Impedans’ Semion and Langmuir Probe systems used to study the SiO2 sputter etch rate in RF-Biased ICP discharge.

INTRODUCTION:

Inductively coupled plasmas (ICPs) with radio-frequency (RF) biased pedestals are commonly used in the semiconductor industry for nanoscale etch and deposition processes.

In this study, the authors investigate the sputter etch rate of SiO2 in this type of reactor as a function of ICP and RF-bias power. The key parameters measured were the ion energy distribution (IED), ion flux and sputter etch rate. It is well known that ion bombardment of the wafer is a key driver of the etch process. However, there are relatively few studies that have attempted to correlate the shape of the ion energy distribution directly with the etch rate. Here, the IED is measured with the Semion system and the other important plasma parameters are measured with the Langmuir probe system over a wide range of discharge conditions. An ion-enhanced etching model is developed to identify the relationship between the measured parameters. A novel method is presented which can be used to control the ion bombardment energy, ion flux and etch rate.

Method:

The experimental setup is shown in figure 1. An industrial plasma etch tool is used which has an ICP source consisting of an inner and outer coil. The match output is split into two to supply power to both coils. Current flowing through each coil is measured, the ratio of which is used as an additional control parameter in the experiment. An Impedans Langmuir probe located in the centre of the discharge, approximately 30mm above the wafer surface, was used to measure the bulk plasma parameters. The probe tip was made of Tungsten with length 9mm and diameter 0.39mm.

The Semion retarding field energy analyzer was mounted in the centre of the wafer on the RF-biased pedestal. The sensor diameter was 50mm and had a thickness of 5mm.

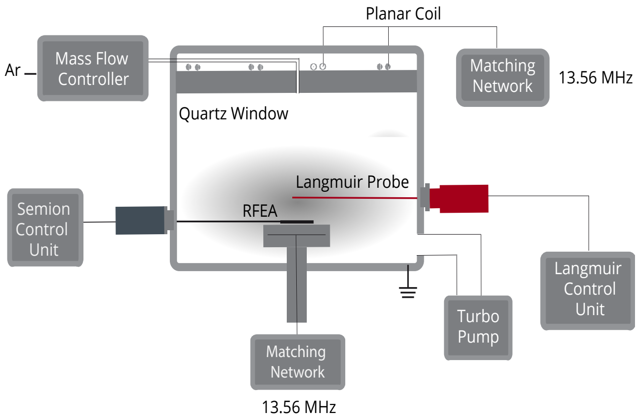

Figure 1. The schematic diagram of experimental setup

Analytical Model:

The experiments were carried out at a discharge pressure of 20 mTorr where it was found that the ion mean free path was approximately 4mm. The maximum sheath width encountered was 1.6mm. Therefore, the sheaths are collisionless and the ion transit time is close to the RF-bias period. The ion transit time is given by

$$\tau_i = 3\bar{s}(M_i/2e\overline{V}_s)^{1/2}$$

where e is the electronic charge, M_i is the ion mass, $\bar{s}$ is the time averaged sheath thickness and $\overline{V}_s$ is the time averaged sheath voltage. The time averaged sheath width is defined as

$$\bar{s} = \frac{2}{3}(2e/M_i)^{1/4}(\varepsilon_0/\bar{J}_i)^{1/2}(\overline{V}_s)^{3/4}$$

Where $\boldsymbol{\varepsilon}_0$ is vacuum permittivity and $\bar{J}_i$ is the ion flux at the sheath edge given by

$$\bar{J}_i \approx 0.61en_e\sqrt{\frac{kT_e}{M_i}}$$

Where n_e is the electron density in the bulk plasma and kT_e is the electron temperature. An expression for the peak separation of the ion energy distribution in this so-called intermediate frequency regime is given by

$$\Delta E = 2\overline{V}_s\left(1 + \pi^2(2kT_e/\overline{V}_s)^{1/2}\left(\tau_i/\tau_{rf}\right)^2\right)^{-1/2}$$

Equation 4 was solved using the Langmuir probe measurements and used to confirm the validity of the experimentally measured IEDs.

An ion-enhanced etching model, for calculating the sputter etching rate, was also presented. It is noted that this model is applicable to ion energies less than 1000 eV

$$ER = \Gamma_{Ar+}Y(\varepsilon_{Ar+})/n_{S_iO_2}$$

Where Γ_{Ar+} is the argon ion flux, Y_{Ar+} is the ion etch yield and n_{SiO2} is the molecular density of 5 x 10^{28} m^{-3}. The ion etch yield is a function of ion impact energy and can be written as

$$Y(\varepsilon_{Ar+}) = C\left(\sqrt{\varepsilon} - \sqrt{\varepsilon_{th}}\right)$$

Where C is the ion etch yield coefficient for S_iO_2 and ε_{th} is the sputter etching threshold energy (18 eV for this material).

Findings:

IED measurements for varying ICP power (fixed coil current ratio) and grounded pedestal are examined initially. For this condition the IEDs exhibit a narrow, single-peaked shape. The ion flux increases with increasing power, at fixed discharge pressure, while the ion energy remains constant. When the coil current ratio is increased there is a corresponding increase in the ion energy accompanied by a decrease in the ion flux as shown in figure 2.

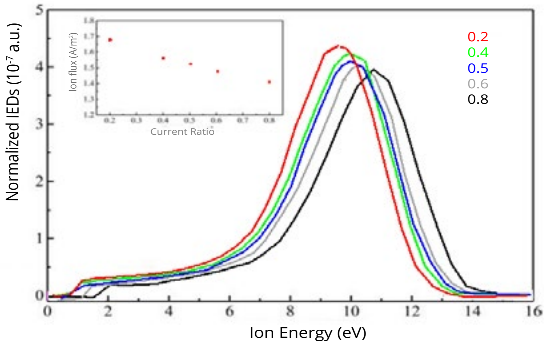

Figure 2 Normalized IEDs plot as a function of coil current ratio at the grounded electrode.

IEDs are also measured for the RF-biased pedestal for various ICP powers, discharge pressures and coil current ratios. The expected double peak structure is seen. For fixed ICP power and discharge pressure the peak separation of the IED increases with increasing RF-bias power. For fixed RF-bias power and discharge pressure the peak separation decreases with increasing ICP power. For fixed ICP and RF-bias powers, the peak separation decreases with increasing discharge pressure. For fixed ICP power, RF-bias power and discharge pressure, the average energy of the IEDs increases with increasing coil current ratio as shown in figure 3.

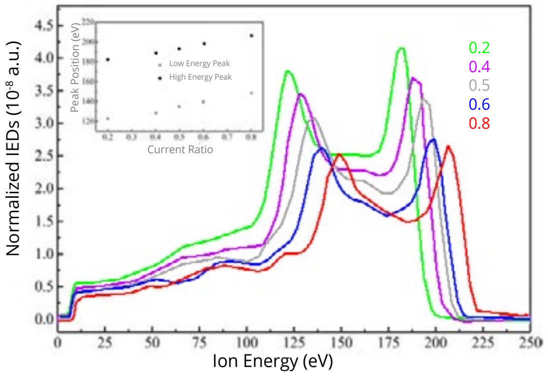

Figure 3 Effect of current ratio on the normalized IEDs.

Finally, the ion flux and the associated sputter etch rate were investigated for the RF-biased pedestal case. Figure 4 shows the variation in ion flux as a function of each of the main control parameters separately (RF-bias power, ICP power, discharge pressure and coil current ratio) with all other parameters held constant. The ion flux increase with increasing RF-bias power and increasing ICP power. The ion flux decreases with increasing discharge pressure and increasing coil current ratio.

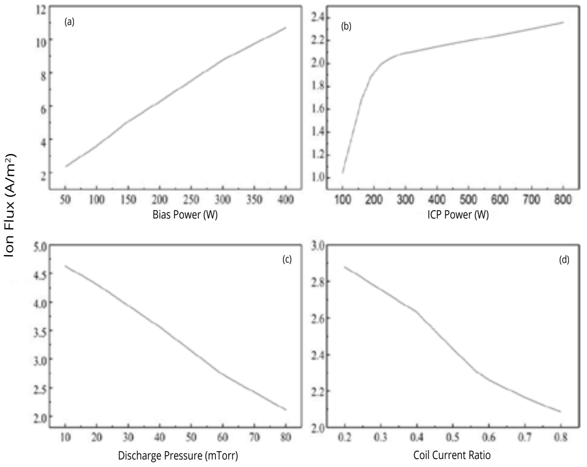

Figure 4. Axial variation of the electron density as a function of pressure at 2MHz and 13.56MHz as measured experimentally and calculated using the simulation.

In figure 5 the sputter etch rate for SiO2, calculated from equation 5, is plotted for the same control parameters. The sputter etch rate increases with increasing RF-bias power. The etch rate decreases with increasing ICP power, discharge pressure and coil current ratio. For the range of conditions investigated the etch rate was in the range from 20 – 150 A/min.

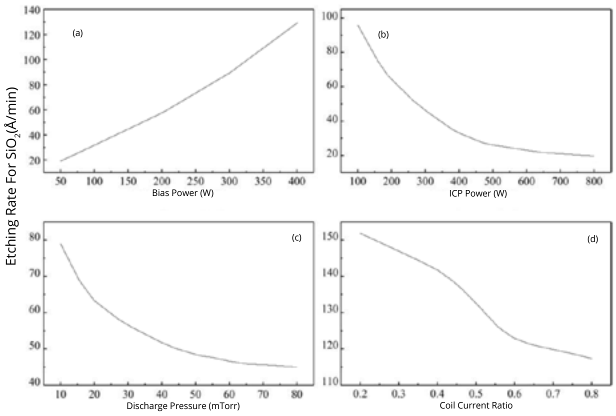

Figure 5. Sputter etching rates obtained by the ion-enhanced etching model plot as function of discharge condtions.

CONCLUSION: The Impedans Langmuir probe and Semion systems were used to study the ion energy distribution, ion flux and sputter etch rate of SiO2 in an industrial ICP reactor with RF-biased pedestal for various discharge conditions. The data allowed the user to carry out a detailed correlation between these measured parameters and etch rate. This gives insight into how the etch rate can be finely tuned in this type of reactor.

REFERENCES

* Chuankun Han, Yiyong Yang and Weifeng Liu

“Experimental Study of SiO2 Sputter Etching

Process in 13.56 MHz RF-biased Inductively Coupled Plasma.” SPIN, Vol. 8, No. 2 (2018) 1850002