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Studies of the discharge properties of unbalanced magnetron sputtering system

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Abstract

In this paper, an unbalanced magnetron sputtering system was set up using a conventional magnetron and a coaxial electro-solenoid. The discharge properties were experimentally investigated. The model of the voltage–current (V–I) property of the unbalanced magnetron sputtering (UBM) system was developed. The comparisons of the simulation with the experimental data indicated that the model expressed the discharge properties of the UBM sputtering system correctly.

Keywords: Plasma; Film; Magnetron

1. Introduction

The discharge property of the magnetron sputtering deposition system is always a highly intensive research area [1–4]. Since Window and Savvides [5] gave their reports on the unbalanced magnetron systems (UBM), further studies indicated that the UBM deposition system had high deposition rate and ionized ratio [6,7]. However, the discharge properties of the UBM still need further research works. In this paper, a set of UBM system was set up by a conventional magnetron and a coaxial coil. The discharge properties were experimentally investigated. The discharge properties were favorably improved by the attached magnetic field (AMF) produced by the additional coaxial coil. The theory model was deduced by the Langmuir–Child law for describing voltage–current density (V–J) property of the magnetron sputtering system under the influences of AMF variation. The comparison with experiments showed better conformity.

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2. The experimental setup and process

The UBM sputtering system was constructed by a circular planar conventional magnetron (CM) (95 mm in diameter) and an axial additional coil (170 mm in inner diameter) around the target. The schematic drawing of the system was shown in Fig. 1. The coil had an adjustable exciting current between 0 and 5 A. The effective sputtering area identified by the sputtering groove was 30 cm^2. The solid spot in Fig. 2 are the experimental values of the axial magnetic field distribution at different solenoid exciting current. In our experiments, the discharge gas was 99.99% pure argon at 0.2 and 7 Pa pressure, respectively, and the sputtering material was 99.8% pure Ti. The sputtering current and the voltage were varied in the range of 0–5 A and 0–1000 V, respectively. The base vacuum was approximately 5×10^{-3} Pa. The gas flow was controlled steadily for preventing the pressure from fluctuation caused by the discharge in the chamber. The system was ignited first before adjusting the coil current to keep the system discharge stable.

3. The axial magnetic field simulation

There existed a couple of two kinds of magnetic field formed by the permanent magnetic material (NdFeB) and

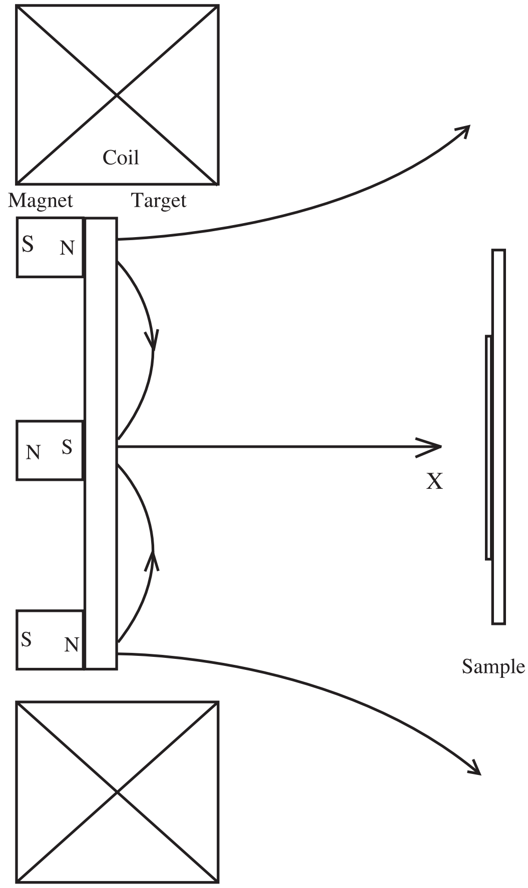

Fig. 1. The schematic drawing of the unbalanced magnetron sputtering system.

the additional coil. The magnetic field peak was formed at about 50-mm distance from the cathode, which confined the electron to escape from the cathode [7], and the measurement values are shown in Fig. 2 as solid spot. The plasma became free-glow state passing the magnetic field peak. For convenience, the magnetic field value was simulated as shown in Fig. 2 by the lines corresponding to variation of exciting current of the additional coil.

4. The AMF's influences on the V–J property of UBM

It is assumed that the magnetron discharge is under ideal space charge limited situation for investigating the influences on the V–J property by the AMF variation. In this situation, the charge distribution before the cathode is fit to the equation [8]

$$\nabla V^2 = -\frac{\rho}{\varepsilon_0} = \frac{en_e}{\varepsilon_0}, \tag{1}$$

where ρ is the charge density, n_e is the electron density, ε_0 is the vacuum permittivity, V is the potential, and e is elementary charge. As shown in Fig. 1, there exists a magnetic field peak before the cathode. It is assumed that the electron density and the velocity are n_e and v, respectively, without the AMF influence, and they are n'_e and v', respectively, under the influence of the AMF variation. In continuity, the current density emitted from the cathode is expressed by

$$J = -en'_e(x)v'(x) = \text{const.} \tag{2}$$

Because the electron before the cathode is confined by the magnetic field, the effective pressure can be expressed by $p' = p(1+\alpha^2)^{1/2}$, where $\alpha = \omega_e/\gamma_{en}$, where ω_e is the electron cyclotron frequency affected by the AMF variation and γ_{en} is the collision frequency of electron with other particles. By the quasi-neutral rule, the charge density in the cathode area is given by

$$n' = n(1+\alpha^2)^{1/2}, \tag{3}$$

The magnetic momentum of the electron is conserved in the magnetic field and can be given by the formula [8,9]

$$\mu = \frac{mv_0^2}{2B_0} = \frac{mv^2}{2B_{CM}} = \frac{mv'^2}{2B_{AMF}}, \tag{4}$$

where v_0 and B_0 are the initial electron velocity and the magnetic field on the cathode surface, respectively, which keep the same value under AMF variation influence, B_{CM} is the peak magnetic field value without the influence of AMF, and B_{AMF} is the peak magnetic field value under the influence of AMF variation. The influence on the electron velocity by the AMF variation is determined by the ratio $\eta = B_{AMF}/B_{CM}$. Only the electron with larger kinetic energy can escape from the cathode area. Corresponding to the CM,

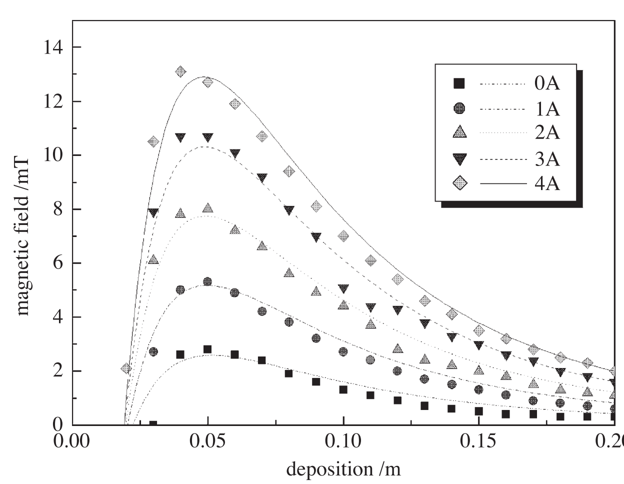

Fig. 2. The comparisons of the axial magnetic field distribution measurement values with the simulation results.