Plasma-Enhanced Chemical Vapor Deposition

Steven Glenn
July 8, 2009
Thin Films Lab 4

ABSTRACT

The objective of this lab was to explore lab and the Applied Materials P5000 from a different point of view. A more hands on approach than usual was used help greater understanding. The P5000 was used to deposit 10000Å at 96 seconds. The tool provided 400 sccm of TEOS and 285 sccm of O_2. The resulting thickness was an average of 8753Å at a standard deviation of 183.71Å .

Keywords: PECVD, CVD, AMAT P5000, TEOS

INTRODUCTION

The Semiconductor Industry like any other industry has to find a way to solve problems and do it quickly. For a long time, Microelectronic Engineers have been able to use the stability that naturally occurs such as silicon dioxide to insulate the gate from the wafer. Silicon cannot be found in nature without a layer of natural silicon dioxide. This native layer while only angstroms thin was studied and grown in a plethora of devices decades ago. While the semiconductor industry no longer purely uses silicon dioxide as the sole gate dielectric, it does serve well as a blocking or sacrificial layer. In some cases, silicon dioxide is needed to be placed on top of the gate to provide sidewalls for the gate, to prevent loss of electrons into the gate dielectric. The problem arises that to grow oxide requires an oxidation furnace which gets so hot; it destroys the active regions on the wafer. Instead, an alternative was found – Plasma-Enhanced Chemical Vapor Deposition TEOS Oxidation; in other words, silicon dioxide growth at low temperatures.

THEORY

Chemical Vapor Deposition (CVD) adds a gas to the deposition chamber that will react and form the desired film on the surface of the substrate. Much like Reactive PVD sputtering, either a single gas or multiple gases are introduced into the chamber to decompose after entering the plasma into atomic elements which will react on the substrate to produce a film. The difference between Reactive PVD and CVD is that Reactive PVD consists of one element which is molecular in nature and then broken to its atomic parts after entering the plasma, like N_2 or O_2 while CVD consists of a multi-element gas or gases which are decomposed into smaller atomic parts and react at the wafer's surface to form multi-element films.[1]

Plasma-Enhanced Chemical Vapor Deposition (PECVD) is a radio-frequency (RF) induced glow discharge that transfers energy to reactant gases. The energy transfer causes reactant gases to lose 1 electron or more and become ionized. This ionization along with the potential across the plasma allows the ions to travel toward the cathode. The wafer is placed below the plasma so that reactive or unstable ions and atomic elements can hit the wafer and react. The great thing about PECVD system is that it does not need high temperatures to deposit a CVD film due to the energy needed to break up and form compound films is provided by the plasma and headed wafer chuck respectively.[1]

Applied Materials P5000 Mark II is a cluster tool with a load lock system and 4 process chambers. Chamber A is for TEOS depositions, Chamber B is for Plasma Nitride depositions, Chamber C is for Oxide and Nitride etching and Chamber D is not active. The P5000 is pumped down using a turbo pump connected to a mechanical pump. The computer software used to power the tool is proprietary software that Applied Materials uses on all its tools. While there may be a few modifications to the code, the layout is usually the same from tool to tool. It may not be a user friendly user interface but it is robust. All recipes and modifications to the run must be done through the computer screen using a self-digitizing pen. Once the recipe is set, the Run button is pressed on the physical tool. The load lock shuts and the wafers are loaded one by one to be processed. A gauge connected to Chamber 1 is the Capacitance Manometer which uses pressure against a flexible, conductive membrane to determine the capacitance which is related to pressure in the chamber based on the distance the membrane is from the stationary plate. After each run, the tool did a dry etch to the sidewalls to minimize particles.[2]

Tetraethyl Orthosilicate (TEOS) is a source of silicon dioxide that once broken up in a plasma into its atomic components, it will react with silicon to form a stable Silicon Dioxide layer with added byproducts. This is favorable in plasma systems like the PECVD because sometimes a layer of oxide is needed after many thermal-sensitive processes such as metal, doped or buried layers have already been performed to a device. There are a lot of byproducts created from TEOS as a result of its complex chemical structure seen in Figure 1. With every one silicon dioxide molecule, there is one carbon dioxide, 5 methane molecules, and an unstable carbon pair. What sticks to the wafer is the SiO_2 molecule, although the purity is reduced due to the large amount of byproducts. While purity in oxide is not a big concern, the impurities trapped in the oxide could be a problem.[1]

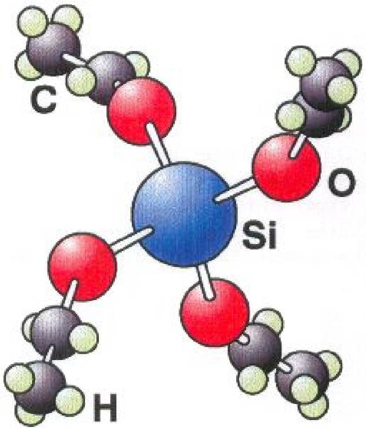

Figure 1: Tetraethyl Orthosilicate Chemical Structure [3]

$$C_8H_{20}O_4Si \rightarrow SiO_2 + CO_2 + 5CH_4 + C_2$$

Equation 1: TEOS Disproportionation into Silicon Dioxide and byproducts [1]

PROCEDURE

The following **Applied Materials (AMAT) P5000 PECVD** preparation is from the manual with few modifications to match the process performed [2]:

Initial State Check

- Verify that the chamber that you need to use is up, by checking the sign on the front of the machine.
- Make sure that the P5000 is on and in the standby state. It is usually in this state if the computer is on. If the computer is off, check with a staff member.
- Verify that the nitrogen valve for the P-5000#1 is on.
- Make sure that the water level in the bucket on top of the chiller is close to the line, if not add water with the orange fill knob.
- Make sure that the chiller is on. If not, press Power Start on the chiller.
- On the computer clear any alarm lines. Go to System, Fault Screen and select Clear Alarm Lines on the top right.
- Make sure that the heat exchanger is on. Go to System, Monitor Facilities, Heat Exchanger Frame, HX1 and select On.
- Press the blue button on the hot box with a pen if the light is blinking. The hot box is located on the back of P-5000. After pressing the blue button, blinking light should go off. This will ensure the hot box does not overheat.

Home the robot.

- Go to Wafer and Control Handler.
- Select Abort Load Chamber operation
- Select Abort current loader operation
- Select Abort automatic sequencing
- Select Home all Robot Axes.
- You can check if this step is working by going to Wafer and Monitor Handler. If this step is working, numbers on each axis should be changing. After this step is done, there will be a message on the top telling you this step is done.
- Make sure the Load Lock Chamber breaker is on. Also make sure the pump breaker is on for the chamber that you will use.

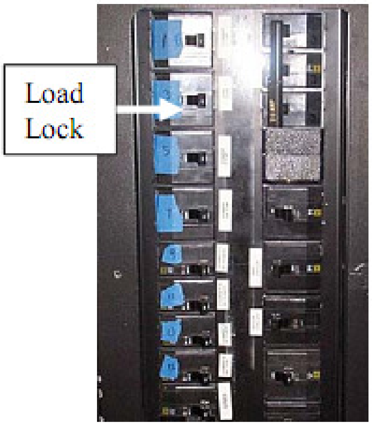

Figure 1: Load Lock Breaker for AMAT P5000[2]

- Make sure the load lock chamber is pumped down. Go to Service, Vacuum Service, Load Lock Chamber. Select Pump On. Go back to Service, Vacuum Service, Load Chamber Idle, and select Start Load Chamber Pump Down.

Procedure for TEOS Depositions (Chamber A)

- After verifying all items in the Initial State Check, pump down Chamber A. Go to Service, Vacuum Service, click on Offline for Maintenance for Chamber A and then select Start Chamber pump down.
- On the back of the tool, make sure that the hot box temperature is 55°C.
- Make sure that the TEOS temperature is 38°C. Go to System, Monitor Remote Panel and Chamber A.
- The standard chamber temperature is 390°C. Do not energize lamps before chamber is pumped down! Go to Chamber A (on top of the screen), Chamber Service and view the lamps temperature. The 1st number is the set point and the 2nd number is readout.
- Change the lamp temperature to 390°C, and start the chamber heating.
- Wait about an hour for the chamber lamps to heat up and stabilize. Now go to Service, Vacuum Service, under Chamber A click on Offline for Maintenance and then select Put Online for Process.
- Wait for all temperatures (hot box, TEOS, chamber) to reach the proper settings before you perform your run. Make sure **Recipe: A6-1M TEOS –LS** is loaded with the following conditions:
    - 96-second Deposition
    - RF Power: 290W
    - Wafers are 366°C
    - 285 sccm Oxygen
    - 400 sccm TEOS
    - 10-second Descum

- Make sure that the system is in Automatic Mode. Go to System, Control System, click Manual and select Automatic.
- Load the wafers with the flats up in the cassette. Make sure not to cross-slot the wafers and make sure that the cassette is well seated. If you are using carrier wafers, only process one at a time.
- Select the recipe to be run. Go to System, Enter Wafer Lot Name, Click the blank next to Cassette A or Cassette B, select New Lot Name, click the blue square, enter in the lot name and select Enter. Select the blank blue square and then select the sequence name for the lot.
- Start the run with the Run button on the front of the tool.
- To quickly delete slots with no wafers go to Wafer, Monitor Wafer and select Start Delete Range and Finish Delete Range
- Press Unload on the front of the tool after all of the wafers are done. (Unload will be flashing)
- Select System, Control System and set to Manual.
- Go to Service, Vacuum Service and click on Online for Process for Chamber A. Select Put Offline for Maintenance.

- If no one else will be using the chamber that day, turn off the chamber lamps. Go to Chamber A, Chamber Service, click on the temperature next to Lamps and select Set to Standby.
- Wait until the chamber temperature goes below 200°C. Go to System, Monitor Facilities and turn off Lamp/Mag Contact for Chamber A.
- Go to Service, Vacuum Service and Chamber A. Turn the throttle off and then the pump.

RESULTS

Wafer Size	**Measurement Medium**	**Measurement Points**	**Mean**	**Standard Deviation**	
6-inch	Oxide	81	8753Å	183.71Å	2.099%

Table 1: Tencor SpectraMap reading of TEOS Oxide wafer

ANALYSIS

Some of the gases connected to the **Applied Materials (AMAT) P5000 PECVD** are a liquid source TEOS, Freon 116 (C_2F_6), Helium, Oxygen, Ammonia, Silane, and Nitrogen to name a few.

For the purposes of this lab, only the first chamber of the P5000 was used to grow silicon dioxide. Chamber A did have the RF connector missing from the top of the chamber. It was unclear as to if a LPCVD process was occurring in the chamber with the lamp lit. It was later understood that the RF from the bottom of the chamber was still connected and providing RF to the chamber. A non-standard hybrid LPCVD and PECVD process was the result.

If a Design of Experiments analysis were taken of this tool, some parameters that would greatly affect the outcome are the following:

Inputs:	Outputs:
o Temperature of Wafer o Pressure o RF Power o Reactant pressure	o Uniformity o Film Thickness o Film Purity (% Byproduct incorporation)

- If the temperature of the wafer increased, the film thickness would increase due to more energy for reactions. The film purity is unknown because higher temperature could lead to more unwanted reactants nucleating on the surface of the wafer or unwanted reactions fleeing the surface.
- If the pressure increased in the chamber this would lead to less uniformity, thicker film and worse film purity due to the abundance of molecules and atoms in the chamber reacting or landing on the surface.
- If the RF power decreased, the plasma would not be as strong thus making the ionization energy of the electrons weaker. This leads to thinner films. Film purity decreases due to the amount of byproducts available and little film growth. Film uniformity is questionable.

- If reactant pressure was increased, the amount of reactions occurring on the wafer increases. This increases the film thickness, increases the purity and more uniformity.

CONCLUSION

This lab was an overall success from an educational standpoint. A focus was placed more on the tool and how it works, from software to hardware. In most labs, the focus is placed on theory and equations that may not be relevant in the future compared to using and running a tool, which is a skill that will be necessary for future jobs to come. The lack of measurements leaves little to conclude about what factors contributed to the lower film thickness. The major cause could very well be the lack of an RF source from the top of the chamber.

REFERENCES

[1] Plummer, James D., Michael D. Deal, and Peter B. Griffin. *Silicon VLSI Technology Fundamentals, Practice, and Modeling*. Upper Saddle River: Prentice Hall, 2000.
[2] "AME P5000 - SMFL Wiki." *Main Page - SMFL Wiki*. Web. 08 July 2009. <http://wiki.smfl.rit.edu/index.php/AME_P5000>.
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