

Electrodeposition of FeCoNiCu Quaternary Alloys

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Electrodeposited iron-group alloys are used widely in the field of microelectronics. For example, permalloy, a soft magnetic material with 80 % Ni and 20 % Fe, is a commercially important material in dual performance magnetic heads.^[1] Co added to NiFe has been found to increase the saturation magnetization^[2]; and Cu addition is a good way to both decrease the coercivity and improve the corrosion resistance.^[3] Therefore, the conditions for the electrodeposition of FeCoNiCu alloy has been explored. Characterization of the anomalous codeposition behavior^[4-5] was also investigated. When the alloy is layered with Cu, we expect a giant magnetoresistance (GMR) effect. To our knowledge, the electrodeposited FeCoNi/Cu multilayers have not yet been examined.

Experimental

In this study, a single sulfate electrolyte, two-compartment cell and a rotating disk cathode were used. Nitrogen was sparged before and during the experiments to suppress the reduction of oxygen. A BAS-Zahner IM6(e) impedance analyser was employed to correct for ohmic drop. An AMEL potentiostat together with a WAVETEK function generator was used in pulsing plating. Deposit composition was obtained using a Kevex Omicron energy dispersive x-ray fluorescence (XRF) analyzer. Partial currents were determined from the analysis in order to interpret results. Multilayer structures were verified with a JEOL-2010 scanning transmission electron microscope.

Results and Discussion

Steady state electrodeposition experiments were conducted. The anomalous codeposition behavior was observed similar to binary alloy systems.^[6-8] By comparing the alloy deposition rate to the elemental rate, the following was observed: *i.* Ni and Co depositions are inhibited, and *ii.* Fe deposition is accelerated. At low current densities a pure copper deposit is obtained and at high current densities a Co-rich FeCoNi alloy was deposited accompanied with a tiny amount of Cu.

Based on these results, pulse plating was carried out between -3.54 mA/cm^2 and -70.75 mA/cm^2 for 48.5 seconds and 1.5 seconds, respectively, to deposit the multilayered structure. Figure 1 is a high resolution TEM negative micrograph of the multilayered structure. The calculated layer thicknesses from steady state experiments are 10 nm for Cu and 20 nm for the alloy. XRF analysis gave the average bulk molar composition of 9.5% Fe, 47.8% Co, 11.0% Ni and 31.5% Cu.

Transient regimes are important to the interface quality and were experimentally verified. Figure 2 shows the relation of the average current efficiency and bulk composition at various pulse plating time steps. The on-time pulse was at the deposition current density used in producing the multilayer (Figure 1), -70.75 mA/cm^2 , for different times. The second pulse was fixed at 0 mA/cm^2 for 5 seconds where no copper layer is expected. Results showed that the transient effect is significant below 0.25 seconds. The current efficiency is much lower when the

pulse time is short. Composition is expected to vary in the multilayer, according to Figure 2, at the beginning of the pulse. However, since the current efficiency is low in this region the transient in composition is confined to a thin region estimated to be about 3 nanometers.

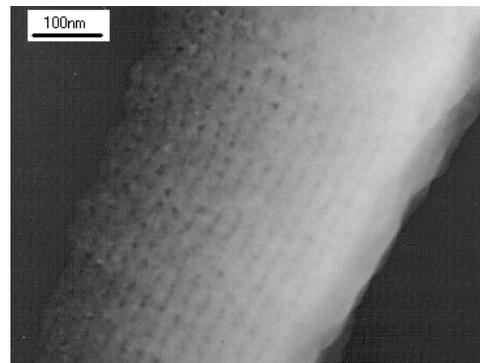


Figure 1. TEM micrograph of Cu/CoNiFe nanomultilayer, rotation rate=1000 rpm

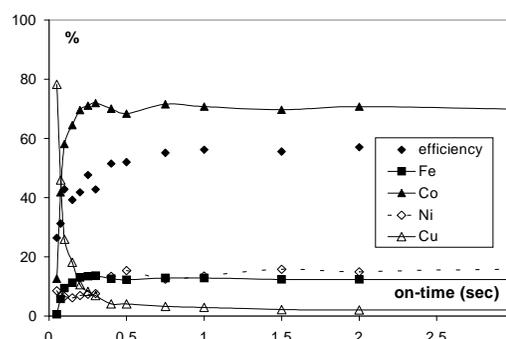


Figure 2. Relation between current efficiency and molar composition vs. step on time

Conclusions

The characterization of Co-rich FeCoNiCu electrodeposited alloys and nanostructured multilayers were presented. The deposition was typified as anomalous codeposition behavior. In addition, an experimental method to assess transient current efficiency and composition in the multilayer was developed as a design tool.

Acknowledgements

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References

1. P. C. Andricacos and N. Robertson, *IBM Journal of Research and Development*, **42** (1998).
2. N. C. Anderson and R. B. Chesnutt, "Electrodepositing CoNiFe Alloys for Thin Film Heads," U.S. Patent 4,661,216, April 28, 1987.
3. P. J. W. Chang, P. C. Andricacos, B. Peteck and L. T. Romankiw, *Proceedings of Second International Symposium on Magnetic Materials, Process and Devices*, The Electrochemical Society, Inc., p.275-287 1991.
4. A. Brenner, "Electrodeposition of Alloys", Vol. I, p.77, Academic Press, 1963
5. Y. Zhuang and E. J. Podlaha, *J. Electrochem. Soc.*, **147**, 2231 (2000).
6. A. T. Vagramyan and T. A. Fatueva, *J. Electrochem. Soc.*, **110**, 1030 (1963).
7. N. Zech, E. J. Podlaha and D. Landolt, *J. Electrochem. Soc.*, **146**, 2886 (1999).
8. K. Y. Sasaki and J.B. Talbot, *J. Electrochem. Soc.*, **145**, 981 (1998).