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High magnetic field induced pillar growth and subsequent magnetic properties of the thermal evaporated Co thin films

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ABSTRACT

This letter studies the effects of in-situ high magnetic field application on the Co film growth via thermal evaporation. It was found that the crystalline structures of Co films were not changed by the application of the 6 T magnetic field. However, high magnetic field induced the Co particles to grow in a pillar mode and align along the magnetic field direction. Furthermore, the pillars prefer to aggregate to a large one (about 1.5 μm in diameter) under the high magnetic field condition. The in- and out-of-plane magnetic anisotropy was significantly influenced by the pillar structure and the film was difficult to be magnetized to saturation due to the pillar structure.

1. Introduction

Co thin films with high saturation magnetization, uniaxial magnetic anisotropy, and low coercivity have been intensively studied because of the promising application in magnetic recording media [1]. Meanwhile, Co thin film is often used as a free magnetic layer to tune the properties of multilayer films [2,3]. Therefore, the properties of Co thin films are of interest not only for fundamental but also for application aspects.

Since the properties of films are closely related to the structures, many experimental techniques have been performed to make Co thin films exhibit the needed properties [4,5]. The structures and properties of Co thin films were often affected by means of annealing [6], controlling underlayer [7], increasing film thickness [8], forming Co nanocluster thin film [9], fabricating multilayer structure [10]. However, for pure Co film, when the growth conditions remain unchanged, it is difficult to vary the structures and properties.

On the other hand, high magnetic fields based on the roles of magnetization energy and magnetic force have been applied to the fabrication of materials [11–13]. It was found that the magnetic properties of Ni–Fe films were obviously improved only by applying a 6 T magnetic field [14]. In order to tune the structures and properties of Co thin film, the high magnetic field was applied to affect the growth of evaporated Co thin films. The various effects of high magnetic fields on the structural evolution and magnetic properties were studied.

2. Experimental details

Cobalt of 99.9998% purity was evaporated from a Co source which was heated with resistance heating wire. Pressure was 2.0×10^{-4} Pa during deposition. The details were described in our previous papers [14]. The substrates were Si(1 0 0) plate and mounted on the position of maximum magnetic flux density. The direction of magnetic field was upward and perpendicular to the substrates. The temperatures of substrate and source were 200 °C and 1400 °C, respectively. Co thin films with 30 nm thickness were prepared.

Film thicknesses were measured by JEOL JEM-2100F transmission electron microscopy (TEM) with the cross-section images. Surface morphologies were obtained using the Multimode IV atomic force microscope (AFM). Structures were analyzed using the grazing incidence of D/MAX 2400 X-ray diffractometer (XRD), which worked in the θ–2θ mode with a monochromatic Cu $K\alpha1$ radiation ($\lambda = 0.154056$ nm). Magnetic hysteresis loops of the samples were measured using the Lakeshore 7407 vibrating sample magnetometer (VSM).

3. Results and discussion

Fig. 1 shows the X-ray diffraction spectra of Co thin films. Standard peaks of hcp and fcc phases are also shown in the figure. The strongest peak of Co thin films is (1 0 1), followed by (0 0 2) and (1 0 0), respectively. The textures of the films were calculated by the orientation index *M*,

$$M(hkl) = \frac{I(hkl)/\sum I(h'k'l')}{I_0(hkl)/\sum I_0(h'k'l')}$$

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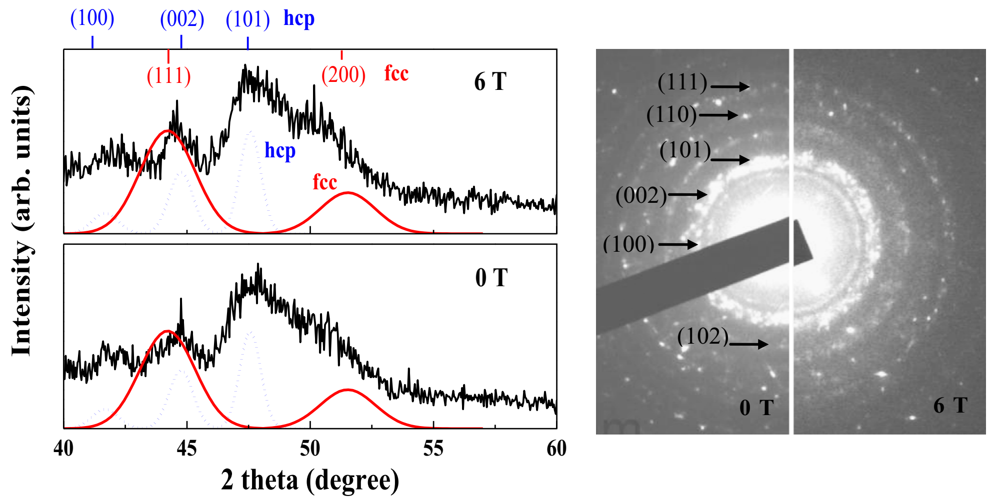

Fig. 1. X-ray diffraction spectra (left) and selected area electron diffraction patterns (right) of Co thin films with 0 T and 6 T magnetic field.

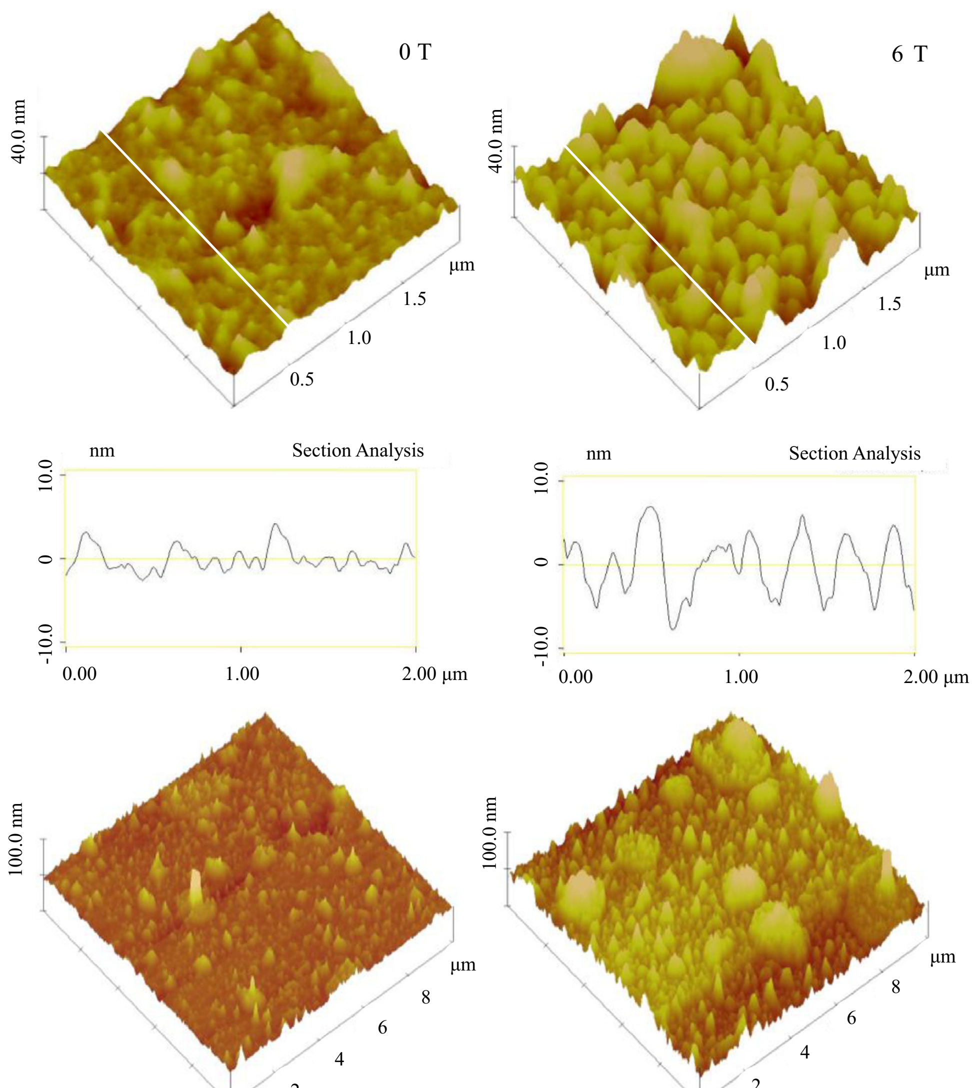

Fig. 2. AFM surface morphologies images and section profiles of Co films with different magnetic field conditions. The white lines indicate the region over which the section profiles have been measured.

where I_0 is standard X-ray diffraction intensity, I is the experimental data. $\sum$ is the sum of the intensities of peaks of (1 0 0), (0 0 2), and (1 0 1). For both films, the M value of (1 0 1) is the largest in these three peaks. This means that both films are the (1 0 1) texture. Furthermore, the preferred (1 0 1) orientation of 6 T film (M=1.20) is enhanced compared with the 0 T film (1.09).