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Plasma Enhanced Chemical Vapor Deposition

Plasma Enhanced Chemical Vapor Deposition (PECVD) is a process widely used in IC fabrication in which thin films of a certain material are deposited from a gas state (plasma) onto a substrate at a relatively low temperature. PECVD is mainly used for the deposition of dielectric films and passivation (scratch protection) layers like silicon oxide or silicon nitride and the SiC layers of poly-Silicon. The layers obtained through PECVD present better characteristics than the ones obtained through regular thermal deposition techniques because more process parameters can be adjusted. These parameters may include adhesion, compressive and tensile stress, etchability of the layer being deposited, etch rate, selectivity in etching, step coverage, stoichiometry (consistence) and cleanliness of the deposited layers. The maximum thickness of the layers and their uniformity are also dependent of the PECVD process parameters. The most important characteristic of PECVD process is the use of gases in their plasmatic state which allows the process to maintain the wafers at a relatively low temperature.

A plasma is typically a gas, or mixture of gases, that has become ionized, usually, through an electrical discharge. This means there is an abundance of electrons and positive ions inside the gas that make it conductive and enable it to respond strongly to electromagnetic fields eventhough it remains macroscopically neutral [1]. A simple way of creating a plasma is by using a discharge tube, for example. The pressure inside the tube is between 10^{-1} to 1 torr and, therefore, applying a voltage to the electrodes in the tube creates only a small electrical current. However, when the voltage reaches a few hundred volts, the current increases abruptly and causes the tube to glow. The gas inside the tube is now a plasma since it has become ionized and, therefore, conductive. In this case, the positively charged ions and the negatively charged electrons move with statistically distributed random velocities [3]. The type of plasma obtained in a discharge tube, which uses a DC discharge, can also be generated by a Radio Frequency (RF) signal discharge at low pressure. In this type plasma, the degree of ionization of the gas is of about 10^{-4}, so the gas is mostly neutral rather than ionized. One important characteristic of this plasma is the lack of thermal equilibrium between the gas temperature and the electron temperature. Due to the small collision rate between the electrons and the gas particles themselves, the electron temperature remains high while the gas temperature remains relatively low. In general, the temperatures caused by the different sources of energy in the gas are as follows: $T_{\text{Electron}} > T_{\text{Vibrational}} > T_{\text{Rotational}} > T_{\text{Gas}}$. This type of plasma called "cold plasma" and is the kind used for PECVD.

The PECVD process uses a reactor in which a cold plasma is produced. The design of the reactor is dependent on the amount of substrates one wishes to process at one time as well as on the substance or substances one desires to deposit on the substrate. Generally the reactor energizes the plasma using two electrodes of varying design. The electrodes can either be excited using a DC or an AC discharge. A simple DC discharge can be readily created at a few Torr between the two conductive electrodes, and may be suitable for deposition of conductive materials. However, insulating films will quickly extinguish this discharge as they are deposited. Therefore, it is more common to excite a capacitive discharge by applying a radio-frequency (RF) signal between the two electrodes. Frequencies of a few tens of Hz to a few thousand Hz will produce time-varying plasmas that are repeatedly initiated and extinguished; frequencies of 10's of kilohertz to tens of megahertz will result in reasonably time-independent discharges [3]. Also the RF method is used more often than the DC one because the frequency of the RF signal can be varied so that a desired deposition rate can be achieved. The plasma will usually become more positive than the substrate and this, associated with the random nature of the gas particles' movement, will speed up the chemical reactions that occur on the surface of the substrate.

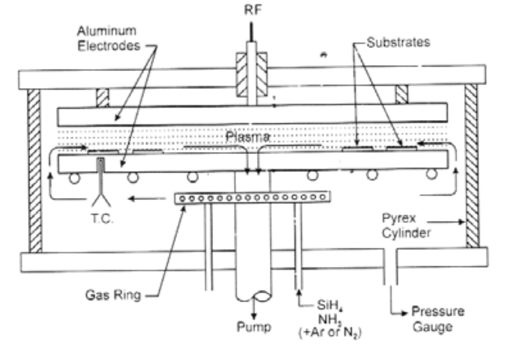

Fig. 1 A parallel-plate reactor in which the reaction gases flow radially [3].

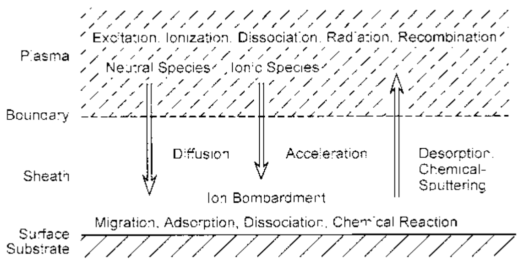

Fig. 2 Schematic representation of the plasma- enhanced reaction process [3].

In the plasma reactor shown in figure 1, the gas molecules are ionized mainly by electron impact. First the plasma is formed and then the gases, which contain the substances to be deposited, are introduced. Thus, the excited molecules, atoms and radicals are produced in the gas phase and then reach the substrate by diffusion through the sheath region, which is an empty space which is created by the plasma and separates the substrate and the plasma cloud. The flow of the reaction gases and the configuration of the electrodes and the substrate create a spatial distribution in the particle density. The particles that reach the substrate surface get absorbed and react with the atoms of the substrate, forming the desired films. The ions act as a compressor pushing down on the deposition layers allowing more of the desired substance to be deposited and therefore increasing the density of the deposition.

The PECVD process has several advantages over other types of chemical vapor deposition processes. One of these advantages is that the wafers can be kept at relatively low temperatures (~400 ^{o}C) during the process; therefore, the PECVD process is less temperature dependent than other CVD processes, which may require temperatures around 1100 ^{o}C [2]. Another advantage of PECVD is that the deposition rate of films can be controlled by means other than temperature changes. It has been experimentally determined that the deposition rate of the PECVD process is determined by the rate at which the gas with the desired substance to be deposited enters and exists the reactor, as well as the electric power applied to the reactor. Generally the higher the flow rate of the gas and the higher the electric power applied, the higher the layer deposition rate. Also, films are exposed to energetic ion bombardment during deposition which can lead to increases in density of the film. This ion bombardment helps remove contaminants from the film and, therefore, improves the film's electrical properties, depending on whether we deposit a conducting or an insulating layer, and reduces the mechanical stress on the film being deposited [1]. In addition, when a high-density plasma is used, the ion density can be high enough so that significant sputtering of the deposited film occurs; this sputtering helps to planarize the film’s surface and fill trenches or holes found on it.

Conventional PECVD is typically performed in vacuum systems at pressures ranging from a few hundred milli-Torr to a few Torr. As a result, PECVD suffers from the same process disadvantages as vacuum sputtering, in that the use of vacuum chambers and pumping systems greatly increases the cost of the equipment and the materials used to create the films, as well as the difficulty in scale-up for large volume manufacturing [8]. Another disadvantage of PECVD is that it requires the use of toxic gases like silane (SiH_4), phosphine PH3 and diboraneB_2H_6. These gases have to be handled with great care and therefore costly equipment must be used to bring them into contact with the substrate and to dispose of them after they are used.

PECVD has many applications inside and outside the IC fabrication world. Besides being used to deposit passivation and polysilicon layers, PECVD can be used to deposit highly doped p+ and n+ layers, Diffusion barrier layers, etch stop layers and encapsulation layers. In the optics realm, it can be used to deposit anti-reflection and anti-scratch layers on lenses, and can also be used in the making of lasers, light detectors, and solar cells. PECVD can also be used to deposit films on different types of equipment to protect them from corrosion, humidity, scratching and chemicals that may fall on them.

[1] "Chemical Vapor Deposition." Wikipedia. 27 Sept. 2007. 11 Oct. 2007 <http://en.wikipedia.org/wiki/Chemical_vapor_deposition>.

[2] Jaeger, Richard C. Introduction to Microelectronic Fabrication. 2nd ed. Vol. 5. Upper Saddle River, NJ: Prentice Hall, 2002. 136-141.

[3] Konuma, Mitsuharu. Film Deposition by Plasma Techniques. Berlin: Spring-Verlag, 1992.

[4] Konuma, Mitsuharu. Plasma Techniques for Film Deposition. Harrow, U.K.: Alpha Science International Ltd., 2005.

[5] "PECVD Process." MicroFAB BREMEN GMBH. 17 May 2004. 14 Oct. 2007 <http://www.microfab.de/services/pecvd.htm>.

[6] "Plasma (Physics)." Wikipedia. 15 Oct. 2007. 12 Oct. 2007 <http://en.wikipedia.org/wiki/Plasma_%28physics%29>.

[7] "Plasma-Enhanced Chemical Vapor Deposition." Wikipedia. 30 Aug. 2007. 11 Oct. 2007 <http://en.wikipedia.org/wiki/Plasma_Enhanced_Chemical_Vapor_Deposition>.

[8] "Plasma Enhanced CVD." Hitech-Projects. 2007. 14 Oct. 2007 <http://www.hitech-projects.com/dts/docs/pecvd.htm>.

[9] Sherman, Arthur. Chemical Vapor Deposition for Microelectronics Principles, Technology, and Applications. Park Ridge, NJ: Noyes Publications, 1987.