Oxides and Surface Magnetism
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Final Report

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The general objective of this program was to study the magnetism and structure of iron oxide films with a view to enhancing control over growth mode, oxidation state and fundamental understanding in this complex system. In particular, we sought to create new magnetic metal/oxide multilayers and composites based on improved knowledge of the magnetic properties at Fe and Fe₃O₄ surfaces and at Fe/Fe₃O₄ interfaces.

The project had three parts: 1) deposition and characterization of iron films up to 0.1 μm on fused quartz, 2) deposition and characterization of Fe₃O₄ films up to 0.1 μm on fused quartz and 3) fabrication and characterization of Fe/Fe₃O₄/Fe/... multilayers.

1) The structure and magnetic properties of sputtered Fe/SiO₂ were studied first. The most interesting result here is the variation of magnetic properties with Fe film thickness, t . M_s is approximately 1680 gauss and $H_c \approx 25$ Oe for $t > 0.1$ micron. Below a thickness of 0.1 micron the magnetization drops monotonically to 1560 gauss at 100 Å but the coercivity peaks at 37 Oe near 400 Å then decreases for thinner films. This interesting behavior is similar to that observed in fine iron particles where the peak in H_c is associated with the onset of single domain behavior. This result is described in detail in Ref. 1.

2) The Fe oxide study (task 2) proved to be very important. By using reactive sputtering, we were able to locate a robust processing region, which would give thickness independent properties for the Fe₃O₄ to be used in the multilayer studies. In addition we synthesized ferromagnetic Fe_{1-x}O, the first report of such a phase. The ferromagnetism is attributed to the cation disorder. Interestingly, the same cation disorder that causes a reduction in moment in sputtered Fe₃O₄ films, induces a moment in Fe_{1-x}O. The Fe_{1-x}O films are believed to contain defective "Fe₃O₄-like" regions that are ferromagnetic. Initial measurements indicate that this phase demonstrates a large magnetoresistance, similar to those obtained in other granular magnetic composites. This result is described in publication 2.

3) The purpose of the multilayer study (task 3) was to see if Fe could be used to enhance the moment and possibly the coercivity of magnetic oxides. We were able to verify that the Fe layers couple ferromagnetically through the Fe₃O₄ layers; there was no sign of double hysteresis loops due to independent switching of the Fe and Fe₃O₄ layers. The saturation magnetization followed a linear mixture rule as expected. The coercivity was not linear, but showed a peak coercivity with a small Fe contribution. The origin of the peak has not yet been determined. The nonlinear dependence of remanence on Fe thickness suggests exchange coupling of the Fe to the Fe₃O₄ layers. A very unexpected and important result was that we were able to control the texture of the film (on a glass substrate!) by altering the deposition sequence and the iron thickness fraction:

[(0.45) Fe/Fe₃O₄] $\rightarrow$ (100)/(100)

[Fe₃O₄/Fe] $\rightarrow$ (311)/(110)

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That is, thin Fe layers deposited on Fe_3O_4 (001) also assumed the (001) orientation. However, Fe_3O_4 layers sputtered onto Fe (110) assumed a (311) orientation.

Publications

1. "Magnetic properties of sputtered Fe thin films: Processing and thickness dependence," Y.K. Kim and M. Oliveria, Appl. Phys. **74**, 1233 (1993).
2. "Magnetic Properties of Reactively Sputtered Fe_{1-x}O and Fe_3O_4 Thin Films," Y.K. Kim and M. Oliveria, IEEE Trans. MAG, September 1993.
- 3.

Personnel

Y.K. Kim received his Ph.D. in 1994. He joined Quantum Corp (Rocky Mountain Magnetics), then returned to Korea in Sept. 1997 to work with Samsung Electronics.

Kevin Fahey transferred to Stanford after the non-renewal of this project. He is completing his Ph.D. there.

Prof. M. Oliveria left M.I.T. to work at Motorola.

Dr. R.C. O'Handley continues as a Senior Research Scientist at M.I.T.

Post script

The sputtering system constructed by Dr. Kim for this project using M.I.T. startup funds has served four other projects: Growth of high T_c superconductors; growth of perpendicular Ba-ferrite/Co bilayers; growth of Fe-Si-N nanostructured films; and growth of novel Co-Cr-Ta textured films.