DOE/ER/45281--T1

MAGNETIC MULTILAYER PHYSICS

TECHNICAL PROGRESS REPORT

January 1, 1994 through December 31, 1994

Submitted to The USDOE Office of Basic Energy Sciences

By Michael J. Pechan

Miami University

September 23, 1994

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ja

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

MAGNETIC MULTILAYER PHYSICS

ABSTRACT

Microscopic magnetic systems, and especially multilayer structures, are providing a wealth of novel phenomena in condensed matter magnetism. Of particular significance are interfacial and interlayer effects. The interface between two magnetically dissimilar materials can significantly alter the bulk magnetic properties of either constituent material; and coupling of magnetic layers across relatively thick nonmagnetic interlayers are observed to have unexpectedly large impact upon electronic transport properties. The PI proposes to determine the *source* of magnetic interface anisotropy in transition metal multilayer systems by varying elemental constituents, magnetic and nonmagnetic layer thickness and temperature. Also both static and dynamic effects associated with *multilayer* interlayer coupling will be investigated using torque and FMR techniques. In particular, the highest frequency "optical" modes of interacting magnetic layers will be examined. A tristable magnetic system is predicted and experimental verification proposed. Enhancements of a novel torque magnetometer are planned.

TECHNICAL DESCRIPTION

Introduction

This past year has seen my research lab undergo a total renovation as part of an NSF Facilities Upgrade Grant. This included more efficient use of space, improved power distribution, new heat exchangers, cabinetry, vibration isolation and networking, among a host of other improvements. In addition to the infrastructure improvements, we were permitted to upgrade ancillary power under the grant. This allowed for purchase of a new power supply for each magnet in the lab. Such an upgrade was requested from DOE in the present project period, however budgetary constraints did not permit funding at that time. So although the renovation has been inconvenient, the long term benefits will be substantial, both in sample throughput and new capabilities.

Multilayers

During the past summer, we performed 9 and 37 GHz ferromagnetic resonance (FMR) measurements and vibrating sample magnetometry (VSM) measurements on Co/Ni multilayers {[Co₂₉/Ni₄₂]₁₃, [Co₁₈/Ni₄₂]₁₆, [Co₇/Ni₉]₆₇, where elemental subscripts are layer thicknesses in Å and bracket subscripts are bilayer repeat number.} obtained from Ivan Schuller at UCSD. The thinnest layer sample showed a broad peak spectrum indicative of significant disorder in the bilayer structure. However the remaining samples yielded very interesting results. Dependence of the FMR spectra upon angle between the film normal and the applied magnetic field implies the existence of Co-Co coupling across the Ni layer. The converse can not be addressed conclusively because the strong, narrow Co resonances dominate the weak, broad peaks arising from Ni. The observation of a series of well separated modes in the parallel orientation, provide impetus extend the investigation of Co-Co coupling to a broader series of samples. This is currently underway.

We also obtained some very interesting magnetization results on the 18Å Co sample. The magnetization exhibits a large peak at approximately 1kOe with subsequent saturation to half its peak magnetization at high fields (> 5 kOe). This effect does not arise from the substrate as the other two samples showed rather ordinary magnetization curves. Because the VSM is new, we are checking it carefully to ensure we are not seeing an experimental artifact.

Sputtered multilayers of Fe/Cr have also been prepared by the UCSD group, with bilayer structures optimized for investigating interlayer coupling with the FMR technique. The Fe layer thicknesses in a given sample alternate between 26 and 30 Å with a fixed Cr interlayer thickness. The intersample Cr thickness is varied from 8 to 50 Å in 2Å steps. This arrangement allows for excitation of the out-of-phase interlayer coupling modes and for systematic investigation of the coupling strength. We have performed preliminary 9 GHz FMR measurements on all samples. Mode structure in the spectra is evident in all but the thinnest layer samples. This structure will be examined as a function of frequency, angle and temperature to determine its origin. Magnetization measurements have also been performed on the samples, but the signal to noise ratio in the VSM system at that time was too great to observe the "switching" associated with the proposed antiferromagnetic interlayer coupling. As discussed below the problem is being remedied. Plans have also been made to investigate the relationship between magnetization and structure in these samples using both x-rays and neutrons (collaboration between Miami, UCSD and U of Missouri). The first stage of this structural/magnetic comparison was completed during the present budget period (see paper below). I have also entered into a collaboration (UCSD and Phil Wigen at Ohio State) to examine the samples for evidence of biquadratic interlayer coupling.

During the budget period, Argonne Scientists and myself agreed to extend the Fe/Mo investigation to include more samples, in an attempt to clarify the unusual thermal behavior of the mode structure.

A comparison was made between anisotropies obtained via dc magnetization, FMR and Brillouin scattering in a series of Fe/Cu multilayers. Owing to the linear nature (first order terms only) of the anisotropy, agreement was obtained from all three methods. This investigation, a collaboration between Miami, UCSD and Argonne, resulted in a paper being written and submitted during this budget period.

Apparatus and Techniques

A fairly sensitive (10^{-3} emu) VSM was constructed this past summer from Mossbauer drive parts and control electronics and pick-up coils from surplus relays. Subsequent addition of commercial (Digital Measurement Systems) pick-up coils produced a fourfold increase in signal level from the same test sample. We have ordered a drive system which will provide twice the vibration amplitude at four times the frequency, which should produce an additional factor of eight in signal level. As a result, our system should be able to operate in the mid 10^{-5} emu level at room temperature. A new variable gap 6" electromagnet has arrived and is being installed. The variable gap will allow for the maximum possible field for any experimental configuration (e.g. small vs. large sample; room vs. cryogenic temperature) of the VSM.

As mentioned above new power supplies have been installed. They are completely digitally controllable, including polarity switching, field setting and built-in auto ramping. We have written rudimentary software to control the supplies via the GPIB bus. Software enhancements to increase flexibility will be made in conjunction with our electronics shop personnel. Therefore, the FMR, VSM and torque systems are now totally under computer control, which provides for greater scan-to-scan reproducibility (and therefore allows multiscan averaging), higher sample throughput and increased run times.

Development of an in-situ, capacitance based torque transducer has been enhanced by initiation of a collaboration with Lance DeLong at the University of Kentucky, whose interests lie mainly in anisotropic superconductors. His magnet is a split coil superconductor similar to Schuller's at UCSD.

DOE SUPPORTED PUBLICATIONS AND PRESENTATIONS (FOR THE PAST YEAR)

Papers in Print and Accepted

"Magnetic Profile As A Function Of Structural Disorder In Fe/Cr Superlattices." Michael J. Pechan, J.F. Ankner, David M. Kelly, C.F. Majkrzak, and Ivan K. Schuller. Journal of Applied Physics 75, 6178 (1994).

Papers Submitted

"Determination of Magnetic Anisotropy in Fe/Cu Multilayers: Equivalence of Dynamic and Static Measurements." Michael J. Pechan, Eric E. Fullerton, W. Robertson, Marcos Grimsditch and Ivan K. Schuller. Submitter for publication.

Presentations Made

"Magnetic Profile As A Function Of Structural Disorder In Fe/Cr Superlattices." Michael J. Pechan. 1994 APS March Meeting. Pittsburg, PA.

"Magnetic Profile As A Function Of Structural Disorder In Fe/Cr Superlattices." Michael J. Pechan. Magnetism and Magnetic Materials Conference. Minneapolis. November 1993.

"Magnetic Multilayer Physics". Michael J. Pechan. Colloquium. Miami University. October 1993.

STUDENT INVOLVEMENT (FOR THE PAST YEAR)

Masters Theses Graduated

"Temperature Dependence of Anomalous FMR Modes in Fe/Mo Multilayers". Jianghong Huang. December 1993.

Masters Theses Presently Directing

"Dynamics of Interlayer Coupling in Co/Ni Multilayers." Laura Adams. August 1995.

"Dynamics of Interlayer Coupling in Tailored Fe/Cr Multilayers." Weixiao Liu. August 1995.

"Variable Temperature Hyperfine Structure in Plasticene". Charles Lynn. December 1993.

UNDERGRADUATE STUDENT PARTICIPATION

Johanna Picconatto. Designed, constructed and tested a sensitive vibrating sample magnetometer during the summer (1994) following her freshman year. Samples measured started with a piece of paper clip, progressed to bits of fine Fe and Ni wire and culminated in Co/Ni and Fe/Cr multilayers. Sensitivity levels of 1×10^{-3} emu were obtained by the end of the summer with modifications proposed to increase the sensitivity by at least a factor of 10.