The Effects of Erosion Groove on Radiofrequency Magnetron Sputtering

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The erosion groove has an effect on the electrical characteristics and deposition rate of magnetron sputtering. These effects are highlighted by electrical measurements and deposition rate. The groove lowers the self-bias voltage by 50% and increases the ionic current density at substrat holder by 30%. Deposition rate decreases by 60% with eroded target and become pressure dependent.

1. Introduction

Magnetron sputtering has experienced a rapid development in recent years [1]. The development of magnetrons remains a topical area in spite of the numerous studies in recent decades. Nevertheless much remains to be done on understanding target erosion effects. As is well known, a magnetron sputtering erodes nonuniformly. Several authors have raised the effect of the target surface state on the sputtering rate and the properties of the deposited films and plasma characteristics [2]. An eroded target affects the characteristic voltage-current [3]. Among the means for measuring and monitoring the effect of target erosion on the characteristics of plasma magnetron sputtering, we may mention the measurement of the excitation voltage present at the input of the magnetron source, which is the simplest and best known. Minea [4] had made a systematic investigation of the role played by the target material, on the power coupling to the discharge in radiofrequency (RF) planar magnetron. The objective of this work is to experimentally study the effect of target erosion groove on electrical and depositing parameters of a RF magnetron sputtering. The study will be based on electrical measurement of plasma impedance, ion current density impinging the growing film and also on deposition rate. The results is a comparaison between a non eroded (*NE*) and an eroded (*E*) target in function of the pressure and the power supply parameters.

2. Experiments

The measurements were carried out in a cylindrical reactor chamber, it is equiped with a 3 inch target copper magnetron source and an anode (substrat holder) of 98mm diameter. The magnetron-anode separation is 75mm. A planar probe of 9mm diameter ,imbeded in the the anode, is used to measure the ion current density I_s. The magnetron is excited by a RF source of 13.56 MHz for power ranging from 50 to 300W. The parametric study will be in function of the pressure of argon gases (0.1 to 5Pa). The plasma is represented electrically by a simple equivalent serie impedance Z_p (=R_p+jX_s) [5]. The resistive part R_p represents plasma conduction. The reactive part X_s is related to the ionic sheath voltage drop V_{dc} essentially at the target surface. The impedance Z_p and the power absorbed by plasma P_{abs} are calculated by the measurement of RF electrical current I_{rf} and voltage V_{rf} using an RF current-voltage sensor. The deposition rate is obtained by weighing the deposited layer.

3. Results and Discussion

3.1. Self-bias voltage V_{dc}

In Fig. 1, we see that the voltage V_{dc} is slightly insensitive to pressure variation (0.5 to 5Pa). Its value is lower for *E* target. This gap is particularly important at high power. This area called the erosion zone will be digged more and more during its use to form a deep trench. Madsen [6] has observed a decrease of V_{dc} with racetrack depth. Nearly towards the end of the target utilization as in our case, V_{dc} had decreased by 100%, this is due to a combination of different factors. The first one is due to the presence of higher magnetic field at the bottom of the trench, as it's closer to the permanent magnets. As the voltage decreases with B_r [7], it results a lowering of V_{dc}.

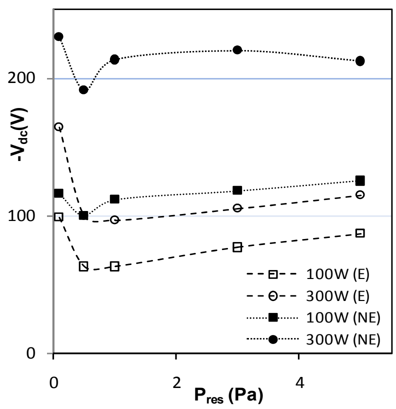

Fig. 1. Evolution of the self-bias V_{dc} versus pressure P_{res}.

The second main cause of the sharp decrease in the voltage V_{dc} from a certain pressure is related to hollow cathode effect (*HCE*) induced by the trench. That is, the plasma penetration into the hollow trench and the electron oscillation in it are needed to effectively ionize neutral gas. Therefore, it is required that the hollow trench width *W* to be more than twice the sheath thickness d_s ($W>2d_s$) for the hollow cathode effect to be present [8]. The other effect of decrease of V_{dc} in the range of P_{res} (0.1Pa to 0.5Pa), and not linked to the trench, as observed in Fig. 1 for the case of *NE* target, is due to the transition from heating mode that passes from combined α (wave-riding) and γ (stochastic) heating for low pressure to the γ regime [4]. Beyond the transition pressure due to the *HCE* effect, a slight increase of V_{dc} with pressure is noted. Simon observed the same increase in his article [9].

3.2. Ion current density I_s

The ionic I_s currrent density is a very important parameter in deposition applications, as it affects the growing layer. Its value must be at least upper to 1mA/cm^2 to have a detectable effect on growing films. The current I_s increases with RF power for both *E* and *NE* target and decreases with pressure (Fig. 2). Voevodin [10] had observed the same decay with pressure. I_s is higher for *E* target due to *HCE* and the difference is more prononced at high RF power P_{inc}. The ionization rate does not vary with pressure [11], thus the decreasing of the ion current density, is due to scattering which increases with the pressure.

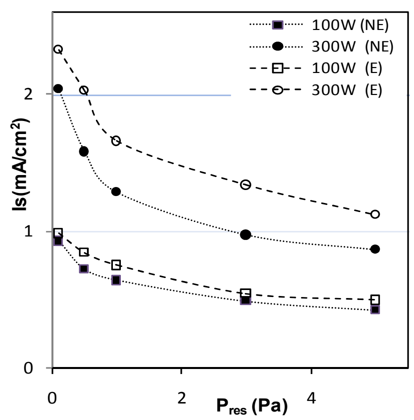

Fig. 2. Ionic currrent density I_s versus pressure P_{res} for *E* and *NE* target for input power P_{inc}: 100W, 300W.

3.3. Plasma impedance Z_p and power efficiency η

The discharge can be characterised electrically by an equivalent serie impedance with resistance R_p and capacitance C_s. The resistance R_p accounts for the electron heating in the plasma body and ion acceleration loss in the sheaths, whereas C_s relates to the RF sheath thickness [12]. The evolution of the two parameters R_p and X_s (α 1/Cs) is not pressure dependent (Figs. 3 and 4), except at lower pressures (<0.5Pa). We could see also that the effect of erosion groove does not appear at very low pressure 0.1Pa. These two parameters vary with the power supply and especially for the *E* target.

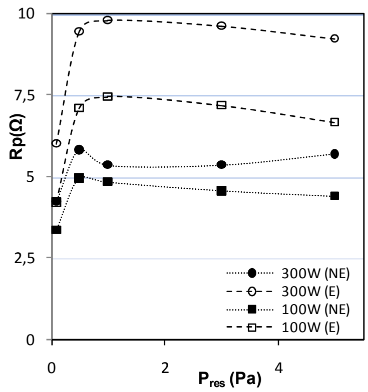

Fig. 3. Resistance R_p of plasma versus pressure P_{res} for *E* and *NE* target; P_{inc}: 100W, 300W.

R_p increases wheras X_s decreases with target erosion, the plasma becomes more resistive and less capacitive. The sheath thickness becomes larger, which leads to a smaller V_{dc}, changing with the progress of erosion groove, and this change is significant even at low power P_{inc}.

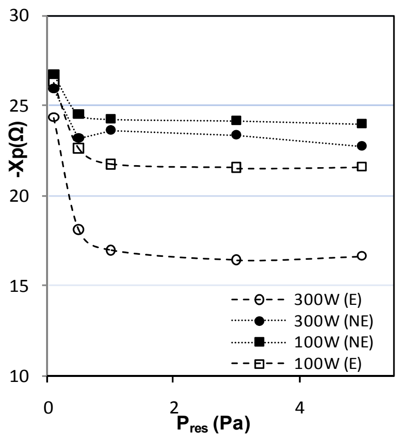

Fig. 4. Reactance X_s of plasma versus pressure P_{res} for *E* and *NE* target; P_{inc}: 100W, 300W.

The erosion affects the plasma impedance (Figs. 3 and 4). Its value varies during the life of the target, which revealed a change in plasma parameters and also in the matching network between power supply and the ionization chamber. We see that at P_{inc}=300W R_p has almost doubled and X_s decreased by nearly 30%. In Figs. 5 and 6 we find the same jump between 0.1Pa and 0.5Pa as for V_{dc} (Fig.1). The two parameters R_p *and* X_s, could be used as a means of monitoring the state of erosion.

We define the power transfer efficiency ($\eta = P_{abs}/P_{inc}$) as ratio of the absorbed power P_{abs} by plasma and the injected power P_{inc}. η is slightly constant and not pressure dependent (Fig.5). Its value is greater for an *E* target (90%) with an increase of about 10% for low power relative to *NE* target. For very low pressures <0.5Pa, its value is low for both cases and that whatever the incident power value P_{inc}. The plasma is less capacitive for the *E* target (Fig. 4), thus a lower current displacement, which gives a lower ohmic loss in the parasitic resistive elements of the reactor and the connections.

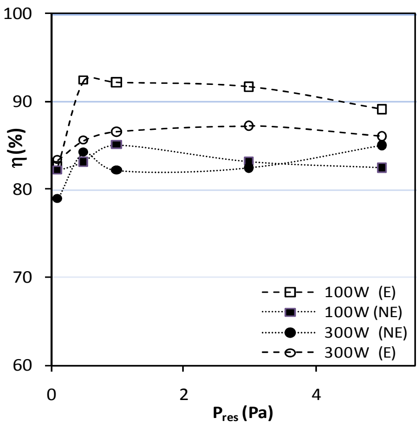

Fig. 5. Power efficiency versus pressure P_{res} for P_{inc}:100W and 300W.

3.4. Deposition rate a_d

We can see clearly (Fig. 6) that the deposition rate a_d decreases with pressure. This would be expected as at high pressures since the sputtered atoms have a shorter mean free path and are, therefore, less likely to arrive at the substrate. Ekpe has developed a model which shows that the copper deposition rate decreases slightly with pressure from 1 to 10 Pa [13]. But its evolution depends on the target profile (Fig. 6). For *NE* target a_d is slightly dependent on pressure, while it decreases more faster for an *E* target, by almost 42% at 5Pa. Knowing that the deposition rate depends on the energy of ions bombarding the target, its lowest value for an *E* target is due primarily to the weakness of self-bias V_{dc}. The side wall of the groove in the racetrack area expands the sputtering particules flux profile, leading to the less deposition rate. Increasing the working gas pressure accentuates also the diffusion of particles flow [14].

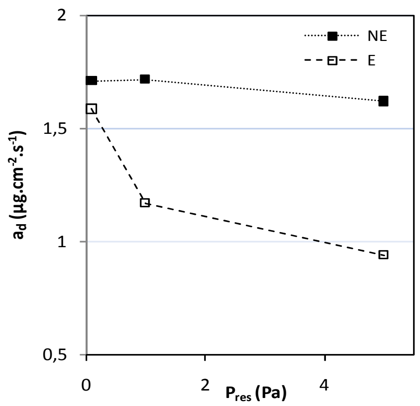

Fig. 6. Deposition rate a_d versus pressure for *E* and *NE* target (P_{inc}=200W)

Fig. 7 shows the evolution of the ratio (I_s/a_d) of the ion flux on the flux of particles emitted by the target and arriving at the anode versus the pressure. First we notice that this ratio decreases for both *E* and *NE* target, but with a more rapid decrease with *NE* target. The ratio is lower for *NE* target. This is due to the fact that the ionic flow *Is* had increased by 27% (Fig.2) while the particles flux had decreased by almost 42% at 5Pa (Fig. 6). This explains the changes of growing layers characteristics observed [2], as a result of progress in target erosion.

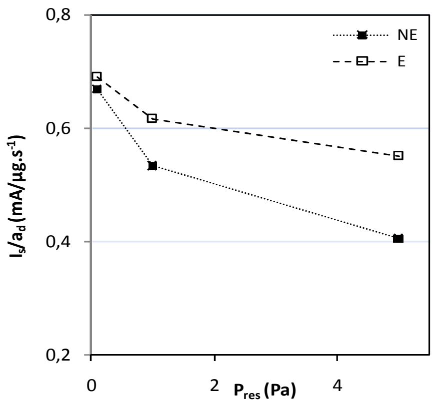

Fig. 7. Ratio I_s/a_d versus pressure for *E* and *NE* target (P_{inc}=200W)

4. Conclusion

The formation of the erosion groove leads to continuous drift of electricals and depositing parameters of the magnetron sputtering. The erosion effect appears from a certain critical pressure and to fairly high power. It is related to the hollow cathode effect induced by groove deepth located in the area where the magnetic field is parallel to the target. It is also linked to the presence of the largest magnetic field at the bottom of the trench. The plasma becomes more resistive and less capacitive which will induce a decrease in the displacement current resulting less ohmic losses and thus a slightly higher yield. The density of the ion current on the growing film rises. The deposition rate is reduced due to the decrease in the self-bias voltage. But the ratio of the ions flux on the sputterred particles flux arriving on the growing layer is more important for eroded target. As the electrical equivalent impedance plasma changes with erosion, measuring its value can be used as non-intrusive means of control and state monitoring of target erosion and plasma.

5. References

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