Effect of substrate biasing on the ion properties of a magnetron sputtering system using Impedans' Semion RFEA System and Octiv Suite 2.0 VI Probe

INTRODUCTION

Magnetron sputtering is an important technology for deposition of thin films. The substrate bias is one of the most important methods used to control the structure and properties of the film. Through plasma-surface interactions, the growth rate and properties of films can be improved. This work investigates how the biasing affects the ion properties within the plasma.

EXPERIMENTAL SETUP:

This experiment was carried out using a 2 MHz RF magnetron sputtering system that has a 13.56 MHz substrate bias. Figure 1 shows the schematic of the system. In this system, the water-cooled circular Ag target (diameter of 50 mm) was used as the discharge cathode, placed at the top of chamber. The electrically floating substrate holder (diameter of 100 mm) was installed at the bottom of chamber, 70 mm away from the centre of the target.

The measurement of IVDF was carried out using an Impedans Semion retarding field energy analyser (RFEA) System at the substrate holder while an Impedans Octiv Suite 2.0 V–I probe, connected between the matching box and Ag target or between the matching box and the substrate holder , was used to measure the electrical characteristics of magnetron discharge and substrate bias discharge, including the discharge current, discharge voltage,

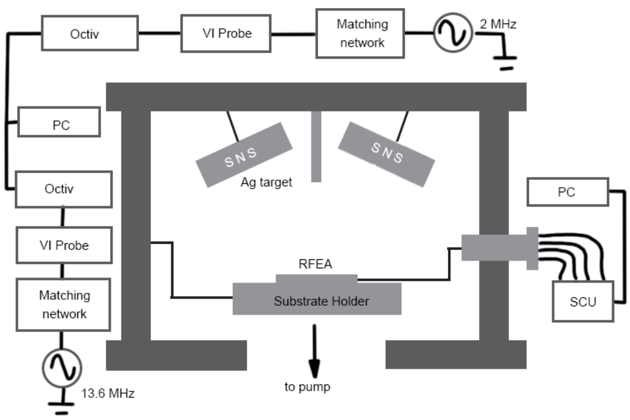

Figure 1. IVDF for driving frequencies ranging from 2 MHz to 60 MHz.

discharge power, and impedance characteristics. This V–I probe was suitable for a RF power range of 200 mW – 12.5 kW, the voltage (root mean square value) range of 20–3000 V, the current (root mean square value) range of 0.1-100 A, and the impedance range of 1–500 Ω at five fundamental frequencies (2, 13.56, 27.12, 60 and 100 MHz).

RESULTS:

The electric characteristics of the Ag target, 2 MHz magnetron discharge were first analysed in terms of the V–I probe measurements. Figure 2 shows the current–voltage (I–V) characteristic of the magnetron discharge. At 5 Pa the IV characteristic follows a power law form of $I=k V^n$, with n=3.5. When the pressure is reduced to 1 Pa the exponent decreases to 2.75 with the power law only being followed for discharge currents ≥0.5A. Usually, the IV characteristics of target

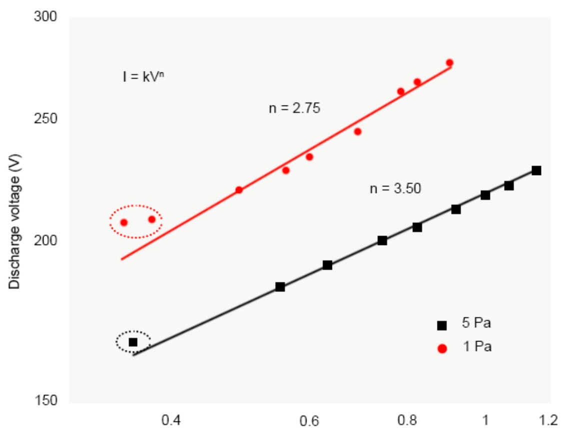

Figure 2. Log(I)-Log(V) curves of 2 MHz magnetron sputtering at 5 Pa and 1 Pa.

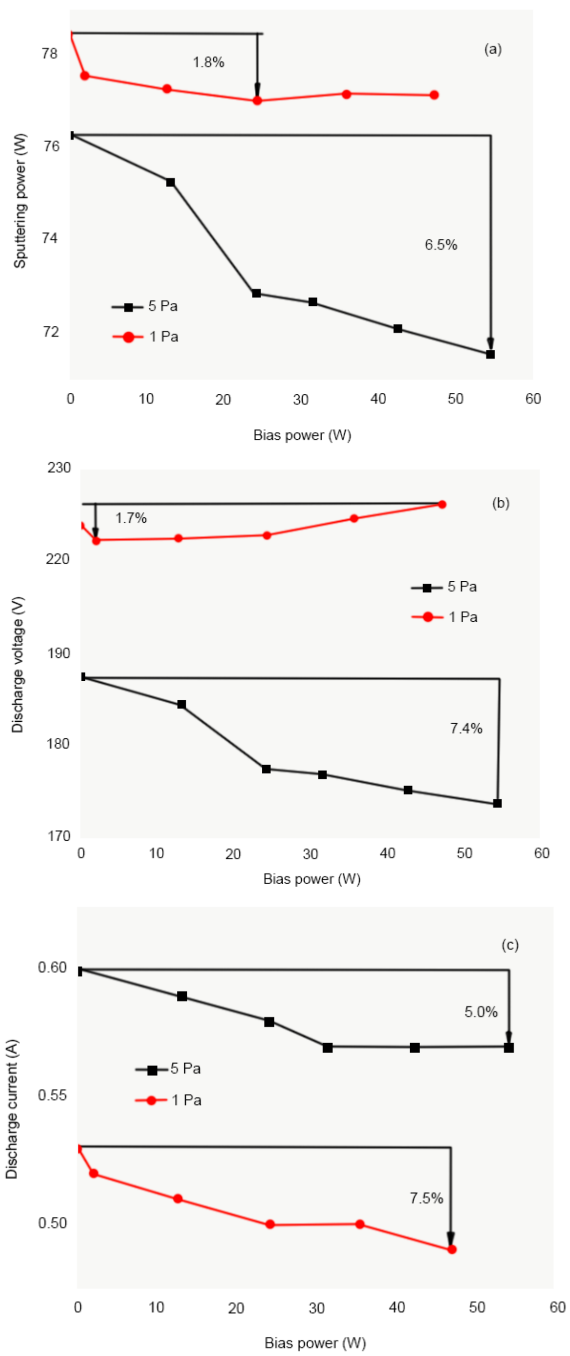

Figure 3. Effect of the bias power on the (a) sputtering power, (b) discharge power and (c) discharge current at 5 Pa and 1Pa.

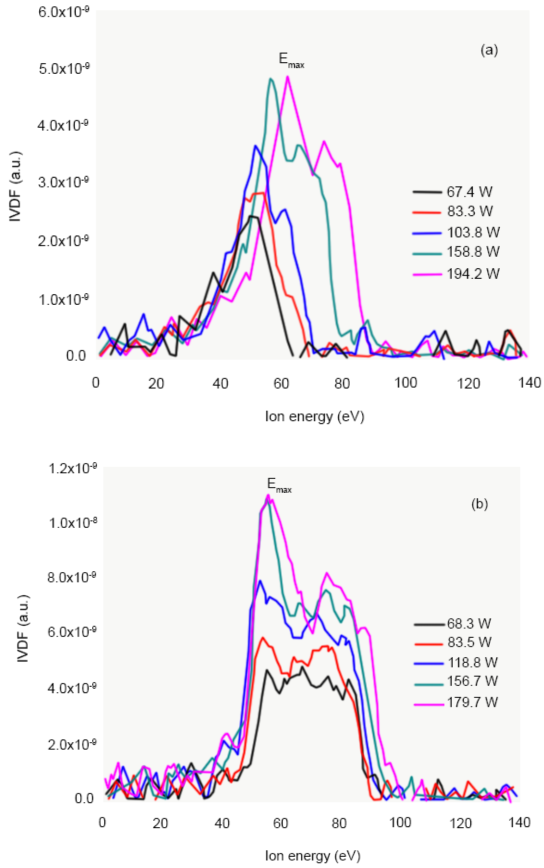

Figure 4. Variation of IVDFs with sputtering power (without bias) at (a) 5 Pa and (b) 1 Pa.

discharges follows the power law with the exponent in the 4 - 10 range for a DC magnetron sputtering system and in the 1 - 3 range for an RF magnetron sputtering system. The sputtering indicates the effectiveness of electron confinement which has a large influence on the production of ions near the target and hence on the sputtering properties.

Figure 3 shows the effect of the 13.56 MHz bias power on the electrical characteristics of the Ag target. At 5 Pa the power and voltage decrease rapidly in the bias power range of 0 to 24.2 W, then decrease slowly while the current decreases rapidly over the larger range 0 to 31.5 W. At 1Pa the trend is different with only a slight decrease in power, a slight increase in the voltage and a large decrease in the current.

Figure 4 shows the IVDFs of 2 MHz RF sputtering discharge without substrate bias. At the pressure of 5 Pa, the IVDFs show a broad unimodal shape at sputtering powers below 83.3 W, and then evolve into a bi-modal structure, and the energy peaks shift to higher energy. As the pressure reduces to 1 Pa however, at the sputtering power of 68.3 W,

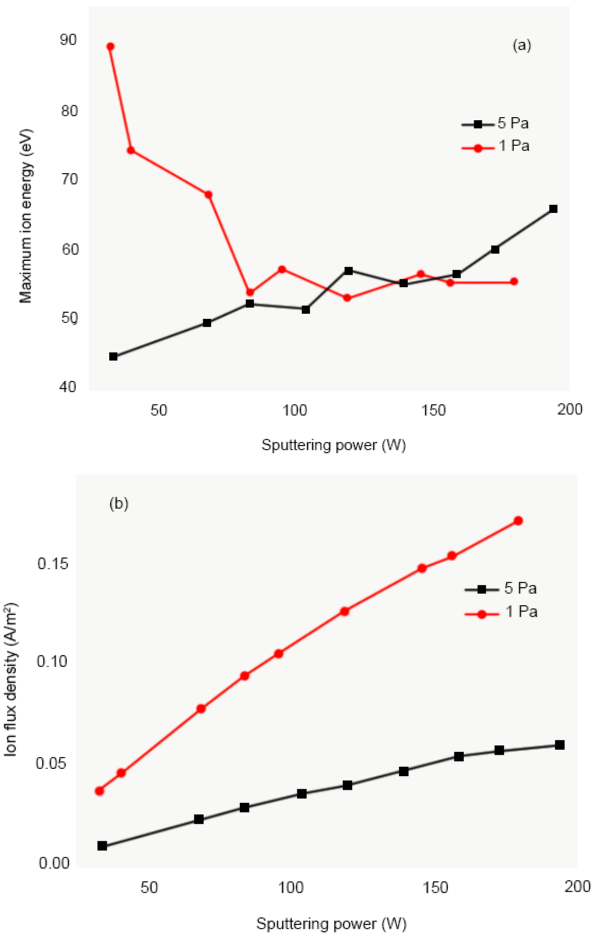

Figure 5. Variation of (a) Max Ion energy and (b) Ion Flux with sputtering power (with bias) at 5 Pa and 1 Pa.

the IVDFs show a wide multi-modal shape across the energy range of 45 – 90 eV. With the sputtering power increase, the IVDFs evolve into a bi-modal structure, the peak widths increase slightly in the low-energy and high-energy regions, but with less shift of the main peak energy. Therefore, the increase of sputtering power led to a bi-modal structure of the IVDF, while the reduction of pressure led to a broadening of the IVDF.

Figure 5 shows the variation of the maximum ion energy (energy at maximum peak) and ion flux obtained from the RFEA against the sputtering power. It can be found that with a sputtering power increase, at the pressure of 5 Pa, the maximum ion energy shows an increasing trend, but at the pressure of 1 Pa, the maximum ion energy decreases at sputtering powers below 83.5 eV and then varies around 55.5 eV. The ion flux densities all increase with sputtering power increase, but the ion flux density at the pressure of 1 Pa is about three times higher than that of 5 Pa. Therefore, the pressure and sputtering power have an obvious influence on both the ion energy and

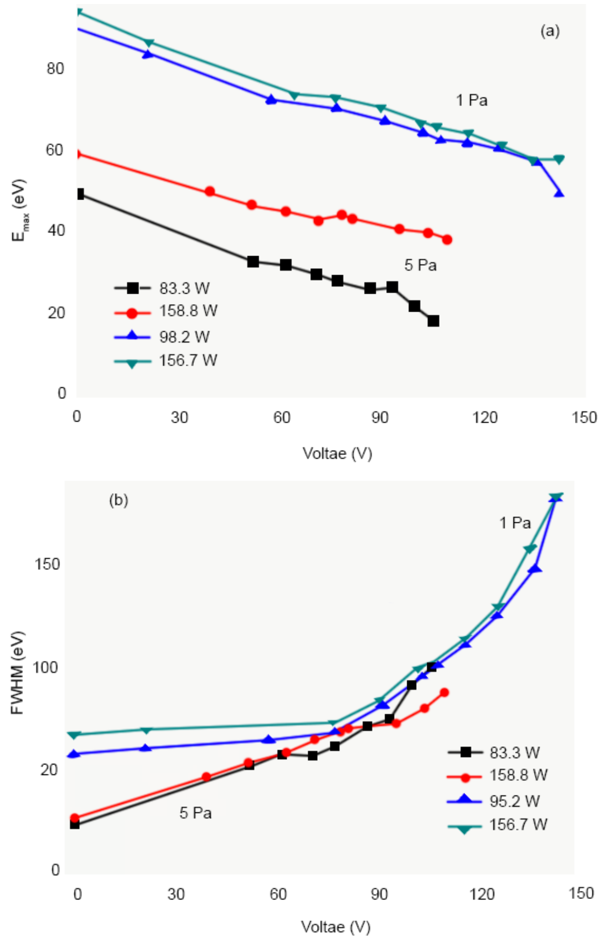

Figure 6. Variation of E_{max} and (b) FWHM with bias voltage.

ion flux density onto the substrate. To obtain a clear relationship between substrate bias and IVDF, the variation of maximum ion energy E_{max} and full width at half maximum (FWHM) of a Gaussian function fitted to the IEDF's with the bias voltage were obtained, as shown in figure 6. E_{max} and FWHM characterise the most probable ion energy and the broadening of the IVDF, respectively. It is found that the increase in bias voltage leads to a decrease of E_{max} and an increase of FWHM. The decrease of E_{max} means athe decrease of the most probable ion energy, while the increase of FWHM means athe broadening of the IVDF, as well as the increase of low-energy and high-energy ions.

The RF substrate bias has an influence on the ion flux onto the substrate. At a pressure of 5 Pa, the ion flux increases with bias voltage increase, as shown in figure 7. At a pressure of 1 Pa however, the ion flux increases with the bias voltage until about 100 V, then decreases with increasing bias voltage. In addition, the ion flux is influenced by the discharge pressure. At 1 Pa the ion flux is at least double that at 5 Pa for similar sputtering powers. Therefore, substrate bias can also lead to the

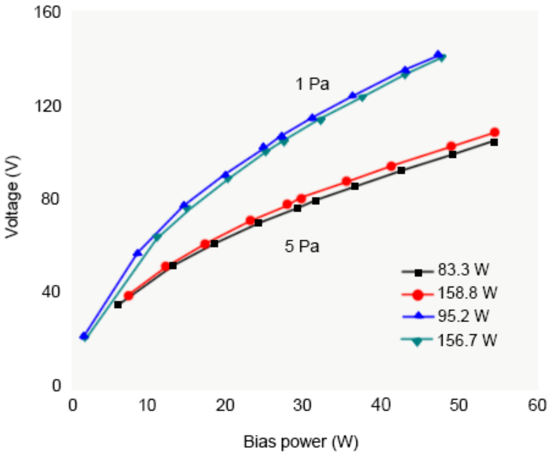

Figure 7. Discharge voltage on the substrate versus bias power for different sputtering power at 5 Pa and 1 Pa.

increase of ion flux density onto the substrate.

Figure 7 shows the variation of bias voltage versus bias power. As expected for all sputtering powers and pressures the bias voltage increases with bias power. The average sheath potential increases with bias voltage which leads to an increase in sheath width. It can also be seen that if the pressure decreases, it leads to an increase in the discharge voltage.

CONCLUSION:

This work investigated the effect of a 13.56 MHz RF substrate bias on the ion properties and sputtering behaviour of a 2 MHz magnetron discharge. The electric characteristics of the target and bias discharges using an Impedans Octiv Suite 2.0 (V-I) probe. The maximum ion energy and ion flux were measured at the substrate from the IVDF by an Impedans Semion retarding field energy analyser. For the 2 MHz magnetron sputtering discharge without substrate bias, bimodal IVDFs were obtained. The 13.56 MHz substrate bias led to the increase of ion flux, the broadening of IVDFs, and the divergence of ion energy onto the substrate. This effect was further enhanced by increasing bias power and reducing discharge pressure. Therefore, the increase in the number of ions bombarding the grown films should be related to the energy density on the substrate, depending on both the ion energy distribution and the ion flux. The substrate bias discharge also had influence on the Ag target discharge, led to the decrease of sputtering power and discharge voltage. Therefore, the substrate bias can have an important influence on both IED, ion flux onto the substrate and the sputtering behaviour.

REFERENCE:

* Zhu M. et al "Effect of radio-frequency substrate bias on ion properties and sputtering behaviour of 2 MHz magnetron sputtering"

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