

286



REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION SECRET		1d. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT <i>unlimited</i>	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE AUG 16 1993		5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR. 02 0506	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)		7a. NAME OF MONITORING ORGANIZATION <i>Same as 8a</i>	
6a. NAME OF PERFORMING ORGANIZATION University of Minnesota	6b. OFFICE SYMBOL <i>(If applicable)</i>	7b. ADDRESS (City, State and ZIP Code) <i>Same as 8c</i>	
6c. ADDRESS (City, State and ZIP Code) Physics - 116 Church St. S.E. Minneapolis, MN 55455		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER F49620-92-J-085	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR/NE	8b. OFFICE SYMBOL <i>(If applicable)</i> NE	10. SOURCE OF FUNDING NOS.	
8c. ADDRESS (City, State and ZIP Code) Bolling AFB Washington, D.C. 20332-6448		PROGRAM ELEMENT NO. <i>11 2F 2305</i>	TASK NO. <i>GS</i>
11. TITLE (Include Security Classification) Epitaxial Iron Films		PROJECT NO.	WORK UNIT NO.
12. PERSONAL AUTHOR(S) E.D. Dahlberg			
13a. TYPE OF REPORT Final	13b. TIME COVERED FROM 3/1/92 TO 3/1/93	14. DATE OF REPORT (Yr., Mo., Day) 93-6-15	15. PAGE COUNT 9
16. SUPPLEMENTARY NOTATION 03 8 11 05 9			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse)	
FIELD	GROUP	93-18774	
	SUB. GR.		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) This research involved studies of the magnetic properties of multilayered magnetic films and high quality thin. Both ultra high vacuum sputtering and molecular beam epitaxy techniques were utilized to prepare the films. Both electrical transport and mageto-optic effects were use measure the magnetic properties of the films. The primary focus during this year was to develop high quality trilayers consisting of a magnetic layer, nonmagnetic layer, and a magnetic layer. These structures are being developed to determine the scattering origin of the giant magnetoresistance phenomena. In addition, other investigations included the determination of the temperature dependence of the magnetic anisotropy energies of epitaxial iron films, the magnetization dynamics of thin films, and the general transport properties of multilayers. The transport effort utilized multilayers of magnetic and nonmagnetic metals to study the interfacial scattering. The combination of a magnetic and nonmagnetic metal in this work facilitates the origin of the scattering by use of the anisotropic magnetoresistance.			
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS <input type="checkbox"/>		21. ABSTRACT SECURITY CLASSIFICATION <i>unclass</i>	
22a. NAME OF RESPONSIBLE INDIVIDUAL E.D. Dahlberg		22b. TELEPHONE NUMBER (Include Area Code) 202-767-4933	22c. OFFICE SYMBOL NE

FORECAST REPORT FOR
AFOSR GRANT NO. AF/FA9620-92-J-0185/P00001

SUBMITTED TO
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
BOLLING AFB, DC 20332-6448

Grant Title: Thin Magnetic Films

Starting Date: 3 March, 1992

Report Date: 15 June, 1993

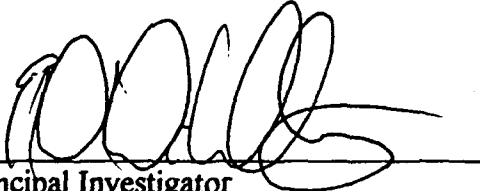
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AFOSR-TR- 93 0596

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I. Statement of Work

This research program was directed at developing new models for a more fundamental understanding of magnetism and to investigate new magnetic phenomena such as the recent discovery of exchange coupled multilayers. The research focused on the use of advanced thin film preparation techniques to prepare high quality multilayered and single layer thin films. Much of the research utilized magneto-transport techniques to probe the magnetic properties of the magnetic films. In particular, the research has investigated the magnetic properties of bcc Co, the role of interfacial disorder in the recently discovered exchange coupling in magnetic multilayers and the giant magnetoresistance phenomena, the magnetization process and related dynamics in high quality films and a continuing investigation of the temperature dependence of the anisotropy energies in epitaxial iron films. The experimental investigative tools include magnetotransport in magnetic fields up to 10 tesla, SQUID magnetometry, and magneto-optic magnetometry used for simultaneous detection of magnetization parallel and perpendicular to the applied magnetic fields.

II. Accomplished Research

During the first year of this grant, two of the senior graduate students received their Ph.D.'s and some of their work is yet to be published. These students have been followed by three relatively new graduate students. As one might expect, the more junior students have not yet reached a high level of productivity. In any event, as a mechanism of describing this research, we will list and discuss the publications which have been either published, submitted for publication, or are currently in draft form. For completeness, those works which were not yet published by the end of the last report for the previous grant will be included.

A. "Magnetization Reversal in (100) Fe Thin Films," Jeffery M. Florczak and E. Dan Dahlberg, Phys. Rev. 44, 9338 (1991).

This publication utilizes the technique we developed using magneto-optics to provide a simultaneous measure of the magnetization in two orthogonal directions in a magnetic film. This work focuses on (100) oriented iron films. These films differ from those we investigated earlier in that they do not possess all three primary three crystallographic directions in the film planes but instead only have the $\langle 100 \rangle$ and the $\langle 110 \rangle$ directions. The lack of the $\langle 111 \rangle$ direction completely alters the magnetization process. The (100) films appear to magnetize in a much more uniform manner. The data taken on these films was modeled with a uniform rotation of the magnetization direction. In the modeling, we were able to determine the anisotropy energies and, as expected, show that prior to a jump in the magnetization direction that the magnetization process is dominated by wall formation.

B. "Comparison of the Spin Valve Effect and the Anisotropic Magnetoresistance in Co/Cu Multilayered Films," Youjun Chen, J.M. Florczak, and E. Dan Dahlberg, *J. Magn. Mater.* 104-107, 1907 (1992).

Of current interest in the physics community is the recently discovered giant magnetoresistance (GMR) effect and the long range coupling (LRC) in magnetic/nonmagnetic multilayers. At the present time, a phenomenological model exists for the GMR (using the same physics as for the Stern-Gerlach experiment using spin projection) but a detailed understanding is lacking. This paper which we submitted to the ICM compares the GMR to the anisotropic magnetoresistance (AMR) in systems which exhibit the GMR. We have analyzed the data with a model of Fert which first was used to describe the AMR as a two-current system and in different limits, the GMR. The result of the work is that the AMR and the GMR are BOTH consistent with this two current model of Fert.

C. "Magnetization Reversal in Fe/GaAs (100) Thin Films," J.M. Florczak and E. Dan Dahlberg, *J. Magn. Mater.* 104-107, 339 (1992).

We are continuing to pursue an understanding of the magnetization processes in thin films; this work is a continuation of that effort. In this work, the angular dependence of the magnetization process in Fe/GaAs (100) thin films was studied using the magneto-optical Kerr effects. The actual experiments relied upon the simultaneous measurements of the magnetization both parallel and perpendicular to the applied field using the technique we pioneered and reported on previously (Florczak and Dahlberg, *J. Appl. Phys.* 67, 7520 (1990)). In the present work, we find the magnetization proceeds in two steps which require the nucleation of 90° domain walls in the films. The interesting point is that there is an angular dependence to the second nucleation process but, within experimental error, not the first. At the present we don't understand this phenomena but are attempting model using the model developed in C. above and a nucleation model of Arrott.

D. "Transport in Co/Ag Multilayered Films," Youjun Chen, P. Rider, E. Dan Dahlberg, E.E. Fullerton, and Ivan K. Schuller, manuscript in preparation.

In this work, we have used two models to understand the transport in multilayered systems; the parallel resistor model and the alloy model. In H. above only the parallel resistor model was used. In this work, both the parallel resistor model and the alloy model were used to describe the transport properties of these films. Again, as in H., the result is that the simple models are lacking and measures of the AMR and the resistivity do not provide sufficient information to improve the models, i.e., we are left with too many adjustable parameters. We do not mean to trivialize the research in

H. and I. as they both are necessary as first steps in this exciting research area and both provide direction for the future work which is described below.

- E. "Thickness Dependence of the Anisotropic Magnetoresistance in Epitaxial Iron Films," by M. Tondra, E. Dan Dahlberg, and G.A. Prinz, accepted for publication in *J. Appl. Phys.*

In this work we determine the value of the anisotropic magnetoresistance (AMR) as a function temperature for the principal crystallographic directions, the (100), (110), and (111), in epitaxial iron films. Averages of the AMR along the different directions is equivalent to the value measured in polycrystalline samples. It is found that for the current applied along the (100) directions in the films with thicknesses over 17.5 nm, it is difficult to saturate the AMR. The reason for this lack of saturation is undetermined. From measurements of the magnetization, this large magnetoresistance can only be associated with a very small percentage of the magnetization of the films, on the order of one percent. One possibility is that for the thicker films, pinning of the magnetization at the interface creates a domain wall and there is a giant magnetoresistance phenomena associated with the wall. For the other directions it is likely that the current is parallel or nearly parallel to the wall and so this behavior does not occur.

- F. "A Method of Separating the Giant Magnetoresistance and the Anisotropic Magnetoresistance in Multilayers," by Y-J. Chen, B.H. Miller, and E. Dan Dahlberg, Accepted for publication in *J. Appl. Phys.*

A number of workers have measured giant magnetoresistance (GMR) samples with rather low values of the GMR. An accurate determination of the GMR in these samples requires one to separate the anisotropic magnetoresistance (AMR) contribution from the measured magnetotransport properties. In this work, we develop a technique which accurately separates the AMR and the GMR in measurements. This technique is applicable for the case where the AMR is unaffected by the GMR scattering phenomena or, at least, in the case of small GMR. The general applicability of this technique will be determined by a detailed understanding of the high resistance GMR state.

- G. "Dependence of the Anisotropic Magnetoresistance on Aspect Ratio in Cobalt Films," by Mark Tondra, Brad Miller, and E. Dan Dahlberg, abstract submitted for consideration of publication.

The anisotropic magnetoresistance (AMR) is defined as the asymmetry in the electrical transport with the current parallel and perpendicular to the magnetization of the sample. This work shows that in large area samples, say a square for instance, with inline contacts, the measured AMR is less than the intrinsic AMR of the material. Essentially what occurs is that at the injection point for the current, the current spreads to fill the space available to minimize the current density. This means that the current does not flow exactly parallel to the line of contacts but has components perpendicular also. As the width of the sample increases with fixed contact separation the measured AMR decreases.

At fixed width, the measured AMR decreases as the distance between the like polarity (either positive or negative) current and voltage contacts is reduced. This work impacts both basic research designs and device work. In particular, it shows that for experiments on the spin valve effect (SVE), that large square samples with either contacts in the corners or inline contacts reduce any potential error in the SVE determination arising from the AMR; the SVE is an isotropic magnetoresistance phenomena and is thus unaffected by the aspect ratio of the sample other than the conventional geometrical factors.

III. Invited Talks for Research Accomplishments

1. "Transport in Magnetic Multilayers," National Institute of Standards and Technology, Solid State seminar, Washington D.C., 21 Feb., 1992.
2. "Interfacial Scattering and the Giant Magnetoresistance Phenomenon," National Institute of Standards and Technology, Solid State seminar, Washington D.C., 18 June, 1992.
3. "What Anisotropic Magnetoresistance Tells Us About the Giant Magnetoresistance Phenomenon," NYU Physics Seminar, New York, NY, 26 June, 1992.
4. "Anisotropic Magnetoresistance in Multilayers: Something Old, Old, New, and New," Texas A&M Physics Department Seminar, College Station, Texas, 30 Nov., 1992.
5. "Transport in Magnetic Multilayers- Giant and Anisotropic Magnetoresistance," University of Texas at Austin Materials Science Seminar, Austin, Texas, 7 Dec., 1992.
6. "Giant Magnetoresistance: Where's the Scattering?," University of Texas at Arlington Physics Colloquium, Arlington, Texas, 8 December, 1992.
7. "Transport in Magnetic Multilayers: Something Old, Something New, Something Borrowed, Something I Blew!," University of Nebraska Solid State Physics Seminar, Lincoln, Nebraska, April, 1993.

IV. Personnel

- A. Florczak, J.T., PhD in Physics received in 1992 (recipient of IBM predoctoral fellowship, 89-90) and currently employed at 3M Corp.
- B. Chen, Y.-J., PhD in Physics received in 1992, currently employed with Nonvolatile Electronics, Inc.
- C. Tondra, M., Ph.D. Graduate Student in Physics.
- D. Miller, B., Ph.D. Graduate Student in Physics.
- E. Engle, E., Ph.D. Graduate Student in Physics
- F. Kaufmann, D., Undergraduate Student in Physics, Graduated Summa Cum Laude, currently in the Carlson School of Management.
- G. K. Sigsbee, K. Undergraduate Student in Physics, Graduated Summa Cum Laude, Currently in graduate school in physics at the University of Minnesota.
- H. Sankar, S., Undergraduate Student in Physics.