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Journal of Magnetism and Magnetic Materials 272–276 (2004) e797–e799
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

Investigation of magnetic anisotropy and role of underlayer in obliquely sputtered metallic thin films

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Abstract

Co and Co–Ni films have been obliquely sputtered on polyethylene terephthalate (PET) with and without Cr underlayer. The spin-reorientation observed in films directly deposited on PET is related to the low magnetocrystalline anisotropy of Co (FCC) and change in microstructure from columns to elongated nuclei. Cr underlayer enhances magnetic anisotropy due to HCP structure of Co, which dominates the shape of columns. The double switching in Co/Cr films grown at 70° is a consequence of low packing density of Cr columns of the underlayer.

PACS: 75.70.–i

Keywords: Thin films; Oblique deposition; Magnetic anisotropy; Hysteresis loop

1. Introduction

Thin films grown by oblique deposition are of significant interest for fundamental and applied research [1–4]. The morphology of such films consists of columnar type structure. The tilt and packing density of columns are strongly dependent on the incidence angle. The shape of columns and magnetocrystalline anisotropy contribute to the magnetic properties of the film. The orientation of the easy axis is governed by the competition between both anisotropies. Since Co is the main element in the composition of our films, its structure (FCC or HCP) is crucial in controlling the anisotropy orientation. In this study, we investigate magnetic anisotropy of Co and Co–Ni films obliquely deposited with and without Cr underlayer.

2. Magnetic properties and structural analyses

The deposition system consists of two sputtering guns together with a solid drum covered with polymer substrate. Both Cr underlayer and metallic film (Co, Co–Ni) have been consecutively sputtered on PET substrate at different incidence angles. Thin and thick films have been prepared. More details about the preparation are reported in Ref. [4]. Fig. 1 shows the in-plane magnetic loops of thick (a) and thin (b) Co–Ni films grown without underlayer at 70°. Both loops have been measured using a VSM with the field applied parallel to directions called longitudinal and transverse (parallel and perpendicular to the projection of the incident beam in the film plane, respectively). It is surprising to see a drastic change in magnetic properties upon changing the film thickness. Despite a constant magnetization M_s estimated at 600 emu/cm^3, a significant reduction of coercivity and hysteresis as well as spin-reorientation are observed upon decreasing the film thickness. At large thickness (130 nm) the longitudinal loop exhibits a large coercivity and a high remanence and confirms that the easy axis is parallel to the longitudinal direction. However in the thinner film (13 nm), the small hysteresis and the large saturation field of the longitudinal loop are a clear indication that the anisotropy switches to be parallel to the transverse direction. It is important to point out that close to a certain critical thickness $t_c = 30$ nm [5] it is hard to see

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doi:10.1016/j.jmmm.2003.12.1251

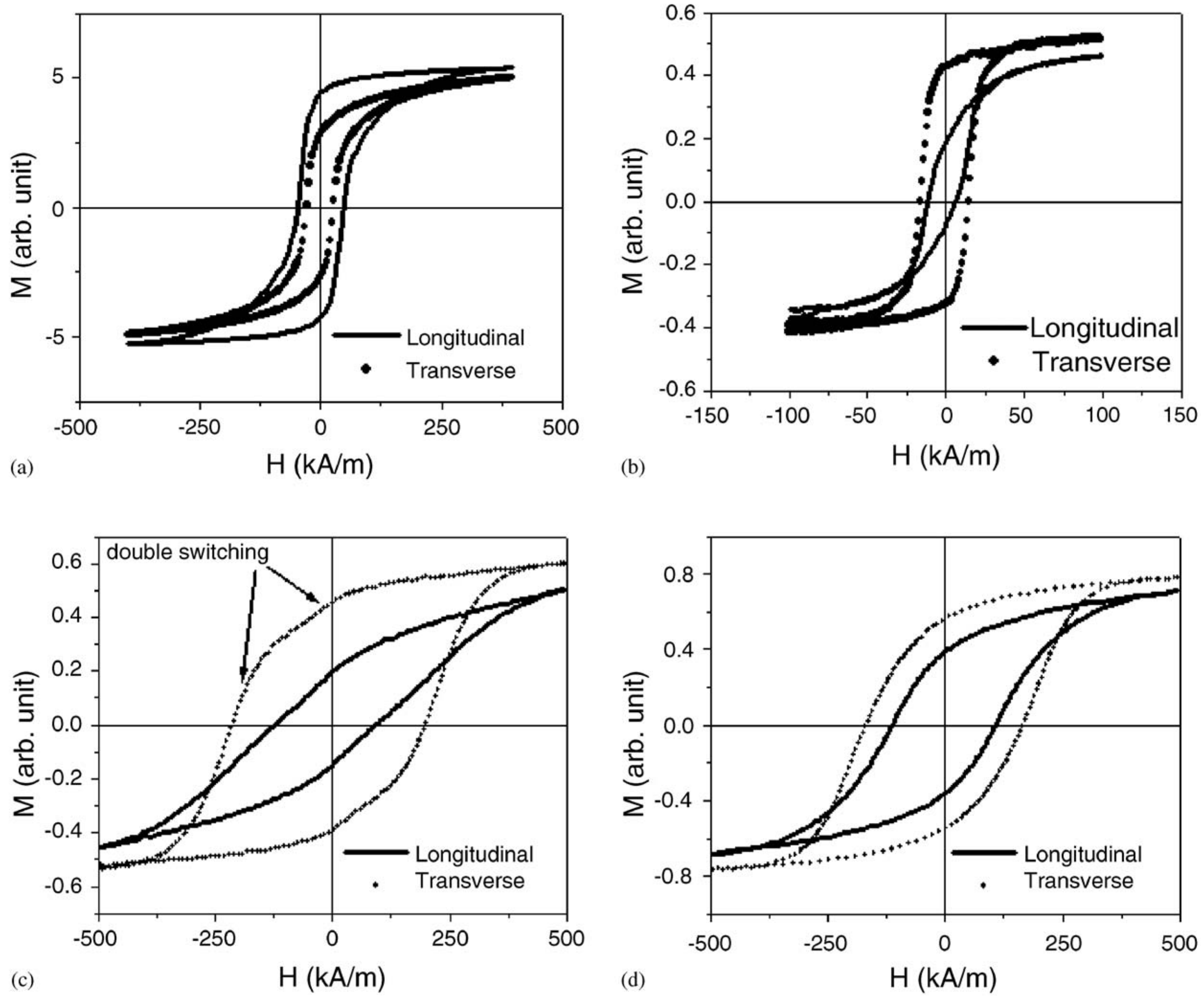

Fig. 1. Longitudinal and transverse loops of (a) thick (130 nm) and (b) thin (13 nm) Co–Ni films deposited at 70° on PET. (c) and (d) are the loops of Co/Cr films deposited at 70° and 50°, respectively.

any significant difference between longitudinal and transverse loops. At t_c both loops exhibit the same coercivity (20 kA/m) and 80% remanence and confirm that both directions are magnetically equivalent. A Cr underlayer has been obliquely sputtered at 70° and 50°, respectively, and the Co film was grown on top of it at the same angle. Fig. 1(c) shows the longitudinal and transverse loops of Co/Cr film deposited at 70°. The coercivity (200 kA/m) and hysteresis are considerably increased in comparison to films prepared without underlayer. Cr underlayer induces a significant enhancement of magnetic anisotropy. In addition, Fig. 1(c) reveals anomalous behaviors, which can be summarized as follows. (i) Existence of double switching in both loops indicating the existence of two magnetic phases in the film. (ii) Magnetic anisotropy remains parallel to the transverse direction and no spin-reorientation has been observed upon changing the film thickness. In-plane magnetic loops of Co/Cr film deposited at incidence of 50° are presented in Fig. 1(d). The anisotropy orientation is not affected by the reduction of incidence angle and the easy axis keeps the transverse direction as the preferential orientation. However, the most drastic change occurs in the shape of the loop, which consists of one switching rather than a double jump as reported before. All these reported effects are discussed based on further structural analyses.

The importance of magnetocrystalline anisotropy is related to the structure of Co (FCC or HCP). Fig. 2 shows XRD spectra ($\theta/2\theta$ scan) of films grown with and without Cr underlayer. The peak positioned at 44.3° in Fig. 2(a) confirms that Co crystallizes in the FCC rather than the HCP phase in films deposited without underlayer. It is surprising to see a complete change in Co

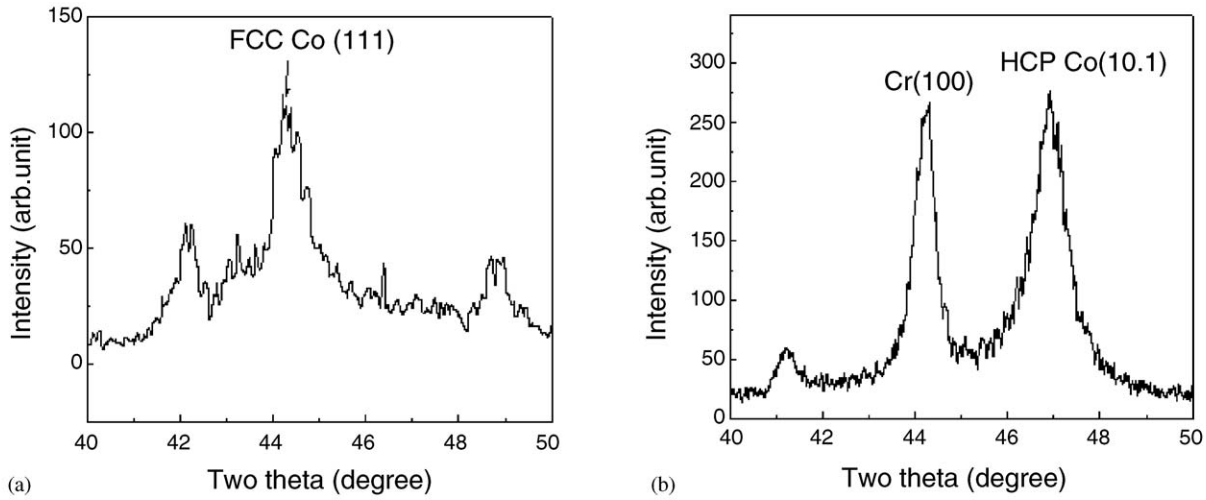

Fig. 2. XRD of Co films prepared (a) without and (b) with Cr.

structure upon introducing Cr buffer layer. In addition to (1 1 0) Cr texture, both peaks relative to Co in Fig. 2(b) reveal the existence of HCP Co. In a recent work [5] we established that the film microstructure consists of tilted columns well isolated from each other and parallel to the incidence plane.

The low packing density of columns estimated at 40–50% is a consequence of the large incidence angle, which controls the shadow effect during deposition. The shape anisotropy of columns is parallel to their elongated axis and dominates magnetocrystalline anisotropy of FCC Co in films prepared without underlayer. The spin-reorientation of Fig. 1 can be explained as follow. At large thickness, the shape of columns holds the easy axis parallel to the incidence plane. However, decreasing the film thickness reduces the length-to-diameter ratio, which becomes equal to 1 at t_c. At t_c the shape anisotropy of columns disappears and the isotropic structure is related to the random anisotropy of FCC Co. Below t_c a structure with elongated nuclei parallel to the transverse direction has been observed [5]. The shape of nuclei confines the anisotropy parallel to the transverse direction. The enhancement of the coercivity and hysteresis in Fig. 1(c and d) is related to the HCP Co with c-axis mainly parallel to the transverse direction. With Cr underlayer, the large anisotropy of HCP Co dominates the shape of columns and the easy axis remains parallel to the transverse direction regardless of film thickness. The double switching observed at large incidence of Cr underlayer is certainly related to both phases of Co (FCC and HCP). When Cr is sputtered at large angle, void exists between Cr columns due to the shadow effect. Consequently, Co can grow at the top of Cr as well as on PET in between Cr columns. On Cr, Co crystallizes in HCP whereas on PET it is mainly FCC. The existence of two phases with different anisotropies induces a double switching in magnetic loops of Co/Cr deposited at 70°. Reducing the incidence angle increases the packing density of columns. Consequently, Co grows only on Cr and exhibits a uniform HCP structure with a single switching.

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