Digital PECVD Machine Construction

ECE4007 Senior Design Project

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Executive Summary

The Microelectronics Research Center (MiRC) has commissioned the construction of a digital plasma-enhanced chemical vapor deposition (PECVD) machine that will be used for semiconductor fabrication. The plasma chamber for the new PECVD machine was removed from an old reactive-ion etching (RIE) machine in the Marcus building. A PLC will be used to control the components, while a touch-screen interface will be used as the human machine interface (HMI). The HMI interface allows users to select key recipes with great ease, thus cutting the need for costly and time consuming training of personnel. The gas recipes control the thin film deposition of each layer during the process. The Programmable Logic Controller (PLC) will control and automate the three fundamentals sub systems of the PECVD including RF power supply, mechanical pump, and mass flow regulators. There are three necessary set points for the PECVD to function: the chamber vacuum pressure, RF power, and gas flow rate. A mechanical pump reduces the plasma chamber pressure to a specific point, depending on the type of gas used. The gas is then ionized by a RF voltage, which can then be deposited on a substrate. The digital PECVD machine will be more efficient, easier to use, and more reliable than its analog predecessor. The cost of materials for construction of the PECVD machine will be $34,275.98. The finished machine will automate the fabrication process and allow for code modifications in the future. This machine will have a market value of approximately $250,000.

PECVD Machine Upgrade

1. Introduction

The Plasma group is requesting $35,000 funding from the Georgia Institute of Technology Microelectronics Research Center (MiRC) to construct and automate a Plasma-Enhanced Chemical Vapor Deposition (PECVD) machine. Jason Harrington, engineer for the MiRC, will be providing specifications and will be overseeing the project. The new machine will allow for digital control of the variables such as RF power, vacuum level, and gas flow rate using a programmable logic controller (PLC) and touch-screen interface.

1.1 Objective

The team was supplied with an old Plasma-Therm 700 series Reactive Ion Etching machine to recover the components necessary to assemble and automate a digital PECVD machine. The final product will be a stand-alone machine directed toward university micro and nanotechnology research facilities, as well as semiconductor manufacture industries. The design will utilize four different types of gases and an external mounted touch screen monitor for the user interface. The PLC will be used to control the three fundamental parameters of a PECVD machine including vacuum pressure, gas flow rate, and RF power. The program to run the PLC will be coded in ladder programming language using the RSLogix5000 software from Rockwell Automation. Ladder logic language is a means of writing program in circuit blocks that can then be converted into machine code by the PLC microprocessor.

A human machine interface (HMI) consists of hardware and software will allow for user interaction with the PLC. The MiRC staff will supply recipes for semiconductor fabrication that will be loaded into the HMI. Recipes are parameters of flow rate, RF power, and vacuum pressure having the correct composition to ignite plasma from a gas. A GUI will be created using the FactoryTalk View software, which will display pre-determined recipes, and users' recipes. For the given time constraint, the completed product will be able to ignite a single gas, N_2, for a pre-determined recipe.

1.2 Motivation

The Georgia Institute of Technology MiRC has requested the group to assemble and automate the machine. There are PECVD machines currently available on the market; however, new PEVCD machine cost in the $250,000 range. With a cost of $35,000, the recovered chamber, and the four flow controllers together with the Allen-Bradley CompactLogix L35E PLC the group will construct a functional machine. The CompactLogix L35E shown in Figure 1.2 utilizes modular cards for it input and output connections thus allowing for future expansion [1].

Figure 1.2. Allen-Bradley CompactLogix L35E PLC.

Using modular components allows for simpler repair as the user can replace any defective components unlike the whole board in the old system. The programs for the PLC are typically stored in battery-backed memory, allowing the system to function immediately after replacement of defective parts. Users can also keep a backup of the programs on hard drives or any storage devices and upload to the PLC via an Ethernet connection. The CompactLogix L35E microprocessor converts ladder logic code to machine code, which can operate at faster speeds [2]. The mounted touch screen monitor provides a larger color display and simpler user interface when compared to the old onboard control and screen of the Plasma-Therm 700.

1.3 Background

Plasma-Enhanced Chemical Vapor Deposition machines are required as semiconductor and electronic component feature sizes push into and past nanometer scale dimensions. The need for close tolerances in substrate manufacturing is most evident in the processing of semiconductor lasers, that require very thin layers when forming a p-n junction [3]. Additional methods of chemical vapor deposition include atmospheric pressure chemical vapor deposition (APCVD) and low-pressure chemical vapor deposition (LPCVD); however, they are limited by temperature and film thickness. PECVD uses RF power to transfer energy into the reacting gas, allowing the substrate to remain at a lower temperature than LPCVD and APCVD; also plasma-enhanced film can achieve thickness up to 5 µm without cracking [4]. Plasma-Therm LLC currently manufactures the 790 series of reactive ion etchers (RIE) which is similar to a PECVD machine except RIE used plasma to etch away the substrate instead of deposit the plasma film onto the substrate. This machine can be retooled to be either RIE or PECVD and generally can process multiple wafers simultaneously [5].

There are three basic components of a PECVD machine including RF power supply, flow regulators, and a roughing pump.

RF power supply

The RF power supply system consists of the RF power generator and an RF power matching network. System matching is important due to the reduction of power lost by reflection in the transmission lines. The matching network monitors the reflections and adjusting the matching impedance to insure the power to the load is maximized and consistent. There are manual matching network and auto matching network manufacture by several companies such as Advanced Energy, Comdel, and Drytek price range from $3,000 to as much as $15,000 [6]. An RF power of 13.5 MHz is often used in industry to create high-density plasma; however, varying the RF power allow for different plasma composition and duration of ignition.

Flow regulator

Flow regulator system controls the rate of gas being input into the chamber. Flow regulators have a set point value specify by the user which govern the output rate. Mass flow regulator measures the flow directly without diversion and can switch between different gases specify by the user. The control circuit compares the flow rate with the set point rate. Deviations from the set point are corrected by compensating valve adjustments maintaining the desired flow rate [7]. There are several companies which market these controllers including Bronkhorst, Litre Meter, and Aalborg. The prices for these controllers range from $650 to $1,500.

Roughing pump

Roughing pumps are used to evacuate a vacuum system. Roughing pump such as the HYVAC 150 can bring the system down to as low as $5x10^{-4}$torr and cost $500. Turbo pump can further invokes to bring the system to as low as 10^{-9}torr. TMG is one of many companies that specialize in turbo pump. The appropriate vacuum pressure depends on the recipes the user selects in a PECVD machine.

2. Project Description and Goals

The purpose of this project is to convert an outdated plasma-therm RIE machine to a digital PECVD machine. This will be accomplished by replacing the outdated knobs and switches with a PLC based controls system and HMI. The device will have the following properties:

PLC:

- Small enough to be enclosed within chassis
- Control power, vacuum, and gas flow sub-systems
- Intuitive modification with Ladder logic programming

Functionality:

- Provide standard recipes for users (created by MiRC staff)
- Allow users to create, modify, and execute deposition processes
- Display current deposition recipe status
- Allow Touch-screen interface
- Incorporate pressure sensor for safety precaution
- Ignite plasma with RF power supply
- Ability to control mixing of gases with mass flow controllers
- Worth $250,000 upon completion
- Cost of parts $35,000.00

3. Technical Specifications

The proposed digitally automated PECVD machine is composed of the following main components:

- Plasma chamber made for two inch wafers
- Four mass flow controllers for different gases
- ATX tuner for RF matching network
- RF power supply
- PLC
- HMI
- Custom built frame to hold all of these components

Along with these main components, there are two sensors on the PECVD machine that communicate with the PLC: a chamber sensor for reading chamber pressure, and a pressure sensor for measuring the roughing pump base pressure. The PECVD machine can utilize four different gases: Ar, O_2, CHF_3, and C_4F_8. The flow rate of each gas is controlled by a Brooks Model 5850E Mass Flow Controller, as seen in Table 3.1. The mass flow controller (MFC) is regulated by the PLC, which is able to send and receive data from the MFC. This ensures that the gas flow rate is regulated and consistent.

Table 3.1. Physical Specifications for Brooks Model 5850E Mass Flow Controller [8]

Flow Ranges	0 to 3 sccm
Performance	Accuracy ±1% of set mark
Repeatability	0.25% of predetermined rate
Command Input Voltage	0 to 5 Vdc
Output Signals	0 to 5 Vdc
Max Operating Pressure	103 bar

The mass flow controller (MFC) is regulated by the PLC, which is able to send and receive data from the MFC. This ensures that the gas flow rate is regulated and consistent.

The RF power supply is controlled by an ATX tuner, which is a "RF matching network designed to convert the complex impedance of a plasma at 13.56 MHz to 50 ohms resistive" [9]. The physical specifications for this device are in Table 3.2.

Table 3.2. Specifications for ATX-600 Tuner

Power Capacity	600 W, 1250 W, 2500 W
Frequency	13.56 MHz nominal
Impedance Range	5 ohms to 2000 ohms
RF Input Connector	600 W: Type N, 1250/2500 W: Type: HN
RF Output Connect	Universal output kit provided
Input Power	115 V ac ±10% or 220 V ac ±10%

This matching network helps maximize power transfer while restricting reflected powered. The ATX tuner specified in Table 3.3 has an automatic mode that allows the device to automatically tune the RF power supply, ensuring that stabilization occurs and a plasmid is achieved. A "Plasma Present" indicator light gives the user a visual display that the device is operating correctly. The "Plasma Present" indictor light is located midway on the panel and to the right of the "Tuned" indicator as shown in Figure 3.1.

Table 3.3. Physical Specifications for RFX-600 Power Supply [10]

Power Output	600 W max into a 50 ohm load
Frequency	13.56 MHz ± 0.005%
Output Impedance	50 ohms
Input Power	115 V ac ±10% or 230 V ac ±10% single phase, 50/60 Hz

The "Plasma Present" indictor light is located midway on the panel and to the right of the "Tuned" indicator. As stated above, the ATX tuner controls the RF power supply. Its physical specifications are listed below in Table 3.3.

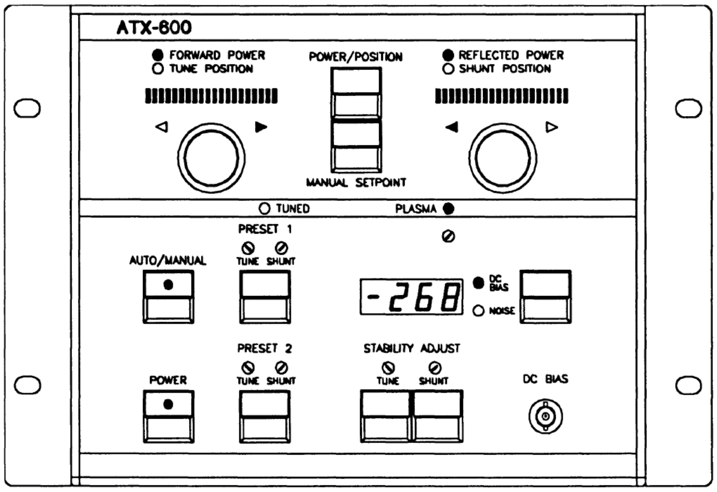


Figure 3.1. Front panel display of ATX-600 tuner [9].

Please note that the power output of the RF power supply matches with the power input of the ATX tuner; the RF power supply output impedance matches with the input impedance of the ATX tuner; and the frequency of both devices are identical. A circuit level representation of the RF power supply can be seen below in Figure 3.2. The plasma chamber is represented in Figure 3.2 by the dome shaped device on the far right. The RF power supply working in conjunction with the ATX tuner transforms a gas into the plasma.

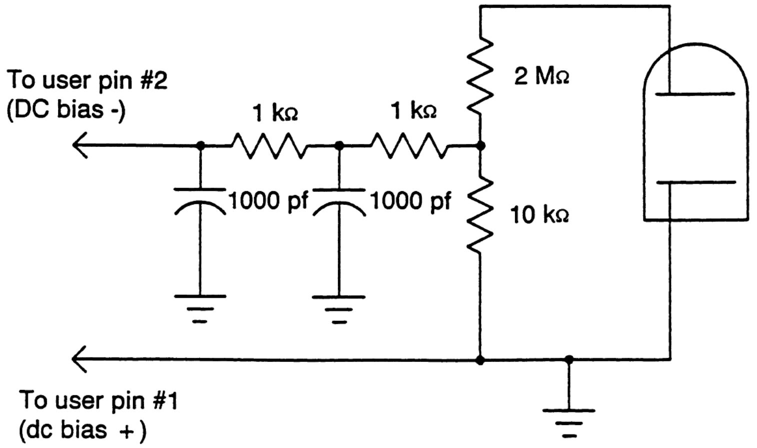


Figure 3.2. Circuit representation of the RF power supply connected to a plasma chamber [10].

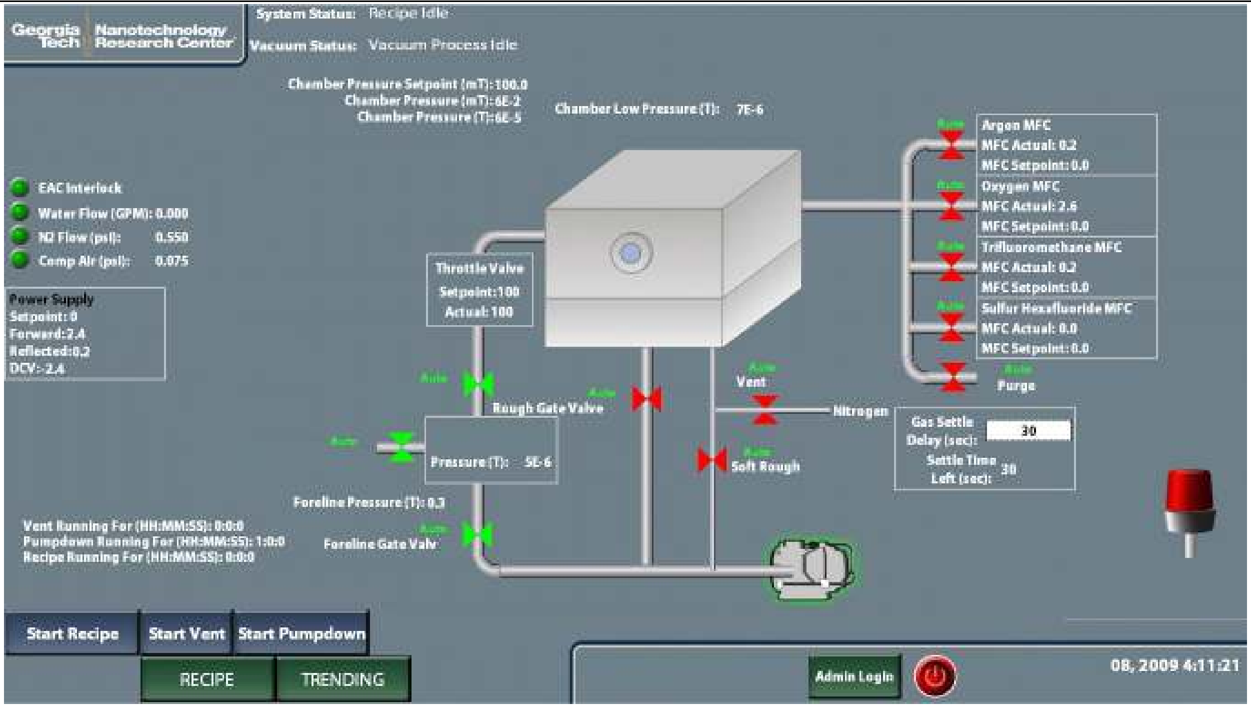
The PLC will interface with the various sensors, MFCs, RF power network, and the HMI. The PLC being used for this project is a CompactLogix 1769-L35E, and its specifications are listed in Table 3.4 [11].

Table 3.4. System Specifications for CompactLogix 1769-L35E

Communication Ports	RS-232 – 19200Kbytes/sec EtherNet/IP – 10/100 Mbytes/sec
User Memory	1.5 Mbytes
Nonvolatile Memory	1784-CF64 CompactFlash
Max I/O Modules	30 I/O Modules
Max I/O Banks	3 I/O banks
Power Supply Distance Rating	4 (logic must be 4 slots from power supply)
Operating Temperature	0 - 60°C
Storage Temperature	-40° - 85°C
Vibration	Operating: 5G @ 10-500 Hz

This project will utilize both communication ports, RS-232 and EtherNet, and five of the I/O modules. Having additional unused I/O modules allows future expansion, if needed.

The HMI for this project is the RSLogix 5000 from Rockwell Automation. It features "easy-to-use, IEC61131-3 compliant interface, symbolic programming with structures and arrays and a comprehensive instruction set that serves many types of applications" [12]. The HMI software will be installed on an ASUS Eee touch screen PC. The graphical user interface (GUI) will resemble the screen shot in Figure 3.3.



System Status: Recipe Idle
Vacuum Status: Vacuum Process Idle
Chamber Pressure Setpoint (mT):100.0
Chamber Pressure (mT):6E-2
Chamber Pressure (T):6E-5
Chamber Low Pressure (T): 7E-6
EAC Interlock
Water Flow (GPM): 0.000
N2 Flow (psi): 0.550
Comp Air (psi): 0.075

Power Supply
Setpoint: 0
Forward:2.4
Reflected:0.2
DCV:-2.4

Throttle Valve
Setpoint:100
Actual: 100

Pressure (T): 5E-6
Foreline Pressure (T): 0.3

Vent Running For (HH:MM:SS): 0:0:0
Pumpdown Running For (HH:MM:SS): 1:0:0
Recipe Running For (HH:MM:SS): 0:0:0

Argon MFC
MFC Actual: 0.2
MFC Setpoint: 0.0

Oxygen MFC
MFC Actual: 2.6
MFC Setpoint: 0.0

Trifluoromethane MFC
MFC Actual: 0.2
MFC Setpoint: 0.0

Sulfur Hexafluoride MFC
MFC Actual: 0.0
MFC Setpoint: 0.0

Gas Settle Delay (sec): 30
Settle Time Left (sec): 30

08, 2009 4:11:21

Figure 3.3. RSLogix 5000 HMI software controlling a PECVD machine [10].

The user will be able to select pre-made recipes, or programmed states, that the PECVD machine performs. Please note the "Recipe" button at the lower left of the screen.

All of these components will be installed on a custom designed Gator Jaw Anodized Aluminum 6063 alloy-tubing frame, see Figure 3.4.

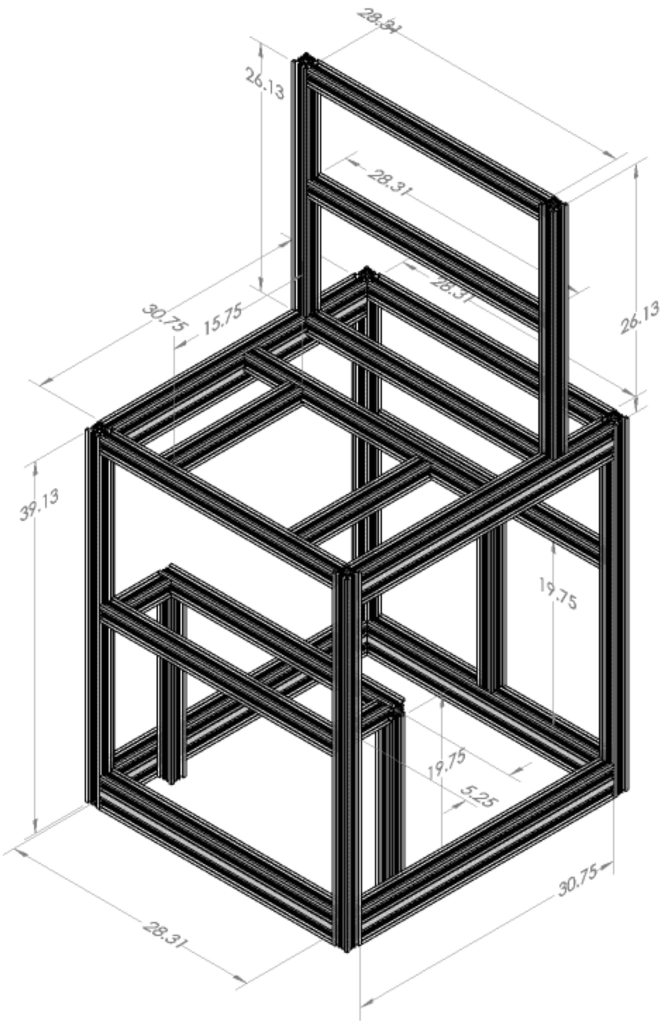


Figure 3.4. Schematic of the frame to house all of the PECVD equipments [11].

This AutoCAD drawling lists all of the dimensions for the various rails needed for construction. All of the wiring and PLC modules will be mounted on Panduit DIN rail inside the Gator frame, see Figure 3.5 for an example of this type of mount.

Figure 3.5. Panduit DIN rail example.

Panduit DIN rail makes wiring clean, efficient, and easily expandable. Please note the large amount of wires in relation to the small amount of space utilized.

4. Design Approach and Details

4.1 Design Approach

Physical Components

The PECVD will be built as a single entity inside a chassis that will be the machine's stand. The chassis is a Gator Jaw Anodized Aluminum 6063 alloy-tubing stand shown in Figure 4.1, it will contain all of the hardware. The stand has been fabricated to meet the needs of housing each individual component. As the components are purchased and installed, the size of the compartments can be adjusted. The HMI will be mounted onto the external of the stand where it will be visible at all times. The display will stay on and monitor the process as each step is activated within the PLC. The plasma chamber was purchased pre-owned and requires corrosion removal and minor refurbishing.

Figure 4.1. Frame used to build the PECVD machine.

Control System

The Allen-Bradley CompactLogix 1769- L35E was chosen as the PLC and it will process all signals through input and output cards. These cards will handle analog and digital inputs and outputs. A back plate will house the PLC, terminal blocks, and all interface connections. In Figure 4.2, the completed back plate, with the approximate location of the components that will be added, is shown. The plate will be secured to the stand and all signals from each individual component of the PECVD will be wired to the appropriate terminal blocks. A PLC programming language called “ladder logic” will be used to control the PLC and process the information [1]. This will allow autonomous control of the throttle valves as well as the mechanical pump to maintain a list of user defined set points. The top-down structure of ladder logic programming will insure the next process does not start until the set point of the previous task is achieved. The PLC will make it possible for the PECVD to reach the set points and maintain all of the values within a given variance. This ensures that the correct pressures, gas ratio, and power are maintained throughout the duration of the cycle. A touch screen HMI will allow users to select and start the process as well as select the combination of gases to use. There will be one preset recipe and an option to input others on demand.

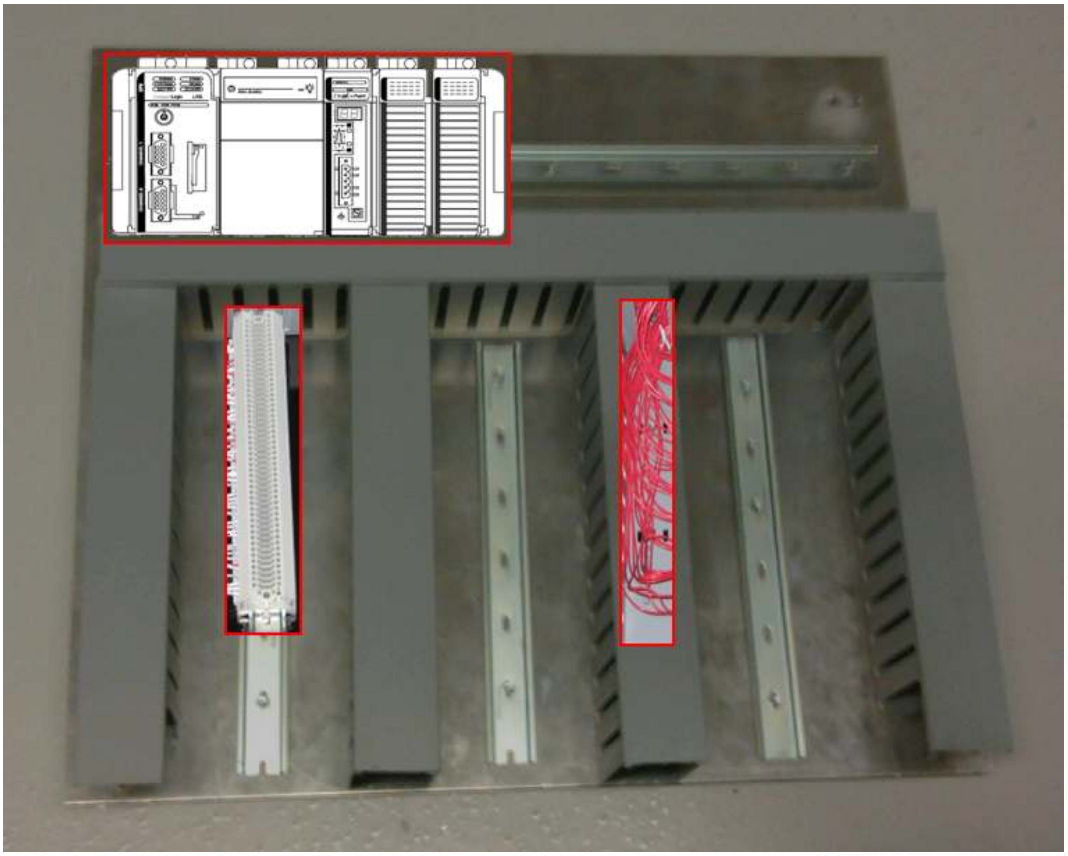


Figure 4.2. Back plate used to mount PLC and terminal boards.

Plasma Generation & Film Deposition

There will be four gases available to generate the plasma: O_2, Ar, CHF_3 and C_4F_8. A predefined recipe, given by the MiRC staff, will determine how much of each gas is required for the process. MFCs will inject the gas into the chamber through throttling valves, that will manage gas ratios in the chamber. These controllers interface with the PLC to keep track of the amount of gas which has been injected. An RF Power supply and a matching network are required to generate a high enough current to ignite and maintain the plasma. The Advanced Turner ADX Generator was chosen because it contains the Power Supply as well as the Matching Network with the controller. Generation of plasma is only possible when the gas has been excited to a level similar to 600 watts of power passing through a 50 ohm load.

A mechanical roughing pump will bring the pressure in the chamber close to 0 Torr. Once the pressure is achieved, gases will be ejected into the chamber. The PLC will stabilize the gas ratio. Next, the RF Power will be applied to generate a cloud of plasma depositing a layer onto the silicon wafer. Based on the desired film a defined amount of time will be required. The gases are then removed from the chamber and atmospheric pressure is restored. The process is shown in Figure 4.3.

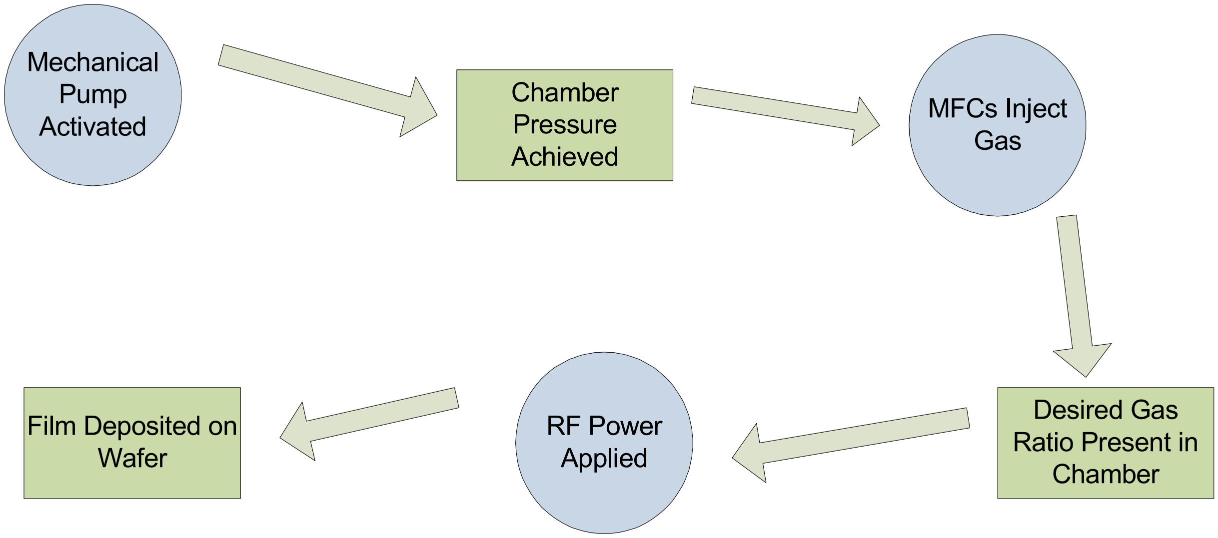


Figure 4.3. Process Flow for PECVD

4.2 Codes and Standards

- The Allen-Bradley 1769-L35E CompactLogix has two communication ports:
  - RS-232 and a RJ-45.
- The RJ-45 will be utilized and uses the 10BaseT standard with Cat5e as the cable type [1].
- The international standard for PLC programming language is IEC 1131 [13].
- The code for electrical wiring in the industrial environment is defined in Article 670 of the National Electrical Code [14].
- All other components are hardware and do not have associated standards.

4.3 Constraints, Alternatives and Tradeoffs

Customer, Jason Harrington of the Georgia Tech MiRC, has defined most of the parameters of the project in explicit detail. This leaves minimal room for design variation. However; rather than simply using a single mechanical pump, a turbo could be implemented. This would ensure that the pressure inside the pump is as low as possible. The turbo pump would raise the cost of production and require the mechanical pump to have two stages, a hard rough followed by a soft rough. It is believed that the plasma can be generated and maintained at the pressure level the single mechanical roughing pump will obtain. Also a new chamber would ensure all seals are vacuum tight. The salvaged chamber has corrosion and minor abrasions. Rather than spending the additional money to purchase a new chamber, the old chamber will be cleaned and polished.

5. Schedule, Tasks, and Milestones

The team is composed of two sub-sections: software and hardware. The software team is responsible for the programming of the PLC and HMI, while the hardware team edits the wiring schematics and installs electrical components. Table 5.1 shows the task, resource names and timeline of each major task. The start date of the project is August 15th and the end date is November 28th. These tasks may also be seen in the Gantt chart located in appendix A. The removal of existing controls systems was done promptly so that construction of the new system will not be hindered. Much of the programming and testing will occur once the system has been entirely assembled.

Table 5.1. Scheduled Tasks

Task Name	**Resource Names**	**Start Date**	**End Date**
Familiarization w/ existing system	All	15-Aug	29-Aug
Identification of existing component and wiring	All	15-Aug	19-Sep
Order replacement/ new parts for system integration	Jason Harrington	22-Aug	19-Sep
Removal of existing controls system	Quan, Zlatan	15-Aug	22-Aug
Installation of new control system	Tim, Zlatan	26-Sep	3-Oct
System Documentation	Will, David	29-Aug	28-Nov
System Testing	All	24-Oct	28-Nov
Programming of PLC and HMI	Quan, Tim	12-Sep	28-Nov
Corrosion Removal	Will, Tim, Zlatan	5-Sep	12-Sep

6. Project Demonstration

The goal of this project is to create a functional PECVD machine that is fully controlled by a user at a touch screen HMI. The HMI, in conjunction with the PLC, will have the ability to set gas flow rates, roughing pump levels, and RF power levels. The HMI will also transmit data back to the user through sensors installed throughout the machine. In addition to this, the user will be able to program recipes in the HMI that will be stored in the PLC. These recipes will allow the user to preselect modes so that every variable does not need to be adjusted each time the PECVD is used.

The automated PECVD machine will be demonstrated on the Georgia Tech campus at the new Marcus Nanotechnology Building's clean room. The PECVD machine will have the ability to use up to four different gases; however, at the request of MiRC only nitrogen will be used to generate a plasma during demonstration, due to its non explosive properties. Viewers should see a bright purple emission when the device reaches the correct operating settings. During operation, the viewers will be able to see the operation of the HMI and its various inputs and feedback. Finally, a recipe will be programmed into the device and then recalled to demonstrate its functionality.

7. Marketing and Cost Analysis

7.1 Marketing Analysis

PECVD units are custom tailored to each client's needs and hence reflect the requirements of the particular user. The types of gases used to generate the transport plasma, the copious organic gases employed in the chamber, and RF power levels are all bespoke to the customers need. The primary target clientele are research institutions along with semiconductor and microelectronic manufacturing companies. More generally, the client spectrum consists of those organizations wishing to deposit substrate layers with a large degree of uniformity and high rate of speed. The ability to deposit controlled layers of poly silicon makes PECVD an outstanding tool for companies working with solar cells and silicon based renewable energy.

This PECVD model features a touch-screen HMI, ideal for environments requiring ease of use and a small operational learning curve. The HMI interface allows users to select key recipes with great ease, thus cutting the need for costly and time consuming training of personnel. Company technicians can readily select a recipe from our pre programmed menus, effectively controlling the deposited substrate composition and thickness with turnkey alacrity. The user centric approach of our HMI display endows this product with a multitude of advantages over its analog controlled counterparts often found in today's research and manufacturing institutions.

Apart from uniformity, user interaction, and substrate choice versatility, this PECVD employs RF generated plasma to facilitate reaction between user specified gases within the chamber. RF generated plasma dictates relatively low operational temperatures, particularly on the order of 300^{o}C or more less that regular Chemical Vapor Deposition instruments. This operating temperature range is particularly attractive to companies working with Silicon substrate formation technology. The ability to abstract away the function of heating elements makes this system highly amicable to the production of photonic crystal waveguides [15]. At the higher temperatures encountered in CVD, many process driven defects can form in the deposited layers, thus lowering yield and consequently process efficiency.

When properly equipped with a magnetic field module, further stimulation of the plasma chamber at an electron cyclotron resonance enables several prospects in ion-implantation and varied doping structures. This feature is of interest to companies working with GaAs, GaN, and other III-V optoelectronic or high frequency microwave materials. The ability to locally modulate temperature driven defects further opens the possibility of depositing novel material thin films for energy research applications.

7.2 Cost Analysis

A comprehensive cost analysis of the PECVD system includes not only parts and labor, but also associated design and testing cost. After carefully itemized review of required materials, the total part cost was determined to be $34,275.98. Considering an annual salary for an ECE graduate to be $77,700.00, a total of 400 man hours, 5 design and implementation team members, the total labor cost comes to $104,711.54. This cost consists of labor, design, reports, meetings, lectures, and final product testing and standards assessment. Unadjusted for inflation or rise in manufacturer costs, the total PECVD cost reaches $138,987.52. At this level, it is anticipated that a sizable margin can be obtained. Table 7.1 shows that nearly 50% of the total cost is associated with the plasma chamber, power supply, mass flow controller, and throttle valve.

Table 7.1. Itemized Cost

Item	**Qty**	**Cost/unit**	**Inflation**	**Total**
Salvaged Plasma Chamber	1	$2,500.00	1.00	$2,500.00
10 Amp-3 pole circuit breaker	1	$122.00	1.12	$163.97
contactor for pump/chiller	2	$170.00	1.12	$456.96
overload for pump/chiller	2	$54.20	1.12	$145.69
enclosure for contactors	1	$388.30	1.12	$521.88
pushbuttons for contactor box - 3 position	1	$37.10	1.12	$49.86
pushbuttons for contactor box - 2 position	1	$37.10	1.12	$49.86
Eee PC Touch screen	1	$500.00	1.12	$672.00
Touch screen Swing Arm	1	$100.00	1.12	$134.40
AutoCAD 2010 Software	1	$3,995.00	1.12	$5,369.28
RF Power Supply + Warranty	1	$4,950.00	1.12	$6,652.80
Rockwell Student Software Package	1	$100.00	1.12	$134.40
end cap right for compactlogix system	1	$31	1.12	$41.66
relay - spst 24vdc coil	13	$16.40	1.12	$286.54
terminal block	120	$0.98	1.12	$158.05
terminal block jumpers	3	$3.78	1.12	$15.24
terminal block anchor	5	$1.77	1.12	$11.89
+/-15VDC Supply	1	$136.86	1.12	$183.94
24vdc power supply	1	$119.09	1.12	$160.06
single pole circuit breaker	1	$33.20	1.12	$44.62
3 pole circuit breaker	1	$122.00	1.12	$163.97
System Frame + Parts	1	$1,600.00	1.12	$2,150.40
120V power supply	1	$428.00	1.12	$575.23
Pressure sensors	1	$37.10	1.12	$49.86
Vacuum Tubing Parts	1	$506.70	1.12	$681.00
Mass Flow Controller	4	$1,500.00	1.12	$8,064.00
Throttle Valve	1	3,600.00	1.12	$4,838.40
				$34,275.98

8. Summary

The Design Team has meets weekly with project manager Jason Herrington. He provided the specifications that are expected from the PEVCD. The program that is required to produce the code for the PLC has been installed. Example software code has been received and is being used as an aid. Jason has ordered most of the parts that will be needed to complete the fabrication. From the list of parts and their technical data, all of the inputs and outputs that the PLC will monitor and control have been determined. This also includes producing AutoCad drawings that will act as a wiring diagram. With the parts that have arrived, the stand has been assembled the back plate is installed. The top-hat rails, which will house the PLC and the terminal boards, and the wire duct is installed on the back plate. Also, all of the corrosion has been scrubbed from the chamber and the components that will not be utilized were removed.

9. References

[1] *Allen-Bradley 1769-L35E CompactLogix System User Manual*, Rockwell Automation, Milwaukee, WI, 2003.

[2] D. Du, X. Xu, and K. Yamazaki, “A Study on the Generation of Silicon-based Hardware Plc by Means of the Direct Conversion of the Ladder Diagram to Circuit Design Language,” *International Journal of Advanced Manufacturing Technology*, vol. 49, pp. 615-626, Jul. 2010.

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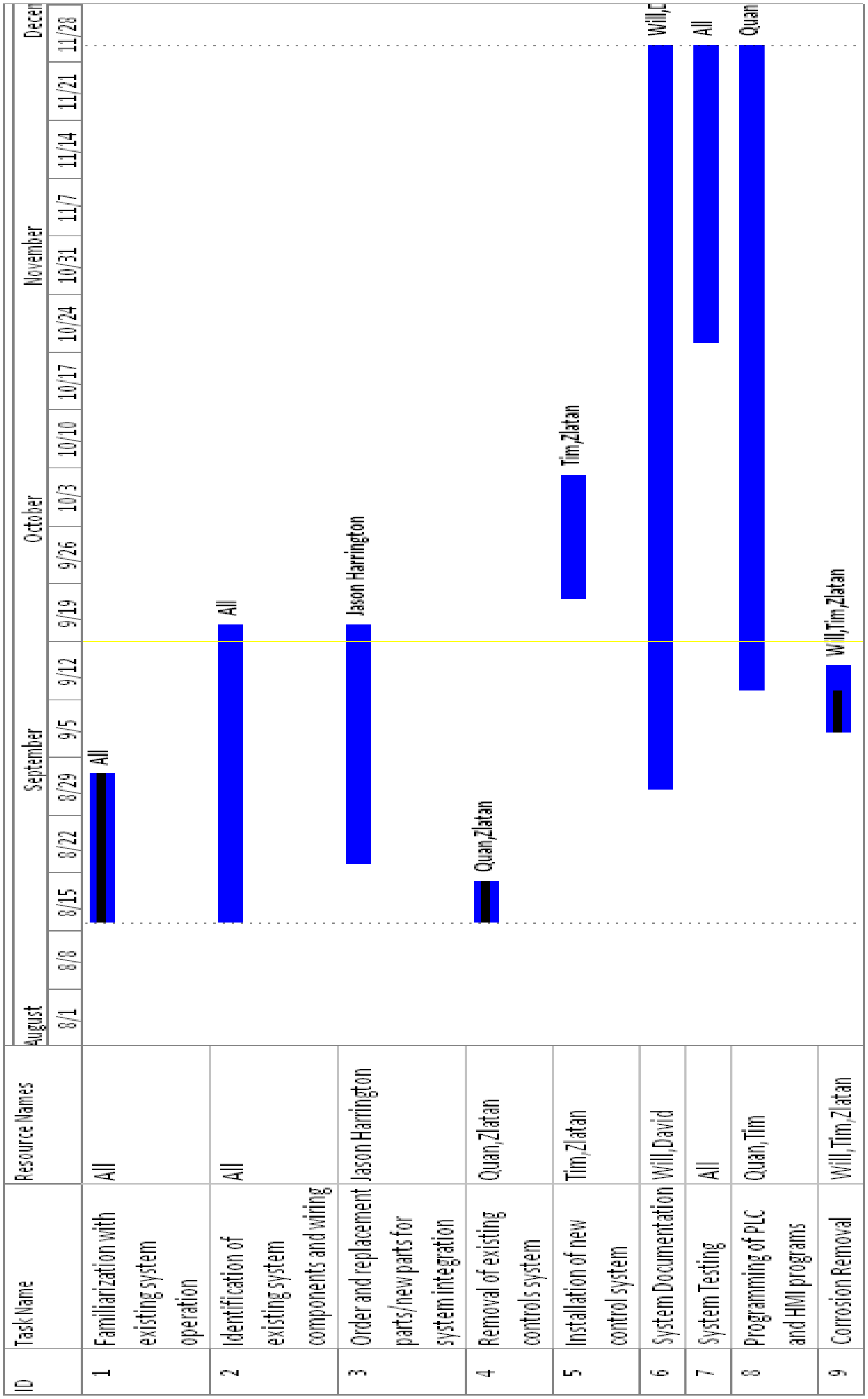
Appendix A – Project Gantt Chart



ID	Task Name	Resource Names
1	Familiarization with existing system operation	All
2	Identification of existing system components and wiring	All
3	Order and replacement parts/new parts for system integration	Jason Harrington
4	Removal of existing controls system	Quan,Zlatan
5	Installation of new control system	Tim,Zlatan
6	System Documentation	Will,David
7	System Testing	All
8	Programming of PLC and HMI programs	Quan,Tim
9	Corrosion Removal	Will,Tim,Zlatan