Effects of Magnetic System Unbalance on Magnetron Sputtering Characteristics

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Deposition rate and ion current density distribution profiles at DC magnetron sputtering of Al, Ti and Cu targets were studied as functions of the process parameters and level of magnetron unbalance. Based on the experimental data the distributions of the ion-to-atom ratio on the condensing surface under various deposition modes were calculated. It was established that in the case of DC magnetron sputtering the ion-to-atom ratio on the condensing surface increased if the sputtering yield of the target's material dropped down. The minimal energy impact on the growing film and the most uniform distribution profile of the ion-to-atom ratio were achieved by applying the I-type unbalanced magnetron system.

Keywords: magnetron sputtering, deposition rate, substrate's ion current, ion-to-atom ratio

1 INTRODUCTION

In microelectronics the magnetron sputtering has been widely used for over three decades for deposition of thin films of various functional applications. Lately, the magnetron sputtering has also been employed to deposit hard, wear-resistant, anti-corrosion and decorative coatings, as well as the films with specific optical or electrical properties [1]. Depending on the type and the functionality of the coating, a number of rather controversial requirements are posed to the magnetron in different cases. For instance, low-energy ion bombardment of the substrate, being one of the features of the magnetron sputtering process, can significantly affect the structure and the properties of a growing film [2]. The ion bombardment negatively affects the properties of the deposited layers of transparent conducting oxides, superconductors and ferroelectrics [3]. Therefore, in some cases minimum energy impact on the growing film must be ensured at magnetron sputtering. However, there has been virtually no reference in literature to the correlation between unbalance level and characteristics of magnetron sputtering. Thus, the objective of this article is to investigate the impact of the discharge characteristics and the magnetron's unbalanced system of magnets on the ion-to-atom ratio observed on the condensing surface.

2 EXPERIMENT

Fig. 1 illustrates the experimental setting for studying the characteristics of the magnetron sputtering system (MSS). The setting is based on the VU-2 vacuum plant. The vacuum chamber is equipped with an internal MSS with additional coil MAC-80 of an original design.

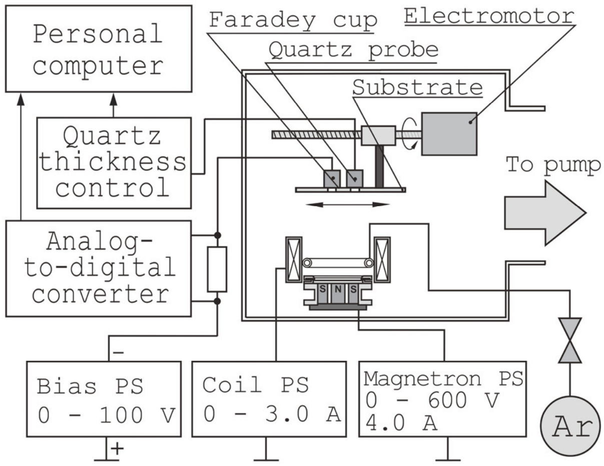

Fig. 1: Experimental setting for studying the characteristics of the magnetron sputtering system

The main magnetic trap in that MSS is formed by the magnetic system on permanent magnets. The additional coil is used to control the distribution of magnetic field in the target–substrate region and as a consequence vary unbalance level of a magnetron. Depending on direction and an intensity of an additional coil magnetic field, was determined the system operation unbalance mode (I- or II-type) [4, 5]. For registration of the substrate's ion current density and the deposition rate distributions in progress, the vacuum setting was equipped with the linear displacement system with the water-cooled quartz sensor and ion current probe. The signal from the quartz sensor was converted using the quartz thickness controller, and was further sent to a PC via a digital data transmission buss RS232. The ion current density was measured using a Faraday-cup single probe. A negative bias potential was applied to the probe to repel the electrons. The sensor signal was converted with an analog-to-digital converter (ADC) and sent to the PC. The vacuum chamber was pumped to a base pressure of 10^{-3} Pa, and Ar was fed into the magnetron gas distribution system. During all the experiments the Ar flow rate was kept constant at the level of 65 sccm, whereas the working pressure in the chamber remained at 0.065 Pa. Discs of Ti (99.9 % purity), Al (99.96 % purity) and Cu (99.9 % purity) ∅ 80 and 5.0 mm in thickness were used as the magnetron targets. The DC power supple having 1300 W at the maximal power out-put was employed to supply power for the magnetron. The magnetron discharge current I_t ranged from 0 up to 4.0 A. The discharge current stabilization mode was used for all the experiments. In order to alter the extent of unbalance the additional coil current I_c was varied from –0.2 to 0.5 A. During the experiments the probes were placed at the distance of 115 mm from the target surface.

3 RESULTS AND DISCUSSION

In the series of DC magnetron sputtering of Al, Ti, and Cu targets it was studied how the process parameters and the extent of magnetron's unbalance affect the deposition rate distribution profiles. As different metals were sputtered, it was established that the deposition rate varied almost proportionally to the magnetron's discharge current (Fig. 2). Normalization of the deposition rate profiles, obtained at various discharge currents, proved practically complete coincidence of the profiles describing a certain material. However, the deposition rate profiles demonstrated dependence on the type of the sputtered materials. Evidently, that can be accounted for unequal angular distribution of sputtered particles when various materials are being sputtered [6]. As the additional coil current (unbalance level) increased, negligible changes were observed in the profiles, and the deposition rate at the magnetron's axis was noticed to drop at constant discharge current (Fig. 3). That process can be associated with a transformation of the sputtering area caused a changing balance of magnetic flows from the outer and central magnetic cores. When the working pressure was varied from 0.04–1.20 Pa the deposition rate for all the studied materials remained almost unchanged. That evidenced the absence of considerable thermalization at given range of pressures.

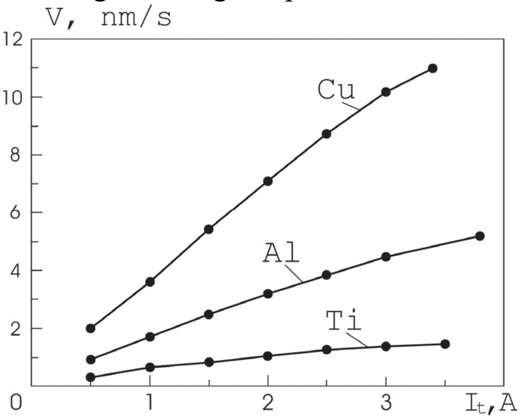

Fig. 2: Magnetron axis deposition rate as a function of discharge current for various types of materials

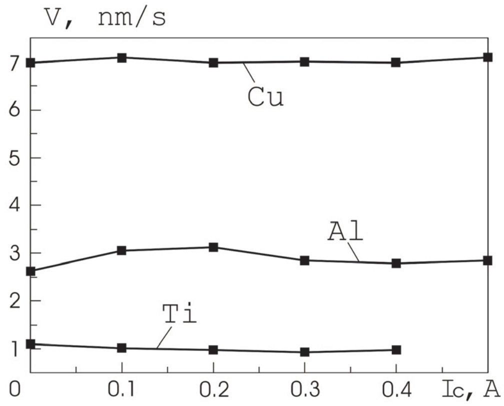

Fig. 3: Magnetron axis deposition rate as a function of the additional coil current for various types of materials (I_t = 2.0 A)

For the same target materials, the ion current density distributions were obtained as functions of the sputtering process parameters and the extent of magnetron's unbalance. It was established that for all the target materials under study the ion current density at the magnetron's axis grew proportionally to the discharge current and the coil current. As various target materials were being sputtered, the comparison of the ion currents proved that the ion current density was determined by the type of the sputtered materials. For instance, in case of the Cu target the ion current density at the magnetron's axis reached 2.5 mA/cm^2, and under the same conditions increased more than 2 times the ion current of Ti or Al targets (Fig. 4). If the additional coil current (unbalance level) grew the ion flow focusing was observed (Fig. 5). At the same time the ion current density at the edges of the discharge area remained practically at the same level.

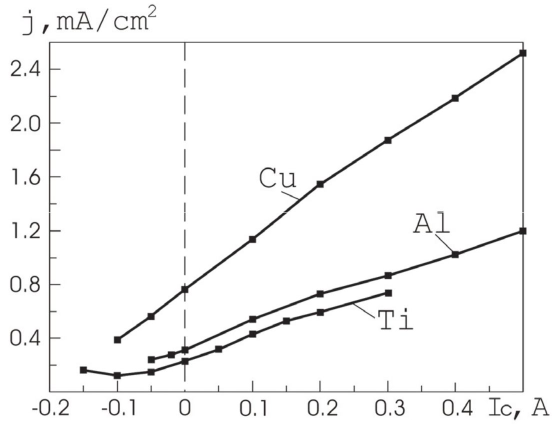

Fig. 4: Ion current density on the magnetron axis as a function of additional coil current for various type of materials (I_t = 2.0 A)

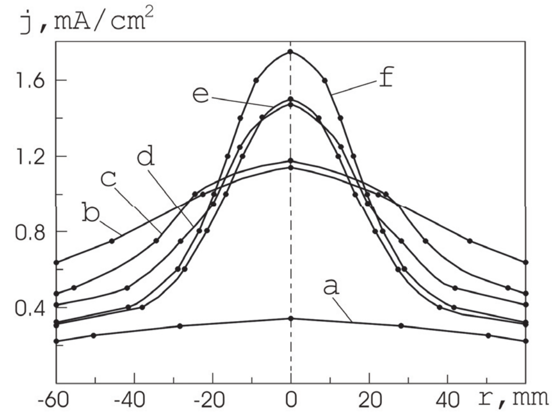

Fig. 5: Distribution of the substrate ion current at magnetron sputtering of Cu target for various additional coil currents

Based on the experimental data obtained, the distribution profiles for the ion-to-atom ratio on the condensing surface were calculated for various deposition conditions. It was proved that in case of DC magnetron sputtering the ion-to-atom ratio on the condensing surface increased if the sputtering yield of the target material dropped down (Fig. 6). When the additional coil current was negative –0.1 A (I-type unbalance) the ion-to-atom ratio for all the sputtering conditions and materials under study did not exceed 0.15 and had the most uniform distribution. That behavior resulted from the electron flow deviating from the substrate area in a form of a radiating magnetic field, bringing about low-density plasma in the substrate area.

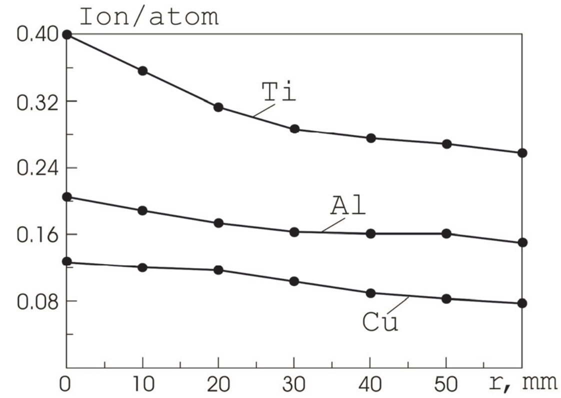

Fig. 6: Ion-to-atom ratio distribution on the condensing surface for various types of materials

4 CONCLUSION

The study of the deposition rate and ion current density profiles at DC magnetron sputtering have shown that the deposition rate varies proportionally to the discharge current and practically does not depend on the unbalance level of the magnetron, whereas the ion current density is determined both by the discharge current and the unbalance level of the magnetron. At the same time the ion-to-atom ratio at the condensing surface is increased when the sputtering yield of the target material goes down. The minimal energy impact on the growing film and the most uniform distribution profile of the ion-to-atom ratio is achieved in the case of I-type unbalance. This MSS operation mode can be used to deposit transparent conducting oxide, superconductor, and ferroelectric thin films.

REFERENCES

[1] Kelly P J, Arnell R D, Vacuum 56 (2000) 159-172.

[2] Kester D J, Messier R, J Mater Res. 8 (1993) 1938-1957.

[3] Colligon J S, J Vac Sci Technol A 3 (1995) 1649-1657.

[4] Svadkovski I V, Golosov D A, Zavatskiy S M, Vacuum 68 (2003) 283-290.

[5] Golosov D A, Svadkovskii I V, Zavadskii S M Surf Eng Appl Electrochem 6 (2002) 56-64.

[6] Ekpe S D, Dew S K, J Vac Sci Technol A 21 (2003) 476-483.