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Advanced Plasma Processing Equipment without Wafer Surface Damage and Chamber Material Contamination

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The effects of magnetic field, excitation frequency, D.C. biases, secondary RF excitation, chamber material and the auxiliary electrode on spatial distribution of potential and self-biases are discussed and illustrated. The plasma potential strongly alters the ion impact energy in the regime of extremely low energy under high RF excitation in a very low pressure environment. The study found the plasma potential, the primary cause of chamber material contamination, can be lowered to sub-ground level by introducing an auxiliary shielding electrode.

I. Introduction

In order to realize a high-quality, damagefree and non-contaminating plasma processing environment, i.e. essentials of energy clean technology, the self-bias of the substrate as well as the time average potential distribution of plasma must be precisely controlled.

This paper discusses the effects of magnetic field, excitation frequency, DC biasing of electrodes, secondary RF excitation, chamber material and the auxiliary electrode on the spatial distribution of potential and self biases.

Advanced plasma processing equipment^{*}, intended for the fabrication of ULSI devices, must be operated under very low pressure(10^{-3} Torr). In low pressure, the collision frequencies of charged particles are reduced so that there is a higher probability of forming high energy particles. Since the bombarding energy of ions striking the chamber wall is determined by the potential difference between the wall and the adjacent plasma, the plasma potential must not exceed the sputter threshold energies of the chamber materials.

II. Experimental

The schematic diagram of the experimental apparatus is depicted in Fig. 1. The system consists of a cylindrical stainless steel vacuum chamber of 400 mm in diameter, a completely oil-free vacuum system and water cooled pole magnets placed in the upper electrode provide magnetical enhancement of 500 gauss at maximum.

A HP 8657A Signal Generator and ENI 5100L RF Power Amplifier supplied RF power to the cathode through 50 ohm coaxial cable. The excitation frequency can be varied in the range of 100 KHz to 1,000 MHz.

The Langmuir probe was inserted in the chamber to measure the spatial potential of plasma¹). Simple probes with Tantalum tips of 0.125 mm in diameter and 2 mm length were exposed to plasma at the end of an Alumina tube to obtain high resolution. The wire was connected to a low pass filter ensuring high impedance between plasma and ground for accurate measurement of plasma potential.

^{*}T. Ohmi: Extended Abstracts of the 176th Meeting of the Electrochemical Society, Hollywood, October, 1989.

III. Results and Discussion

The presence of moderate magnetic field significantly curtails the electron mobility along the electric field. Hence, the plasma potential remains relatively low where the magnetic field is strong as shown in Fig. 2.

For the capacitive plasma and a constant power system, the displacement current increases with an increase in the excitation frequency. Consequently, the self bias at the cathode is significantly reduced for excitation frequencies greater than 50 MHz, as shown in Fig. 3.

The RF amplitude may be determined from the figure and is plotted against the inverse of the square root of frequency in Fig. 4.

A cylindrical shield is installed and biased with an external DC power source to effectively confine electrons and protect chamber walls from excessive film deposition and exposure to a high density plasma. The effects of biasing the shield are shown in Fig. 5. The floating potentials(self biases) of both electrodes increase monotonically for a positively biased shield. The plasma potential monitored at the maximum magnetic field follows the shield bias(Vshield) for Vshield > 20 Volt. However, when the shield is biased slightly negatively, the plasma potential becomes very close to the shield potential. This implies that there is no net potential difference between the time average of the plasma potential and the shield and metal contamination from the chamber materials will be minimized.

For a shield potential of -5 Volt, the plasma potential at various radial positions is measured(Fig. 6). The potential distribution remains near that of shield over the area extending to the edge of the target.

Ohmi, et al.²⁾ reported that the ion bombardment conditions must be optimized for the sputter deposition of epitaxial silicon at 250 °C. In the Low Kinetic-Energy Particle Process, the deposited atoms receive adequate amount of activation energy from low energy Ar ions. In their report, the substrate is biased positively to reduce the bombarding energy of Ar ions. Fig. 7 illustrates the potential distribution of the plasma across the parallel electrodes for various substrate potentials. The change in plasma potential is less than 5 Volts when the potential of the substrate is varied from +20 to -20 Volts.

The plasma processing on surfaces of dielectic materials require the utilization of a high frequency field ³⁾ and self biases to control the ion impact energy. The effects of altering the excitation frequency are shown in Fig. 8. The self-bias of the substrate can be controlled simply by the selection of excitation frequencies and an independent control of the ion bombardment energy and density can be realized.

IV. Conclusion

Advanced plasma processing equipment for critical plasma processing has been proposed. The equipment is capable of independent control of plasma density and ion impact energy. New features include the followings:

(1) Significant reduction of chamber material sputtering by precise control of plasma potential by introducing an auxiliary shielding electrode.

(2) Minimum radiation damage under low pressure process environment by utilization of extremely high frequencies(10^8 Hz).

(3) Independent control of self biases necessary for film depositin of dielectric materials.

References

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Fig.1 Schematic diagram of experimental apparatus.



Fig.2 Plasma potential and magnetic field strength in radial direction without a shield for z = 20 mm from the target. Radial position is measure from the center.



Fig.3 Self-bias voltage(Vdc) of the target and plasma potential(Vp) for frequencies from 10 to 215 MHz at r = 20 mm and z = 15 mm with a grounded shield. The difference (Vp - Vdc) determines the ion impact energy.



Fig.4 Effect of excitation frequency on RF amplitude(2Vp - Vdc).



Fig.5 Effects of shield biasing on the target and substrate self-biases and plasma potential at r = 20 mm and z = 15 mm.



Fig.6 Plasma potential in radial direction for the shield bias of -5 Volt. The probe is inserted through an opening, which causes the apparent plasma potential to increase near the shield.



Fig.7 Effects of substrate biasing on potential distribution in vertical direction at r = 20 mm. Note that target self-bias(vertical position = 0 mm) does not change with substrate potential.



Fig.8. Effects of secondary RF excitation on self-biases of target and substrate.

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