Low-pressure CVD and Plasma-Enhanced CVD

Ronald Curley, Thomas McCormack, and Matthew Phipps

Introduction:

Chemical vapor deposition (CVD) is a key process in semiconductor fabrication that deposits thin films on semiconductors. In this report we describe Low-Pressure CVD and Plasma-Enhanced CVD (PECVD). We also compare their characteristic strengths and weaknesses and the applications in which they perform best.

Low-Pressure Chemical Vapor Deposition: LPCVD

LPCVD is a process used in the manufacturing of the deposition of thin films on semiconductors usually ranging from a few nanometers to many micrometers. LPCVD is used to deposit a wide range of possible film compositions with good conformal step coverage. These films include a variety of materials including polysilicon for gate contacts, thick oxides used for isolation, doped oxides for global planarization, nitrides and other dielectrics. LPCVD is similar to other types of CVD in that it is a process where a gaseous species reacts on a solid surface or wafer and the reaction that occurs produces a solid phase material. Each and every CVD process has the same four steps that must happen. First, the reacting gaseous species must be transported to the surface. Second, the gaseous species must absorb into the surface of the wafer. Third, the heterogeneous surface reaction produces reaction products.[1] Finally the gaseous reactants need to be removed from the surface.

The low pressure distinguishes LPCVD from other CVD processes: atmospheric pressure CVD, of course, is CVD performed without pressurization or depressurization. The main reason for using LPCVD instead of APCVD is the ratio of the mass transport velocity and the velocity of reaction on the surface. During APCVD the ratio is close to one as the two velocities are of the same order of magnitude. The velocity of the mass transport depends mainly on the reactant concentration, diffusion, and thickness of the border layer. When the pressure is lowered during LPCVD, the diffusion of the gas decreases proportionally to the reciprocal of the pressure. The pressure for LPCVD is usually around 10-1000 Pa while standard atmospheric pressure is 101,325 Pa. If the pressure is lowered from atmospheric pressure to about 100 Pa the diffusion will decrease by almost 1000. This means that the velocity of mass transport will decrease meaning the substrates can approach more closely and the deposited films show better uniformity and homogeneity.[2] So there is less dependence on the resulting layer on mass transport velocity.

The LPCVD process has a quartz tube placed in a spiral heater that starts with tube pressure at very low pressure around 0.1 Pa. The tube is then heated to the desired temperature and the gaseous species ("working gas") is inserted into the tube at the pressure predetermined between 10-1000 Pa. This working gas consists of dilution gas and the reactive gas that will react with the substrate and create a solid phase material on the substrate. After the working gas enters the tube it spreads out around the hot substrates that are already in the tube at the same temperature. The substrate temperature is extremely important and influences what reactions take place. This working gas reacts with the substrates and forms the solid phase material and the excess material is pumped out of the tube.

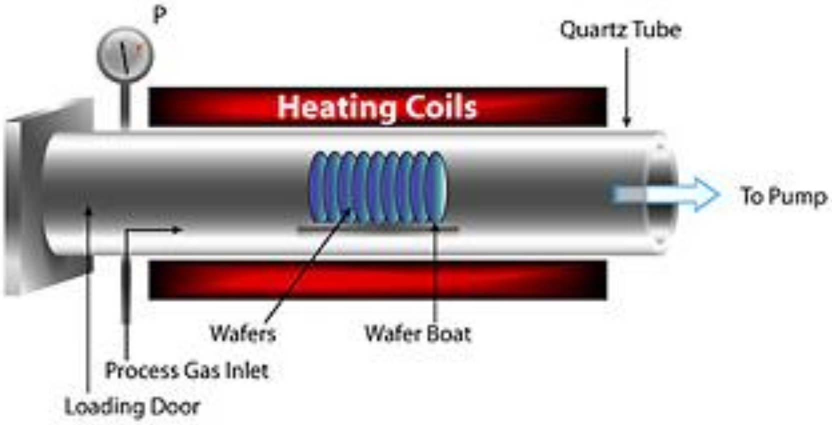

Figure 2: LPCVD Process [3]

LPCVD is most successfully applied in deposition of polysilicon thin films. These films are used for gate contact and short interconnect lines. This is done using compounds like SiH_4 in the temperature range 600-660°C. Other thin films include undoped and doped oxides that use compounds like Dichlorosilane at 900 °C and Tetraethoxysilane at 700 °C for undoped oxides that will leave SiO_2 and other by-products. Doped oxides include PSG (phosphorosilicate glass) at 950-1100 °C and BPSG (Borophosphorosilicate glass) 850-950 °C which are useful for smooth interconnects. Figure 2 below shows an example of LPCVD of phosphorous. LPCVD can also be used for nitrides that are used for encapsulation. This is done by adding compounds like Silane at 700-900 °C.

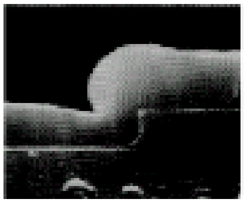

Figure 1: step coverage of phosphorus [4]

Comparing LPCVD to other CVD processes the main advantages of LPCVD are the excellent uniformity of thickness and purity, simple handling, high reliability, homogeneity of deposited layers and high reproducibility. Disadvantages include lower deposition rates than APCVD and high temperatures usually above 600°C needed for process. The deposition rate is controlled by pressure and temperature. The temperature is a limiting factor in the type of material you can use but the higher the temperature the greater the uniformity with less defects. Figure 3 below shows the deposition rate that is limited by the reaction rate and arrival rate. The reaction rate is the blue arrow and is controlled by temperature and pressure. The arrival rate is the red arrow and is controlled by pressure. Another disadvantage that is for most CVD processes is the excess material after the reaction has taken place is sometimes very harmful. Since the materials are deposited during the gaseous state the excess material is volatile so it must be handled properly.

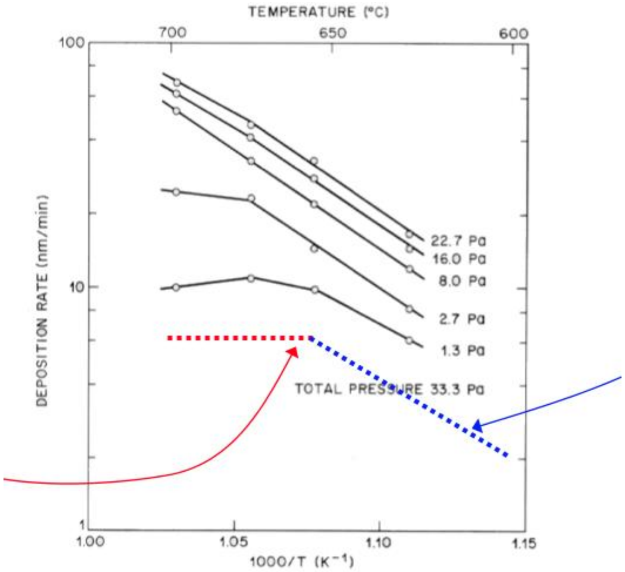

Figure 3: deposition rate of polysilicon [4]

Plasma-Enhanced Chemical Vapor Deposition: PECVD

PECVD is a fabrication method for depositing thin films on a wafer. PECVD is used to deposit SiO2, Si3N4 (SixNy), SixOyNz and amorphous Si films. In this method of CVD, plasma is added in the deposition chamber with reactive gases to create the desired solid surface on the substrate.

Plasma is a partially ionized gas with high free electron content (about 50%). Plasmas are divided into two groups; cold (also called non-thermal) and thermal. In thermal plasmas, electrons and particles in the gas are at the same temperature; however, in cold plasmas the electrons have a much higher temperature than the neutral particles and ions. Therefore, cold plasmas can utilize the energy of the electrons by changing just the pressure. This allows a PECVD system to operate at low temperatures (between 100 and 400 degree Celsius).

The energy from the electrons in cold thermal plasmas is useful in PECVD. When the mean free path is large and the system size is small, the free electrons won’t exchange energy with ions before they collide with other outside objects. The energy from the electrons is then used to dissociate the reactive gas in order to form the solid film on the substrate. In order to excite and sustain excitation state, a voltage must be applied to the plasma. The voltage is usually applied using an RF signal between two electrodes.

PECVD systems must contain two electrodes (in a parallel plate configuration), plasma gas, and reactive gas in a chamber. To begin the PECVD process, a wafer is placed on the bottom electrode and reactive gas with the deposition elements is introduced into the chamber. Plasma is then introduced into the chamber between the two electrodes, and voltage is applied to excite the plasma. The excited state plasma then bombards the reactive gas causing dissociation. This dissociation deposits the desired element onto the wafer.

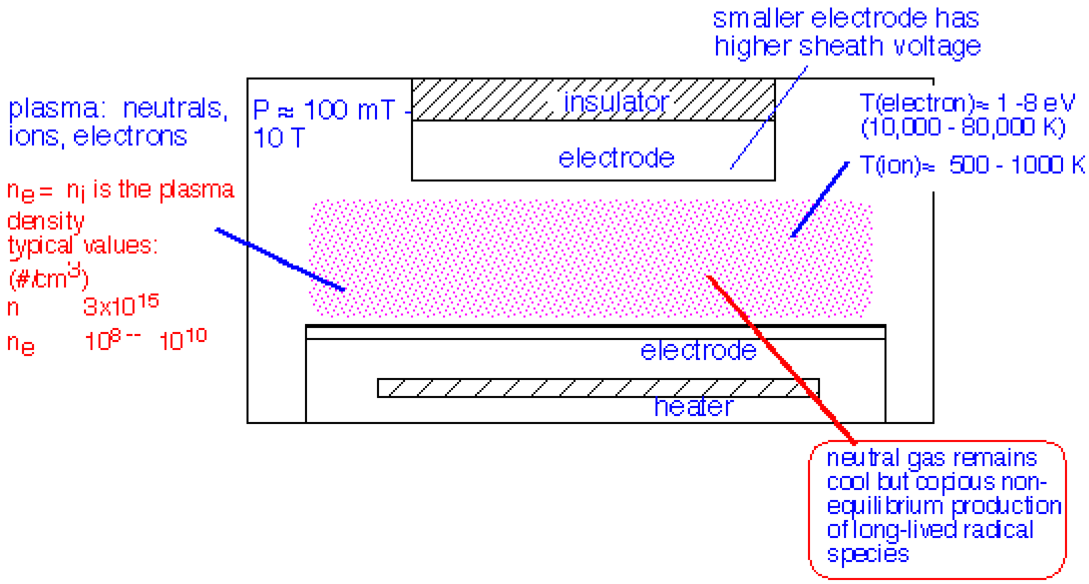

Figure 4: http://timedomaincvd.com/CVD_Fundamentals/plasmas/capacitive_plasma.html

Advantages of PECVD include the low temperature, higher film density for higher dielectric and more compression, and ease of cleaning the chamber. Disadvantages include the expense of the equipment and the stress of plasma bombardment. Batch size is also small: PECVD can only deposit the film on one side of 1-4 wafers while LPCVD can deposit films on both sides of at least 25 wafers.[5]

Conclusion

LPCVD, while it can only be performed at high temperatures, reduces the rate of the reaction permitting greater control over film thickness and reducing thickness variations. It also improves the film's purity and internal structure. The simplicity of the process permits the processing of large wafer batch sizes.

PECVD permits energetic reactions at low temperatures (even 100°C in some cases), due to the formation of cold plasma by electrical ionization rather than thermal ionization, so that only the electrons are energetic while the ions remain relatively cool. But the process is more complicated than LPCVD, so batch sizes are small.

References

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