

Synthesis and Magnetic Properties of Electrodeposited Cobalt-Iron-Vanadium Thin Films

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CoFeV thin film alloys were fabricated by electrodeposition, and the dependences of their magnetic properties on the current density were investigated using an X-ray diffractometer and a vibrating sample magnetometer. The deposited Co increased from about 45 to 60 wt.% with increasing current density until 25 mA/cm² whereas the deposited Fe decreased from about 55 to 40 wt.% with increasing current density until 25 mA/cm². The deposited V, about 2 wt.%, was independent of the current density. The current efficiencies of electrodeposition decreased linearly from about 40 to 29% with increasing current density. The X-ray diffraction measurement showed that all peaks of the CoFeV films were consistent with those of a typical Co hcp and Fe bcc mixed phase. An increase in the current density decreased the grain size and increased the lattice constant. The saturation magnetization increased from about 2.2 to 2.5 T with increasing current density. The coercivity measured in the perpendicular direction decreased from 260 to 120 Oe with increasing current density; a drastic drop of 60 Oe occurred at 5 mA/cm². The coercivity measured in the in-plane direction remained almost unchanged, at about 20 Oe, with increasing current density.

Key words : electrodeposition, thin film, current density, magnetic saturation, coercivity

1. Introduction

Magnetic films are interesting due to their many application in the magnetic industry, and they show various crystallographic and magnetic properties. Considerable interest has recently been focused on in the fabrication and the properties of nano-sized particles of magnetic materials [1-3]. The electrodeposition technique has been shown to be very convenient for thin films because of its simplicity of use and low cost [4, 5]. One of the principle merits of the electrodeposition technique is that by varying the exact conditions of deposition, it is possible to fine tune the properties of the layer to suit specific requirements and to prepare ferromagnetic thin films, multilayers, and nanowires [6-8]. The electrodeposition technique can provide multicomponent compounds with homogeneous compositions, so it has been employed to prepare various magnetic materials. Recently, Lopez *et al.* [9] synthesized and characterized electrodeposited Cu₉₀Co₁₀ thin films. They showed that the as-deposited samples consisted of superparamagnetic clusters and diluted Co

atoms. Upon annealing, greater superparamagnetic and ferromagnetic clusters appeared. Jones *et al.* [10] observed in electrodeposited Co_xRe_{100-x} that the magnetic behavior was compatible with superparamagnetism in the crystalline phase at low Co concentrations whereas for higher Co concentrations, the alloys were ferromagnetic. Also, the effect of nitrogen content on the magnetic properties of Co-Ni-Mg-N thin films has been studied [11].

Although numerous studies have been carried out to investigate binary (CoFe, NiCo, NiFe) and ternary (CoNiFe) iron-group magnetic thin films, they mostly focused on the mechanism of anomalous codeposition, the effects of various additives, the effects of pulse plating, and the corrosion properties. To our knowledge, there have been a few detailed studies on CoFeV films prepared by using electrodeposition. The purpose of the present work was to study the effects of current density on the composition and on the crystallographic and the magnetic properties of electrodeposited CoFeV thin films. In this work, CoFeV films were electrodeposited at various current densities ranging from 3 to 50 mA, and the crystallographic and magnetic properties were studied by means of x-ray diffractometer (XRD) and a vibrating sample magnetometer (VSM). We discuss the influence

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of the current density on the composition, structure, and magnetic properties of the films.

2. Experimental

Solutions were made using conventional methods [12, 13]. The effect of the current density on the composition of the deposited CoFeV film was investigated for current densities of 3, 5, 10, 25, and 50 mA/cm² at pH=7.00, with constant current at room temperature. The CoFeV films were electrodeposited on brass substrates; Fe, Co, or V was used as the soluble anode.

The deposited Co, Fe, and V contents were determined using atomic absorption spectroscopy (AA), and the alloy compositions are given in weight percent. The magnetic properties, coercivity and magnetic saturation were determined using a vibrating sample magnetometer. The electrodeposited CoFeV films were etched using a solution of equal parts de-ionized water, H₂O₂, and H₃PO₄. An x-ray diffractometer with Cu-K α radiation was used to identify the phases.

3. Results and Discussion

Figure 1 shows the deposit Co, Fe, and V compositions and the current efficiency of electrodeposition as functions of the current density measured at room temperature. The Co content increased from about 45 to 60 wt.% with increasing current density until 25 mA/cm² whereas the Fe content decreased from about 55 to 40 wt.% with increasing current density until 25 mA/cm². The V content, at about 2 wt.%, was independent of the current density. The current efficiencies of electrodeposition decreased linearly from about 40 to 29% with increasing

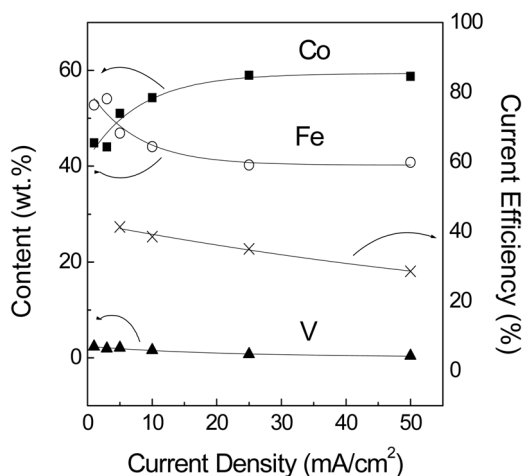


Fig. 1. Dependence of the composition and the current efficiency of CoFeV films on the current density.

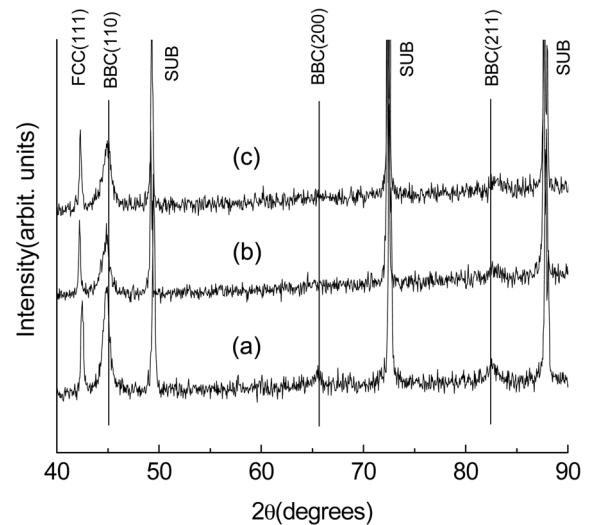


Fig. 2. X-ray diffraction patterns of CoFeV films at current densities of (a) 3 mA/cm², (b) 10 mA/cm², and (c) 50 mA/cm².

current density. Kim *et al.* [13] investigated the deposited CoFe alloy and observed the current efficiencies (approximately 52%) were independent of the Fe⁺² concentration in chloride baths, but decreased to a level of about 18% in sulfate baths.

To study the influence of the current density on the structure of the electrodeposited CoFeV, we carried out XRD measurements as shown in Figs. 2(a), (b), and (c) for current densities 3 mA/cm², 10 mA/cm², and 50 mA/cm², respectively. All XRD patterns have sharp peaks, which means all samples were crystallized. The presence of bcc (200) and bcc (211) peaks means our samples were alloys. Similar results were observed for electrodeposited CoFe alloy [13]. From the XRD patterns, we know that all the peaks of the CoFeV films are consistent with those of a typical Co hcp and Fe bcc mixed phase. An increase in the current density yielded a decreased sharpness of the major peaks, as shown in Fig. 2, a decrease in the grain size of our samples. Also, the peak position shift to lower angle means the lattice constant increased with increasing current density. For an electrodeposited Cu₉₀Co₁₀ thin film, Lopez *et al.* [9] found in as-deposited and annealed samples a mixed Cu-Co fcc phase with peaks close to those of the Cu fcc peaks. No peaks of the Co fcc or the Co hcp phase were found in any sample. In a study of deposited CoFe alloys, Kim *et al.* [13] observed a mixed hcp and bcc phase. They showed that the anion types did not affect the phases of the deposited CoFe, but influenced the magnetic properties.

Figure 3 shows the variation of the saturation magnetization (M_s) of electrodeposited CoFeV. The saturation magnetization increased from about 2.2 to 2.5 T with

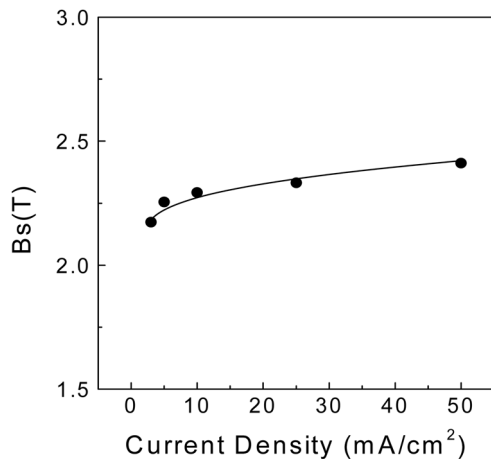


Fig. 3. Magnetic saturation variation of CoFeV films with current density.

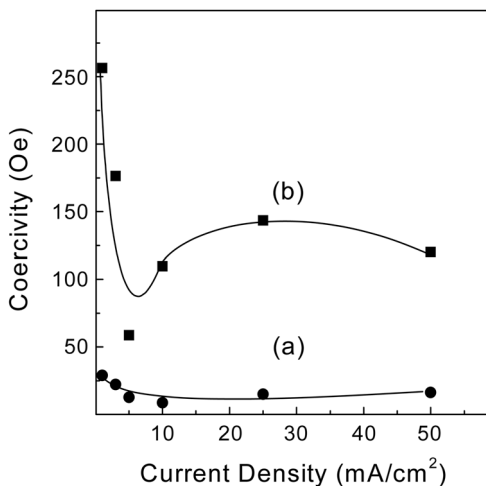


Fig. 4. Coercivity variation of CoFeV films with current density measured in the (a) in-plane and (b) perpendicular directions.

increasing current density. The saturation magnetization of electrodeposited CoFeV increased with increasing deposit Co contents, as shown in Fig. 1. The observed saturation magnetization variation is reasonable from the fact that the saturation magnetization is an intrinsic magnetic property, which depends only on the film composition. In a study of deposited CoFe alloys Kim *et al.* [13] observed that the saturation magnetization of electrodeposited CoFe was independent of the anion type and increased with increasing Fe content. It is known that the Fe-Co alloys have large saturation magnetizations; the maximum occurs in a 50Co-50Fe alloy (Permendur). The addition 2% vanadium reduces the coercive force and the hysteresis losses and increases the electrical resistivity and ductility [14].

Figure 4 shows the variation of the coercivity (H_C). The

coercivity measured in the perpendicular direction decreased from 260 to 120 Oe with increasing current density; a drastic drop of 60 Oe occurred at 5 mA/cm². The coercivity measured in the in-plane direction was almost unchanged, at about 20 Oe, with increasing current density. These magnetic properties could be relate to the compositions of the films. As Fig. 1 shows, the Co contents increased with increasing current density, so the films became more strongly ferro-magnetic. In the CoFe alloy [13], the coercivity for a chloride bath increased from 17 (at 0 wt.% Fe) to 40 Oe (> 18 wt.% Fe) and then reached a plateau. In electrodeposited Co_xRe_{100-x}, Jones *et al.* [10] also observed that for higher Co concentrations, the films were ferromagnetic.

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References

- [1] S. S. Parkin, Appl. Phys. Lett. **60**, 512 (1992).
- [2] C. Petit and M. P. Pileni, J. Magn. Magn. Mater. **166**, 82 (1997).
- [3] J. Hong, E. Key, and S. X. Wang, IEEE Trans. Magn. **32**, 4475 (1996).
- [4] V. M. Fedosyuk, O. I. Kasyutich, D. Ravinder, and H. J. Blythe, J. Magn. Magn. Mater. **156**, 345 (1996).
- [5] R. Ropez Anton, M. L. Fdez-Gubieda, M. Insauti, A. Garcia-Arribas, and J. Herreros, J. Non-Cryst. Solids **287** (1-3), 26 (2001).
- [6] C. Tsang, H. Santini, D. McCowan, J. Lo, and R. Lee, IEEE Trans. Magn. **32**, 7 (1996).
- [7] V. M. Fedosyuk and J. M. Riveiro, J. Non-Cryst. Solids **143**, 99 (1996).
- [8] J. M. D. Coey and G. Hinds, J. Alloys and Compounds **326**, 238 (2001).
- [9] R. Ropez Anton, M. L. Fdez-Gubieda, G. Kurlyandskaya, and A. Garcia-Arribas, J. Magn. Magn. Mater. **254**, 85 (2003).
- [10] G. A. Jones, C. A. Faunce, D. Ravinder, H. J. Blythe, and V. M. Fedosyuk, J. Magn. Magn. Mater. **184**, 28 (1998).
- [11] V. Georgescu and M. Georgescu, J. Magn. Magn. Mater. **242**, 416 (2002).
- [12] D. Y. Park, N. V. Myung, M. Schwartz, and K. Nove, Electrochimica Acta **47**, 2893 (2002).
- [13] Daheum Kim, D. Y. Park, B. Y. Yoo, P. T. A. Sumodjo, and N. V. Myung, Electrochimica Acta **48**, 819 (2003).
- [14] A. H. Morrish, The Physical Principle of Magnetism, The Institute of Electrical and Electronics Engineers, New York (2001) pp. 410.