Oxides and Surface Magnetism
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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 Fe$_3$O$_4$ surfaces and at Fe/Fe$_3$O$_4$ interfaces.

The project had three parts: 1) deposition and characterization of iron films up to 0.1 $\mu$m on fused quartz, 2) deposition and characterization of Fe$_3$O$_4$ films up to 0.1 $\mu$m on fused quartz and 3) fabrication and characterization of Fe/Fe$_3$O$_4$/Fe/... multilayers.

1) The structure and magnetic properties of sputtered Fe/SiO$_2$ 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 $H_C = 25$ Oe for $t > 0.1$ micron. Below a thickness of 0.1 micron the magnetization drops monotonically to 1560 gauss at 100Å 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 Fe$_3$O$_4$ 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 Fe$_3$O$_4$ films, induces a moment in Fe$_{1-x}$O. The Fe$_{1-x}$O films are believed to contain defective "Fe$_3$O$_4$-like" regions that are ferromagnetic. Initial measurements indicate that this phase demonstrates a large magentoresistance, 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 Fe$_3$O$_4$ layers; there was no sign of double hysteresis loops due to independent switching of the Fe and Fe$_3$O$_4$ 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 Fe$_3$O$_4$ 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:

$$[(0.45) \text{Fe/Fe}_3\text{O}_4] \rightarrow (100)/(100)$$
$$[\text{Fe}_3\text{O}_4/\text{Fe}] \rightarrow (311)/(110)$$

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That is, thin Fe layers deposited on Fe$_3$O$_4$ (001) also assumed the (001) orientation. However, Fe$_3$O$_4$ layers sputtered onto Fe (110) assumed a (311) orientation.

Publications


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.