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Structure and magnetic anisotropy of epitaxial fcc-Co(110) and hcp-Co(1100) films

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Fcc-Co(110) and hcp-Co($1\bar{1}00$) films of 200 Å thickness were grown on MgO(110) and bcc-Cr(211)/MgO(110), respectively, by the molecular beam epitaxy method. Reflection high energy diffraction was used to *in situ* characterize the crystal structure. Co films grown directly on MgO(110) were pseudomorphic fcc structure. Twofold symmetrical hcp-Co(1100) films on top of the bcc-Cr(211)/MgO(110) were grown and confirmed. The magneto-optical Kerr effect (MOKE) was used to investigate the magnetic anisotropy of these films. The magnetization of these samples was found to be in-plane. The magnetization of fcc-Co films has cubic symmetry with texture induced uniaxial anisotropy. For hcp-Co(1100)/bcc-Cr(211) bilayer films, the magnetization was strongly anisotropic, but independent of the thickness of the Cr layer. © *1996 American Institute of Physics.* [S0003-6951(96)01415-1]

Surface magnetism is recently a much studied topic both because of fundamental physics and the demands of high-density magnetostorage technology. The orientation of the magnetization for a ferromagnetic thin film is determined by the competition between shape anisotropy, magnetocrystalline anisotropy, magnetic surface anisotropy, etc.[1] Experimentally, the magneto-optical Kerr effect (MOKE) has become a powerful tool and has been widely used to search magnetic anisotropies as a function of thickness, layer modulation, surface Curie temperature, etc.[2] It is known that magnetism is sensitive to the crystalline structure.[3] Due to the surface reconstruction or epitaxial strain, the structure of an artificial film may energetically favor a pseudomorphic structure. Co possessing metastable bcc,[4] fcc,[5] and stable hcp phases at different preparation conditions provides an excellent model system for studies of structure-related magnetism.

In a previous work,[6] the authors reported the properties of Co/Cr superlattices; however, their properties are far too complicated, and in this letter, therefore, are presented a systematic analysis of the effect of crystal structure on magnetic anisotropy of epitaxial Co films grown on MgO(110) with or without a Cr buffer layer.

The growths of Co and Cr films on MgO(110) were carried out in a molecular beam epitaxy (MBE) system (Eiko EL-10A) that is equipped with three independent electron beam evaporators and a high energy electron gum. Prior to deposition, epitaxial grade substrates were outgassed at 900 °C for at least 30 min under ultrahigh vacuum in the MBE chamber to clean the substrate surface. The temperatures of the substrates were kept between 300 and 350 °C during the deposition. The base pressure of the system is lower than 1×10^{-10} Torr. During the growth of the superlattices the pressure of the system was kept below 5×10^{-9} Torr, and the growth rates were kept at about 0.1 Å/s. The growth rate and film thickness were monitored by a quartz crystal thickness monitor (Leybold Inficon XTC). Reflection high energy electron diffraction (RHEED) with energy of 15 keV was used to *in situ* examine the crystal structure of the film surface throughout all growth. The magnetic anisotropy of the Co films was *ex situ* characterized at room temperature in a magnetic field up to 2 kOe by MOKE. According to the incident plane and the orientation of the magnetization **M**, MOKE is classified into three configurations: polar MOKE (PMOKE), where **M** is perpendicular to the sample surface and lies on the incident plane; longitudinal MOKE (LMOKE), where **M** lies on both the sample surface and the incident plane; and transverse MOKE (TMOKE), where **M** lies on the sample surface but is perpendicular to the incident plane. MOKE depends on the magnetization of the sample and not on the external applied field, which is just a driving force to modulate the magnetization of the sample. In this study, only PMOKE and LMOKE were used to examine the magnetic anisotropies. The magnetic hysteresis loop was picked up by monitoring the change of the MOKE signal on the reflected beam as a function of the applied field. For the LMOKE measurements, the sample can be rotated about its surface normal to determine the in-plane easy and hard axes.

The unit cell of fcc-Co(110), 3.44 Å×2.44 Å, has a 7%–8% mismatch on both axes with MgO(110), 4.21 Å×2.98 Å. At a rough estimate from the RHEED patterns of Figs. 1(a) and 1(d), the 3D geometry of fcc-Co(110) has a tilt of 19° off axis on MgO(110) as sketched in Fig. 2 and hence the possibility of textured fcc-Co films growth. The unit cell of hcp-Co(1100), 4.07 Å×2.51 Å, matches perfectly with that of Cr(211), 4.07 Å×2.50 Å, as shown in Figs. 1(c) and 1(d), but there exists a 1.7% mismatch of Cr(211) with the unit cell of MgO(110) as shown in Figs. 1(e) and 1(f). The schematic diagram of the hcp-Co(1100)/bcc-Cr(211) on MgO(110) is shown in Fig. 3 (Ref. 6). The shown structural quality of hcp-Co is reached only after the Co thickness exceeds 15–20 Å.

No PMOKE was observed for all samples, indicating strong in-plane anisotropic magnetization. Figure 4 shows

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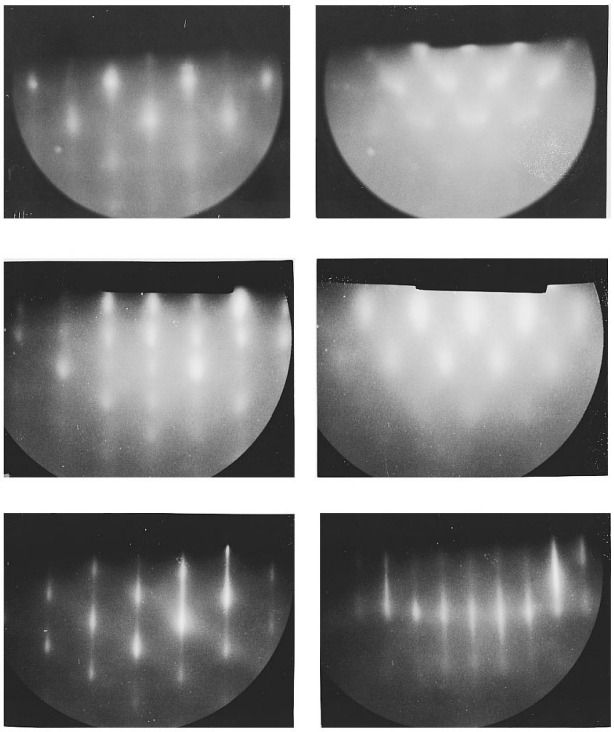

FIG. 1. The RHEED patterns of (a) fcc-Co(110)/MgO(110); (b) bcc-Cr(211)/MgO(110); (c) hcp-Co(1100)/bcc-Cr(211)/MgO(110); (d) fcc-Co(110)/MgO(110); (e) bcc-Cr(211)/MgO(110); and (f) hcp-Co(1100)/bcc-Cr(211)/MgO(110). For (a)–(c), the incident electron beam of 15 keV was along MgO[110]; for (d)–(e), the e-beam was along MgO[001]. The thicknesses of the Co and Cr films were 200 and 20Å, respectively.

the LMOKE of Co films as a function of the azimuthal angle ϕ. In Fig. 4(a), the magnetic anisotropy of the Co(110) film on MgO(110) has cubic symmetry; however, there also exists a uniaxial magnetic anisotropy due to surface roughness, etc.;[7] the authors estimate its magnitude at about 5% or less of the cubic anisotropy energy, although in other samples (not shown) it may be somewhat larger (up to 15%). The hcp-Co(1100) films on bcc-Cr(211)/MgO(110) were anisotropic, as seen in Figs. 4(b) and 4(c). The thickness of the 6 Å Cr(211) film may not cover the substrate completely, and therefore, the specimen consists of cubic Co(100) and uniaxial Co(1100) clusters. This is revealed by the shape of the magnetic hysteresis loops and the nonzero loop area at any angle, as seen in Fig. 4(b), which is a superposition of Figs. 4(a) and 4(c). The latter plot shows the uniaxial anisotropy of the hcp-Co($1\bar{1}00$) films on the top bcc-20 Å Cr(211)/MgO(110), where ϕ is the angle between the in-plane crystal axis MgO[001]‖Co[0001] and the applied field. A series of hcp-Co(1100) films with a thicker Cr buffer layer were measured and showed the same behavior as in Fig. 4(c). Clearly, this magnetic property originates from the crystalline anisotropy of hcp-Co. The anisotropic behavior of the hcp-Co(1100)/bcc-Cr(211) superlattices on MgO(110) has also been confirmed by the measurement of anisotropic magnetoresistance and reported elsewhere.[8]

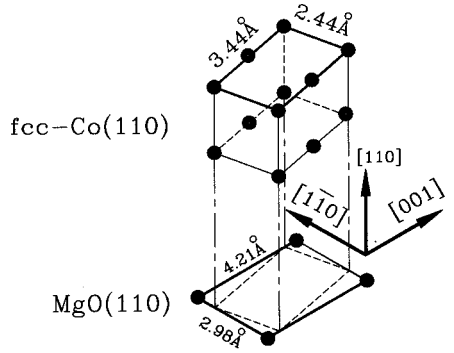

FIG. 2. Schematic diagram of fcc-Co(110)/MgO(110).

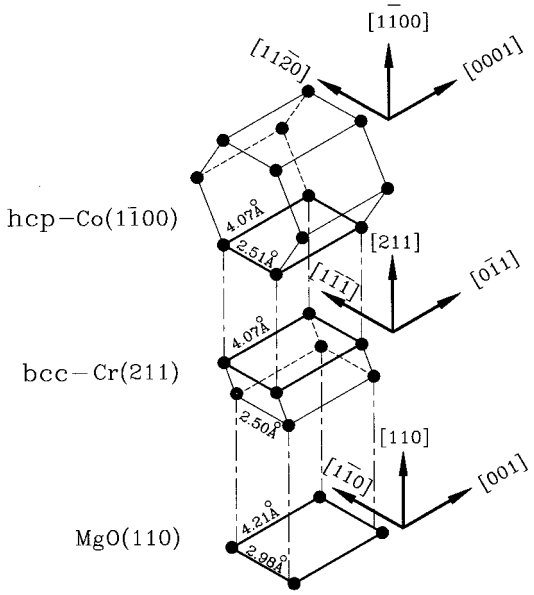

FIG. 3. Schematic diagram of hcp-Co/bcc-Cr(211)/Mg(110).

The magnetization of 200 Å Co films on MgO(110) with or without Cr buffer layer has been shown to be in-plane. Co films grown directly on MgO(110) were pseudomorphic fcc

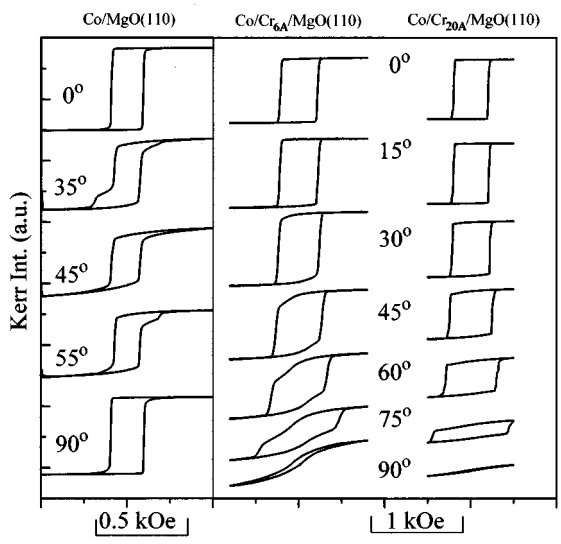

FIG. 4. LMOKE hysteresis loops of (a) 200 Å fcc-Co(110) on MgO(110), (b) 200 Å hcp-Co(1100) on 6 Å bcc-Cr(211)/MgO(110), and (c) hcp-Co(1100) on 20 Å bcc-Cr(211)/MgO(110). In (c), the azimuthal angle ϕ runs from 0° (easy axis‖MgO[001]‖Co[0001]) to 90° (hard axis ‖MgO[110]‖[1120]). The width of the loop at zero field is proportional (to within less 5%) to cos ϕ as expected for a uniaxial system. The Kerr intensity in the three sets of plots is not to scale.

structures with isotropic magnetization. A strong anisotropic magnetization of uniaxial hcp-Co(1100)/bcc-Cr(211) films grown on MgO(110) was demonstrated by the angular dependence of the coercivity in LMOKE hysteresis loops.

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