"GROWTH INDUCED MAGNETIC ANISOTROPY IN AMORPHOUS THIN FILMS"

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Progress report year 1 DOE DE-FG03-95ER45529

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Previous year's research:

The work in the past year has primarily involved three areas of magnetic thin films: amorphous rare earth-transition metal alloys, epitaxial $CoPt_3$ thin films, and exchange coupled antiferromagnetic insulators. In the amorphous alloys, we have focused on understanding the cause and the effect of the growth-surface-induced perpendicular magnetic anisotropy. Using the results of our previous work, we are able to control this anisotropy quite precisely. This anisotropy is predicted to have dramatic and as-yet unobserved effects on the underlying nature of the magnetism. Neutron scattering and specific heat measurements have shown clear but unexpected and not yet understood results.

The work on the epitaxial Co-Pt alloys was originally undertaken as a comparison study to the amorphous alloys. Crystalline Co-Pt alloys have many striking similarities to the amorphous rare earth-transition metal alloys: perpendicular magnetic anisotropy (as unexpected in a cubic material like Co-Pt which is fcc as it is in an amorphous alloy), magneto-optic activity, and a T_C (for $CoPt_3$) somewhat above room temperature. We have discovered that these alloys exhibit a remarkable new phenomena; a surface-induced miscibility gap in a material which is believed to be completely miscible in the bulk. This miscibility gap is 100% correlated with the perpendicular anisotropy, although the connection is not yet clear, and is presumably linked to a magnetic energy of mixing which tends to drive a material towards clustering. Co-Pt alloys have been extensively studied for a wide variety of purposes, ranging from magnetic and magneto-optic properties (it was for a long time the best hard magnet at room temperature, and is currently under consideration as a magneto-optic recording media), to the possible use as a catalytic agent, to basic studies of its phase diagram, which includes an order-disorder transformation at high temperatures, and the importance of magnetic interactions in determining the phase diagram. The discovery that in thin film form, it is immiscible, leading to tiny regions of Co-rich and Pt-rich material, is completely unexpected. In recent years, it has become increasingly apparent that the vapor deposition process allows access to metastable portions of phase diagrams (this in fact has been the heart of the work I have done on surface-induced ordering of amorphous alloys). For example, strain caused by epitaxial or atomic size mismatch can induce miscibility in vapor-deposited mixtures that are immiscible in bulk, including the formation of long range ordered phases not present in the bulk phase diagram. Growth-induced *immiscibility*, on the other hand, in systems which are *miscible* in the bulk (as we are suggesting for Co-Pt) has not been previously observed. This work has just been accepted as a Physical Review Letter; a more complete presentation of the data is also being prepared in a longer paper.

The problem of exchange coupling in multilayers impacts many of the current research areas in magnetism. Antiferromagnets are in some ways the cleanest systems in which to study these effects. NiO/CoO multilayers can be prepared with coherent interfaces, and have been previously shown by neutron scattering to be magnetically coherent across many layers, even above the Neel temperature of the CoO. The specific heat shows unambiguously the ordering of the spins in the layers; we are the only people in the world capable of measurements of the specific heat of materials such as these, weighing less than 20 μg. The results show clearly the transition from a single transition temperature to two distinct transitions with increasing thickness of the individual layers. From this data, we are able to determine the interface magnetic exchange coupling constant and the effect on the transition temperature of finite layer thickness. This work is being presented in an invited talk at the next MMM conference. A paper on this is currently being prepared.

Summary of Future Research:

In the amorphous alloys, we are currently preparing samples of amorphous rare earth-Fe/Ni with a varying Fe/Ni ratio in order to vary the exchange constant in a controlled manner; specific heat, small angle neutron scattering, and magnetization measurements are planned. This systematic study of the effects of local anisotropy, macroscopic (perpendicular) anisotropy, and exchange constant on the fundamental (and practical) properties of these magnetic alloys is as originally described in the grant proposal; the unexpected results found to date will presumably be part of a larger pattern. The planned work on the Co-Pt alloys involves changing compositions, both within the Co-Pt alloy system and with other Co-X alloys. The cause of the growth induced perpendicular anisotropy and the relationship to the observed thin film immiscibility will be explored. It is possible that these observations are directly related to the perpendicular magnetic anisotropy observed not only in the amorphous rare earth-transition metal thin films but also in Co-Cr alloy films (potentially used for perpendicular recording, not magneto-optic) and in Co/Pt and Co/Pd multilayers; connections will be explored. Understanding the source of perpendicular anisotropy, and its effects on the magnetic structure of a thin film, is important both for these materials where anisotropy is crucial to their proposed use and for materials where anisotropy is an unwanted feature (for soft magnetic materials). There are also fundamental questions and untested theoretical predictions for its effect on a material whose underlying nature is to be a spin glass.

In addition, our unique microcalorimeters allow us to perform specific heat measurements on thin films of magnetic materials, as a function of both temperature and magnetic field. In addition to the work proposed in the original proposal, we are therefore ideally positioned to collaborate with other researchers who are making novel magnetic materials. We have worked with A. Berkowitz on the NiO/CoO multilayers and with I. K. Schuller on FeF_2 films and are exploring the possibility of collaborating with a group working on the novel magnetic perovskites (the "colossal magneto-resistance" materials); future collaborations will depend on what new materials are found. Specific heat is a powerful measurement tool, complementary to magnetic measurements and neutron scattering; it is not an exaggeration to say that we can make measurements on thin films which are three orders of magnitude more sensitive than anyone else in the world, allowing us to study magnetic thin films for essentially the first time. We have recently re-designed the devices to allow higher temperature operation, which allows an even wider range of materials to be measured.

Personnel associated with program:

In addition to the Principal Investigator, there are currently two graduate students (Noel Abarra and Alex Shapiro) and part of a post-doc (Minh Tran) involved with the research described above.

Federal Support:

Current

Supporting Agency	Project Title	Award Amount	Period Covered	Man-Months CAL/ACAD/SUM	Location
NSF	In situ determination of thermodynamic, magnetic, and transport properties of doped and undoped thin film C_{60}	$85,000/yr	08/01/92-07/31/97	2	UCSD
DoE	Growth induced magnetic anisotropy in amorphous thin films	$85,000/yr	11/01/94-10/31/97	1	UCSD
NSF	Focus group on highly correlated electron systems	$375,000/yr (for 7 P.I.s)	07/01/94-06/30/97	1	UCSD

Pending:

Supporting Agency	Project Title	Award Amount	Period Covered	Man-Months CAL/ACAD/SUM	Location
NSF	Aquisition of instrumentation for a machine shop of the 21st century	$414,458/yr (Infrastructure)	09/01/95-08/31/98	1	UCSD
NSF	Development of instrumentation for microcalorimetry of biological systems	$86,507/yr	10/01/95-09/30/98	1	UCSD
U.C. Office of the President	Basic studies and potential applications of novel magnetic materials	$130,000/yr (2 P.I.'s)	07/01/95-06/30/98	5%	UCSD/ Los Alamos