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The structure and magnetic properties of thin films of Ni and Co deposited in Penning discharge

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Abstract

The results of investigation of the structure and magnetic properties of thin Ni and Co films obtained in Penning discharge with simultaneous bombardment of the growing films by low energy Ar^+ and Kr^+ ions are presented.

1. Introduction

In present work we consider the structure and magnetic properties of thin Ni and Co films obtained in Penning discharge with simultaneous bombardment of the growing films by low energy Ar^+ and Kr^+ ions. Negative bias voltage is applied to film substrate during the deposition. In this case the substrate is affected simultaneously by several particle fluxes: the flux of nickel atoms sputtered from cathode target, the flux of neutral atoms of inert gases reflected from cathode, the flux of ions of inert gases from the zone of discharge. The interaction of fluxes of charged and neutral particles with the surface of films causes the appearance of various radiation-induced defects which result in too many changes of surface physical properties.

2. Experimental

The film deposition was carried out under two discharge conditions of the pressure of worker gas: $P = 10^{-4}$–10^{-5} Torr (regime 1) and $P = 10^{-3}$ Torr (regime 2). The thickness of the films was 1000–4000 Å. The X-rays and magneto-optical methods were used in our investigations.

3. Results and discussion

At Fig. 1 the dependences of deposition rate S, Ar and Kr concentration C, lattice parameter a, the equatorial Kerr effect (EKE) for nickel films the on bias voltage of the substrate are presented for two regimes of discharge. It was found that the dependences have oscillations with a period of about 20 V for both conditions of discharge. The amplitude of the oscillations of the parameter of fcc Ni was appreciably higher for the second regime of discharge than for the first regime. These oscillations were bound up with a discreteness of the ionization region in the discharge volume. It was shown that the lattice constant lattice for nickel films was more than for the bulk and correlates well with the Ar content in the Ni films. It appeared that the atoms of Ni were substituted by atoms Ar in the site of the lattice and distorted it. The microde-

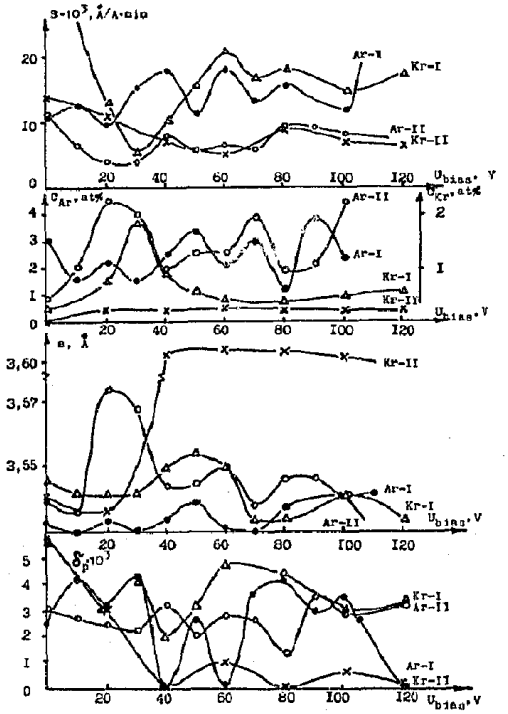

Fig. 1. Dependences of deposition rate S, Ar and Kr concentration C, lattice parameter a, equatorial Kerr effect δp on bias voltage of substrate for two regimes of discharge: at pressure of the worker gas $p = 10^{-4}$–10^{-5} Torr (regime 1) and $p = 10^{-3}$ Torr (regime 2).

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formations of the film lattice were very small for all values of ion energy ($E = 10$–100 eV) and the smearing of a peak of X-ray pattern was caused by small (40–90 Å) dimensions of crystal line grain. Besides such a peak corresponding to fcc structure of Ni, a reflex of hexagonal phase of Ni was found. The constants of this phase were $a = (2.66 \pm 0.01)$ Å, $c = (4.34 \pm 0.01)$ Å, $c/a = 1.63$ and practically did not depend upon the ion-bombarded energy and the Ar content in the films.

The investigation of nickel films by methods of magneto-optics showed that its magnetic properties markedly depend on the regimes of discharge and the ion-bombarded energy. The spectral dependences of EKE for two regimes of discharge had the typical form for Ni polycrystal. However the value of Kerr effect proportional to the magnetization value was determined by the regime of film deposition (see Fig. 2). The surface of some samples had zero magnetization because the EKE was absent (see inset of Fig. 2). The asymmetrical X-ray investigations also acknowledged the localization of non-magnetic hexagonal phase of Ni near the surface of the sample. Non-magnetic and weak-magnetic films obtained in the work were put to vacuum annealing. X-ray and magneto-optical investigations showed the existence of non-magnetic hexagonal phase up to $T = 200$°C. Above $T = 200$°C the irreversible hexagonal-phase–fcc-phase transition was obtained.

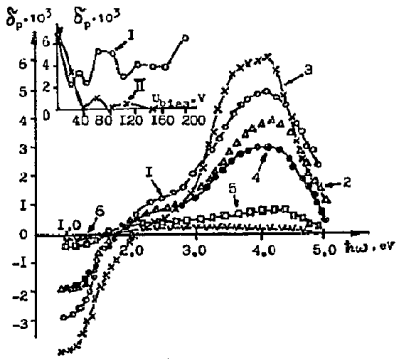

Fig. 2. Dependences of equatorial Kerr effect δp on quantum energy of incident light $\hbar\omega$ for the Ni films deposited at the two regimes of discharge and measured for incident light angle $\varphi = 70°$. Regime 1: $U_{bias} = 80$ V (curve 1), 160 V (curve 2) and 200 V (curve 3). Regime 2: $U_{bias} = 20$ V (curve 4), 60 V (curve 5) and 100 V (curve 6). The inset shows the magnitude of equatorial Kerr effect in dependence on both regimes for $\hbar\omega = 4.0$ eV.

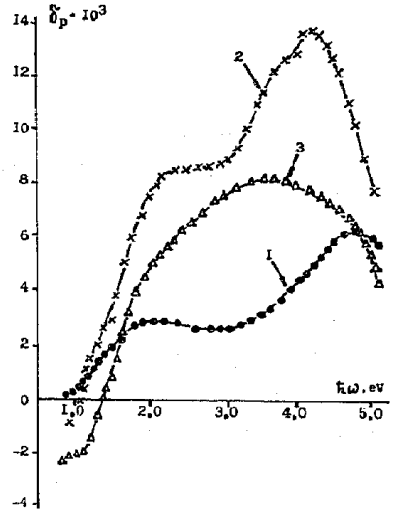

Fig. 3. Dependences of equatorial Kerr effect δp for cobalt films deposited at regime 2 of discharge for $\varphi = 70°$ and $U_{bias} = 0$ V (curve 1), 60 V (curve 2) and 100 V (curve 3).

X-ray investigation of thin Co films showed that all films were Röntgen-amorphous. During magneto-optical investigation it was found that the Co films obtained in the first discharge had the spectral dependences of EKE typical for crystalline Co with a maximum about $\hbar\omega = 4.5$–5.0 eV. However for the films obtained in the second regime of discharge three forms of dependences were observed (see Fig. 3). The spectral dependence of EKE typical for crystalline state was found for zero Kr^+ ion energy. When the ion energy increased, the dependences of EKE indicated a high degree of dispersion. Subsequent increasing of Kr^+ ion energy led to the amorphous structure of the films. The bell-like form of the spectral dependence of EKE, with a maximum at about $\hbar\omega = 3.5$ eV, for Co film deposited at regime 2 of discharge, is typical for the amorphous state and is presented in Fig. 3. The formation of amorphous phase could be connected with an increasing Kr^+ ion flux in the second regime of discharge.

4. Conclusions

The existence of two modifications of Ni structure in thin films was found. The fcc modification is magnetic and the hexagonal one is non-magnetic.