in depth later). This should allow the gases to exit. Wait until the flow drops to ~0 SCCM. Then turn off the gas flow and return to normal operation. Go back to the chase and verify that both gauges read zero (or negative on the output side) and then close down the regulator. Remove the tank and put on the new tank. Before opening the tank, open the regulator slightly to allow the two sides of the line to equilibrate and then re-pump the line. Finally, close the regulator and now open the tank. Using snoop or some other leak detector, check for leaks and immediately turn off the tank if you find any. If no leaks are found, you can now slowly open the regulator until it reaches the required pressure. Go back to the ICP and flow some gas just to make sure the line is full of gas and also that it has proper flow and pressure. Return the ICP to normal operation mode and the gas change is complete. For the highly toxic gases in the gas cabinets such as chlorine, there are additional purge capabilities built into the gas cabinets, which are outlined in the binder located to the left of the 3 cabinets for the chlorine ICP. Before replacing any cylinders in the gas cabinets, please contact EHS for any special procedures that need to be followed.

#### **5.4.2 MFC Calibration**

The Mass Flow Controllers (MFCs) are the actual controllers of the gas flow into the chamber. They use the density of a gas along with a measurement of the mass it measures moving through the controller to precisely determine the flow rate of

the gas into the chamber. Over time they drift and have to be re-zeroed to maintain the recipe integrity.



**Figure 5.10 MFC connections to IO boards in the ICP front compartment used for calibrating the MFC readings**

To re-zero the MFC you have to take voltage readings of the analog outputs from the MFC to the processor and adjust a potentiometer on the MFC. To access the outputs, you have to open the top right panel on the left side of the machine (panel to the side of the touch screen). This will reveal several circuit boards configured on a rack (Figure 5.10). There are some terminal blocks, which have inputs going to them. You need to find M#PC and M#PV where the # refers to the

specific number of the MFC. These should read 0mV when they are correctly zeroed. Since they read very small mV values, you should obtain a good multimeter for measurement (use a Fluke or equivalent, not a \$5 meter). It is easiest to perform the calibration with two people, one to take the measurement and one to adjust the potentiometer. The MFCs are located behind the panel to the left of the panel where voltage measurements are being taken. Before adjusting the zero of the MFC, first close all GV and GSV to be sure that there is no gas flow through the MFC, which could cause a bad calibration. Once this is done, slowly adjust the potentiometer on a given MFC while monitoring the voltage until ~0mV is reached. Be careful because the adjustments are very sensitive. After zeroing the MFCs, the present values on the display should also read ~0 sccm. Close the panels and you are done.

## **5.5 Sensors**

The fluorine and chlorine ICP have several gas sensors for safety. These sensors are Cl<sub>2</sub>, HCl, and H<sub>2</sub>. This system was installed by Applied Energy Systems. The cleanroom coordinator and Janusz should be able to provide some help with troubleshooting the system if you have problems. Overall the system requires little maintenance except for gas sensor replacement and calibration. The gas sensors are calibrated yearly to make sure that they are operating correctly. The indication of the sensors needing to be replaced is a blinking amber strobe but no horn coming from the cleanroom alarm system. By looking at the individual sensors controllers, you should be able to determine which of the sensors needs to be replaced. To replace them, go into the menu and select maintenance and replace sensor. These units are password protected. The password can be obtained from the cleanroom coordinator. Along with gas sensors, there is also an emergency stop button next to the Cl-ICP and in the

chase. These will turn off the gases and set off the alarm. To silence the alarm and/or reset the system press, **hold** the reset button until the alarm stops. In certain situations if the cause of the alarm has not been addressed, it will restart as soon as the reset button has been released or not stop at all. Remember, before resetting the system be sure to know the cause of the alarm to prevent a possibly hazardous situation. In the event that a gas leak is detected, the building fire alarm will also be tripped once the concentration reaches the high level alarm setting.

## **5.6 Chamber**

The chamber of the ICP should rarely need to be opened except for cleaning and replacement of worn parts. To open the chamber, you need to be in service mode, which requires the knowledge of the service mode password. If you do not have the service mode password, you cannot open and most likely should not be opening the chamber. The first step to venting the chamber is to make sure the load lock is vented, which can be done through auto mode or manually. To manually vent the load lock, open LV3 and wait until the pressure stops rising and begins to level off. Now you can open LV2 and wait until the load lock is at atmospheric pressure. After the load lock is vented, close LV2 and LV3. The next step is venting the chamber.

To begin venting the chamber, you first need to close the CGV valve. It is possible to open the chamber with the TMP still on but if you are not careful you can cause major damage to the TMP. So it is safer to turn off the TMP and let it spin down before venting the chamber. In the meantime, close off both of the ISOV valves since these gauges are not made to go up to atmospheric pressure. Once the TMP has stopped, you can close TPV if it is open and also close BV2. Now open LV1 to vent

the system. DG3 will provide pressure in the chamber until it maxes out. You will know when the chamber is vented by the loud bang noise that the chamber makes as it breaks the seal. At this point, close LV1 to stop venting the chamber. To open the chamber, go to the Config Robot screen. Then select UP under the LID Operation section. On the side of the ICP, hold both green buttons under the chamber to open the chamber. Continue holding these buttons until the chamber stops and then release them.

After you are done with the maintenance in the chamber, make sure that all parts of put back together correctly and the chamber is clean of any particulate or foreign objects. Change the LID Operation from UP to DOWN and hold the chamber buttons on the side again until it is fully closed. Now you can go into auto mode and choose system start up to have it turn on the pumps and pump down the chamber. NOTE: Sometimes when you try to select this option it will beep with an error such as RP1 or RP2 not off. Correct each of these errors until you no longer receive any errors at which point you can perform the system start up.

#### **5.6.1 Fluorine ICP Chamber Parts**

The top of the chamber has a quartz window which is held in place by a metal ring. This quartz window provides a barrier between the chamber gases and the ICP window. The ICP window is a thick glass plate that separates the chamber from the atmosphere and is very thick because it has a large pressure difference between the two sides. On the atmosphere side sits the RF coils, which are used for striking the plasma in the chamber. The quartz plate will slowly get etched away over time and should be inspected to make sure it does not get too etched and need replacing. Along with the solid quartz window, there is also an optional quartz window that has a small



opening in the center for a quartz window insert that can be used. The purpose of this window is to allow for a laser and camera to image the wafer during processing for End Point Detection (EPD). This style of window gets etched even faster because the rings for holding the sapphire wafer are thinner than the rest of the window. So it has to be replaced more frequently. To replace the window, carefully take out the screws holding in the metal retaining ring around the window and lower it down. When replacing the window, make sure to wipe down and blow off both the window and retaining ring so that they are clear of particles.

The parts in the lower half of the chamber are the wafer chuck, a quartz ring, and a chamber shield. The wafer chuck sits in the center and has grooves for helium flow as well as 3 holes in the center for the lift pins that raise and lower the wafers during the load and unload. The chuck is not a consumable part but should be kept clean. Every time you open the chamber, you should make sure to vacuum it off and wipe it down with a little IPA. Do not use too much IPA as it can cause damage if it gets into the lift pin holes. One important reason to wipe it thoroughly with IPA is sometimes vacuum grease ends up on the chuck which affects the seal and allows helium to leak into the chamber thus changing an etch process.

Outside of the chuck is a quartz ring. This ring has a recess in which the wafer sits. It has the purpose of protecting the underside of the edge of the wafer and helping to keep the wafer centered during loading and processing. To remove this ring, carefully lift it out of the chamber. The cleaning procedure is the same as most parts, just wipe it down and make sure it is clean before replacing. Along with cleaning, this ring will slowly get etched over time. It should be replaced when it becomes etched to the point that the edge and underside of the wafer are exposed to

processes gases. At this point the ring needs to be replaced to help maintain etch recipe consistence.

Around the inside of the chamber, there is the shield going around the chamber. It is held on with screws around the outer rim and is removed by taking out the screws and lifting it out. Alternatively the shield and supporting outer disk can be removed by removing the 4 screws that hold the outer plate. Sometimes this ring can be hard to remove so use caution when removing and replacing this ring. Usually the shield does not require any maintenance and does not need to be removed. In some situations, the shield has to be removed for cleaning or access to the lower portion of the chamber. However this is rare in the F-ICP.

On the sides of the chamber outside of the shield there are sapphire windows. These are the view ports located on both the right and left sides of the chamber. They are made from sapphire usually so that they are not etched significantly during processing. However, it is possible to replace them with quartz if sapphire is not available. The etch rate of the windows will just be increased by using quartz. To replace these windows, you need the chamber vented. To remove the window on the right side of the machine, take off the protective shield over the window. Then remove the screws that hold the actual retaining ring for the window. You may have to gently twist the ring to get the window out as sometimes the seals get stuck. You will want to grease the seals with Fomblin® grease as it will help protect them from corrosion and it will also help prevent them from sticking when they are removed in the future. The window on the left side of the machine is hidden behind the back top panel. Remove this panel and you will see the window has the metal ring holding it in but does not have the protective cover that the other window

had. This window only needs to be replaced if it becomes structurally weak as it is not used for viewing.

There are two o-rings on the sealing surface of the chamber. The inner, white o-ring is Kalrez® and provides the vacuum seal. It is a chemically resistance fluorinated seal material. The outer o-ring is a metallic seal, which provides grounding between the two halves, thus providing RF shielding. These seals should not require much maintenance except being kept clean. They should be wiped down with IPA and wiped dry to keep them clean and to make sure that there are no particles embedded in them. No vacuum greases needs to be applied to these seals; they are fine on their own. Do not remove either of these o-rings without first having a replacement available as they are easily damaged and once they are damaged they cannot be reused and they are very expensive.

## **5.7 Robot**

Along with the controls to open and close the chamber, the Config Robot screen has settings and controls for the robot load arm. These settings are important for testing and programming the robot. These are used in service mode when the chamber is open for verification of robot arm motion along with wafer placement. Along with the LID operation controls, there are also controls for raising and lowering the lift pins for the wafer and manual controls for opening and closing the load lock gate.

On the left column are some very useful and important controls for testing the loading and unloading of the wafers. After replacing the quartz ring around the chuck, you should check the loading using the load test button. This will load the wafer, lower it, and retract the pins. Be sure that the gate is open before performing a

load test. Often times when the wafer is lowered while the chamber is open, it will slide because of trapped air. To fix this problem, you can place three small washers on the chuck so the wafer still will sit where it is placed but will not slide around. After the wafer is loaded, there is also the unload test to make sure that the wafer is correctly lifted and unloaded. Once a wafer is loaded, you will see the WAFER FLAG become illuminated showing that there is a wafer in the chamber. If you want to manually unload and retest the load test, to save time you have to click the button to turn off the flag, otherwise it will not perform a load test as it will think there is still a wafer in the chamber.

In the middle of the screen, there is the ROBOT Setting panel which controls the start and stop points of the robot arm. There are very important for reprogramming the robot. In the case that the robot arm has lost the origin or setpoints, contact Samco® for instructions on how to reprogram the robot arm. In this box, there is also the MOTOR FREE button, which allows the robot arm to be disengaged and to be freely moved by hand. This is important at times when the arm has to be reprogrammed or sometimes if the arm gets caught in an error. It will free the motor for safety reasons and you must re-engage the motor for it to properly operate.

## **5.8 Vacuum Gauges**

The ICP has many different vacuum gauges, each with their own purpose and operating range. The different gauges are IG, DG1, DG2, DG3, and XG. The purpose of each along with maintenance will be covered in this section. DG means diaphragm gauge, IG is ion gauge, and XG is a crystal gauge.

The first set of gauges that will be discussed are the diaphragm gauges. Diaphragm gauges must be heated to a certain temperature to be accurate. So if the machine has been turned off for an extended period of time, it is best to let the gauges warm up for several hours before starting a process. There are several diaphragm gauges in the system. DG3 is an overall chamber pressure sensor that is always open to the chamber. When the chamber is under sufficient vacuum, it should read  $\sim < 2$  Pa. This is the gauge that increases when you are venting the chamber. It is the only one that is open to the chamber during venting. DG2 is the helium back pressure. This gauge monitors the helium pressure on the back of the wafer during processing and its value provides feedback to adjust VPos so that the desired helium pressure is met. The last and most important is DG1. DG1 is your process gauge. It opens during processing to read the relative chamber pressure. At times, the zero of this gauge can shift and it must be re-zeroed to maintain reproducibility. To zero it, first make sure that the machine has been on long enough for the DG to be at temperature and then make sure that the chamber is at a pressure of  $7 \times 10^{-3}$  Pa or lower (for F-ICP and  $3 \times 10^{-2}$  for Cl-ICP) that can be read from the IG.

There are two different ways to zero this gauge, using the VAT® controller box or through the software. To do the zeroing, connect the VAT® controller remote to the APC (PM-4) on the front of the machine. Enter local control mode by pressing and holding the local button until the light on local illuminates. Then press zero and then the DG1 should read 0.00 Pa. Using the software, you go to Config Device screen and click the zero ADJ for Process APC. In extreme cases, the gauge can drift enough as to not be able to be zeroed in the software. In this case, you have to perform a zeroing using the potentiometer on the top of DG1. Refer to the

manual or contact Samco® for more information/assistance on performing this zero. There are other zero adjusts for gauges such as DG3 but these zeroes are normally not used except in situations of large drift ( $>5$  Pa). Using the VAT® controller box is the method preferred by Samco®. Besides zeroing, these gauges usually do not require much maintenance.

Along with the diaphragm gauges there are also the XG and IG gauges. The XG is the crystal gauge and measures the pressure of the load lock. It is located on the left side of the load lock. At times the crystal can become worn out and has to be replaced. This can be determined by examining the indicator lights on the XG housing that is behind the same panel as the computer circuit boards. To replace the crystal, you need to replace the entire head of the gauge. Instructions can be found in the manual for this gauge.

The IG is the last gauge of interest. It is an ion gauge and is used to measure the absolute pressure of the chamber. In order for the IG to take a reading, ISOV must be open and IG FIL (filament) must be on. The filament provides the ions that are measured to determine the pressure of the chamber. When turning on the filament, you should let it sit for several minutes to outgas and thus provide a more accurate reading. This is the gauge that is read by the system before processing to determine if it has reached a sufficient pressure to begin processing. At times, the filament can go bad and has to be replaced. The gauge head has two filaments and they can be switched simply by switching a dip switch on the gauge that is located in the same section of the tool as the MFCs. If both filaments burn out, it is necessary to replace the entire gauge head. The procedure for changing the filament along with changing gauge heads can be found in the manual for the gauge.

## **5.9 Vacuum Lines and Valves**

The ICP contains many different valves and vacuum lines. This section will briefly cover the purpose and operation of the various valves. The valves are broken into ISOV, HV, BV, LV, PV, and CGV. The purpose of each will be discussed along with any required maintenance. The CGV valve will be discussed in the following section (5.9.1) which discusses gate valves.

First there are the two ISOV (or isolation valves) which isolate the vacuum gauges from the chamber at different times. These are important as they protect the IG from seeing too high a pressure or from seeing process gases which can cause damage. At times, these valves can leak which can be seen by noticing a change in pressure while the valve is closed. In these cases, the valves have to be removed and the seals have to be inspected and possibly replaced. These are pneumatic vacuum bellow valves. They operate by using compressed air to contract a vacuum bellow. The end of the vacuum bellow has an o-ring that provides the seal and isolation. For more information on the servicing of these valves, see their manuals located in the back of the ICP manual.

LV and PV valves are used to provide nitrogen flow for various purposes. LV1 is a chamber vent whereas LV2 and LV3 are two different flow rate lines for the lock vent. LV3 is a slow vent for the load lock and LV2 is a faster vent valve that should not be opened until the vent rate from LV3 has slowed. TLV is a leak valve that relieves the vacuum on the TMP after it has been turned off. PV and TPV provide nitrogen to the gas flow during the process, thus helping to dilute the gases. As long as no unusual operation is noticed, no maintenance should be required.

HV valves are like LV except they are for the helium flow. HV3 is a controlled flow just like LV3 for the load lock. HV1 is the main helium shut off that

cuts the helium flow when it is not used. PCV is the pressure controller that sets the VPos based on the set value and DG2. Like LV and PV, these should not require any maintenance.

The last set of valves are the BV valves. These control the flow in the vacuum system and provide isolation between the pumps and chambers. BV3 provides the pumping path from RP2 to the load lock, allowing it to be pumped down during wafer loading. BV1 allows RP2 to pump down the chamber. During normal operation, BV1 remains closed and only opens when the chamber needs to be roughed down from atmosphere as RP2 is a much bigger and more powerful pump than RP1. After the chamber is under vacuum, TMP provides the pumping and thus the vacuum flow is through CGV and BV2. BV2 opens and closes to allow RP1 to back the TMP. RP1 is the process gas pump and serves the purpose of providing backing for the TMP during normal low pressure and processing applications. As long as these valves provide a good seal and do not leak they should not require any maintenance. In the case that they do leak, their manuals should be in the binder, otherwise contact Samco® for more information.

#### **5.9.1 Gate Valves**

The ICP has two gate valves. The first gate valve is the CGV, which is to control flow through the TMP. The second is the load lock gate valve that seals off the load lock from the chamber and also allows for sample transfer in and out of the chamber.



### **5.9.1.1 Control Gate Valve (CGV)**

The Control Gate Valve (CGV) is the large gate valve that seals the TMP from the chamber. It also provides flow control during processing to achieve the desired pressure for processing. It is located right above the TMP and is actually bolted to the TMP. The control of the position of the CGV is done through the Auto Pressure Controller (APC). The CGV under normal use requires no maintenance as long as it is sealing properly. There is a set of Kalrez® seals that close off the CGV, which can become worn out. In this case, they need to be replaced. However, this process requires removing the TMP from the system and taking the CGV off the TMP. It is quite an undertaking and is best performed by Samco® if possible. So in the case that a leak develops, contact Samco® immediately to try and rectify the situation as soon as possible.

### **5.9.1.2 Load Lock**

There is a gate valve that separates the load lock and reaction chamber. This is a VAT® 78485-R9 (or –R1) with a Viton® seal. There is a Kalrez® version available, which is more chemically resistant but more expensive. Every time the chamber is opened, the seal on the gate should be inspected as it does deteriorate over time. It should be wiped down with a dry wipe and if it seems to have deteriorated clean it with IPA and inspect for damage. Also, when wiping down the seal wipe, down the sealing surface to provide a good seal. A small amount of Fomblin® grease should be applied to the gate to help prolong its life. It will keep it from drying out and also, more importantly, help protect it from the process gases, which tend to deteriorate the Viton® seals.

Sometimes if the seal is badly damaged, it has to be replaced. Some signs that it needs to be replaced are visible wear, a leak in chamber pressure, or the load lock pumping down when left idle at atmosphere. To replace the gate, you need both the load lock and chamber vented. Then loosen the two screws at the bottom of the gate but do not take them all the way out! They are just there to clamp the gate and do not thread through the gate but connect to a piece that clamps onto the opposite side of the gate. After the screws are loose, there is a metal piece that should come out from the clamp, thus loosening and allowing the gate to be removed. If it does not come out, use something to carefully slide it out against the screw. After loosening the screws, open the gate and remove it. It may be hard to pick the gate up when it is all the way lowered, so you may want to hold your hands under the gate as it lowers to lift it out of the holders. Replace it with a new gate (which should be greased with Fomblin® grease) and raise it to the closed position. Once it is in the raised position, tighten the screws. If the screws just spin, hold the clamping metal behind the screw out as you tighten the screw, which should cause the screw to catch. Then you can tighten it the rest of the way by hand. Make sure that it is level and seals correctly before pumping down the chamber. Used gates can be returned to VAT® for seal replacement (re-vulcanization).

## **Chapter 6**

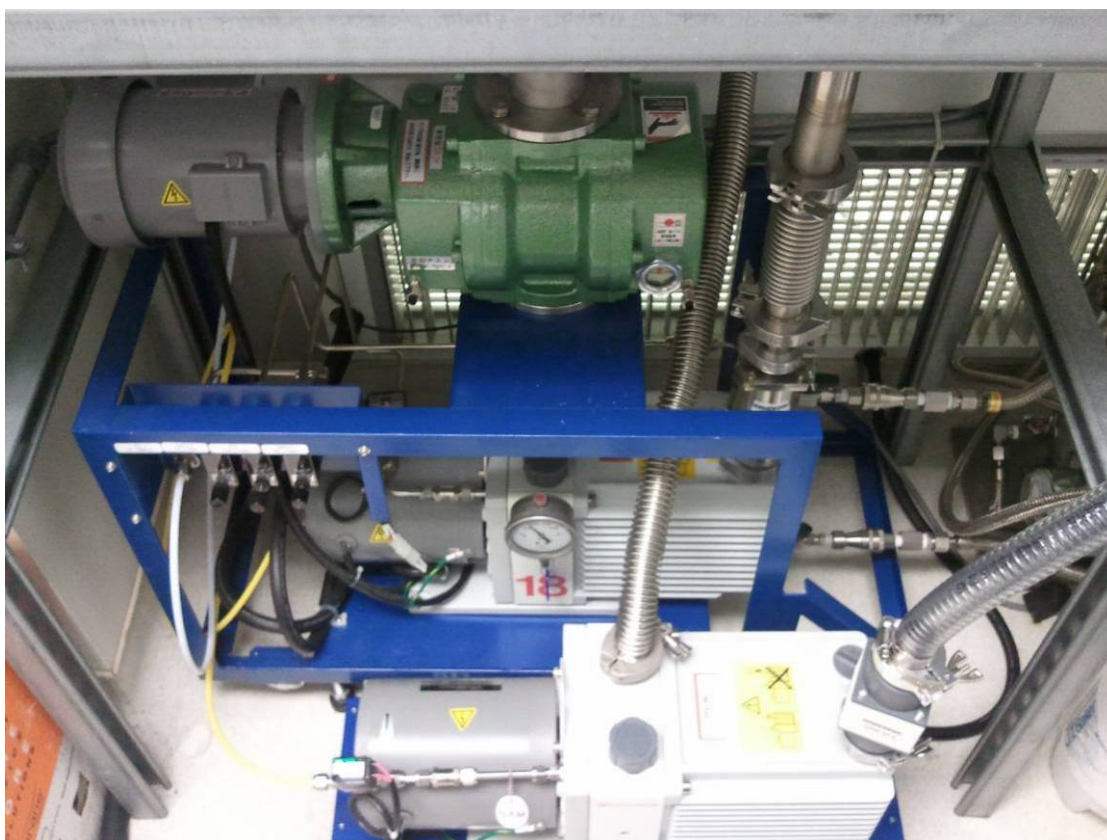
### **PECVD MAINTENANCE**

Chapter 3 covered basic use and maintenance of the PD-220N PECVD. The maintenance of this tool is much more complicated than was covered in Section 3.5. In addition to the actual tool itself, there are many other utilities such as vacuum pumps, water chillers, compressed gases, and the burn box, which are needed for the PECVD to operate. This chapter covers many of these topics more in-depth to discuss preventative and emergency maintenance. Much more information can be found in the Samco® PD-220N manual [29] or in manuals from the manufacturer of the component of interest. As one becomes more familiar with the PECVD, performing maintenance will be easier and more efficient. Appendix C lists contact information of several people at Samco® who can provide additional help with PECVD operation and maintenance problems.

#### **6.1 Pumps**

The PECVD has four pumps compared to the three pumps of the ICP. There are two mechanical pumps, an E2M18 (RP2) for chamber roughing and TMP backing and an E2M18-PFPE (RP1) for Mechanical Booster Pump (MBP) backing shown in Figure 6.1. The E2M18-PFPE uses Fomblin® as it is a process pump whereas the E2M18 is not a process pump. This brings up the main difference between the PECVD and ICP vacuum pump system. In the PECVD, the TMP is not a process pump, all of the process gases are pumped through the MBP. This is why

there are four pumps instead of three pumps as with the ICP. We will now discuss the maintenance of each of these different types of pumps.



**Figure 6.1** Pumps for the PECVD. From top to bottom: mechanical booster pump, E2M18-PFPE, and E2M18.

The maintenance of the E2M18 pump is very similar to that of the E2M30-PFPE of the ICP. The major difference is that this pump uses hydrocarbon oil instead of Fomblin® since it does not see process gases. Also, the oil mist filter housing is OME 25S instead of the OME 25 C/H, which is on the E2M30. However it

still uses the AV-066800 from Kurt J. Lesker. The procedures for changing the oil and mist filter are the same as they are for the ICP.

The E2M18-PFPE, which is located below the MBP, uses Fomblin® (Y-LVAC 06/6) just as the ICP pump uses. It has the same OME 25 C/H and filter as the E2M30 does. The difference with this pump is that it will collect a lot of particle build up from the deposition process. To take care of this, there is an oil filter, which is connected to the pump and filters out the particulates (Figure 6.2). To add oil to the pump, just turn it off and add as you would for the other pumps. To change the oil however, both the pump and the filter need to be turned off. To turn off the filter, open the front panel and flip the breaker (Figure 6.3) so that the front lights turn off. Then you need to close all the valves and disconnect the fitting from the pump oil outlet and drain the oil. It is also possible to drain the oil from the filter and replace all of the oil. This needs to be done when you are replacing the filter element. The filter needs to be replaced when the gauge on the left side of the filter unit (Figure 6.2) reads above the red line. To replace the filter, turn off the system and drain all the oil from the filter housing and pump. This will require quite a bit oil to refill so make sure you have enough to refill everything. Once it is drained, open the top of the filter container and carefully remove the oil filter. You may want to wipe out the inside with dry wipes and try to remove as much particulates as possible. Then put in the new filter and refill the filter. After refilling it, open the valves to allow some of the oil to flow into the pump. Then fill the pump part way and turn on the filter. Keep adding oil until the view window on the pump shows a good level and the view glass on the filter line is filled with oil. This makes sure there is not extra air trapped in the system.



**Figure 6.2** Filter unit for the PFPE oil for the PECVD



**Figure 6.3** Inside of the filter control, showing the breaker with the orange mark on the switch.

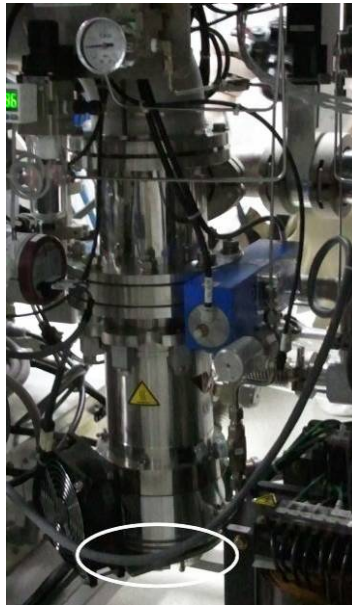
These are the main things that need to be serviced on these pumps. As with the ICP pumps, sometimes they need to be removed and sent in for servicing. Also, the gas ballasts do the same as they do for the ICP just the flows are 1.5 L/min N<sub>2</sub> for the ballast and 5 L/min N<sub>2</sub> for the purge.

Along with the mechanical pumps, there is the MBP, which is the green pump located above the E2M18-PFPE in the chase as shown in Figure 6.1. It takes the place of the TMP during the actual process. The only maintenance that is done on this pump is to replace the oil when it gets low or turns a dark yellow color. The oil should be replaced once a year or two, or whenever it gets low or discolored. The oil used is SAM oil from Samco®. It is in a green metal container. To drain it, have the system off and remove the metal plug from the bottom and let it drain out. Then replace the plug and open the top plug and add the oil. The level should be around the

max line on the diagram as the level will drop once the pump is turned on. Besides this, the MBP requires little maintenance.

Finally there is the TMP pump, which unlike the other pumps is housed inside the PECVD itself (Figure 6.4). It is mounted to the vacuum line of the chamber and is used for fine pumping of the chamber before and after processing. There is a display and controller inside the front panel that lets you know the status and hours run. At normal speed, it rotates at 48,000 RPM. The major difference from the ICP is that this pump does not pump during processing. Because of this, the pump is smaller, has more delicate blades, and is not magnetically levitated. Instead this pump has bearings and oil. The oil should be replaced if it becomes severely discolored (gray-black) or drops below the fill line. There are 3 fill lines on the oil container. The top is the new oil fill line, the middle is the minimum standing oil level with the TMP off, and the bottom is the minimum oil line with the TMP on. To replace the oil, turn off the machine and open the two bottom side panels. The clear plastic container on the bottom of the TMP is what is removed to replace the oil. Remove the screws and carefully lower the oil, careful not to spill any. Empty the container and wipe it clean. Then refill to the top line with NTL-F500 (the F500 specifies how many milliliters the container is so it could have a different value after the F), which can be purchased from Samco® if more is needed. Then replace the dish and carefully tighten the screws. Be sure to alternate which screw is tightened and to not over tighten or you may crack the plastic. This is the only real maintenance required for this TPM. If the oil is kept in good condition, it should continue to run smoothly.





**Figure 6.4** TMP located inside the PECVD with the plastic oil holder circled

## **6.2 Burn Box**

Located above the pumps is the Enviromatrix –Altair burn box system. It has the purpose of safely dealing with the exhaust of the system. It has a series of baffles inside it and it flows the exhaust through these baffles where it is mixed with air. During this process it allows for the silane/ammonia to decompose and be diluted. At the outlet of the box, the gases have either decomposed or been reduced to a level that is safe for release into the atmosphere. The flow should be between 200 and 230 LFPM (ideally 210-220 LFPM). The temperature should be around room temperature. If the temperature increases above 30°C, there may be excess gases flowing through the burn box. This can cause problems and should be investigated.



**Figure 6.5 Front panel of the burn box showing the indicator lights, control switches, and display screen**

There are several buttons on the front of the unit as shown in Figure 6.5. There are indicators showing that the system is running and has good air flow. There are also indicators for interlock errors along with airflow and temperature alarms. If the “Low Air Maint” light is illuminated, it means at some point it dropped below the setpoint. However, as long as the buzzer is not on, it is working fine. If the buzzer is going off, press “Alarm Silence” to turn off the alarm. Be sure that the flow rate is back to normal operation before trying to use the PECVD for a deposition. The fault reset button will clear the Low Air Maint light but is not required to be depressed to allow the system to come back to normal operation.

The inside of the burn box does require some cleaning to remove built up pump oils and deposits. When opening the burn box, make sure that the PECVD

and all of the pumps are off along with the burn box itself. Also, close down the exhaust slightly so that it still pulls some air through but not too much. Remember the position so you can set it back afterwards! You can then open the front cover of the burn box. Once it is open, you'll see the many different baffles. You can remove these carefully and wipe them down with IPA and a clean wipe. Also thoroughly wipe down the inside of the burn box and make sure it is free of solvents afterwards. Place the baffles back in and seal the unit. On the right side of the unit there is a filter for dust that can be removed so that it can be cleaned. It should be cleaned periodically to help maintain good air flow through the system. After cleaning the unit, adjust the exhaust position and turn the unit back on. Let it run and make sure there are no errors before starting the PECVD.

### **6.3 Chiller**

The PECVD has a Neslab Merlin M33 chiller that provides cooling to the seals as does the ThermoFlex chiller for the ICPs. Like the others, it also uses a 1:1 DI:Glycol mixture. The maintenance is much the same as other units. This one is kept at 20°C instead of 15°C. To add water to the reservoir, open the hatch on the top left, unscrew the cap and add the coolant. The level can be seen through the frosted plastic container on the front left of the unit. To drain the unit, there is a pipe fitting on the bottom right of the chiller. To drain the unit, first turn it off and then open the valve. You will either want a container under it to catch the liquid or to connect some tubing to redirect the flow into a container. After draining, you can close the valve and refill with coolant. Besides this, the only major maintenance is replacing the pump as is done with the ThermoFlex chiller. The pump head and connectors are the

same, the placement and access to the pump are slightly different on each unit. With proper water level and pump replacement, the unit should run with no problems.

## **6.4 Gases**

The gases used for the PECVD are different from those used in the ICPs. The purpose of these gases is to deposit a material rather than etch it away. However, these gases are just as toxic and dangerous and should be handled with great care. The gases located in the chase are nitrous oxide ( $\text{N}_2\text{O}$ ), silane ( $\text{SiH}_4$ ), ammonia ( $\text{NH}_3$ ), oxygen ( $\text{O}_2$ ), argon ( $\text{Ar}$ ), nitrogen ( $\text{N}_2$ ), and hexafluoroethane ( $\text{C}_2\text{F}_6$ ). Nitrous oxide, silane, and ammonia are stored in gas cabinets. The nitrous is in the one just on the left as you enter the room. Along with the gases in the chase there is TetraEthyl OrthoSilicate (TEOS), which is located in the thermostatic bath to the left of the PECVD. More information on TEOS will be discussed in the heaters section (6.5). The procedures with the gases are very similar to that of the ICP with a few slight differences.

### **6.4.1 Gas Cabinets**

A noticeable difference is that the gas cabinets are setup differently. The silane and ammonia cabinets have a large display (Figure 6.6) and the nitrous has a smaller display (Figure 6.6), which is not seen on any of the ICP gas cabinets. The displays provide a lot of functionality but usually they are just used to verify that the system is normal and gas is ready for use. Inside the cabinets there is a red line on some of the regulators. These are limit switches and will set off an alarm for either high or low pressure depending on the switch type. If more information is needed, please contact Applied Materials as they are the providers of the gas cabinets. The

smaller display for the nitrous tank should always have the Valve Open and Power lights illuminated. Sometimes when power is lost, the valve open light (on the nitrous tank) turns off and thus the outlet valve is closed. To open it, turn the key to purge, press station reset, turn the key to normal, and press station reset again. The valve should now be open (you should hear pneumatic valves actuating) and the light illuminated.



**Figure 6.6** Left: Display type for silane and ammonia tanks, Right: nitrous oxide tanks controller

#### 6.4.2 Operation and Cylinder Replacement

The last major part of the gas system is the manifold system. It includes two sets of valves and Mass Flow Controllers (MFC). The GV# are gas

valves that control the flow of the individual gases to the mixing line that leads to the chamber. There are also GSV#, which are gas safety valves that isolate the gas tanks from the MFC and the rest of the tool. Unlike the GVs, the GSVs are normally open once the machine has been turned on and finished its start up procedure. The GSV sometimes have to be closed for troubleshooting, leak checking, and MFC calibration. In addition to the GSVs and GVs, there are also the SSVs, which are not on the ICP systems. The SSVs are between the GVs and the chamber. The area between these valves is a gas mixing manifold so that the gases are well mixed before entering the chamber. In order for gases to flow, both the appropriate GV and SSV have to be opened. Both SSV1 and SSV2 cannot be opened at the same time due to safety and contamination that would be caused by gases from the two manifolds mixing. Unlike the gas valves, the MFCs need to be periodically calibrated to remove drift of the zero point which can affect deposition rates and stoichiometry. This will be discussed in the next section (6.4.3).

To purge the lines and/or replace a tank, follow the same general procedure as done with the ICPs. The major differences between the two gas setups are the gas cabinets and the controls on the machine side for venting the gases. To evacuate the gas lines on the PECVD, first close the tank valve as was done for venting the ICP lines. However, to pump down the lines, follow the same general procedure as you would for switching between nitrogen and argon (see the PECVD maintenance Section 3.5 in Chapter 3 for the gas line venting procedure). To do this, one at a time set each gas flow in Recipe 101 (to at most their max value) and then open up SSV1 or SSV2 to pump out the line. When flowing silane and ammonia, you may want to first leave the nitrogen (or argon) tank open and flow about 100 sccm to

dilute the silane and ammonia as they leave the system. In addition to venting through the MFC, silane, ammonia, and TEOS have a bypass valve (BPV#) that allows for better evacuation of the lines. Do not use the BPV for these lines unless the line has already been evacuated or it will trigger an access flow sensor on the gas cabinets, thus setting off an alarm. Also, the large amount of flow may be a bit much for the burn box to handle. When switching between evacuating gases on SSV1 and SSV2, you should have the system pump down with the TMP. This is to make sure that there is no cross contamination. SSV1 and SSV2 cannot be both opened at the same time for contamination and safety reasons.

In addition to pumping out the lines, the silane, ammonia, and nitrous oxide cabinets have the ability to evacuate and purge the lines. The silane and ammonia cabinets are the easiest to perform as they are automatic. To perform the purge make sure that the gas cylinder is closed and the line is evacuated. To run the purge, turn the key from normal to purge and then select purge down and follow the directions on the screen. Purge up is for purging the lines after a new gas cylinder has been installed in the cabinet. For the nitrous tank, please see the manual venting procedure in binder for the ICP gas cabinets. Before replacing any of the gases located in the gas cabinets, contact EHS for any special procedures that may have to be followed.

#### **6.4.3 MFC Calibration**

As with the ICP, the gas flow is controlled through MFCs. These also need to be adjusted over time to rezero the values. This is done by adjusting a potentiometer on the back of each MFC. They are located in the gas box. To get to them for adjustment, you first need to open the back door of the machine. This is

done by unscrewing the screws on the right side. They unscrew but do not come out of the door. Then swing the door open, you may want to walk around the side of the machine to look inside since the door swings towards the left. Inside the machine there is a box with a bunch of screws. That is the gas box. To open the gas box, take out the screws and remove the cover, revealing the MFCs and mixing manifolds.

After revealing the MFC units, the next step is to locate the signal lines where you will read the voltage. These are on units 005 and 006 of the PLC. They are labeled M#PV and M#PC (#=1-8 but no 6). This is the present value and present value common. The voltages are in the millivolt range. While reading the voltages with a sensitive multimeter (use a Fluke or equivalent, not a \$5 meter), carefully adjust the pot to get as close to 0mV as possible. You may need two people to do this as sometimes it is difficult to hold the meter and adjust the pot at the same time. MFC8 is the TEOS and usually does not have to be adjusted unless people are using the TEOS in processing. After completing the calibration, the displayed values should be very close to 0 SCCM. Close the gas box and the back of the machine.

## **6.5 Heaters**

The PECVD has several different heaters and different displays which are visible on both the front of the machine and front of the thermostatic bath. These heaters are both for the chamber and the gas lines. The gas lines are heated since TEOS is a liquid if not kept heated. On the front of the PECVD there are 5 temperature indicators, shown in Figure 6.7. The top is for the “Lower Substrate Heater” which is the temperature set for running a recipe. It usually reads cooler than the touch screen, which is normal. Next to this controller is CP2, which is a breaker for this heater. The lower row of indicators is for the gas line heaters. The left most



display is the heater for the gas inlet, which is the point where the gases mix and go into the shower head and the chamber. There is also line heater 1 and line heater 2 which are lines running from the TEOS cabinet through the gas cabinet and to the mixing point. All of these should read around 100°C. The last indicator is a safety sensor. It is a safety switch for the inlet heater and will trip the breaker if the heater gets too hot. As with the substrate heater, CP3 is the breaker to turn off these heaters.



**Figure 6.7** Temperature controller displays on the front panel of the PECVD

Along with the heaters in the PECVD there are also heaters for the thermostatic bath. These are the panel heater, the MFC heater, and the band heater. They should read about 80, 85, and 80°C, respectively (Figure 6.8). Sometimes after a power outage, these get turned off and need to be turned back on. To turn them on, remove the bottom front cover by pulling the top of it forward. Then push the green on button and it should become illuminated indicating that the heaters are now on. You can now close the cover. If you are going to use TEOS, make sure that the heaters

have reached their setpoints and had time to stabilize to prevent liquid from getting into the system.



**Figure 6.8 Heater displays on the TEOS thermostatic bath**

## **6.6 Vacuum System**

The PECVD has seven valves in the vacuum system and two for the gas inlets. The two gas valves SSV1 and SSV2 are to separate the gas manifolds from the chamber and are opened during deposition to allow the gas into the system. However, both SSV1 and SSV2 cannot be opened at the same time for safety reasons since it would allow silane and oxygen to directly mix, which would be a very hazardous situation. The vacuum valves are ISV1, ISV2, BV1, BV2, BV3, BV5, and CTV. The ISV1 and ISV2 are actually isolation valves that isolate the DG and FRG from the chamber.

### **6.6.1 Vacuum Gauges**

The DG is a diaphragm gauge that reads a relative pressure and is used during processing. It operates off of the same principles as the ICP and thus has to heat up after being off for an extended period of time. The DG usually does not

require any maintenance as long as it is working properly except for occasional zeroing. The zeroing process is the same as the process for zeroing the DG on the ICP using the VAT® controller box.

Along with the DG, there is the FRG (Full Range Gauge) that ranges from atmosphere to high vacuum. It is the gauge which is used to confirm a high vac of  $5 \times 10^{-3}$  Pa before starting processing. It includes both a penning and pirani gauge. This is a very complex and important gauge. Over time (several years), the penning gauge will accumulate build up and need to be cleaned, which is a delicate process as the centering of the rod is important to correct operation. There is a rebuild kit sold through Samco®, which provides the parts to clean out and re-center the gauge. The manual includes instructions on how to perform the rebuild along with instructions on how to perform the calibration, which must occur after cleaning/rebuilding the gauge. In the short term, the FRG does not require any maintenance as long as it is working properly.

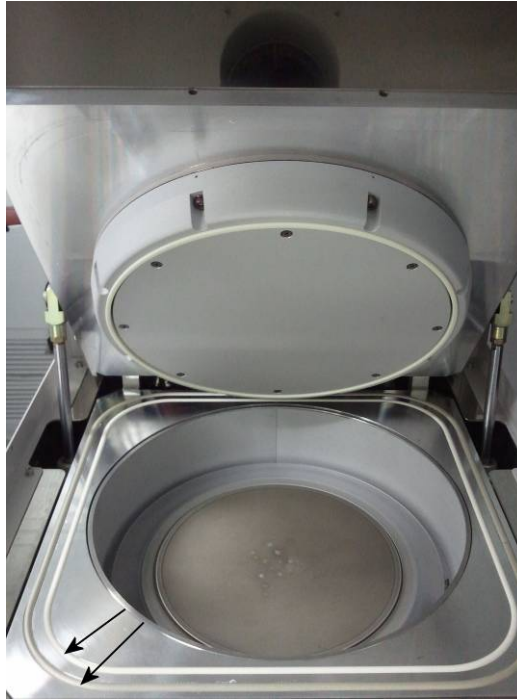
#### **6.6.2 Vacuum Lines and Valves**

The other valves actually control the flow of the vacuum lines. BV3 is the roughing valve that allows RP2 to rough down the chamber. BV5 is the turbo backing valve that is important for the operation of the TMP. When the TMP is on, TPV2 is also open. It is a vent valve that flows nitrogen through the turbo during normal operation. This is the vacuum line that will pump the chamber down to high vacuum before and after processing. BV2 opens to expose the TMP to the chamber thus pumping through BV2, TMP, BV5, and down into RP2. BV3 and BV5 are standard vacuum bellows valves (maintenance can be found in their manuals). BV2 on the other hand is a butterfly valve for providing isolation from the chamber.

The other vacuum line is the process line that has MBP and RP1. BV1 isolates the MBP from the chamber and is opened for process gas pumping. Unlike the other valves, BV1 is a gate valve. CTV is the control valve that modulates to control the pressure during processing. It is a butterfly valve much like BV2 except it is an electrically drive analog valve and can open part way to constrict the flow. The CTRL icon on the display means that the CTV is being controlled to keep a constant pressure. Once again, the maintenance of these can be found in their manuals. One note about BV1 concerns the replacement of the gate plate and seals. The gate sits on a shaft and is held in place by ball bearings. A good method for removing the gate and putting on the new gate is to use spanner piers (used for retainer ring placement) to open the clamped bottom of the gate to allow it to be easily placed over the shaft or removed. Under normal operation, most of these valves need little to no maintenance unless they show signs of leaking, in which case a seal may need to be replaced.

## **6.7 Chamber**

The chamber consists of two parts which are hinged. There are two seals on the bottom section of the chamber (shown in Figure 6.9). The inner white seal is the Kalrez® vacuum seal and should be kept clean of particulates. To make sure it is clean, wipe it with a dry wipe and possibly a wipe with a very small amount of IPA if there are makings that do not come off with a dry wipe. This seal being clean is very important as it can become damaged and possibly not hold a vacuum. The outer seal is an RF seal, which is for RF shielding. It should mechanically be in good condition but does not hold a vacuum.



**Figure 6.9** Inside of the PECVD chamber showing the inner, white Kalrez® seal and the outer, gray RF seal. The top half has the gas delivery shower head, isolation ring and ground ring.

The top half of the chamber is what delivers the gases to the chamber and houses the RF system. The parts are shown in Figure 6.10. There is a outer ring which is a ground ring and also holds together the other parts of the top half. There is an alumina insulator and spacer just to the inside of this ring and then there is the shower head. These can be removed by removing the screws on the outside of the ground ring. This will allow the outer ring and alumina spacer to come out. The shower head is then removed by taking out the screws around the rim of the shower head. This will reveal the gas delivery system (Figure 6.11). The plates and rings that are visible now are for directing and spreading the gases out under the shower head

and properly adjusting the spacing of the top portion when the lid is closed on the chamber. These inner pieces should be clean and not need any maintenance. However, there are spares of these available in the extra parts cabinet and from Samco®. Overall, the parts on the top of the chamber should not need to be removed or maintained during normal operation.

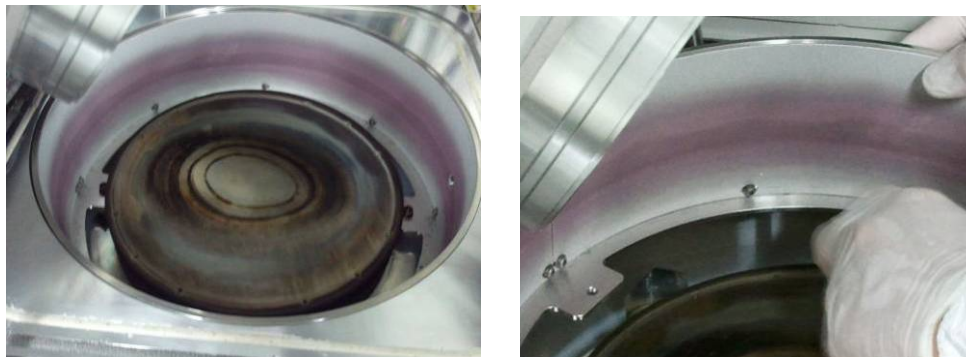


**Figure 6.10 Top parts of the chamber. Left is the ground ring with the insulation ring installed inside it. Right is the shower head plate.**



**Figure 6.11** Top of the chamber with parts removed revealing the gas shower head. The gas enters through the center where it hits a baffle that redistributes the gas across the entire shower head area.

The bottom of the chamber is a little more complicated than the top half and sometimes does require maintenance. There is the quartz ring around the outside of the center portion where the samples go. This quartz ring can begin to wear away over time and sometimes needs to be replaced. This part simply lifts out of the chamber, just be careful as it is fragile. The center portion where the samples go also can be lifted straight up. It sits in a little groove on the metal base that houses the heating elements. Once these two pieces have been lifted out, they reveal the bottom of the chamber and the outside, shown in Figure 6.12. The only piece left that can be removed is the outer shield. During normal use, the only piece that should have to be removed is the quartz ring as it does wear thin over time.



**Figure 6.12** Left: the heating pedestal with the quartz ring and sample holder removed. The outer ring with the purple color is the side shield. Right: a close up of the shield showing the screws that hold the shield to the ring as well as the tab where the retainer ring attached to the chamber.

In the event that debris falls down into the bottom of the chamber, you can take out the above mentioned pieces along with the side shield to clean out any debris or build up. The side shielding is made of 3 pieces: a bottom holder, the actual curved shield, and a top retaining ring. To remove this, first take out the 4 screws holding the bottom holder to the base of the chamber. This will allow you to move the assembly and lift it out. However, notice that it is not possible to take it out in this form due to the chamber lid. To remove it, you have to take off the top retaining ring and unscrew the screws holding the shield to the bottom ring. Once these are unscrewed, you can carefully pull the shield into a tighter circle and lift it out of the bottom ring and take it out of the chamber. Then the bottom ring can easily be removed and the inside of the chamber is now fully accessible. To reassembly, repeat the steps in reverse. Be sure to try and keep the shield circular and to not deform it when handling it. To reform the ring, gently press it against the outside rings to reshape it. After reassembling the



chamber, you should run a 30 minute oxygen plasma clean to remove any excess water vapor and organics that may have been introduced into the system.

Other parts that sometimes have to be replaced are the two view ports on the front and right side of the chamber. They are made from quartz so over time they will be etched by the cleaning process just as is the quartz ring. To replace them, make sure the chamber is vented and then take out the screw on the front of the machine that holds the cover plate over the window and remove the plate. Next unscrew the screws that hold the actual window in place and carefully remove the metal ring. The window may fall out if it was well greased by the previous installer. Otherwise the window may be stuck to the o-ring and have to be carefully removed. The best way to remove is to put some IPA around the seal to help loosen it up and carefully try and twist side to side as to not break the o-ring. After removal, inspect the seal and replace it if needed. When reinstalling the new window, make sure to grease the o-rings and seal with some Fomblin® grease. This will keep them from sticking and also protect them from corrosion due to process gases. As always, just use enough grease. Do not have extra clumps of it as it can cause problems. Tighten the screws alternating cross wise, make sure they are snug but not overly tight, which could cause the glass to crack as the chamber cycles between atmosphere and vacuum. The side view port uses the same installation process. However this view port cannot see inside the chamber. So there is no reason to replace it unless it is becoming structurally weakened and causes a vacuum issue.

## **Chapter 7**

### **CONCLUSIONS**

Micro and nanophotonic fabrication is a quickly maturing field that builds on many of the advancements of VLSI and MEMS. Fabrication of nanophotonic devices requires highly specialized equipment to get the precision and quality required for good devices. Because of this specialized equipment, the training and skill set for nanophotonics researches is quite demanding. Learning this equipment is a slow process that takes time. While a new user can follow instructions to complete a process and produce a device, to really have a mastery of the equipment and be able to control results, a more thorough understanding is required.

#### **7.1 Last Words about this Thesis**

This thesis covered a large range of materials in a rather quick fashion. Because of the manner in which the items were covered, some items and processes may be more clear to some readers than others. This thesis is in no way an excuse for hands on training and experience but provides a basic background on the use of the equipment. It provides an additional reference to the manuals and experienced users to help answer questions about the equipment and further one's knowledge on its use. Sections 2.7 and 3.7 discuss the physics behind the systems to some degree. The physics of plasma processing in and of itself is quite a complex topic and has spawned many papers, theses, dissertations, and books. Maintenance of the equipment is important and though a major portion of it may lie on one user, it is the responsibility

of every user to help keep the equipment in working order. Proper use and preventative maintenance are key to keeping the equipment in good working order.

This thesis will be of the most use if it is reread and annotated. Each time it is read, new and important information may be gained. In addition to just reading it, using it in front of the equipment and taking personalized notes can be of great help in the learning process. At times, questions may arise that are not answered in this thesis. A more experienced user may be able to provide help or in some cases the company may have to be contacted for more help. Appendix C provides a listing of some common contacts at several companies for more assistance. A word of caution using other people as a resource, the best way to learn something is to do it yourself. If possible, try and figure out small problems yourself as you may determine a new way of approaching a problem and may learn something new in the process. Other users are a good resource but by spending time to learn the equipment, you not only enhance your knowledge about a piece of equipment but help to improve your technical skill set.

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Daniel,

I am writing a master's thesis in electrical engineering at the university of Delaware. I is entitled "Fabrication of Micro and nanophotonic devices". It covers the fabrication and testing of some devices. Part of the testing uses your IHR320 and I would like to include the following image from page 2 of the IHR320 manual. I have been trying to contact the correct person to get this permission. I was wondering if you could forward me to them as I need this permission as soon as possible so I can complete my thesis.



Thank you

--

Michael Roman



## APPENDIX B: MATLAB CODE

```
%File for plotting measured PECVD film thickness data and fitting
with a
%linear curve.
clear
clc
%Enter the required data for SiO2 (RCP 6)
duration=[.5,1,2.5,5]; %time in minutes
thickness_spec=[34,68,170.5,338]; %thickness in nm
thickness_ellips=[35,69.9,171.6,339.7];

%plot the SiO2 data
figure(1);
clf
plot(duration,thickness_spec,'o');
hold on;
%get fitting data for a linear line and plot it
[p,s]=polyfit(duration,thickness_spec,1);
output=polyval(p,[.5:.1:5]);
plot([.5:.1:5],output,'LineWidth',2);
%put the fit equation on the plot and set the axis
text(2.5,150,0,strcat('y=',num2str(p(1)),'x+',num2str(p(2))), 'FontSize
e',14);
title('SiO_2 Calibration','FontSize',16),xlabel('Deposition time
(min)','FontSize',16)
ylabel('Thickness (nm)','FontSize',16)
set(gca,'FontSize',16),legend('Experimental','Fitted
line','Location','NorthWest')

%Log plot of SiO2 data
figure(2);
clf
loglog(duration,thickness_spec,'o');
hold on;
loglog([.5:.1:5],output,'LineWidth',2);
title('SiO_2 Calibration','FontSize',16),xlabel('Deposition time
(min)','FontSize',16)
ylabel('Thickness (nm)','FontSize',16)
set(gca,'FontSize',16),legend('Experimental','Fitted
line','Location','NorthWest')
text(1.5,90,0,'Linear Fit Curve','FontSize',14)
text(1.5,70,0,strcat('y=',num2str(p(1)),'x+',num2str(p(2))), 'FontSize
',14);

%SiNx RCP5 data

duration=[.5,1,2.5,5]; %time in minutes
```

```

thickness_spec=[28,56.5,142,282]; %thickness in nm
thickness_ellips=[28.6,57.4,143.08,283.5];

%plot the SiNx data
figure(3);
clf
plot(duration,thickness_spec,'o');
hold on;
%get fitting data for a linear line and plot it
[p,s]=polyfit(duration,thickness_spec,1);
output=polyval(p,[.5:.1:5]);
plot([.5:.1:5],output,'LineWidth',2);
%put the fit equation on the plot and set the axis
text(2.5,100,0, strcat('y=', num2str(p(1)), 'x+', num2str(p(2))), 'FontSize',14);
title('SiNx Calibration', 'FontSize',16), xlabel('Deposition time (min)', 'FontSize',16)
ylabel('Thickness (nm)', 'FontSize',16)
set(gca, 'FontSize',16), legend('Experimental', 'Fitted line', 'Location', 'NorthWest')

%Log plot of SiNx data
figure(4);
clf
loglog(duration,thickness_spec,'o');
hold on;
loglog([.5:.1:5],output,'LineWidth',2);
title('SiNx Calibration', 'FontSize',16), xlabel('Deposition time (min)', 'FontSize',16)
ylabel('Thickness (nm)', 'FontSize',16)
set(gca, 'FontSize',16), legend('Experimental', 'Fitted line', 'Location', 'NorthWest')
text(1.5,75,0, 'Linear Fit Curve', 'FontSize',14)
text(1.5,55,0, strcat('y=', num2str(p(1)), 'x+', num2str(p(2))), 'FontSize',14);

```

## APPENDIX C: CONTACT INFORMATION

### **Samco® (RIE-200iP or PD-220N):**

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