THE FLOW DENSITY OF ATOMS SPUTTERED FROM A CATHODE OF CYLINDER MAGNETRON

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The results of calculations of atom flows, sputtered from a cathode of special cylindrical magnetron sputtering system, presented. The atoms flow in cylinder magnetron will be larger with respect to planar magnetron due to the axial symmetry of the system. It is shown that deposition rate weakly depends on the diameter of substrate. The atoms flow through the sidewall is calculated. The estimations of sputtered atoms concentration near cathode surface are done.

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1. INTRODUCTION

Magnetron sputtering systems (MSS) are widely employed for covering manufactured goods by optical, protecting, technological and decorative films with thickness about one micrometer [1]. In particular, the multiplayers transparent films of metal or binary compounds are applied on windows glasses, which diminish the heat losses through the windows of industrial and living buildings [2]. MSS with cathode of disk, lines, hollows or rode cylinder form are designed for this purposes [3-6].

These types of MSS are differed by angle and space distribution of the atom flows sputtered from a cathode. If the film on substrate consists on one metal the different constructions of MSS are differed by covering rates and its surface distribution only.

In a case of complex (for example, binary) compounds, created by reactive covering method, the films are formed on a surface of the material sputtered from the cathode and a gas coming from discharge atmosphere. The film is formed on a substrate surface due to the phase transitions between the components of chemical reaction. Since the density of these flows near surface, in generally, has different space distribution the composition and quality of a film will be non homogeneous. The calculations of the atom flows sputtered from a cathode of hollow cylinder magnetron were performed in order to determine the conditions of the homogeneous binary film application.

2. MAGNETRON CONSTRUCTION

The cylinder magnetron was designed for application films on outer surface of cylinder substrate. Inner diameter of magnetron is 230 mm [7], anode consists of nine rods of 10 mm diameter which are allocated on 50 mm from a cathode surface. The cylinder coaxial to cathode substrate is immersed inside the magnetron. Diameter of sample is up to 100 mm.

Magnetic field near cathode surface is created by permanent magnets system consisted of nine segments near cathode surface and is orientated perpendicular to cylinder-generated line. Consequently the discharge is distributed along magnetron in nine strips form. Hall's current is closed over the cathode face ends where the magnetic field turns over. Magnetic field system and anodes are rotated around magnetron axis in order to get the uniform deposition.

3. CALCULATION OF ATOM FLOWS, WHICH ARE SPUTTERED FROM CATHODE

Calculation of extension of the atoms sputtered by ions in hollow cylinder magnetron is done under supposition that the atom free pass is larger than character dimension of system. Besides the linear and angle dimensions of anode are neglected. In this case the flow from a differentially small area dS_M in M point on cathode surface to the dS_A element in A point on substrate surface is determined by known relation [8, 9]:

$$d^2\Phi_{_A} = B\cdot\frac{\cos(\varphi_A)\cdot\cos(\varphi_M)}{R_{MA}^2}dS_M dS_A, \qquad (1)$$

where $\varphi_{A,M}$ is the angle between normal to corresponded areas and vector radius $\mathbf{R_{MA}}$, directed from M point to A point. B is cathode "brightness", that is the atom flow in solid angle unit from area unit. In generally brightness depends on emission angle. Admitting that angle distribution of sputtered atoms is in correspondence with Lambert's law (cosine law), that is B=const and suppose B=1, one gets the value of flow density, which comes to surface element in point A:

$$\Phi_A = \int_{S_M}\frac{\cos(\varphi_A)\cdot\cos(\varphi_M)}{R_{MA}^2}\cdot dS_M\,. \qquad (2)$$

Results of numerical calculations are presented on figures where the linear values are expressed in cathode radius units since the density values are depended on relative dimensions only. Dependences of atom flow density (deposition rate) on substrates of different diameter as a function of distance from a cathode along its axis are presented on fig. 1. It is followed from calculation that maximum flow density equal π. It is practically reached near substrate surface of radius equal 0.8. Flow density decreases to 2.2 for thin substrate with radius ~ 0 (see fig. 1).

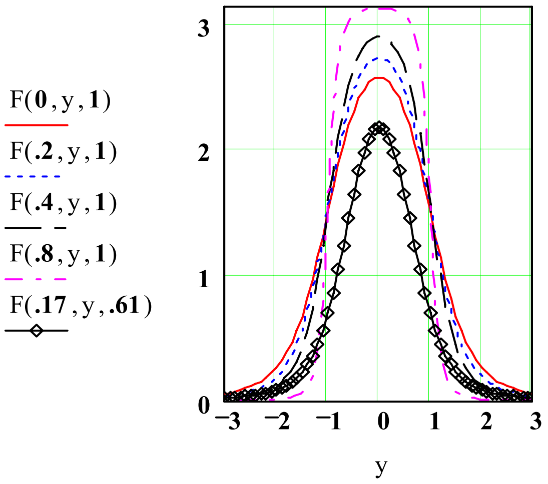

Fig.1. Distribution of deposition rate along magnetron system. Linear dimensions are normalized to the magnetron radius. The another parameters of the function F(r,y,l) are: r-substrate radius, l- cathode length. Real experimental results are symbolized by rhomb

About 60% of sputtered atoms go out through the magnetron ends for short system (l ~ 0.5) if a substrate distanced from a cathode. Loses value decreases for thick substrate on a value approximately equal to ratio of cross section of substrate and cathode since the radial distribution of outing flow is practically homogeneous.

An important peculiarity of cylinder magnetron is that in contrast with planar systems part of sputtered atoms return to the cathode. In a case when substrate is distanced from discharge region the atom flow from cathode will be determined by integral equation:

$$\Phi_A = J + \frac{1-\alpha}{\pi}\cdot\int_{S_M}\Phi_M\cdot\frac{\cos(\varphi_A)\cdot\cos(\varphi_M)}{R_{MA}^2}dS_M \quad ,(3)$$

where J is a flow of atoms sputtered from cathode by ion bombardment, α is a sticking coefficient. It is followed from this equation that: 1) the cathode surface state is determined not only by ion bombardment as in planar system but by deposited atoms also, 2) the concentration of sputtered atoms increases in discharge what influence on both state of discharge and cathode sputtering. Besides this the cathode sputtering along length will be inhomogeneous since the distribution of returning to target surface atoms is inhomogeneous. It is easy to show that for semi-infinite target the value of back flow is equal to π in its depth and π/2 near the end of target. So the sputtering of ends will be larger than in center of magnetron when only the part of sputtered atoms are deposed on substrate surface.

Solution of equation (3) for real magnetron can be found by well-known successive approximation method. Here we will be restricted by obvious result for infinite long magnetron. In consequence of translate symmetry of infinite order along cathode axis $\Phi_{A,M}$ = const , and integral over surface is equal π. Then one gets from equation (3):

$$\Phi_A = \frac{J}{\alpha}\ . \qquad (4)$$

Taking into account the fact that sticking coefficient depends on the falling down angle its mean value comes about less than 1. So the value of sputtered atom flow near target surface will be larger than the flow of atoms sputtered by ions. Besides this two contrary and equal by value flows of atoms exist near the cathode surface. One of them is determined by ion bombardment of considering part of target area. Second is determined by redeposition of the atoms sputtered from a surface of target surrounding the considering part of cathode. So the concentration of atoms in discharge atmosphere will be in two times greater with respect to planar system. If one inserts the substrate into cathode the redeposition atom flow will be decreased by a value equal to sample radius (normalized on cathode radius) because of atom deposition on substrate surface.

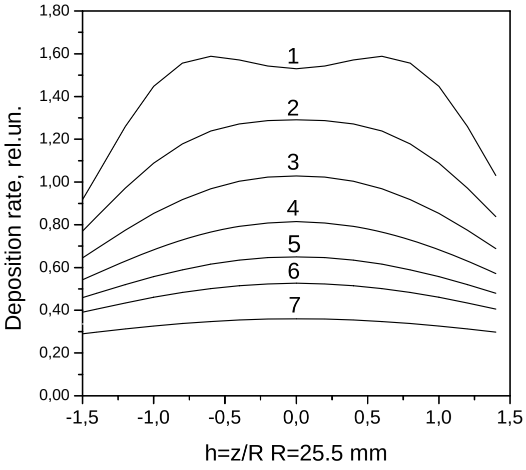

Fig. 2. Deposition rate by ring magnetron with diameter of desorbtion zone 2R= 51 mm as a function of a distance from a cathode center. Z is a distance from a cathode plane to substrate. 1-z=30; 2-40; 3-50; 4-60; 5-70; 6-80; 7-90

Fully collision less regime in real magnetron is realized enough rarely. A consideration of this effect is complicated problem and need to investigate more detail. An applicability of collision less approximation is indirectly confirmed by good agreement of calculation done in this work (see fig. 2) and experimental results obtained in [9]. Note that pit of deposition on substrate surfaces is appeared in planar systems.

4. CONCLUSIONS

1. Calculations of atom flows sputtered from a cathode of cylinder magnetron are presented.

2. It is shown that in collisionless regime the deposition rate weakly depends on substrate diameter.

3. The sputtered atom flow through the magnetron ends can reach 60% for short systems (magnetron length is equal about to target radius). This value can be decreased up to ~ 20 % for cathode length equals about two its diameter or more.

4. The estimation of sputtered atom concentration near target surface is done. Transport of sputtered material along target is taking into account. It is assumed that mean value of sticking coefficient is less than 1.

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ПЛОТНОСТЬ ПОТОКА АТОМОВ, РАСПЫЛЕННЫХ С КАТОДА ЦИЛИНДРИЧЕСКОГО МАГНЕТРОНА

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Представлены результаты расчетов потока атомов, распыляемых с катода магнетрона специальной цилиндрической формы. Поток атомов в цилиндрическом магнетроне оказывается больше, чем в плоском магнетроне, из-за аксиальной симметрии системы. Показано, что скорость осаждения атомов слабо зависит от диаметра подложки. Рассчитан поток атомов через торцы катода. Сделаны оценки концентрации распыленных атомов вблизи поверхности катода.

ГУСТИНА ПОТОКУ АТОМІВ, РОЗПИЛЕНИХ З КАТОДУ ЦИЛІНДРИЧНОГО МАГНЕТРОНУ

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Представлені результати розрахунків потоку атомів, що розпилюються з катоду магнетрону спеціальної циліндричної форми. Потік атомів в циліндричному магнетроні виявляється більшим, ніж у плоскому магнетроні, через аксіальну симетрію системи. Показано, що швидкість осадження атомів слабо залежить від діаметру підкладки. Розрахований потік атомів крізь торці катоду. Зроблені оцінки концентрації розпилених атомів поблизу поверхні катоду.