CHARACTERISTICS OF TiN COATING DEPOSITED BY VACUUM-ARC METHOD ON ROTATING CYLINDRICAL SAMPLE

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The dependences of the growth rate and intrinsic stress on the accelerating potential for coating TiN deposited from the Ti^+ ion flow on the surface of cylindrical article are investigated theoretically. The sample rotates around the symmetry axis perpendicular to the flow of incident ions. The study is carried out within the framework of the model of the nonlocal thermoelastic peak of the low-energy ion, taking into account the sputtering of the coating atoms. The cases of the DC mode and the pulsed potential mode are considered. It is shown that the intrinsic stress in the coating TiN to be deposited on the rotating cylinder are ~ 20 % less than in the coating deposited on the flat substrate located perpendicular to the incident ion flow.

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INTRODUCTION

Inhomogeneities of intrinsic stress and thickness of deposited coating arise when the vacuum-arc deposition of the coating on object of complex shape. It is possible to reduce inhomogeneities in the deposition of the coating on the surface of cylindrical sample by rotating the article around the axis of symmetry. When forming the coating, ions participate that fall at different angles and contribute differently to the rate of growth and the stresses in the coating.

In this paper we theoretically investigate the dependence of the growth rate *v* and intrinsic stress σ on bias potential on substrate for the TiN coating deposited on the surface of the cylindrical sample rotating around the symmetry axis perpendicular to incident Ti^+ ions flow.

MATHEMATICAL MODEL

Earlier we modified the formula describing intrinsic stresses which arise in coating deposited from flow of ions [1]. We generalized Davis formula [1] on the case of flow of differently charged ions and arbitrary angle of incidence α of ions. The expression obtained in the framework of the model of nonlocal thermoelastic peak (NTP) of the low-energy ion has the form [2-4]:

$$\sigma(U,\alpha) \sim \frac{E_Y}{1-\Pi} \frac{\sum_i \left[ft_p \chi_i \zeta\left(i\left(U+U_f+E_{0i}\right),\alpha\right) + \left(1-ft_p\right)\chi_i \zeta\left(i\left(U_1+U_f+E_{0i}\right),\alpha\right)\right]}{1+\sum_i \left[ft_p \chi_i w\left(i\left(U+U_f+E_{0i}\right),\alpha\right) + \left(1-ft_p\right)\chi_i w\left(i\left(U_1+U_f+E_{0i}\right),\alpha\right)\right]} . \quad (1)$$

Here E_Y and Π are the Young modulus and the Poisson ratio of the target material, t_p is the duration of the rectangular pulse of potential with amplitude U, f is the repetition rate of the pulses, U_f is the floating potential, U_1 is the potential applied to the substrate between pulses, χ_i and E_{0i} are the fraction of ions with charge i (in units of proton charge), and the initial ion energy per unit of charge, respectively. $\zeta(E,\alpha)$ is the number of interstitial defects produced by primary ion without those that were sputtered; $w(E,\alpha)$ is the number of thermoactivated transitions in NTP with the activation energy of defect migration. Summation is carried out over n charge states of ions (as a rule, $n \le 5$). The NTP parameters, the volume, temperature and others, which are necessary for calculation of $w(E,\alpha)$ and $\zeta(E,\alpha)$ functions were defined by using the SRIM2000 software package [5].

Formula (1) describes the intrinsic stresses that arise in the coatings during deposition of a one-component beam with differently charged ions in modes of both the DC ($ft_p = 1$) and the pulsed potential on the substrate.

Rotation of the sample leads to uniform mixing and averaging of the contributions of ions falling at different angles to each point on the surface of the cylinder. The number of produced defects is averaged as well as the rate of their relaxation. The expression for the intrinsic stress in the coating deposited on the rotating cylinder is obtained by the following substitutions in (1):

$$\zeta(E,\alpha) \Rightarrow \bar{\zeta}(E) = \int_0^{\pi/2} \zeta(E,\alpha)\cos\alpha \, d\alpha ; \quad (2)$$

$$w(E,\alpha) \Rightarrow \bar{w}(E) = \int_0^{\pi/2} w(E,\alpha)\cos\alpha \, d\alpha . \quad (3)$$

Similarly the coefficient of sputtering of the coating atoms is transformed to:

$$K(E,\alpha) \Rightarrow \bar{K}(E) = \int_0^{\pi/2} K(E,\alpha)\cos\alpha \, d\alpha . \quad (4)$$

RESULTS AND DISCUSSION

Calculation of intrinsic stresses in the TiN coating was carried out at the following values of the parameters: u = 0.58 eV, U_f = 20 V. In accordance with the experimental conditions, the pulse frequency f and duration t_p were selected from the term ft_p = 0.12. The

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NTP parameters of Ti ions in the TiN coating material, necessary for calculating the functions $w(E,\alpha)$ and $\zeta(E,\alpha)$ were determined using the software package SRIM2000 [5]. The calculations also assumed flux density of ions, which corresponded to the average deposition temperature T_0 = 400 K in the pulsed potential mode and at the normal incidence of the deposited beam on the coating surface. The values of the parameters χ_i and E_{0i} for Ti ions are the same ones as in [3, 4].

Fig. 1 displays the result of calculation of the average sputtering coefficient $\bar{K}(U)$ of atoms Ti at the Ti$^+$ ion flux falling onto the TiN coating deposited in DC mode (curve 1) and in pulsed potential mode (curve 2) on the surface of the rotating cylindrical sample. The mode of the pulsed potential with a duty cycle $ft_p = 0.12$ is considered. For comparison, the sputtering coefficients for ion incidence on the flat surface at the angle $\alpha = 0°$ (curves 1` and 2`) and at the angle $\alpha = 70°$ (curves 1`` and 2``) are also given.

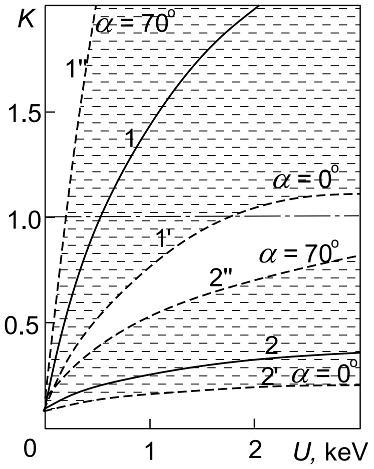

Fig. 1. Average sputtering coefficients at TiN coating deposition on rotating cylindrical sample in DC mode (solid curve 1) and pulsed potential mode (solid curve 2). Dashed curves correspond to cases of incident of ion beam on flat surface

The growth rate of the coating can be calculated by the formula

$$v(U) = \frac{M}{\pi\rho} j\left[1-\bar{K}(U)\right], \qquad (5)$$

where M and ρ are the molecular weight and density of the coating material, respectively, j is the flux density of the ions.

Fig. 2 shows the calculated curves of intrinsic stresses in the coatings deposited on the rotating cylindrical sample in the DC mode (curves 1) and in the pulsed potential mode (curves 2). Dashed curves show the dependence of intrinsic stresses in the coating at normal incidence of ions on the flat substrate.

As can be seen from (see Fig. 2), the intrinsic stress in the TiN coating deposited on the rotating cylinder are ~ 20 % less than in the coating on the flat substrate.

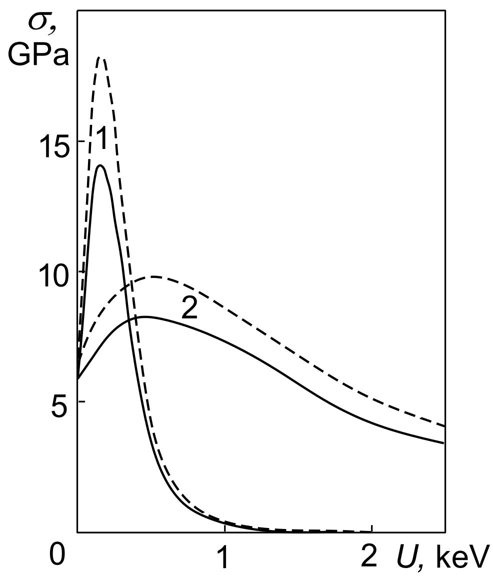

Fig. 2. Intrinsic stresses in TiN coating deposited on rotating cylindrical sample in DC mode (solid curve 1) and pulsed potential mode (solid curve 2). Dashed curves correspond to case of normal incident of ion beam on flat surface

In Fig. 3, the rate of growth of the TiN film on the rotating cylinder (solid curve) and on the flat substrate at various angles of incidence of ions (dashed curves) is shown. The calculation was carried out for the pulsed potential mode (see [3]). The black symbols are the experimental data [6].

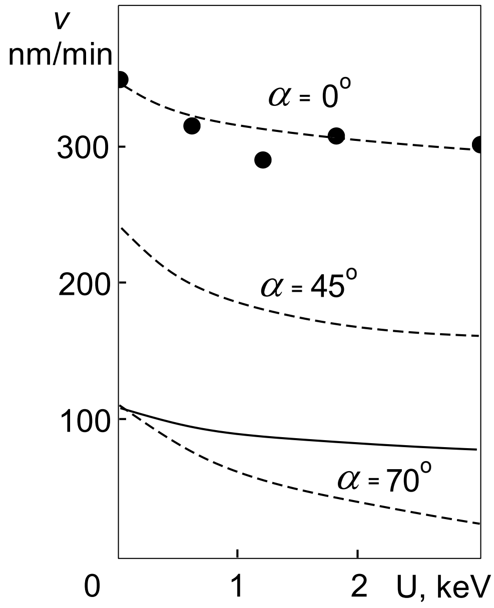

Fig. 3. The rate of deposition of the TiN film on the rotating cylinder (solid curve) and on the flat substrate at various angles of incidence of ions (dashed curves)

As can be seen from Fig. 3, the rate of growth of the coating on the rotating cylinder is much smaller than when the coating is deposited on a flat substrate from the ion flux falling normally on the substrate. This decrease in the growth rate is due both to the shadowing effect of the inverse surface of the cylinder and to the sputtering effect of the coating atoms, which plays more important role in the deposition of ions on the cylindrical surface.

CONCLUSIONS

Within the model of the nonlocal thermoelastic peak of the low-energy ion, the growth rate and the intrinsic stress in the TiN coating deposited from the Ti^+ ion flux incident on the surface of the rotating cylindrical sample were theoretically investigated. The average sputtering coefficient and growth rate are calculated for deposition of the TiN coating on the rotating cylindrical sample in cases of the DC and the pulsed potential modes. The growth rates of coatings deposited on the rotating cylinder and on the flat substrate at different incidence angles of ions are compared. Formulas for intrinsic stresses for cases of the DC and pulsed potential modes are obtained. It is shown that the intrinsic stress in the TiN coating deposited on the rotating cylinder are ~ 20 % less than in the coating deposited on a flat substrate located perpendicular to the incident ion flux.

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ХАРАКТЕРИСТИКИ ПОКРЫТИЯ TiN, ОСАЖДАЕМОГО ВАКУУМНО-ДУГОВЫМ МЕТОДОМ НА ВРАЩАЮЩИЙСЯ ЦИЛИНДРИЧЕСКИЙ ОБРАЗЕЦ

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Теоретически исследуются зависимости скорости роста и внутренних напряжений от ускоряющего потенциала для покрытия TiN, осаждаемого из потока ионов Ti^+ на поверхность цилиндрического изделия, вращающегося вокруг оси симметрии, расположенной перпендикулярно потоку падающих ионов. Исследование проводится в рамках модели нелокального термоупругого пика низкоэнергетического иона с учетом процессов распыления атомов покрытия. Рассмотрены случаи постоянного и импульсного потенциалов на подложке. Показано, что внутренние напряжения в покрытии TiN, осаждаемом на вращающийся цилиндр, на ~20 % меньше, чем в покрытии, осаждаемом на плоскую подложку, расположенную перпендикулярно падающему потоку ионов.

ХАРАКТЕРИСТИКИ ПОКРИТТЯ TiN, ЩО ОСАДЖУЄТЬСЯ ВАКУУМНО-ДУГОВИМ МЕТОДОМ НА ЦИЛІНДРИЧНИЙ ЗРАЗОК, ЩО ОБЕРТАЄТЬСЯ

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Теоретично досліджуються залежності швидкості росту і внутрішнього напруження від прискорюючого потенціалу для покриття TiN, що осаджується з потоку іонів Ti^+ на поверхню циліндричного виробу, що обертається навколо осі симетрії, розташованої перпендикулярно потоку падаючих іонів. Дослідження проводиться в рамках моделі нелокального термопружного піку низькоенергетичного іона з урахуванням процесів розпилення атомів покриття. Розглянуто випадки постійного та імпульсного потенціалів на підкладці. Показано, що внутрішні напруження в покритті TiN, що осаджується на циліндр, що обертається, на ~ 20 % менше, ніж у покритті, що осаджується на плоску підкладку, розташовану перпендикулярно падаючому потоку іонів.