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X-ray Interference Effects in Thin Equiatomic Co–Pt Single Crystal Films

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Abstract—Thin single crystal films of an equiatomic $Co_{50}Pt_{50}$ alloy synthesized by magnetron sputtering on a MgO single crystal substrate were studied by X-ray diffractometry. Interference oscillations with a period depending on the Co–Pt alloy film thickness were observed in the region of (001) reflection, characterizing the $L1_0$ type ordering, and in the region of small diffraction angles ($2\Theta < 10°$). *© 2004 MAIK "Nauka/Interperiodica".*

Thin magnetic films of equiatomic alloys such as CoPt, FePt, and FePd are considered as potential high-density magnetic data recording media. The hysteresis behavior of these alloys is related to the formation of an ordered uniaxial magnetic superstructure of the $L1_0$ type [1]. One of the main conditions for the use of such films as magnetic recording media is the homogeneity of composition: this very property provides for the constant tetragonal $L1_0$ type superstructure and, hence, for the absence of fluctuations in the crystallographic anisotropy field. Another critical condition is the constant film thickness over the entire area that ensures the absence of magnetostatic charges on the surface. The third important condition for the use of thin films as magnetic recording media with perpendicular magnetic anisotropy is a monodomain character, that is, the presence of a single domain in the magnetic structure, with the tetragonal axis C in the whole film volume being parallel to the normal to the film surface.

In order to check that all these conditions are fulfilled, it is necessary to develop integral methods sensitive to homogeneity of the synthesized films. One such method could be the X-ray diffractometry of thin single crystal films, which can readily detect thickness-related oscillations in the interference contrast provided that the above conditions are valid. The problem of quality monitoring is now of considerable importance for thin films (made of semiconductors, superconductors, etc.) used in microelectronics [2].

The samples of thin $Co_{50}Pt_{50}$ single crystal films were obtained by magnetron sputtering in an argon atmosphere at a pressure of 2.7×10^{-2} Pa. In order to avoid chemical inhomogeneity, the films were synthesized by deposition of alternating Co and Pt layers. The deposition time τ_i was selected so as to provide that each layer would be one atomic monolayer thick. The total deposited layer thickness d was varied from 2 to 20 nm. The films were deposited onto (001)-oriented MgO singe crystal substrates. The thickness d_0 and the chemical composition of each film were determined by X-ray fluorescence measurements. Isothermal annealing of the films was performed in a vacuum chamber at a pressure not exceeding 6.7×10^{-4} Pa.

The sample structure was studied at room temperature by X-ray diffraction on a DRON-4 diffractometer using CuK_α radiation (λ = 0.154 nm) from an X-ray tube operating at U = 32 kV, I = 32 mA. The measurements were performed using a two-crystal scheme with flat and bent crystal monochromators with Soller slit widths of 2 mm (vertical) and 6 mm (horizontal) and an output vertical slit width of 0.25 mm. The diffraction angle was scanned at a rate of 1 deg/min with an 0.02° detector angle step in the automated regime.

Figure 1 shows a large-angle X-ray diffraction pattern for a 7-nm-thick $Co_{50}Pt_{50}$ film annealed for 3 h at T = 873 K. As can be seen, the region of the (001) reflection characterizing the ordered $L1_0$ superstructure displays thickness-related oscillations of the interfer-

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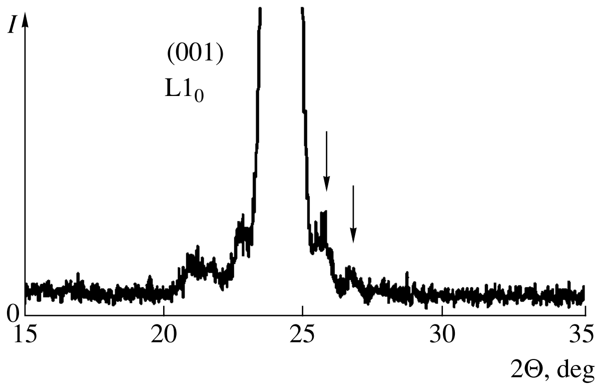

Fig. 1. Typical large-angle X-ray diffraction pattern for a 7-nm-thick $Co_{50}Pt_{50}$/MgO film annealed for 3 h at T = 873 K.

ence contrast. According to the experimental [2, 3] and theoretical [4] data, the full width at half maximum (FWHM) of the central peak equals the oscillation period, while the distance from the central maximum to the first satellite reflection is one and a half times the FWHM value (Fig. 1). The thickness contrast measurements for $Co_{50}Pt_{50}$ films show evidence of a homogeneous thickness and confirms the high quality of the films obtained by magnetron sputtering.

The film thickness can be estimated from these data using the well-known Selyakov relation [4] modified for the case when the diffraction vector is perpendicular to the surface of a plane-parallel crystal plate:

$$d = \lambda/\Delta(2\Theta)\cos\Theta. \quad (1)$$

Here, λ is the wavelength, Θ is the Bragg angle, and $\Delta(2\Theta)$ is the period of oscillations of the thickness contrast.

Figure 2 presents a small-angle diffraction pattern for a 12-nm-thick $Co_{50}Pt_{50}$ film after isothermal annealing for 3 h at 873 K, also clearly displaying interference oscillations. It should be noted that the thickness contrast oscillations in as-prepared films were observed as well. The small-angle diffraction pattern with equidistance peaks (Fig. 2) is due to the interference of X-rays reflected from the outer (air–metal interface) and inner (film–MgO substrate interface) surfaces of the film. For this reason, the values inverse to the wave vectors $k = \sin\Theta/\lambda$ are proportional to the film thickness d_0.

The small-angle diffraction pattern can also be used for evaluation of the film thickness. Indeed, the distance between neighboring reflections obeys the Bragg condition $2d\sin\Theta = n\lambda$. Assuming that $\sin\Theta = \Theta$ for small angles, we obtain the formula for the film thickness

$$d = \lambda/\Delta(2\Theta), \quad (2)$$

where $\Delta(2\Theta)$ is the period of oscillations. This formula is a particular case of the Selyakov expression (1) for the region of small diffraction angles ($\cos\Theta = 1$).

Figure 3 shows the plot of d_0 versus the ratio $\lambda/\Delta(2\Theta)$. As can be seen, the experimental points fit to the bisector of the right angle well. Estimates show that the effect of interference oscillations will not be manifested at a film surface roughness on the order of ±1 nm.

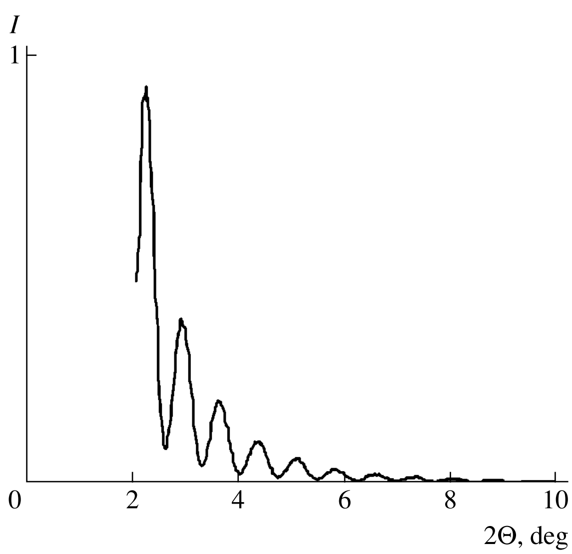

Fig. 2. Typical small-angle X-ray diffraction pattern for a 12.7-nm-thick $Co_{50}Pt_{50}$/MgO film annealed for 3 h at T = 873 K.

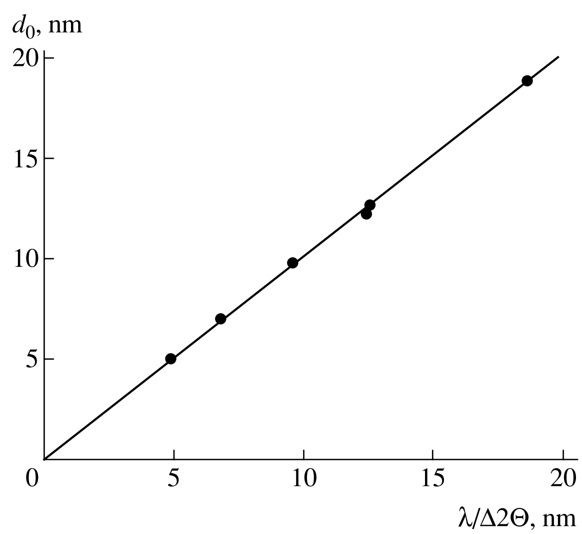

Fig. 3. A plot of the $Co_{50}Pt_{50}$/MgO film thickness (d_0) determined from X-ray fluorescence data versus the thickness $d_0 = \Delta(2\Theta)$ estimated from small-angle X-ray diffraction patterns.

To summarize, we have studied the peculiarities of X-ray diffraction from $Co_{50}Pt_{50}$/MgO structures, where the $Co_{50}Pt_{50}$ single crystal film obtained by magnetron sputtering has a disordered fcc structure in the as-prepared state and acquires an $L1_0$ superstructure upon thermal treatment. The presence of oscillations in the interference contrast is evidence of a high homogeneity of the film thickness. This effect provides a very good method for checking the morphological homogeneity of thin metal films used in microelectronics.

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