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Figure 1: Fig. 2. Orientations of crystallites of the α- and β-phases of cobalt relative to the substrate (NaCl crystal) in an epitaxial film

Abstract

Full Text

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Corresponding Member of the Academy of Sciences of the USSR L. V. KIRENSKII, V. G. PYN' KO

ANISOTROPY OF EPITAXIAL COBALT FILMS

In a comparatively low vacuum (10^{-4} mm Hg), by thermal evaporation onto fresh cleavages of NaCl crystals heated to 200°, it is possible to obtain completely oriented cobalt films (the electron diffraction patterns do not contain Debye–Scherrer rings). From the electron diffraction patterns (Fig. 1, see inset to p. 1260) it follows that films obtained under such conditions consist of crystallites of the cubic β-phase and crystallites of the hexagonal α-phase. The orientations of the crystallites of both phases relative to the substrate are shown schematically in Fig. 2. The electron diffraction patterns also contain streak reflexes, whose origin is attributed to the presence of oxygen in the defective metal lattice ([1]).

Our study of the domain structure and hysteresis loops of such films revealed in them an instability of the position of the easy-magnetization axes. In most cases the easy axes coincided with the [100] directions of the β-phase, which is clearly seen from Fig. 3 (see inset to p. 1260), which shows an electron-microscope photograph of a domain structure of the "checkerboard" type. The structure was formed after demagnetization of the film in an alternating field. The 90-degree boundaries run along the [110] directions of the β-phase, which are therefore hard directions. Films were encountered more rarely in which the easy axes coincided with the [110] directions of the β-phase.

Fig. 2. Orientations of crystallites of the α- and β-phases of cobalt relative to the substrate (NaCl crystal) in an epitaxial film.

From the literature ([2]) it is known that the constant K_1 of the magnetic anisotropy of β-Co is less than zero and is equal to $-6 \cdot 10^5$ erg/cm^3. Consequently, the crystallites of the β-phase should create in the film a strong biaxial

Figure 2

Figure 2: Figure 2

Figure 3

Figure 3: Figure 3

anisotropy with easy-magnetization axes parallel to their crystallographic directions [110]. The anisotropy fields of films deposited on NaCl, measured by the ferromagnetic-resonance method, proved not to exceed 200 Oe, which is considerably smaller than the usually accepted values $2K_1/J_s$. The reduction of the anisotropy field, and also the rotation in some cases of the easy-magnetization axes by 45° ("positive" anisotropy) in cobalt films epitaxially grown on NaCl, can be explained by the presence in them of α-phase crystallites with two equivalent orientations (Fig. 2), if at the same time the second constant K_2 of magnetic anisotropy is taken into account in the expression for the energy for uniaxial crystals:

$$E = E_0 + K_1 \sin^2 \varphi + K_2 \sin^4 \varphi. \quad (1)$$

If $K_2 < 0$, then the polar diagrams of the anisotropy energy of the α-phase crystallites will take the form shown in Fig. 4. The addition of the energy of cry-

To the article by A. S. Litonov and L. G. Yuzheselleva, p. 1260

Fig. 2. Pattern of a p–n junction in silicon, developed with a liquid electrophotographic developer

Fig. 3. Pattern of the region of negative space charge, developed with a liquid electrophotographic developer at voltages: a–1.3 V, b–50 V, and v–80 V

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Fig. 1. Electron diffraction pattern of a cobalt film deposited in a vacuum of 10^{-4} mm Hg on an NaCl crystal heated to 200°

Fig. 3. Electron-microscopic image of the domain structure of a cobalt film grown on NaCl. The structure arose as a result of demagnetization of the film in an alternating field. 1100×

crystallites of the α phase of two mutually perpendicular orientations, when their volumes are equal, leads to the relation

Figure 1

Figure 4: Figure 1

Figure 3

Figure 5: Figure 3

Fig. 4. Polar diagrams of the anisotropy energy of crystallites of the cobalt α phase for $K_2 < 0$ and the total energy diagram

Figure 6: Fig. 4. Polar diagrams of the anisotropy energy of crystallites of the cobalt α phase for $K_2 < 0$ and the total energy diagram

$$E = E_1 + E_2 = E_0' + \frac{K_2}{4} \cos 4\varphi. \tag{2}$$

The total energy diagram obtained by adding the anisotropy energies E_1 and E_2 of crystallites of these two orientations will correspond to the "rosette" of biaxial "positive" anisotropy.

Fig. 4. Polar diagrams of the anisotropy energy of crystallites of the cobalt α phase for $K_2 < 0$ and the total energy diagram

Thus, the presence in an epitaxial cobalt film of crystallites of the α phase reduces the negative anisotropy and, for a certain quantity of them, can create a "positive" total anisotropy.

Electron-diffraction studies carried out by us on cobalt films deposited on LiF crystals at a substrate temperature of 250° show that such films contain almost no crystallites of the α phase. The anisotropy of such films is always negative, and measurements on them of the anisotropy field give values of 500–600 Oe. These facts confirm the assumption stated above that the crystallites of the α phase are responsible for the "positive" anisotropy in cobalt films epitaxially grown on NaCl.

It should be noted that all the arguments presented above are valid if it is assumed that, in epitaxial films, for α-Co the second anisotropy constant $K_2 < 0$. However, as is known (3), in bulk single crystals of α-cobalt $K_2 > 0$. Several reasons may be suggested for the negative sign of K_2 in crystallites of the hexagonal phase in epitaxial films. In our view, the following is the most probable. In a film deposited in a vacuum of $\sim 10^{-4}$ mm Hg, crystallites of the α phase, as well as of the β phase, may contain, in comparison with bulk single crystals, an increased number of oxygen atoms. Heidenreich, Nesbitt, and Burbank (1) showed that, for induced anisotropy to arise during magnetic annealing of alloys with a face-centered lattice, oxygen must be present in them. Therefore it is quite possible that it is precisely the presence of oxygen in crystallites of the α phase of the films that changes the sign of K_2 in them.

Deposition of films with oxygen admitted into the chamber at the moment of deposition confirms this view. Films deposited on NaCl in this case are regularly obtained with "positive" anisotropy.

Institute of Physics
Siberian Branch of the Academy of Sciences of the USSR

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Note: Figure translations are in progress. See original paper for figures.