THE ROLE OF IONS IN SiO₂ DEPOSITION WITH PULSED AND CONTINUOUS HELICON PLASMAS

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Abstract

Good quality silicon dioxide films have been deposited using continuous and pulsed oxygen/silane plasmas coupled in a high density low pressure helicon reactor. Silicon-containing ions contribute to the film growth and the total ion flux determine much of the structural properties of the deposited oxide.

4. Introduction

The use of the helicon radiofrequency source for plasma processing has been widely demonstrated over the past decade. Silicon dioxide deposition from oxygen/silane plasmas has been successfully carried out for continuous and pulsed excitation. It has been shown that the ion flux impinging onto the substrate (which can be left “floating” or biased) during the deposition process is an important parameter. The time-averaged ion flux is different in continuous or pulsed mode and charging of the reactor walls (covered with silica) also affects the equilibrium of the plasma. Consequently, a control of the deposition process necessitates a good understanding of the plasma diffusion from the helicon source to the diffusion chamber and of the plasma-surface interaction at the substrate and at the walls.

3. The helicon deposition reactor and diagnostics

The helicon deposition reactor shown in Figure 1 consists of a 15 cm-diam, 30 cm-long glass tube (the source) surrounded by a helicon antenna and two solenoids, which are contiguous with a 35 cm-diam, 30 cm-long aluminum diffusion chamber surrounded by two solenoids. For the present results, the magnetic field configuration induces a B₂ component of the field of about 80 Gauss in the source and 70 Gauss in the chamber. The reactor (source and chamber attached) is pumped down to a base pressure of about 10⁻⁵ Torr by using a turbomolecular pump placed on top of the source. The silane and oxygen gas inlets are situated on top of the chamber and total gas flows of 10 to 100 sccm lead to pressures of a few millitorr, measured by a baratron gauge mounted at the back of the chamber. When operating in its resonant regime, this type of reactor produces high plasma densities which is used for depositing good quality oxides with continuous and pulsed excitation. Operating conditions are a radiofrequency power of 800 W, a total gas flow of 30 sccm inducing a pressure of 2 mTorr. In pulsed operation the rf generator/matchbox system has rise and fall times of about 80 and 60 μs, respectively.

The reactor is equipped with an in-situ ellipsometer (632.8 nm) and an energy selective mass spectrometer (Hiden). Pure oxygen and argon plasmas are also diagnosed by using electrostatic probes (Langmuir probe and energy analyser). Analysis of experimental data acquired during and after the deposition in oxygen/silane plasmas, as well as data acquired in
oxygen and argon plasmas leads to the development of simple analytical models of the deposition mechanisms.

9. The deposition process

The deposition process is characterised for continuous and pulsed excitation. In high density mode and at low pressure (a few mTorr), the silane is fully dissociated and the total ion density in the processing chamber is in the $10^{11} \text{cm}^{-3}$ range. Consequently, our deposition process strongly differs from standard processes in capacitive systems using diluted silane. The positive and negative ion spectra are measured using the spectrometer. Powder formation is not present. The positive silicon-containing ions contribute to the growth. An excess of oxygen-containing ions is necessary for obtaining near stoichiometric oxides. The presence of insulating walls affects the plasma potential as a result of wall charging to positive voltages at the initiation of the discharge. An enhanced control of the deposition process (stress control) can be obtained by pulsing the plasma, i.e., by decoupling the role of the ions and neutrals,
but this also alters the time-averaged ion energy distribution function. A more detailed study of the ion flux on the substrate and at the wall for continuous and pulsed mode is necessary.

10. The plasma diffusion

Additional diagnostics such as a Langmuir probe and an energy analyser are used when investigating the details of the plasma diffusion and plasma-surface interaction in oxygen and argon plasmas. For electronegative plasmas, two regions are present in the diffusion chamber, an inner region (image of the helicon source projected along the magnetic field lines) with mostly positive ions and hot electrons and an outer region with mostly positive and negative ions, and cold electrons. The plasma potential across the processing chamber is constant and the transition between the inner and outer region mostly affects the floating potential. The highest value of $V_f$ is at the wall where positive charging occurs at the initiation of the discharge. The capacitive effect at the wall is also observed in pulsed excitation where the plasma potential is increased during the three plasma phases (breakdown, steady-state, and post-discharge). In silane rich plasmas, the charging effect is maximum as a result of changes in the wall state during the deposition. Argon plasmas are also studied in order to obtain additional data such as the plasma potential and ion flux time constants in the post-discharge.

11. Conclusion

Analytical models have been developed which relate the plasma parameters to the deposition process in continuous and pulsed modes (deposition rate, stress formation...). The full development of those models necessitated a fundamental study of the plasma diffusion in the high density mode of the helicon reactor: ion energy distribution functions in pulsed and continuous oxygen and argon plasmas have been obtained which lead to a better understanding of the plasma breakdown, equilibrium and post-discharge phases and the determination of the radiofrequency electric fields in the helicon source.

References
