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PLASMA ASSISTED CHEMICAL VAPOR DEPOSITION (PACVD)

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Abstract

Plasma Assisted Chemical Vapour Deposition (PACVD) is an excellent alternative for depositing a variety of thin films at lower temperatures than those utilized in CVD reactors without settling for a lesser film quality. Plasma-assisted deposition of thin films is widely used in microelectronic circuit manufacturing. Deposited materials include conductors such as aluminium, tungsten, copper, transition-metal silicides, and refractory metals, semiconductors such as gallium arsenide, epitaxial and polycrystalline silicon, and dielectrics such as silicon nitride, silicon oxide, and silicon oxynitride. The main focus of this paper is on applications of plasma-assisted chemical vapour deposition (CVD) and techniques for thin films. It gives introduction to the PACVD, plasma theory and implementation of the process, advantages, disadvantages and its applications along with conclusions and its future scope. In particular, it focuses on the integration, process, and reliability requirements for thin films used for isolation, passivation, barrier and antireflective-coating applications in ultra large-scale integrated (ULSI) semiconductor circuits and for other applications too. In addition, manufacturing issues and considerations for further work are discussed.

Keywords: *Plasma, Reactors, Radio Frequency, Glow Discharge, Chemical Vapor Deposition (CVD).*

1. Introduction

In thermal CVD, heating of initial reactants results in generation of gas-phase reactive species. In plasma CVD, the plasma energy is supplied by an external RF source to take the place of the heating to generate the species that subsequently reactant deposit on substrate surfaces. PACVD uses electrical energy to generate a glow discharge (plasma) in which the energy is transferred into a gas mixture. The gas mixture is transformed into reactive radicals, ions, neutral atoms and molecules, and other highly excited species. These atomic and molecular fragments react with a substrate and, depending on the nature of these reactions, at the substrate etching or deposition processes occurs. Since the formation of the reactive and energetic species in the gas phase occurs by collision in the gas phase, the substrate can be maintained at a low temperature. Hence, film formation can occur on substrates at a lower temperature than is possible in the conventional CVD process, which is a major advantage of PACVD. Some of the desirable properties of PACVD films are good adhesion, low pinhole density, good step coverage, and uniformity [4].

For example, high quality silicon dioxide films can be deposited at 300 to 350 degrees centigrade while CVD requires temperatures in the range of 650 to 850 degrees centigrade to produce similar quality films [3].

2. Plasma Theory and Implementation of the System

Plasma is defined as an ionized gas. It is often described as the fourth state of matter. Plasma Enhanced Chemical Vapor Deposition facilitates the deposition of many types of films at much lower temperatures than would be possible with chemical vapor deposition alone [1].

2.1 Generation of Plasma for PACVD

A glow discharge is plasma formed by the passage of electric current through a low-pressure gas. It is created in a glass tube containing gas by applying a voltage between two metal electrodes.

The gas in the tube ionizes, when the voltage exceeds the striking voltage. The gas becomes plasma, and begins conducting electricity, causing it to glow with a colored light [5].

The color is determined by the gas used. Glow discharge is used as a light source in devices such as neon lights, plasma-screen televisions, etc.

By examining the light produced by spectroscopy we get to know much about the atomic interactions in the gas, so glow discharge is used in analytical chemistry and plasma physics.

It is also used in the surface treatment technique called sputtering.

2.2 Reaction kinetics

Reactions during plasma deposition are hard to understand. The table shown below gives various reactions during PACVD.

Elementary reactions that occur in plasma have been discussed by various authors. The initial reaction between electrons and reactant gas molecules or between reactant gas molecules in plasma can be

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classified as elastic or inelastic. Minimal translational energy transfer occurs between the gas molecules and reactant gases, in the elastic collisions. For plasma processing, a less important role is played by the elastic collisions in reactant dissociation.

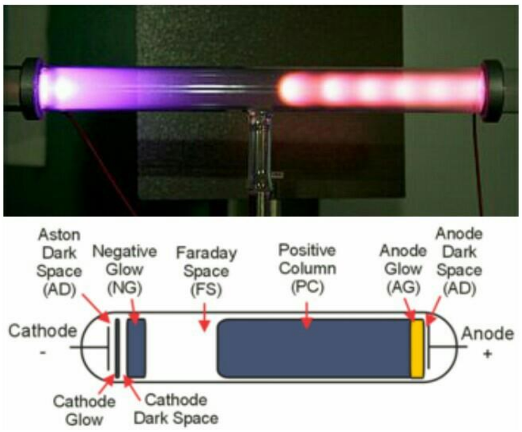

Fig. 1. Crookes Glow Discharge Tube. [7]

In the inelastic collisions more translational, rotational, vibrational and electronically excitational energy transfer occurs. Some of the inelastic collisions between inert gases and reactants (such as helium or argon with silane) remarkably affect the properties of the deposited films and the chemical nature of the discharge.

In many plasma deposition processes, to create more controlled reaction pathways via Penning reactions between carrier and reactant gases, and to suppress gas-phase reactions between reactive species, inert carrier and diluents gases such as helium and argon have been used to form "cooler" plasma. As a result, plasma diluted with inert gases such as helium can be used to deposit higher-quality insulators.

1. Typical electron impact reactions of silane molecules in a RF plasma discharge.

REACTANT	REACTION PRODUCTS	ENTHALPY OF FORMATION (eV)
$e^- + SiH_4$	$SiH_2 + H_2 + e^-$	2.2
	$SiH_3 + H + e^-$	4
	$Si + 2H_2 + e^-$	4.2
	$SiH + H_2 + H + e^-$	5.7
	$SiH^* + H_2 + H + e^-$	8.9
	$Si^* + 2H_2 + e^-$	9.5
	$SiH_2 + 2H_2 + 2e^-$	11.9
	$Si + 2H_2 + 2e^-$	13.6
	$SiH + H_2 + H + e^-$	15.3

2.3 Deposition Mechanisms

Plasma deposition process is very useful for depositing various layers of films in order to get the desirable properties. By changing the composition and/or type of reactive species properties like physical and chemical properties of deposited film related to its stress, conformality, density, moisture resistance, and gap-fill properties can be changed for conventional thermal CVD.

In plasma-assisted CVD, by varying deposition parameters such as temperature, RF (Radio Frequency) power, pressure, reactant gas mixture ratio, and type of reactant this can be accomplished. For example, silicon oxide films deposited with TEOS generally show higher step coverage or conformality than those deposited with silane in a plasma-assisted CVD process. Not only by changing the type of reactive species, but also by the extent of ion bombardment, properties for plasma-assisted CVD of silicon oxide films can be modified. In general, the deposition mechanisms for a plasma CVD process can be qualitatively divided into four major steps, as shown in Fig. 2.

In first step the radial and ions reactive species form by the primary initial electron impact reactions between electron and reactant gases.

In step 2 reactive species which formed in the first step transport from the plasma to the substrate surface due to which many elastic and inelastic collisions occurs in both the plasma and sheath regions which are classified as ion and radical generation steps.

In step 3 radical absorption and ion incorporation takes place onto the substrate surface.

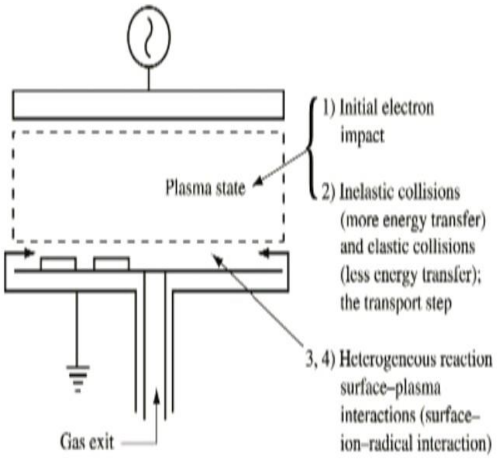

Fig. 2. Steps of mechanism of plasma CVD process. [7]

Finally, in step 4, the reactive species and/or reaction products re-emit from surface back to the gas phase or incorporate into the deposited films. The last two steps are difficult to study because of its complexity.

Ion bombardment and various heterogeneous reactions between ions and radicals play an important role with the depositing surface in the sheath region. The two steps critically affect film properties such as conformality, density, stress, and "impurity" incorporation. With hundreds of publications on their deposition kinetics and mechanisms, the plasma CVD of amorphous and microcrystalline silicon are the most studied plasma CVD processes. By various techniques the basic gas-phase chemistry of the silane plasma has been studied. For the dominant reaction pathway of silicon deposition different mechanisms have been suggested. One mechanism describes the decomposition of silane to SiH_2 (silylene) and then SiH_2 insertion into gas-phase SiH_4 to form higher silane species as the main silicon deposition mechanism while other mechanism describes SiH_3 (silyl) radicals playing a dominant role.

3. Advantages, Disadvantages and Applications of PACVD

Plasma Assisted Chemical Vapor Deposition has many advantages, disadvantages over conventional CVD and its applications are discussed below:

3.1 Advantages

a) Low operating temperature.
b) Lower chances of breaking of deposited layer.
c) Good dielectric properties of deposited layer.
d) Good step coverage.
e) Less temperature dependent.

3.2 Disadvantages

a) Harmful by products.
b) Costly equipments.
c) Cannot be used with plastic.
d) Complex setup of equipments.

3.3 Applications

a) Deposition of silicate layers on integrated circuits.
b) Deposition of dopants.
c) Anti-reflection and anti-scratch layers in optics.
d) Solar cells (amorphous silicon).

4. Conclusions and Future Scope

4.1 Conclusions

Radio frequency (RF) plasma deposition is an adaptable and reliable way of producing hard thin carbon films. The process parameters have a complex relationship with each other and their effects on the resultant film properties. The three most important process parameters are substrate temperature, induced bias and system pressure In terms of the film‘s growth environment, these affect the atom surface mobility, dissociation efficiency of the gas, ion impact energy on the surface and the residence time of atoms or molecules m the reaction zones. The resultant carbon films varied dramatically depending on the deposition settings. They ranged from soft polymer-like to hard films of a strong amorphous structure, which demonstrated hardness qualities of 3000 Vickers.

4.2 Future Scope

Research papers on carbon films, shows that these films can be produced by different techniques and exhibit very unusual properties as discussed previously. The main problems with carbon films, namely the high internal stress and poor adhesion of these films can be identified by their application. These two factors are the limiting criteria in the production of hard carbon films. Poor adhesion and highly stressed films are related in that stress forces can be so great as to cause determination of the film from the substrate, hence leading to poor adhesion results. Primary objectives would be to deposit hard carbon films and investigate the deposition parameters effect upon the film characteristics. For the development of carbon films into the areas of wear protective coatings reduction in the film stress and improved adhesion are essential.

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