

*Journal of Chemistry, Vol. 47 (5), P. 591 - 595, 2009*

## INFLUENCE OF MAGNETIC FIELD ON PROPERTIES OF ELECTRODEPOSITED FeCo LAYER

*Received 21 November 2008*

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### ABSTRACT

*Effect of magnetic field on the electrodeposition of FeCo layers has been investigated with respect to the orientation of the magnetic field to surface electrode e.g magnetic field is parallel and perpendicular to electrode. Electrochemical behaviours, morphology, composition, structure and magnetic properties were investigated using cyclic voltammogram (CV), Scanning Electron Microscopy (SEM), Energy Dispersion Spectroscopy (EDS), X-Ray Diffractometer (XRD), Vibrating Sample Magnetometer (VSM). Results show that morphology and structure of the deposited layers are not effected by external magnetic field. Meanwhile, the Fe content of the layer decreases by following sequence  $C_{Fe}(B=0) > C_{Fe}(B//) > C_{Fe}(\perp)$ , resulting in the following sequence of coercivity  $H_C(B=0) > H_C(B//) > H_C(\perp)$ . These results were explained based on the magnetohydrnamic (MHD) effect caused by the Lorentz force ( $\vec{F}_L$ ) when magnetic field is superimposed.*

### I - INTRODUCTION

Soft magnetic films are essentially applied for thin-film recording heads to meet the future trends in high-density magnetic recording. For this purpose, it is necessary to develop recording heads using material with optimized magnetic and corrosion properties. Three groups of magnetic films can be distinguished: nickel — iron, cobalt — iron, and ternary alloys composed of cobalt — iron and a third element like nickel, copper, or chromium [1-5]. The electrochemical deposition of these films seems to be technologically interesting since the electrodeposition is a fast, cost effective technique and suitable for covering of large areas and applicable to mass production. It is known that magnetic fields ( $B$ ) influence the process of electrodeposition of layers [6-8]. The explanation of the influence of magnetic field is

mainly based on the magnetohydrnamic (MHD) effect caused by the Lorentz force ( $\vec{F}_L$ ). However, influences of magnetic field on the structure, composition, morphology and magnetic properties of electrodeposited magnetic layers have so far been studied only on few systems [6 - 9].

In this paper, we present results of study on the influence of a uniform magnetic field with different orientation to electrode surface on the magnetic properties of the electrodeposited FeCo layers.

### II - EXPERIMENTAL

Electrochemical investigations were carried out by means of potentiostatic technique using potentiostat (Jaissle). All potentials are measured vs. the saturated Ag/AgCl reference

electrode (SSE). The FeCo layers were deposited from 0.02 M FeSO<sub>4</sub> and 0.2 M CoSO<sub>4</sub> with addition of 0.1 M Na<sub>2</sub>SO<sub>4</sub> as a supporting electrolyte. A pH value of 3 was adjusted with H<sub>2</sub>SO<sub>4</sub>. The substrates 100 nm Cu on Si (100) — wafer with 5 nm Ta seed layer were used as the working electrode. Homogeneous magnetic fields of 700 mT strength have been applied in the gap of an electromagnet. Two different magnetic field to electrode configurations have been investigated. In the first configuration, the surface is parallel to magnetic field and in the second configuration, electrode surface is perpendicular to magnetic field.

Surface morphology of the obtained electrodeposited layers was investigated using scanning Electron Microscopy (SEM). The composition of the alloys was determined by Energy Dispersion Spectroscopy (EDS). Texture and phase formation of the films were analyzed

by X-ray Diffractometer (XRD). Magnetic hysteresis loop and magnetic coercivity  $H_c$  of the electrodeposited layers were measured using Vibrating Sample Magnetometer (VSM).

### III - RESULTS AND DISCUSSION

Fig. 1 displays the cyclic voltammogram of the substrate Cu (111) without magnetic field ( $B=0$ ) (curve a), with  $B = 700$  mT parallel to the surface (curve b) and with  $B = 700$  mT perpendicular to the surface (curve c). In the forward scan, the electrodeposition of the FeCo layers occurs at  $-1300$  mV/SSE. In the reverse scan, the anodic dissolution of the formed CoFe layers appears at  $-950$  mV. It is interesting to note that the current density increases in the presence of external magnetic field and the perpendicular configuration results higher current density than the parallel mode.

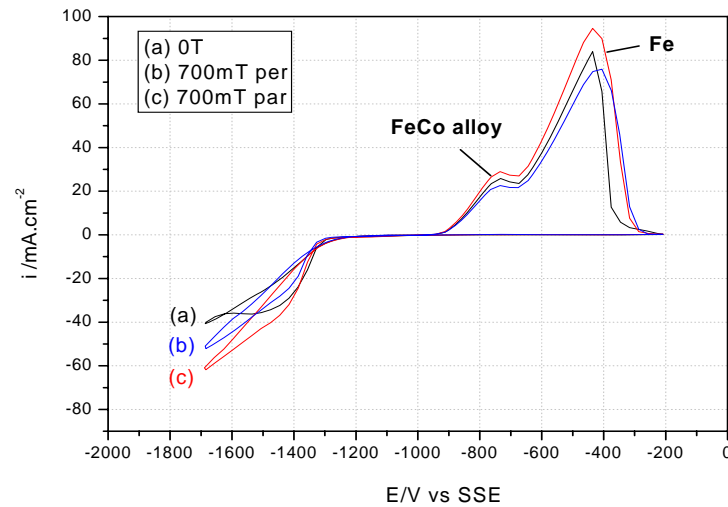


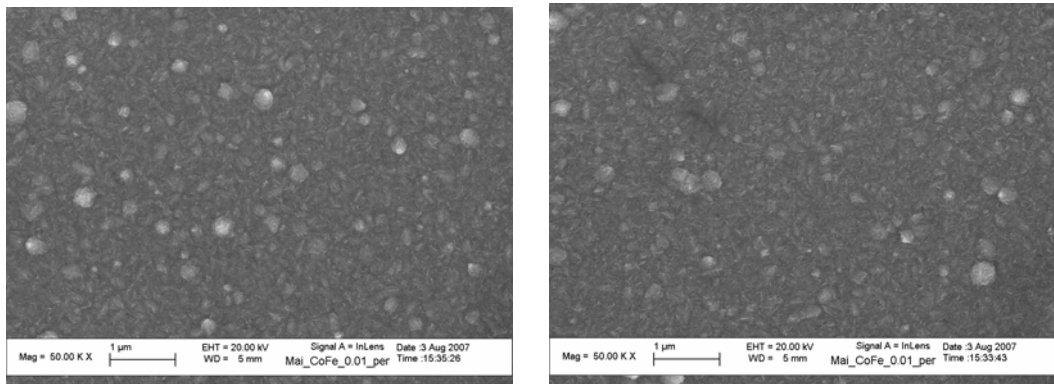
Fig. 1: Cyclic Voltammetry curves without  $B$  (curve a) and with  $B = 700$  mT parallel to the surface (curve b) and with  $B = 700$  mT perpendicular to the surface (curve c).

Fig. 2 shows SEM images of the CoFe deposited at a cathodic potential of  $-1400$  mV/SSE without an applied magnetic field, as well as with parallelly and perpendicularly oriented applied magnetic field of 700 mT. Results show that the morphology of the FeCo deposits does not change significantly as magnetic field is applied. In both cases with and without magnetic field, FeCo deposits show

quite visible grains.

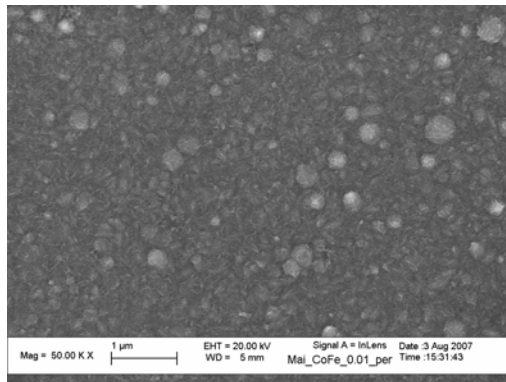
Fig. 3 displays XRD pattern of the electrodeposited FeCo layers without  $B$  and with superimposed magnetic field  $B = 700$  mT. It can be observed that the electrodeposited layers are solid solution with the basic fcc phase ((111) texture) of Co. No appearance of other structures is found in the XRD spectra of electrodeposited FeCo layers under external

magnetic fields oriented parallelly and perpendicularly.



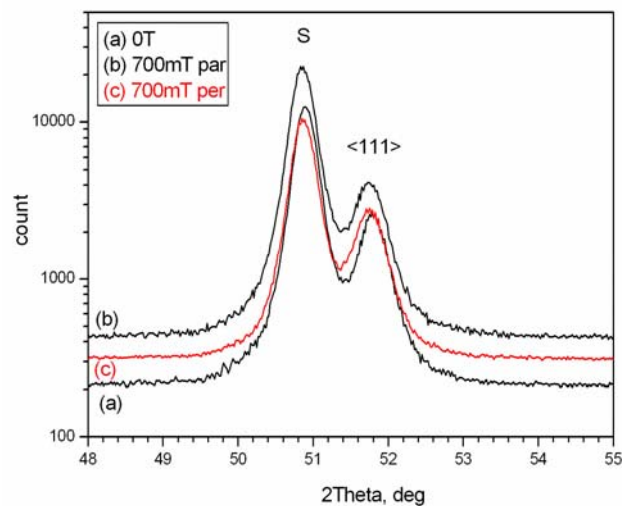
(a)  $B = 0$  T

(b)  $B = 700$  mT parallel to the surface



(c)  $B = 700$  mT perpendicular to the surface

*Fig. 2:* SEM images of electrodeposited FeCo layers in solutions (a)  $B = 0$  T; (b)  $B = 700$  mT parallel to the surface; (c)  $B = 700$  mT perpendicular to the surface.



*Fig. 3:* XRD pattern of electrodeposited FeCo layers (a)  $B = 0$  T; (b)  $B = 700$  mT parallel to the surface (curve b)(c)  $B = 700$  mT perpendicular to the surface

Composition (wt.%) of FeCo films obtained by EDS are shown in Tab. 1. It can be seen that Co content increases or, in other words, Fe content decreases as magnetic field is applied, and the Fe content with parallel configuration is

higher than that of the perpendicular configuration ( $C_{Fe}(B=0) > C_{Fe}(B//) > C_{Fe}(\perp)$ ). This result indicates that the magnetic field influences clearly on the deposition mechanism, which resulting in the change of alloy composition.

Tab. 1: Composition (wt.%) and magnetic coercivity ( $H_c$ ) of FeCo layers electrodeposited with  $B = 0$  T and with different orientation of the magnetic field ( $B = 700$  mT)

	$B$ (mT)		
	0	700 parallel	700 perpendicular
Composition (wt.%)			
Co	84%	87%	88%
Fe	16%	13%	12%
Magnetic coercivity $H_c$ (Oe)	65	63	59

This behaviour can be explained by magnetohydrodynamic (MHD) effect. When magnetic field  $B$  is parallel to the electrode surface, MHD effect is re strong [6, 8]. The origin of this effect lies in the Lorentz force,  $\vec{F}_L = \vec{j} \times \vec{B}$ , where  $j$  is the current density and  $B$  is the magnetic field. During the electrolysis, this force acts on the migration of ions and induced a convective flow of the electrolyte close to the electrode surface [6,8]. The largest convection generated by  $B$ -oriented perpendicularly to the electrode surface supports

the desorption of hydrogen bubbles, which leads to a change of the hydrodynamic conditions in the solution. On the contrary, when a magnetic is applied parallel to the electrode surface, the Lorentz force is zero. As a result, hydrogen evolution reaction occurs more easily for the perpendicular mode. Moreover, since hydrogen evolution reaction is related to the formation of  $M(OH)_x$  compound ( $M = Fe, Co$ ), which in turn relates to the reduction of Fe and Co to form the FeCo alloy, Co content for perpendicular configuration is higher than that for parallel configuration and with magnetic field  $B=0$ .

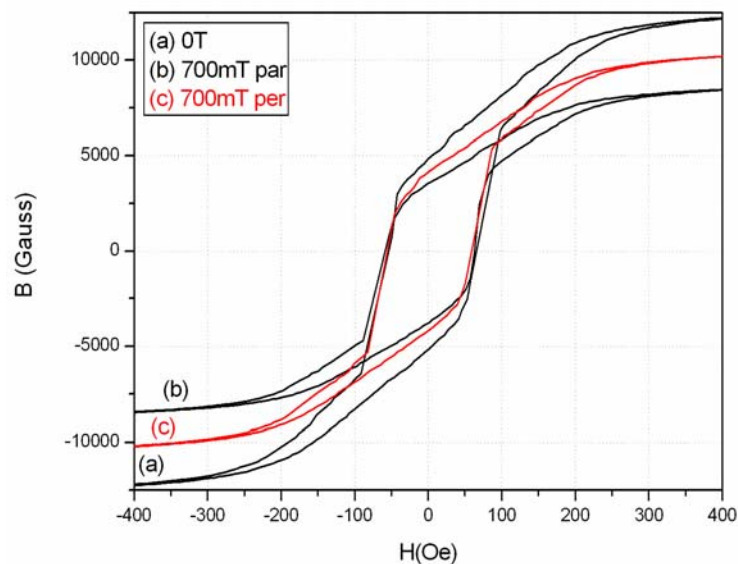


Fig. 4: Hysteresis loops of FeCo layers electrodeposited from solutions  $B = 0$  T (curve a);  $B = 700$  mT parallel to the surface (curve b);  $B = 700$  mT perpendicular to the surface (curve c)

In order to examine the magnetic properties of the obtained layers, hysteresis loops were recorded (Fig. 4). The magnetic coercivity  $H_c$  of layers obtained from Fig. 4 are shown in Tab. 1. It can be seen that coercivity ( $H_c$ ) decreases by following sequence:  $H_c(B = 0) > H_c(B//) > H_c(\perp)$ . This behavior is directly related to the change in the composition of electrodeposited films since structure and morphology of the films do not change with external magnetic fields. A correlation between the composition and soft magnetic properties reveals that softer magnetic properties are achieved when electrodeposition processes is carried out with external magnetic field.

#### IV - CONCLUSIONS

Influence of magnetic field with two configurations (i) parallel to electrode and (ii) perpendicular to electrode were investigated. Results showed that the magnetic field with both configurations did not influence on the surface technology and crystal structure of the deposited film. Meanwhile, the magnetic field and magnetic to surface configuration influenced remarkably on the alloy composition, namely Fe content decreased as magnetic field was applied, and the Fe content with parallel configuration was higher than that of the perpendicular configuration ( $C_{Fe}(B = 0) > C_{Fe}(B//) > C_{Fe}(\perp)$ ). The changes in the composition of obtained layers could be explained by magnetohydrodynamic (MHD) effect by Lorentz force. As a result, magnetic coercivity ( $H_c$ ) decreases by following sequence:  $H_c(B = 0) > H_c(B//) > H_c(\perp)$ .

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**Acknowledgements:** *The authors thank Ministry of Science and Technology for financial support of this work (project KHCB. 5.028.06). The author also wish to acknowledge German Academic Exchange Agency (DAAD) and Leibniz Institut fuer Festkoepfer- und Werkstoffforschung Dresden (IFW) for supporting this work.*

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