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Electrodeposition of Magnetic Multilayers

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Compositionally modulated multilayers at the nanoscale are viable industrial materials exhibiting giant magnetoresistance (GMR), a change in a materials resistance with a magnetic field, as shown in Figure 1. Additionally, nanostructured multilayers can also improve the mechanical properties of the alloy. However, the improved alloy property, such as GMR, is generally larger with physical vapor phase deposition techniques compared to electrodeposition. The interest in the electrodeposition technique stems from its comparable low cost, and ease to deposit into small recesses and irregular surfaces, that would be otherwise problematic with physical vapor phase methodologies. The ability to deposit nanostructured multilayers into recessed geometries is imperative for the generation of nanowires and MEMS components. Therefore, our goals include not only examining electrodeposited metal alloy multilayers in order to improve their magnetic and mechanical properties, but to also apply the electrodeposition technique to novel architectures.

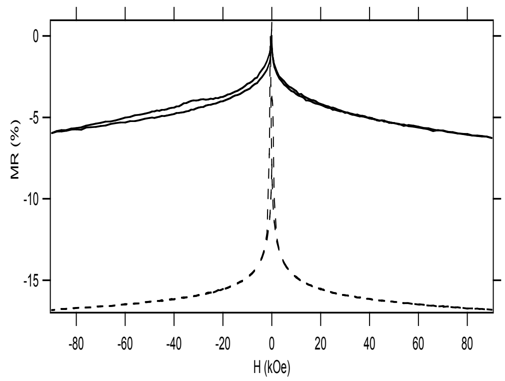

Figure 1. Transverse GMR of electrodeposited multilayers [1.8 nm Cu / 2 nm FeCoNiCu]$_{730}$ at 4 K (- - -) and 300 K (—).

Our NIRT group is organized as follows. Electrodeposition processing is carried out in the Department of Chemical Engineering at LSU (PI: E. J. Podlaha, with graduate students: Q. Huang, Y. Li, D. Davis and postdoc: J. Zhang). The magnetoresistance measurements are completed in the Physics Department at LSU (PI: D. Young, postdoc: M. Moldovan). XRD analysis is carried out in the Chemistry Department at LSU (PI: J. Y. Chan, graduate student: E. Lawson). Sensor design and microfabricated MEMS are directed by PIs in the Mechanical Engineering Department at LSU (PIs: M. Murphy and W. Wang, graduate students: D. Iyer and Ruili Fan) and will use the materials developed in our project.

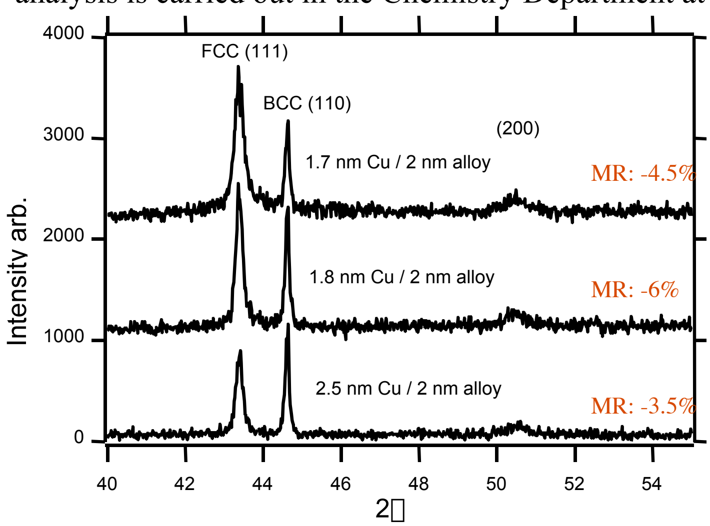

Figure 2. XRD of CoFeNi/Cu multilayers with different room temp magnetoresistance.[1]

While many electrodeposited studies have focused on ideal binary systems, such as Co/Cu, results from our NIRT have achieved the first observation of GMR in electrodeposited CoFeNi/Cu nano-size multilayers,[1,2] rendering it possible to deposit compositional

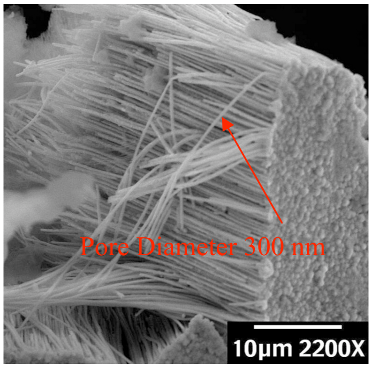

Figure 3. CoNiFe/Cu nanowires electrodeposited into alumina templates.

variations of this alloy system. Figure 1 shows that at room temperature the GMR of the alloy multilayer is roughly 6 % while at 4 K it is over 15 %. The thin film multilayer alloys were also analyzed with XRD to determine the crystallographic orientation, Figure 2. Both FCC and BCC phases are present. The absence of preferred orientation correlated with the higher GMR value.

We have also deposited the multilayered materials into alumina and polycarbonate filter templates to produce CoNiFe/Cu nanolayered nanowire arrays (Figure 3). The TEM micrographs in Figure 4 shows the nanolayers achieved. Figure 4(a) is a single nanowire having alternating layers of 4 nm CoFeNiCu and 2 nm Cu. The layers are evident at the edge of the 200 nm diamerter nanowire. XRF analysis of electrodeposited bulk alloys was used to estimate the composition of the alloy layer: 66 at % Co, 20 at % Fe, 9 at % Ni and 5 at % Cu. Figure 4 (b) shows a TEM micrograph of larger electrodeposited layer sizes. These wires were fabricated from polycarbonate filters (0.05 microns).

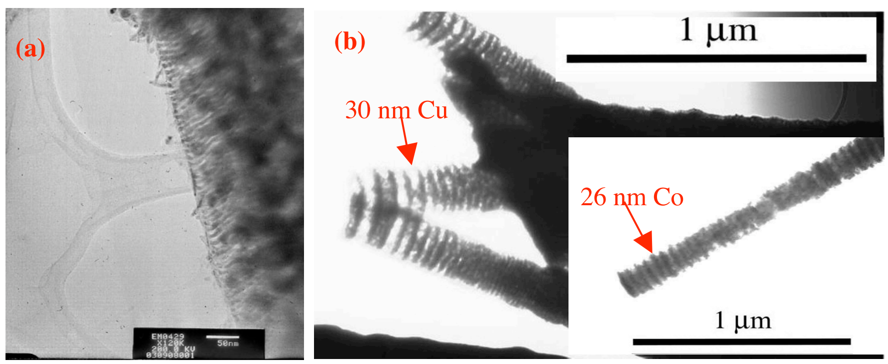

Figure 4. CoNiFe/Cu nanowire showing (a) 4 nm CoFeNiCu/ 2 nm Cu nanolayers and (b) an order of magnitude larger size layers.

The first steps have been taken to create CoCu alloys in microposts (Figure 5), with synchrotron x-ray lithography in collaboration with the Center for Advanced Microstructures and Devices (CAMD) at LSU. Multilayers with nanometer dimensions (1-5 nm) of NiFeCu/Cu have been realized, in a similar pattern. These Invar-like microposts are being considered as potential materials for micro-molds. We have found that the coefficient of thermal expansion was slightly improved with the nanostructured layering.[3] NiFeCu/Cu microposts had a CTE of 0.85 μm/m-K over a temperature range of (50-300 ^{0}C) compared to a value of 4.2 μm/m-K (260 ^{0}C) and 1.3 (93 ^{0}C) for typical bulk Invar.

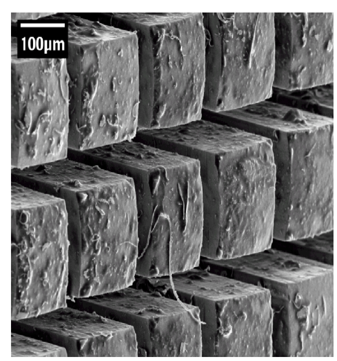

Figure 5. CoCu alloy micro-posts 500 microns tall, 180 microns square.

References

[1] Q. Huang, D. P. Young, J. Y. Chan, J. Jiang and E. J. Podlaha, "Electrodeposition of FeCoNiCu/Cu Compositionally Modulated Multilayers," *Journal of the Electrochemical Society*, **149** (6): C349-C354 (2002).
[2] Q. Huang, D. P. Young, and E.J. Podlaha, Magnetoresistance of Electrodeposited FeCoNiCu/Cu Multilayers," *Journal of Applied Physics* **94** (3): 1864-1867 (2003).
[3] E. J. Podlaha, Y. Li, E. Lawson, Q. Huang, J. Y. Chan, J. Zhang, M. Moldovan, D. Young, D. Palaparti, and M. C. Murphy, "Electrodeposited GMR Multilayer Thin Films, Nanowires and Microposts," Materials Research Society, Boston, MA (2003).