Film thickness distribution in magnetron sputtering system with the round cathode

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Abstract –Thickness distribution of the substrate-disposed film deposited by magnetron sputtering system with a round-cathode was calculated by means of an analytic formula. The formula contains the function Ψ(r) describing the cathode erosion rate that was deduced from the profile of the erosion groove obtained at this cathode. It was established that spatial distribution of the sputtered atoms was described by the expression $\cos^{0,7}(\theta)$. Close coincidence of the calculated distributions of the film thickness with the experimentally obtained ones was shown. It was found out that the latter weakly depended on the operating gas pressure and discharge power in the investigated regions equal to 0.12 - 0.4 Pa and 0.8 - 2.5 kW, respectively.

1. Introduction

Magnetron sputtering is a widely spread method of the thin-film coating deposition. One of its advantages is possibility to obtain coatings with a high degree of their thickness uniformity (± 1-5 %) [1]. Uniform coatings of this type are necessary in many fields of science and engineering, e.g., in microelectronics, optical industry, etc.

However, because of the specific character of magnetron sputtering systems, at a simple deposition of films onto fixed substrates the thickness nonuniformity of these films is very high owing to inhomogeneity of the target erosion rate caused by the presence of the arched magnetic field over its surface. The main decision of this problem is the substrate displacement during sputtering. The screens correcting spatial distribution of the sputtered atoms or special constructions of magnetron magnetic systems are used in some cases.

Particle transport in the magnetron sputtering systems and resulting thickness distribution of the deposited film were the subject of investigations in many publications. Calculations made both by Monte Karlo method [2-4] and by means of the analytical formulae [5-7] were used in them.

This paper presents a model for calculation of the thickness distribution of the coating deposited by a planar magnetron with a round-target. Comparisons of calculation results with the experimental ones were carried out. It is expected that this calculation method can be used to forecast uniformity of coating depositions by other magnetron sputtering systems as well.

2. Experimental

Experiments on the coating deposition were carried out in the 600×600×600 мм^3 vacuum chamber equipped with a magnetron sputtering system. Fig. 1 presents the schematic diagram of this system. The magnetron cathode was a 120-мм diameter and 8-mm thickness Zr disc. Magnetic field over the cathode surface was generated by a magnetic system based on permanent magnets made of NdFeB alloy. The internal Magnet 1 was made in the form of a ring and had the internal diameter of 40 mm, the external diameter of 60 mm, and the height of 10 mm. The same parameters of the external Magnet 2 were equal to 85, 100 and 10 mm, respectively.

Coating deposition was carried out in the argon atmosphere onto the glass substrates that were installed at a 8-cm distance from the magnetron. The following parameters were changed: pressure in the chamber (from 0.12 to 0.4 Pa), discharge power (from 0.8 to 2.5 kW). Two cathode types were used: a new cathode and a cathode having a deep erosion groove formed after several hours of magnetron operation. Fig. 2 presents the profile of the groove. The coating thickness at a substrate was measured by the interference microscope MII-4.

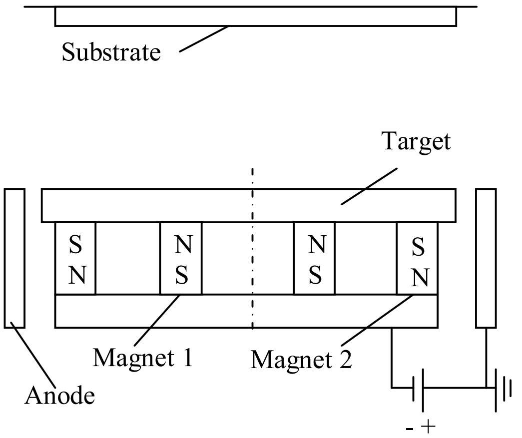

Fig. 1. Schematic diagram of the magnetron with the round target.

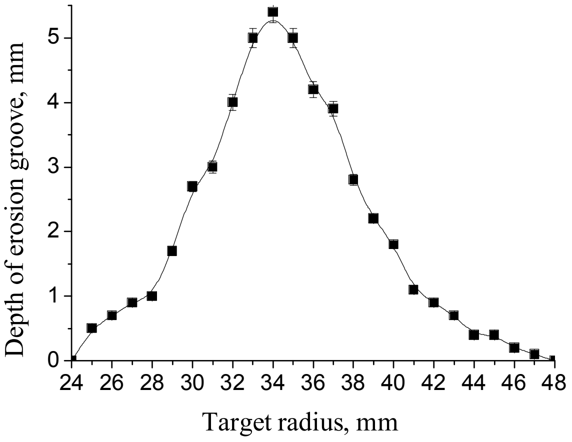

Fig. 2. The profile of erosion groove.

3. Results

Thickness distribution of the deposited films is proportional to their growth rate at each point of the processing surface. The film thickness distribution *T* in magnetron sputtering systems can be determined in the general form by the following equation:

$$T = \int_0^{2\pi}\int_0^R \Psi(R)\cos^n(\theta)R/c^2 dRd\varphi \,, \qquad (1)$$

where $c^2 = a^2 + b^2$, $b^2 = R^2 + r^2 - 2Rr\cos\varphi$. All geometrical parameters are presented in Fig. 3. Spatial distribution of the flow of sputtered atoms is characterized by the expression $\cos^n(\theta)$. The cathode erosion rate is described by the function Ψ(r).

Formula (1) is applicable is case of a free flight regime of atom transfer. This regime is observed at the pressure less than 1 Pa and characterized by straight-line collisionless motion of the sputtered atoms towards the substrate [8]. At high pressures the length of the atom free path becomes essentially less than the cathode-substrate distance resulting in relaxation of their energy and motion directions. Re-evaporation and surface diffusion of the atoms deposited onto the substrate were considered to be absent during calculations.

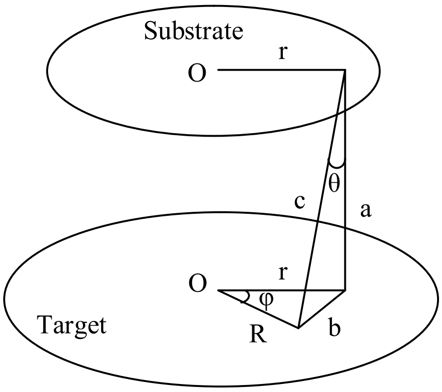

Fig. 3. Geometrical parameters in system "target-substrate".

For the magnetron sputtering system under investigation, the function Ψ(r) was determined from the profile of the erosion groove presented in Fig. 2. The same approach should be used to calculate other magnetron sputtering systems. Film thickness distributions at different values of *n* were calculated in order to determine the spatial distribution characteristics of the sputtered atoms $\cos^n(\theta)$. Then these distributions were compared with the experimental data obtained as a result of the experiment at which the operating pressure and the discharge power were equal to 0.2 Pa and 1.5 kW, respectively.

In the calculations, the values of *n* from 0 to 1.5 were used. The best coincidence of the calculated and experimental data was obtained at *n* = 0.7 as it is seen from Fig. 4. Thus, the expression $\cos^{0.7}(\theta)$ is the most suitable to characterize the spatial distribution of the sputtered atoms in the formula (1).

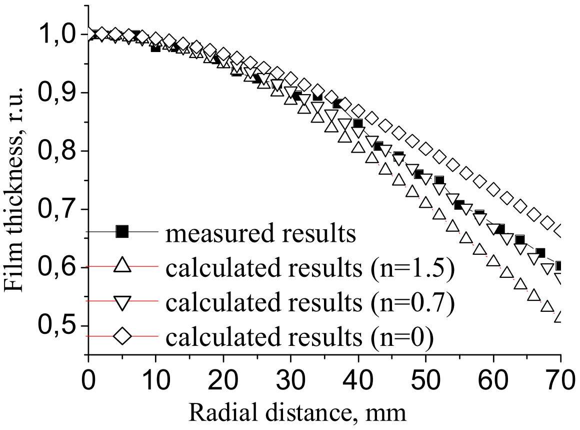

Fig. 4. Dependence of film thickness distribution on index *n*.

Ref. [6] informs that the operating pressure in the chamber can influence the coating thickness distribution. However, detailed investigation devoted to this subject is not presented. The present paper describes the investigation of the gas pressure, sputtering power, and target type (with erosion groove and without it) influence on the coating thickness distribution. Figs. 5-7 present results of these experiments. The diagrams also present the curves calculated by the formula (1) with *n* = 0.7.

It is seen from Fig. 5 that in the investigated pressure range (up to 0.4 Pa) the difference between the thicknesses of the films obtained in different modes made up no more than ± 3%. Most likely, this is related to the absence of collisions between the sputtered atoms.

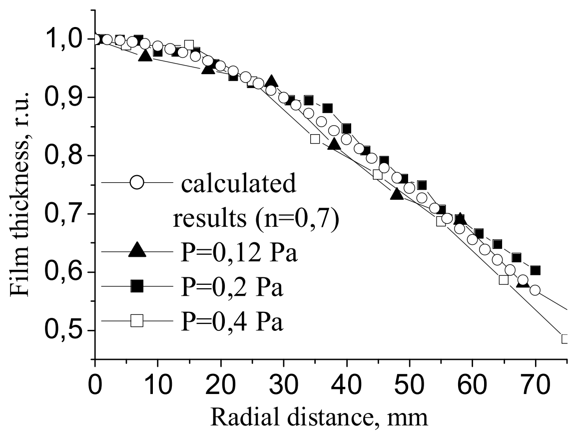

Fig. 5. Dependence of film thickness distribution on working pressure (sputtering power – 1.5 kW).

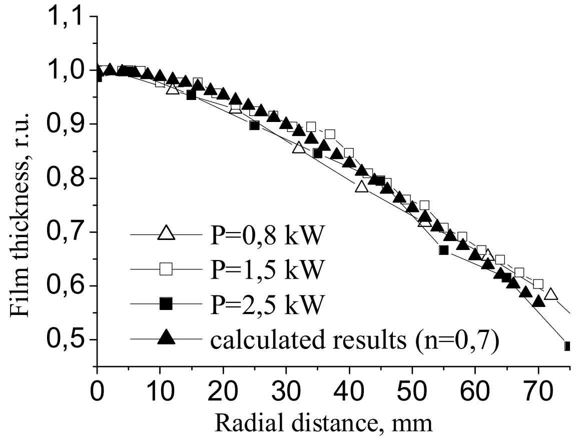

Fig. 6. Dependence of film thickness distribution on sputtering power (Ar pressure – 0.2 Pa).

Availability of these collisions begins making influence on the atom motion direction at the pressure of 1 Pa and higher.

It was found out that the discharge power and, hence, the cathode sputtering rate has insignificant influence on the thickness distribution of the deposited coating as it is seen from Fig. 6. Any essential differences in the thicknesses of the coatings deposited by sputtering of a new target and the target with the erosion groove depth of the order of 6 mm (Fig. 7) were not observed.

The suggested model allowed easily calculating the coating thickness distribution at the substrates situated at different distances from the cathode. Fig. 8 presents the calculated results. As it follows from the diagrams, the cathode sputtering inhomogeneity influence becomes weaker with increase of the distance from the magnetron and the coatings become still more uniform.

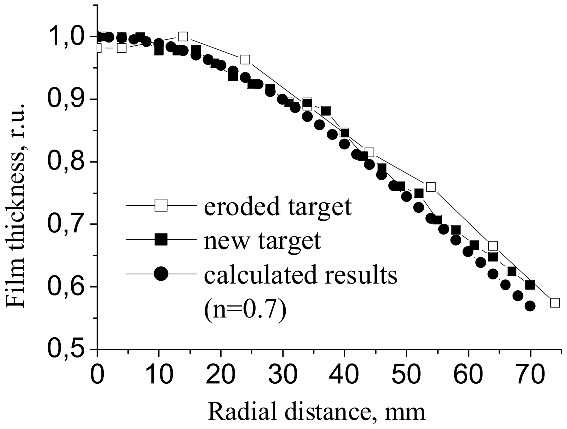

Fig. 7. Dependence of film thickness distribution on target type (Ar pressure - 0.2 Pa, sputtering power - 1.5 kW)

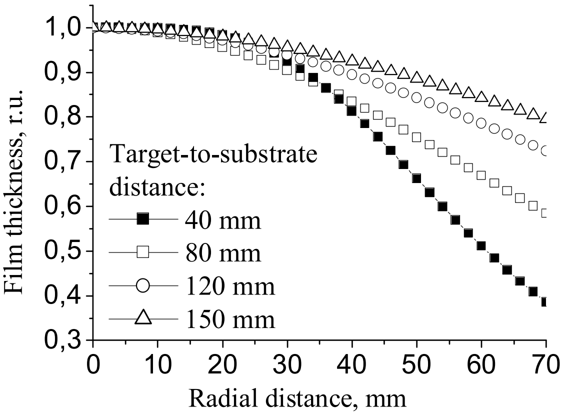

Fig. 8. The calculated film thickness distribution at different target-to-substrate distances.

Conclusion

This paper presents the model allowing by means of the analytical formula calculating the thickness distribution of the coating deposited by the magnetron sputtering system with a round-cathode.

The formula is the following:

$$T = \int_0^{2\pi} \int_0^R \Psi(R) \cos^n(\theta) R / c^2 dr d\varphi$$

In this formula, the function describing the cathode sputtering velocity was derived from the measured profile of the erosion groove. The degree value n in the expression $cos^n(\theta)$ characterizing the spatial distribution of the sputtered atom flow was determined for the investigated magnetron. In our case it was equal to 0.7. The suggested model can be used as well in other magnetron sputtering systems with axial symmetry.

It was shown experimentally that the pressure in the chamber (in the range from 0.12 to 0.4 Pa), the discharge power (in the range from 0.8 to 2.5 kW) as well as the target erosion in the course of time have inessential influence on the coating thickness distribution.

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