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Effect of Magnetic Field on Surface Morphology and Magnetic Properties of FeCu/Cu Nano layers Prepared by Electrodeposition Technique: Investigation of Magneto-hydrodynamic Effect

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Abstract

In this paper, the effect of magnetic field on the morphology, structure and magnetic properties of electrodeposited FeCu/Cu thin films was investigated. The films were deposited on Au_2PdAg/glass substrates using electrodeposition technique in potentiostatic control. The magnetic fields of 5000 and 7000 Oe were applied on deposition bath during deposition. Two series of thin films were prepared in the same deposition conditions, one in the presence and the other in absence of magnetic field and the products were compared. The results indicate that applying the magnetic field has a significant effect on the growth process, i.e. morphology, crystal structure and magnetic properties of the films. The morphology and structure of the FeCu/Cu Nano layers were studied using X-ray diffraction (XRD) and scanning electron microscopy (SEM). The weight percentages of the elements in the deposited multilayers were determined by energy dispersive X-ray spectroscopy (EDS). Magnetic properties of thin films were studied using the vibrating sample magnetometer (VSM).

1. Introduction

Interest in artificially tailored nanostructures has greatly surged in recent years because of their novel magnetic properties and potential technological applications [1-3]. One of the excellent examples of artificially tailored nanostructure is Fe/Cu, which is composed of mutually insoluble metals such as iron and copper. Multilayer thin film, by alternatively depositing nonmagnetic and magnetic layers of only some nanometer thickness could induce the giant magneto-resistance (GMR) effect [4-5]. Extensive studies have been done on the crystalline

structure and magnetization properties of the multilayers of Fe/Cu prepared by physical methods such as sputtering [6, 7], molecular beam epitaxy [8], and e-beam evaporation [9]. However, these methods require an ultra-high vacuum to control their film thicknesses. In contrast, the electrochemical method employs the liquid phase, which is relatively simple, inexpensive, and efficient for growing multilayers at the atomic level [10]. Morphologies of electrochemically obtained metal deposits can be strongly changed if metal electrodeposition is performed in the presence of a magnetic field [11]. The effects of an applied magnetic field on electrochemical reactions have received attention in recent years because of their theoretical implications and potential practical applications in industry, such as enhancing mass transfer, improving electrodeposition quality, and controlling potential distribution and current, etc [12]. These changes in morphology are usually and mainly ascribed to the Lorentz force. During the electrolysis, this force acts on migration of ions and induces convective flow of electrolyte close to the electrode surface[13-19]. This effect on the electrodeposition process is known as magneto hydrodynamic (MHD) effect. The largest effect of this force is realized when magnetic field B is applied parallel to the electrode surface (i.e. an external magnetic field is oriented perpendicular to the direction of the ion flux) [15, 20]. In this work, the effect of magnetic field on the deposition process, morphology, structure and magnetic properties of electrodeposited FeCu/Cu layers are investigated.

2. Experimental

[FeCu(4nm)/Cu(1nm)]×200 multilayers were prepared by electrodeposition using a single bath method and three electrode system, consisted of a working electrode (Au_2PdAg/glass substrates) with 0.5 cm^2 of surface area, a counter electrode (platinum, mesh) and a reference electrode (saturated calomel). The electrolyte solution contained 0.06M iron sulphate ($FeSO_4.7H_2O$), 0.002M copper sulphate ($CuSO_4$) and 0.3M Boric acid (H_3BO_3) that purchased from Merck Co. All experiments were performed in potentiostatic control (constant potential), at temperature of 25 °C and pH of 3.8±0.1 .The electrochemical cell was inserted between the poles of an electromagnet, so that the magnetic flux lines run parallel to the cathode surface. The magnetic field applied during experiments was H=0, 5000 and 7000 Oe.

The morphological structure of the alloys was studied by SEM using a Hitachi S-4160 and LEO 1455VP instruments. Images were recorded in the backscattered electron or secondary electron mode at 10 KeV or 20 KeV primary beam energy. The crystallographic structure of the alloys was studied by XRD using an X-Pert Philips X-ray diffract meter with a CuK_α radiation. The magnetic measurements were carried out at room temperature with an ac induction method with computerized data acquisition (frequency of 50 Hz and in a maximum field of 80 kA/m) using an AGFM machine made by Meghnatis daghigh kavir, Iran.

3. Results and discussion

X-ray diffraction pattern of FeCu (4nm)/Cu (1nm) multilayer thin films at parallel magnetic field of H=0, 5000 and 7000 Oe are shown in Fig. 1a-1c respectively. It can be seen that applying a magnetic field during electrodeposition, leads to reduce of copper peak and increase of iron peak intensities. So that, no copper peak appear in the

XRD patterns of the multilayers when a magnetic field of 7000 Oe is applied.

The percentage contents of iron and copper in multilayer samples were determined on the basis of the data recorded with EDX microanalysis in the scanning electron microscope (SEM). The obtained results are presented in Fig.2 and Fig.3. The results show that applying the magnetic fields lead to reduce of the percentage of copper and increase of iron contents in the deposited films. These results are consistent with the results obtained by XRD analysis completely.

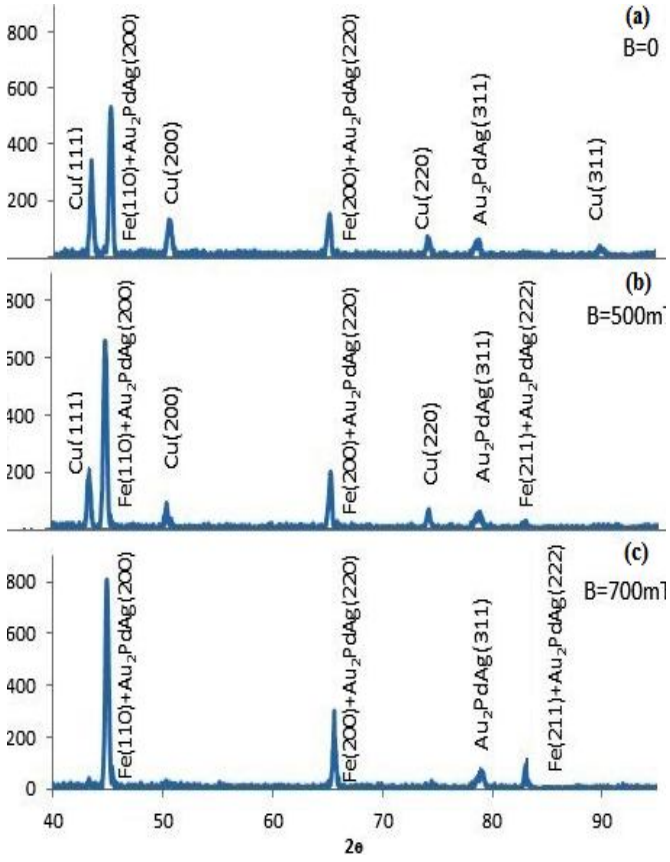

Fig. 1. XRD pattern of [FeCu(4nm)/Cu(1nm)]✕200 in presence of magnetic field of: a) B=0, b) B=5000 Oe and c)B=7000 Oe

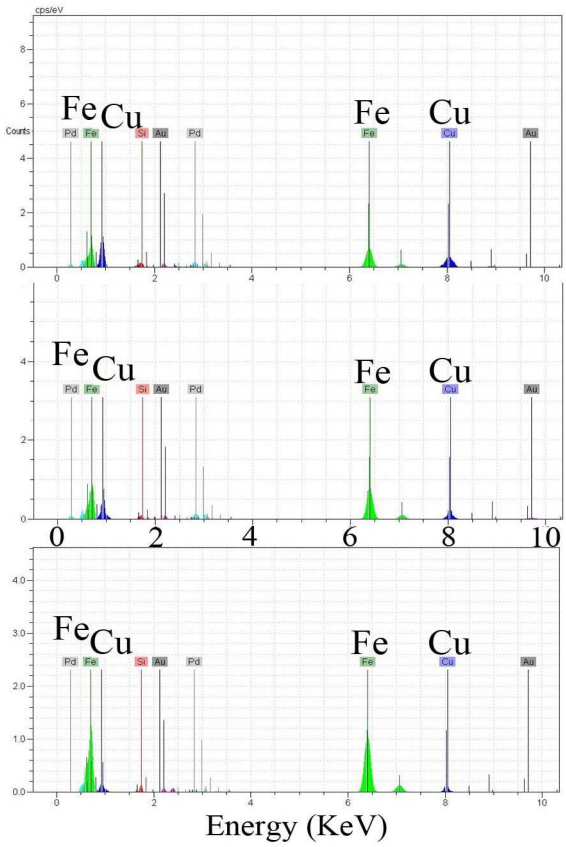

Fig. 2. EDX analysis of FeCu/Cu multilayers for samples grown under applying magnetic fields of 0, 5000 and 7000 Oe.

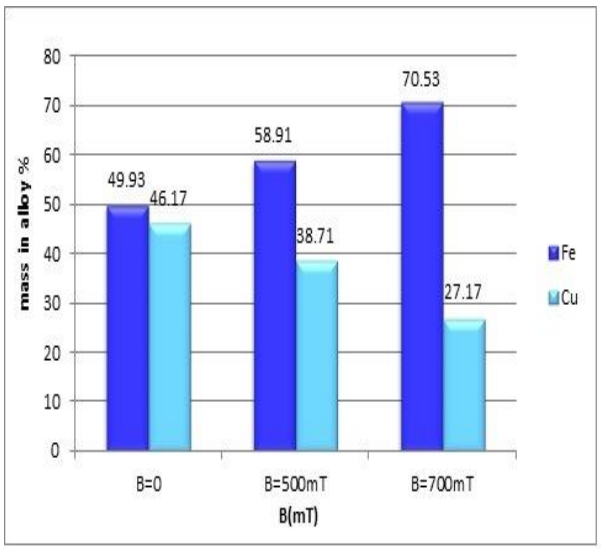

Fig .3. The weight percentages of the Fe and Cu in the deposited films were determined by EDX for samples grown under applying magnetic fields of 0, 5000 and 7000 Oe.

Fig. 4.a shows the SEM images of FeCu/Cu multilayers deposited in the absence of magnetic field, while the SEM images of the films deposited in the presence of magnetic field of 5000 and 7000 Oe Fig. 4.b-c respectively.

It is apparent that applying the magnetic field during deposition influences on the surface morphology. As can be seen applying a magnetic field parallel to the surface plane, the grain arrangement are more regular, so that the deposited films has a smoother surface.

The magnetic properties of the deposited layers were determined by means of VSM. Hysteresis loops obtained from VSM for thin films, deposited without and with applying a magnetic field are presented in Fig. 5. As the figure shows application magnetic field during the deposition process affects the magnetic properties of the deposited FeCu/Cu films. The comparison between the hysteresis loops reveals that the magnetization is slightly increased and coercivity is decreased with increasing the applied magnetic field.

An external magnetic field has the ability to alter the rate of molecular transport of electrochemical species by forced convection [11]. The force, F(N), acting on electrolyte ions and charged redox molecules in a magnetic field is given by,

$$F = \mu_0 q(v \times H) \qquad (1)$$

where q is the charge on the species moving at the velocity of $v(\frac{m}{s})$ and H is the applied external magnetic field. Momentum transfer between the accelerated species and the solvent results in local convective flow of the solution, altering the rate at which redox species (including neutral molecules) are transported to the electrode surface [15]. Such magneto-hydrodynamic (MHD) flow in electrochemical systems is conveniently described by the force per unit volume F_{MHD} acting on the solution,

$$F_{MHD} = \mu_0 J \times H \qquad (2)$$

Where, J is the local ion flux[17].

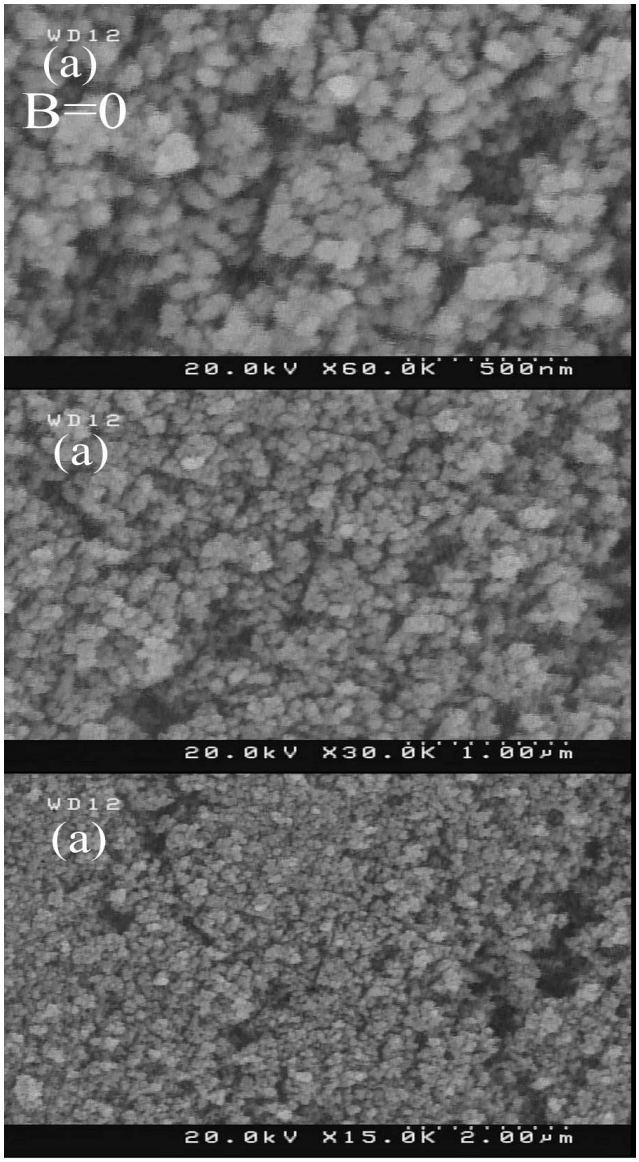

Fig. 4a. SEM images of [FeCu(4nm)/Cu(1nm)]□200 in presence of magnetic field a) B=0

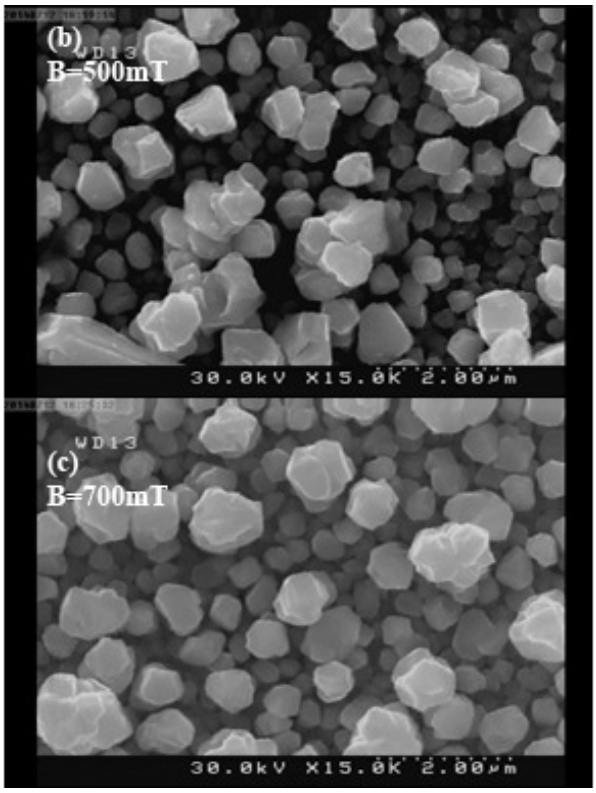

Fig. 4b, c. SEM images of [FeCu(4nm)/Cu(1nm)]×200 in presence of magnetic field b) B=500mt and c) B=700mT

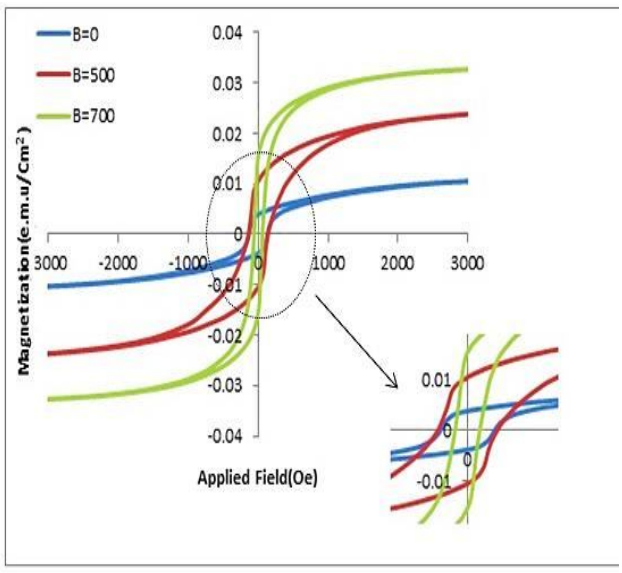

Fig. 5. Comparison between hysteresis curves of the FeCu/Cu multilayers electrodeposited without and with magnetic field

When the external magnetic field is oriented perpendicular to the direction of the ion flux (i.e., H is parallel to the electrode surface) MHD force reaches its maximum value and induced a convection flow in the vicinity of the electrode surface. Therefore the mass transfer rate and the current density increases by applying a magnetic field, leading to an increase to nucleation rate and providing sufficient magnetic ions for nucleation [13].

4. Conclusion

The CuFe/Cu electrodeposition is affected by a magnetic field applied parallel to the electrode surface. The results of XRD and EDX analysis of the deposited film support each others. The results show that the application of magnetic field causes changes in the chemical composition of the alloys. Thus, due to difference in susceptibility of iron and copper ions, by applying magnetic field, amount of iron in FeCu layer increases and amount of copper decreases. It has also been clearly demonstrated that the imposition of magnetic field, influences significantly on the morphological properties of electrodeposited layer. The layers deposited under the influence of the parallel-to-electrode magnetic field are smoother and more homogeneous than those obtained without a magnetic field perpendicular to the film plane. The magnetic properties of the deposits were found to be affected by a magnetic field applied during the deposition. The coercivity is reduced and the magnetization is increased when a magnetic field is applied. These observed phenomena could be explained based on MHD convection of charged ions at the interface of electrode and electrolyte induced by Lorentz force.

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