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Gas pressure distribution in ion plasma deposition system

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A method to determine the working gas pressure in the region of sputtered target during ion-plasma deposition of thin films is proposed. Using the sputtering monatomic targets of Ti and Nb, calculated (Monte Carlo simulation) and experimental dependences of their deposition rate on the working gas pressure are obtained. Comparison of these results made it possible to determine the pressure distribution in the region of drift of sputtered target–substrate atoms. A radical difference is shown between the pressure sensor in chamber (0.6 Pa) and the real corrected pressure from 5 Pa in the target sputtering zone to 1 Pa in the deposition zone on the substrate.

Keywords: ion-plasma deposition of films, correct determination of the working gas pressure.

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The technology of ion-plasma deposition of thin films is widely used for obtaining components of microelectronics and energy transformation elements [1–10]. The present work shows that the pressure in the region of films deposition radically differs from the readings of the pressure sensor located, as a rule, at a high distance from the discharge region. The proposed method of determination of the gaseous medium pressure value in the region of drift of sputtered atoms target–substrate in experimental technological systems of ion-plasma deposition. The method relies upon the comparison of experimental dependences of the deposition rate on the working gas pressure with similar results of numerical experiment for monoatomic targets, which are quite reliable for the determination of the gaseous medium pressure value.

With given geometry of the sputtered system and technological parameters of gaseous discharge the film growth rate on the substrate will actually depend on the gaseous medium pressure value directly within the region of drift of sputtered atoms target–substrate. At the same time, the gaseous medium pressure value in experimental technological sputtering systems is measured at the distances from the zone of target sputtering and target–substrate drift, several times higher than the region of gaseous discharge.

In the sputtering chamber of ion-plasma deposition there is heterogeneous distribution of the working gas temperature associated with the difference of the magnetron temperature and various parts of chamber [11]. At stationary (steady-state) mode of deposition the working gas T temperature in the chamber causes corresponding distribution of the pressure of working gas P.

In order to obtain the distribution of the value of gaseous pressure, we compared the simulation results with the experimental dependence of the deposition rate on the working gas pressure for the monoatom targets, which are quite reliable for the experimental study. Titanium and niobium targets were taken as sputtered materials, whose atoms vary considerably by mass (Ti — 47.87 u, Nb — 92.91 u).

The deposition was performed on Pt/Si substrates with the area of 12×12 mm at different distances of target–substrate: 7.5 cm for Ti and 21.5 cm for Nb. The working gas pressure in the films deposition chamber was kept at the level of $P = 0.6$ Pa according to the pressure sensor readings. At that, the Ar working gas inflow speed was $12\,\mathrm{cm^3/min}$, its removal rate — 80 l/s. The gaseous discharge parameters during sputtering of Ti and Nb targets were the following: discharge current $J = 250$ mA, bias voltage of cathode–anode $U = 485$ V. For determination of the growth rate of Ti and Nb deposited films, the thicknesses of flims were measured during their deposition.

The following experimental values of the rates of deposition of Ti and Nb films on the substrate at the fixed value of Ar working gas pressure of 0.6 Pa: 1.74 nm/min for Ti film and 0.71 nm/min for Nb film.

Simulation of the target ion sputtering process within the regress model of the cascade of biased atoms developed by us [12]. Simulation of the transfer process of sputtered atoms in the space of drift target–substrate was performed based on the mathematical model of the processes of thermalization of atomic particles in gases [13,14] and their further diffusion motion in the space of drift target–substrate [15,16]. The processes of scattering of atomic particles were described under the interatomic potential of interaction of quasi-rigid spheres developed by us [16] with application of Born–Mayer potential.

Static simulation of the processes of ion-plasma deposition of Ti and Nb films in the Ar gaseous medium was performed with the geometry of the sputtering system and technological parameters of the gaseous discharge, similar to the experimental measurement of their deposition rates, performed in advance. The dependences of the Ti and Nb films deposition rates on the Ar working gas pressure within the range from 0.6 to 5.0 Pa were numerically studied. As the first approximation we took that the value of the specified value of Ar working gas pressure in the sputtering system corresponds to the middle of the space of drift of sputtered atoms target−substrate. The results of static simulation of the dependence of Ti and Nb films growth rate on the Ar working gas pressure are given in Fig. 1. The same figure shows experimental values of the deposition rate corresponding to the readings of the pressure sensor located at the system outlet $P = 0.6$ Pa. Dashed line denotes correspondence of that pressure to the real one in the region of drift of sputtered atoms target−substrate, which indicates an apparent distribution of the pressure in the chamber.

Analysis of comparison of the results of experimental study and statistical simulation of the dependence of the Ti and Nb films deposition rate on the Ar working gas pressure allowed determining the value of real pressure of working gas in the space of drift of sputtered atoms target−substrate. Therefore, when comparing the middle spaces of drift target−substrate of sputtered Ti and Nb atoms with the obtained values of the pressure of Ar working gas we determined the distribution of Ar working gas pressure (Fig. 2, b) in the sputtering system (Fig. 2, a). The value of pressure of the Ar working gas varies from $P \approx 5.0$ Pa in the zone of sputtered target to $P = 0.6$ Pa in the pressure measurement zone.

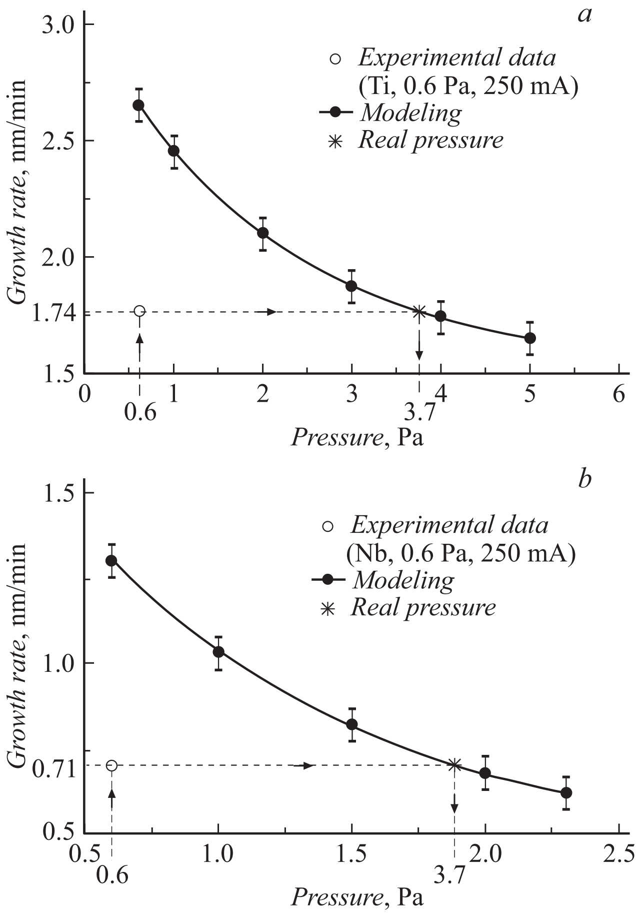

Figure 1. The results of comparison of experimental study and statistical simulation of the dependence of the Ti (a) and Nb (b) films growth rate on the Ar working gas pressure.

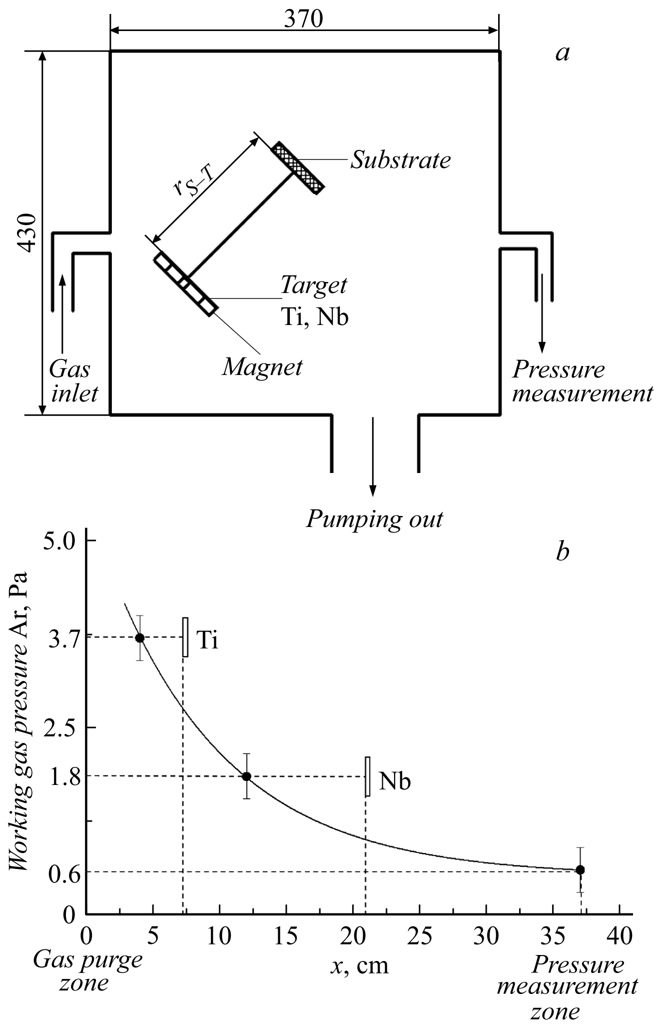

Figure 2. a — diagram of experimental technological sputtering system; b — results of determination of the Ar working gas pressure distribution in the experimental technological sputtering system.

Determination of distribution of the pressure of working gas in the sputtering system is the basis for selection and setting the technological mode of ion-plasma deposition of quality multi-component films with the type determined in advance for the components composition distribution by thickness during their deposition [17].

Energy range for the proposed algorithm of determination of the pressure of gaseous medium in the vacuum system is of interest for many applied problems of the physics of plasma, gas discharge and ion deposition processes.

Conflict of interest

The authors declare that they have no conflict of interest.

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