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Kinetic roughening and magnetic study of Co electrodeposited thin films

Mojtaba Goodarzi[1*], **Kambiz Hedayati**[1]

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[1] Department of Science, Arak University of technology, Arak, Iran

Abstract

In this article, cobalt thin films with 250, 500, and 1000 nm thicknesses were grown on the copper substrate by electrodeposition method. The crystal structure of the cobalt thin film was studied using X-ray diffraction (XRD) and found that the layer and substrate both have orientation (111) and (200). The roughness of the layers was investigated using an atomic force microscope (AFM) and the saturation roughness were measured 5.8, 7.9 and 10.1 nm for 250, 500 and 1000 nm thickness, respectively. Examination of the kinetic roughening of cobalt thin layers showed that they have an anomalous scaling. The magnetic properties of the thin films were checked using a vibrating sample magnetometer (VSM) and their hysteresis loops were drawn and coercivity of samples obtained about 2800 Oe.

Keywords: Electrodeposition, Roughness, Cobalt, Thin Film

1.Introduction

Electrodeposition refers to the deposition of a pure or alloy material from an electrolyte solution as a result of passing an electric current on a metallic or semiconducting substrate, which depending on the type of electrolyte and the accumulation conditions of the resulting layer can be amorphous, crystalline, metallic or non-metallic [1, 2].

For electrodeposition in cell, three electrodes are needed. Electrolyte is an aqueous, non-aqueous or molten conductive solution in which the electric charge moves with the movement of ions. The amount of current or potential between the electrodes is adjusted by the potentiostat device at the time of layering. Two electrodes, cathode and anode, are used to generate current in the electrolyte, and the potential of the cathode electrode is more negative than the potential of the anode. The cathode is called the working electrode (WE) in which the reduction reaction takes place and the positive ions become uncharged by taking electrons. The anode is known as the secondary electrode (SE). In order to control the potential difference between the working electrode and the electrolyte, a third electrode called the reference electrode (RE) is used. The potential difference between the reference electrode and the electrolyte is constant, because no current flows through it. Therefore, the potential difference between the reference electrode and the working electrode, which is measured by the potentiostat, is equal to the potential difference between the electrolyte and the working electrode, and the potentiostat can control this potential difference by applying current between the working electrode and the secondary electrode. The reference electrode is placed near the working electrode to minimize the ohmic potential drop during potential measurement [3-5].

Cobalt thin films have magnetic properties and have many applications in the fields of magnetic recording and sensors [6, 7]. Surface kinetic roughening in a wide range of materials is observed and become important when a substance is added to their surface or a substance is removed from their surface.

In this article, cobalt thin films with three different thicknesses were synthesized by electrodeposition method and the effect of thickness on its roughness and magnetic properties was investigated [8].

2.Experiments

An electrolyte containing 100 ml of 0.5 M cobalt sulphate solution and 50 mM boric acid was used for coating. electrodeposition was done in galvanostatic mode using a potentiostat model SAMA 500 made in Iran. A platinum electrode was used as a secondary electrode and a saturated calomel electrode was used as a reference electrode. Also, copper foil with 99.9% purity was used as the substrate and working electrode.

On the substrate, a circle with a diameter of 1 cm was considered as the area of the coating, and the rest of the substrate was masked with anti-acid glue. The thickness of the layers is determined by giving the value with electrical charge (q) to the electrodeposition device, which is obtained by using Faraday's relation (Eq. 1).

$$q = \frac{\pi F \rho n R^2 h}{M} \qquad (1)$$

Corresponding Authors: Mojtaba Goodarzi
m.goodarzi@arakut.ac.ir

where F is the Faraday constant (96485 C/mol), h is the thickness of the layer, R is the radius of the accumulation area (0.5 cm), ρ is the density of cobalt (8900 kg/m^3), *M* is the atomic weight of cobalt (58.933), and د is its atomic valency (2) [9].

3.Results and discussion

The crystal structure of cobalt thin film with a thickness of 1000 nm was investigated by X-ray diffraction. As can be seen in Fig. 1, the copper substrate compatible with the JCPDS standard card No. 01-1241, with cubic crystal system, Fm-3m space group, 225 space group number and has a preferential orientation of (111), in addition, it has a smaller peak in the direction of (200). It can also be seen that the cobalt thin film with the JCPDS standard card No.15-0806 also has two peaks in directions (111) and (200) and has followed the direction, crystal system, space group, and space group number of the substrate for growth.

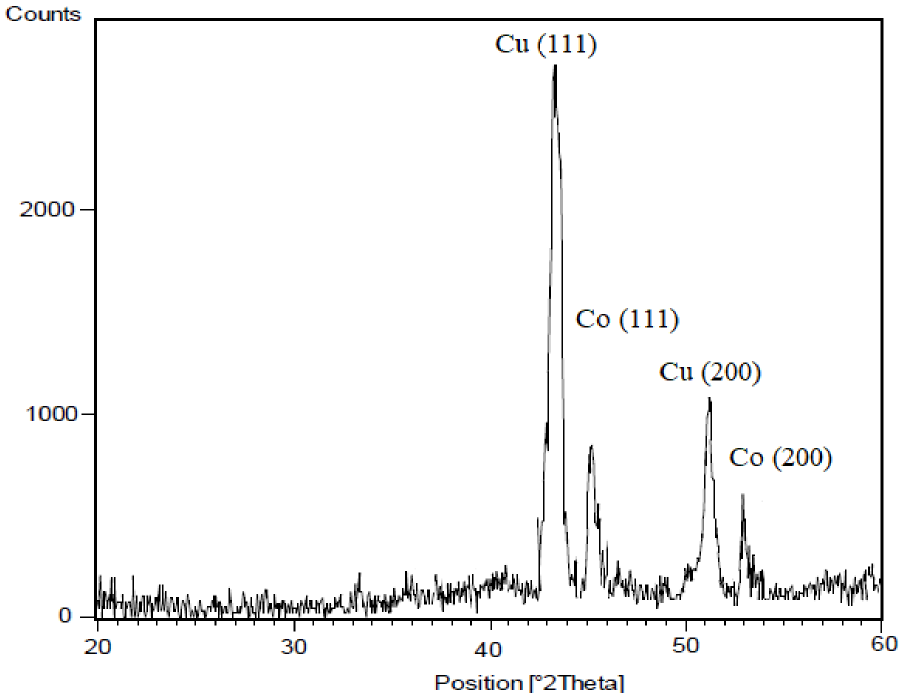

Fig. 1. The XRD of a cobalt thin film with a thickness of 1000 nm on the copper substrate.

Usually, surface roughness is shown experimentally by means of root-mean-square of the surface with Eq. 2.

$$w(l) = \sqrt{\langle (h - \langle h \rangle)^2 \rangle} \tag{2}$$

where h is the height of the surface for each point, l is the size of the area, and w is the surface roughness [10].

To calculate the surface roughness, it is necessary to check roughness as a function of t, which is the average thickness of the layer. Therefore, surface roughness is represented by w(l,t). In the normal dynamic scale, roughness is proportional to Eq. 3.

$$w(l,t) \propto l^H \ \text{ for } l \ll l_c \tag{3}$$
$$w(l,t) \propto t^\beta \ \text{ for } l \gg l_c$$

where H is the Hurst exponent, β is the growth exponent and l_c is a crossover length [11]. In some systems, roughness takes the form of more complex expressions of Eq. 3, which is known as anomalous scale. In this equation, βl_{oc} is called the local exponent.

$$w(l,t) \propto l^H t^{\beta_{loc}} \ \text{ for } l \ll l_c \tag{4}$$

$$w(l,t) \propto t^{\beta+\beta_{loc}} \quad \text{for } l \gg l_c$$

Atomic force microscope was used to investigate the surface kinetic roughening of cobalt thin films. The two-dimensional AFM image for the thin film with a thickness of 250 nm is shown in Fig. 2 (a). Also, the AFM image of 500 and 1000 nm thin films is shown in Figs. 2 (b) and 2 (c), respectively. As you can see in the images, the roughness and the size of the grains on the surface increases with the increase of the thickness of the film.

In order to investigate the surface kinetic toughening more accurately, using Eq. 1, the curve of surface roughness according to the scan length in the logarithmic scale for cobalt thin layers with thicknesses of 250, 500 and 1000 nm was drawn in Fig. 2 (d). According to the graphs, the saturation roughness for layers with thicknesses of 250, 500 and 1000 nm was obtained as 5.8, 7.9 and 10.1 nm, respectively. Therefore, as the thickness of the layer increases, the surface roughness increases.

Due to the fact that during small scans, the roughness of films with different thicknesses is different, the roughness follows Eq. 3 and the samples have an anomalous scale.

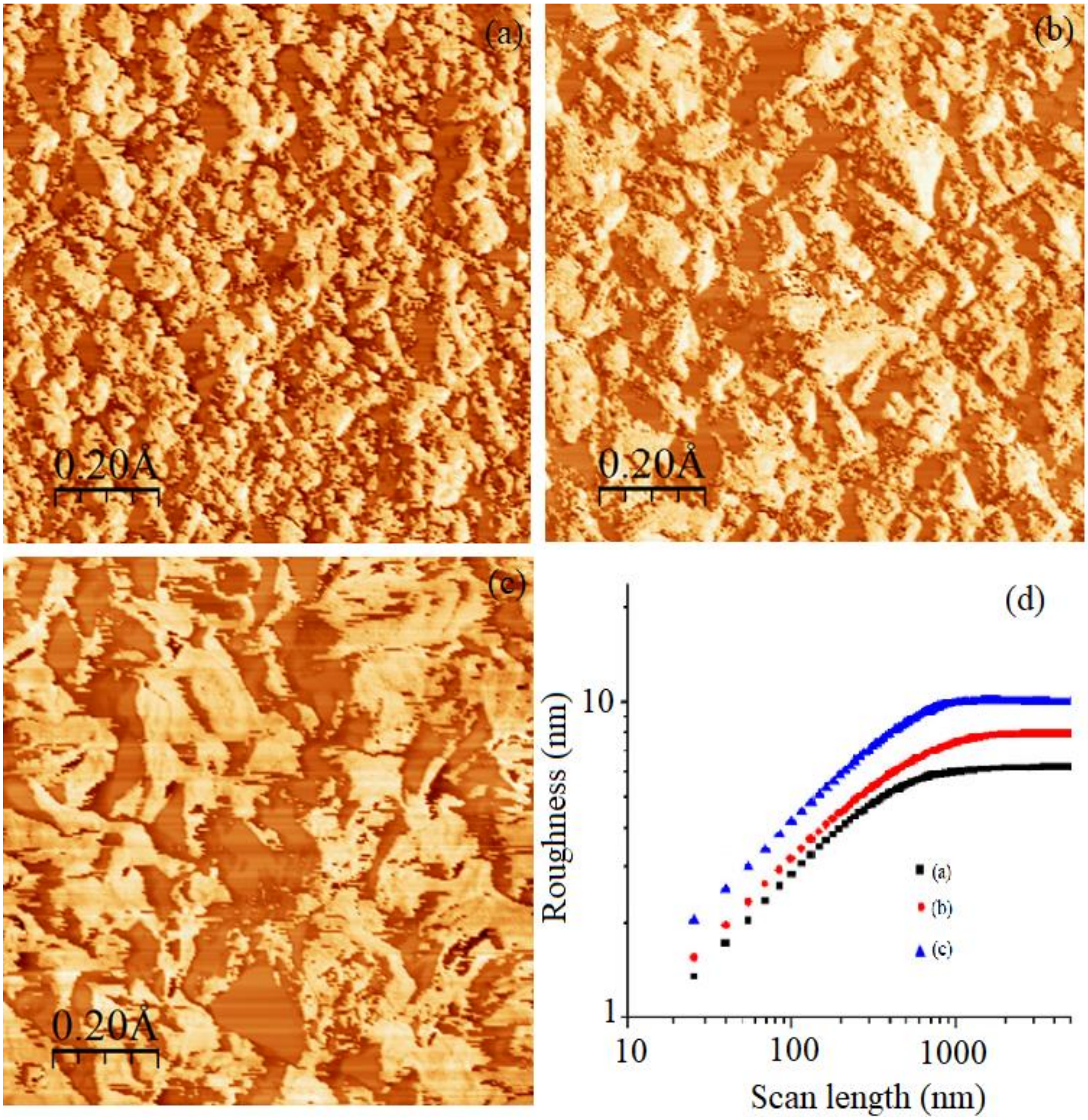

Fig. 2. The AFM image of a cobalt thin film with a thickness of (a) 250 nm, (b) 500 nm, and (c) 1000 nm on the

copper substrate, and variation of roughness as a function of scan length in logarithmic scale for the cobalt thin film with different thickness.

The magnetic properties of electrodeposited cobalt thin films were investigated by plotting the magnetic hysteresis loop using a vibrating sample magnetometer. The hysteresis loop of the samples is shown in Fig. 3. According to the curves, the value of saturation magnetization for films with thicknesses of 250, 500 and 1000 nm was obtained as 0.24, 0.86 and 1.35 emu/g, respectively.

The coercivity value for the sample is almost equal and has a value of 2800 Oe, but the remanent magnetization for films with thicknesses of 250, 500 and 1000 nm was obtained as 0.06, 0.32 and 0.65 emu/g, respectively.

The increase in the amount of saturation magnetization and remanent magnetization can be due to the increase in the amount of magnetic material that makes up the layer, and the non-change of coercivity is due to the non-change of the magnetic hardness of the layer.

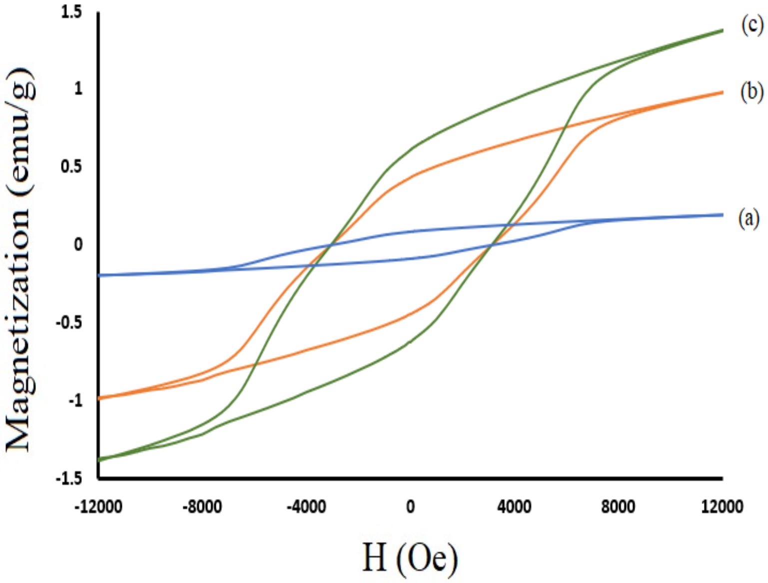

Fig. 3. Hysteresis loops of the cobalt thin film with a thickness of (a) 250, (b) 500 and (c) 1000 nm.

4.Conclusion

Cobalt thin films were grown in three thicknesses of 250, 500 and 1000 nm using the electrodeposition method in galvanostatic mode. The X-ray diffraction pattern showed that the cobalt thin film followed the orientation of the substrate to grow. Using the atomic force microscope, it was found that the surface roughness increases with the increase in the thickness of the cobalt thin films. Also, the roughness pattern of the layers has an anomalous scale. Using the magnetic hysteresis loops, it was observed that with the increase in the thickness of the films, the amount of saturation magnetization and remanent magnetization increases, but the coercivity remains constant.

Conflicts of Interest

The author declares no conflict of interest.

Author information

*Corresponding Author: Mojtaba Goodarzi
E-mail address: m.goodarzi@arakut.ac.ir

ORCID

Mojtaba Goodarzi: 0000-0001-5181-2269

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