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Fabrication of Co thin films using pulsed laser deposition method with or without employing external magnetic field

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ABSTRACT

In this work, the external magnetic field effects on growth condition during deposition processes of the Co thin films were studied. Two specimens of Co films with different condition (with and without external magnetic field) were synthesized by pulsed laser deposition method. Structural and magnetic properties of the Co thin films were systematically studied, using atomic force microscope analysis and magnetization measurement, respectively. During the deposition processes, the external applied magnetic field had been provided by a permanent magnet. The experimental results show that the external magnetic field enables one to tune the magnetic properties of the deposited thin films. To clarify this effect, using Multi-Physics COMSOL simulation environment, a study of vapor flux by applied magnetic field during deposition were performed. Comparison between experimental data and output data of the simulation show promising accommodation and approve the existence of a strong correlation between the structural and magnetic properties of the specimens, and deposition rate of Co thin films.

1. Introduction

Physical vapor deposition (PVD) techniques are widely used methods for the deposition of thin films. In this technique, thin films are fabricated by the condensation of a vaporized form of the desired film material originated from a target onto various substrates. The vapor flux trace is highly directional and this can create some disadvantages for application where uniformity of a layer is important. There are several ways to manipulate the vapor flux condition in PVD processes such as Controlling the chamber pressure [1], controlling the substrate condition (rotating, tilting, and rotation with tilting) [2,3]. Also, the effect of external electric or magnetic fields on the vapor flux path [4,5] have been reported to approach this purpose.

Among PVD techniques, the pulsed laser deposition (PLD) technique is one of the simplest and most versatile methods for the deposition of thin films of a wide variety of materials [6–8].

In this study, the effect of an external magnetic field on structural and magnetic properties of the Co thin films was studied. Also using Multi-Physics COMSOL software the effect of external magnetic field on vapor flux and surface of film has been simulated.

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2. Experimental details

The Co films were deposited on ultrasonically cleaned single crystal silicon-(100) substrates by PLD technique with and without the presence of magnetic field using high purity (99.99% from Aldrich) Co pellet as target. The target was rotated during deposition to avoid pinhole formation and maintain ablation rate constant. A KrF excimer laser (k=248 nm and duration=20 ns) with the repetition rate of 10 Hz and energy per pulse of 200 mJ was used for the ablation of the Co target. The base pressure in the deposition chamber was 1×10^{-6} Torr. The Co films were deposited by 10,000 laser shots at room temperature. Two samples were deposited with external magnetic field of about 1000 G and without external magnetic field which are called CoM and Co, respectively.

The prepared samples were systematically studied by the following techniques. X-ray diffraction (XRD) (ADVANCE–D8 model) equipped with CuK_α radiation source with λ=1.5406 acceleration voltage of 40 kV, and electron current of 40 mA which is configured in horizontal theta–2theta (θ–2θ). DC magnetization measurement were performed by a Quantum Design SQUID magnetometer.

3. Result and discussion

Fig. 1 shows the XRD patterns of Co thin films deposited on Si

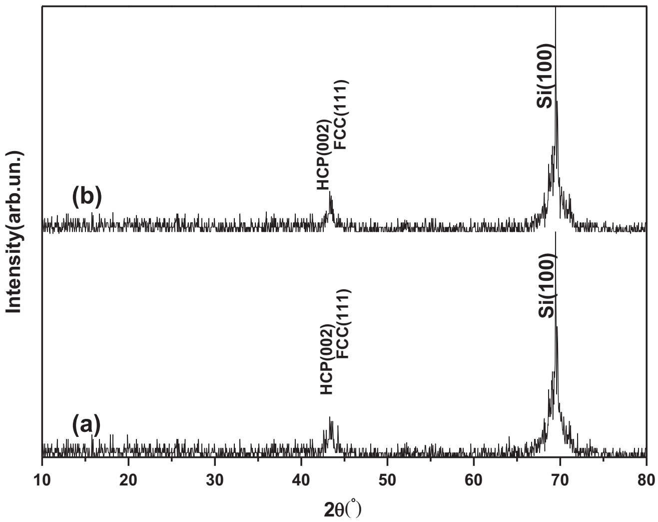

Fig. 1. XRD patterns of Co/Si thin films (a) without external magnetic field, (b) with external magnetic field.

substrates. The XRD pattern of films shows two well resolved peaks at around 2θ values of 43° and 69°. First one is related to Co film. This peak arising due to the combination of HCP (0 0 2) and FCC (1 1 1) reflections. The same behavior is reported by others [9,10]. Second one is due to reflections from Si (100) substrate which it is usually observed in the XRD pattern of others films grown on Si substrate [11,12].

The crystallite size is calculated using the width of the diffraction peak corresponding to hcp (002) reflection at $2\theta=43°$ using Scherer formula, and it was found to be 20 nm and 16 nm for CoM and Co samples, respectively.

Variation of surface morphology and roughness of both films has been investigated by Atomic force microscopy (AFM) technique. Fig. 2(a and b) show the AFM images and surface roughness for the films which is evaluated by averaging (rms) on 1000 and 200 nm windows.

The AFM images indicate the changes in surface morphology and roughness of the obtained samples with and without application of the magnetic field. The RMS surface roughness of the Co and CoM samples were found to be 5.8 and 11 nm, respectively. The mean grain sizes of the samples estimated by software are found to be 22 nm and 77 nm for Co and CoM samples, respectively. The micrographs as shown in Fig. 2 clearly indicate that with applying magnetic field during deposition process the grain size increases which is indicative of the improved crystallinity at (002) plane. The increase in the grain size and the perfection in the crystallinity of thin films grown under the applied external magnetic field have been reported earlier [13,14]. The larger grain size of the film supports the XRD results. In fact, the applied external magnetic field helps the ad-atoms to growth easier and with the increase in grain size, the dislocation density of the sample decreases. Therefore, the crystallinity of the film is improved.

Fig. 3(a and b) shows the results of magnetization (M) versus magnetic field for the samples at various temperatures which is measured using a conventional superconducting quantum interference device (SQUID).

The curves for the horizontal magnetization ($M_{\parallel}$) show ferromagnetic behavior with a very small coercivity. Comparing the hysteresis loop obtained at 20 K for both sample as shown in Fig. 4, exhibit the magnetic parameters dependence to external magnetic field.

Saturation magnetization (M_s) values are found to be 2.1×10^{-2} emu/cm^2 and 1.4×10^{-2} emu/cm^2 for CoM and Co samples, respectively. This change observed in the Ms values, as well as in the shape of hysteresis loop indicate the difference in magnetic moment anisotropy distribution of these samples. Larger the M_s and remanence magnetization (M_r) with lower coercivity (H_c) value for CoM sample indicate the soft magnetic behavior

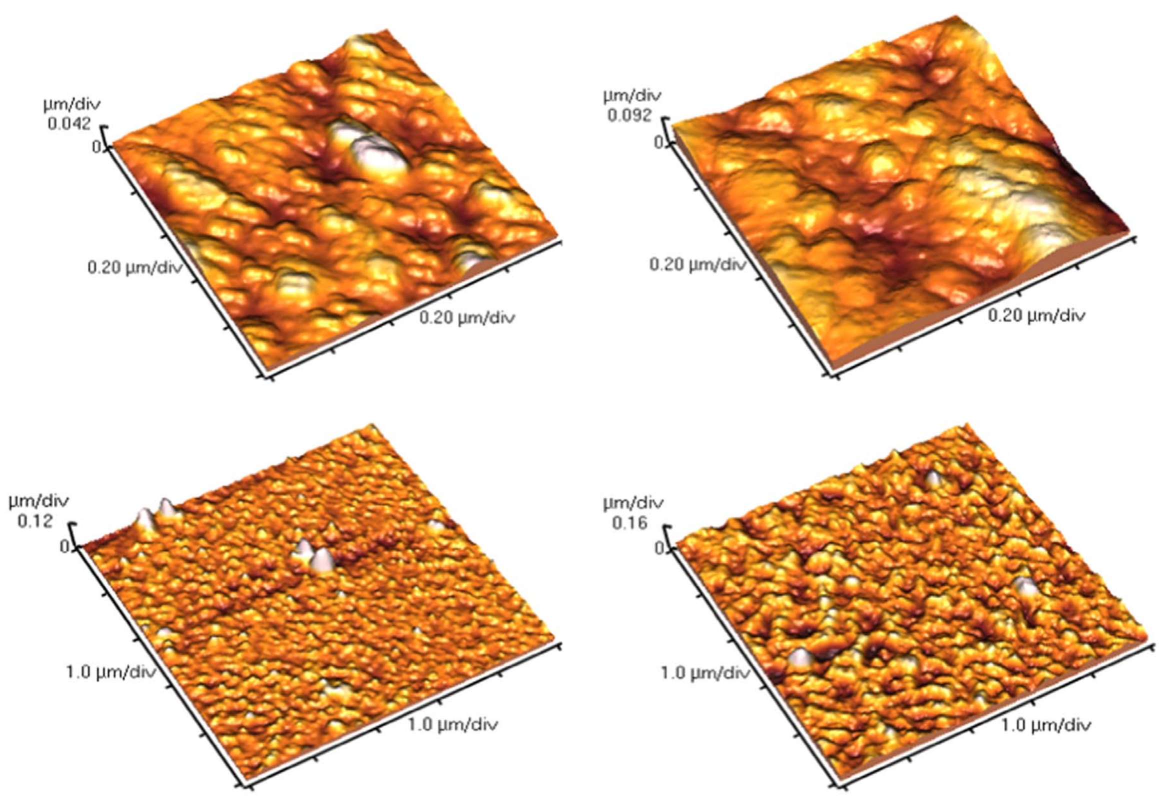

Fig. 2. AFM images of Co films, left: Co without external magnetic field, right: with external magnetic field.