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13. ABSTRACT (Maximum 200 words)  This research involved studies of the magnetic properties of multilayered magnetic films. Ultra high vacuum sputtering techniques were utilized to prepare the films. The physics of the Giant Magnetoresistance (GMR) and multilayer exchange coupling was investigated by precise measurements of the GMR in both anisotropic magnetoresistance (AMR) states. It was found that the AMR affected the GMR by altering the electron mean free path. A Boltzmann equation approach was found to qualitatively predict the results.
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FINAL REPORT FOR  
AFOSR GRANT NO. AF/F49620-92-J-0353

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

Grant Title: Epitaxial Magnetic Films

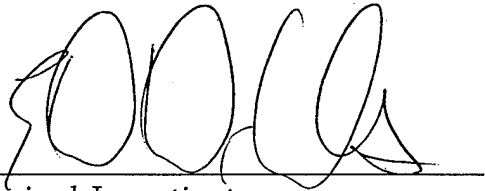
Starting Date: 3 March, 1992

Report Due Date: 31 August, 1995

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**I. Statement of Work**

The fundamental goal of this research program is to develop advanced thin film preparation techniques to prepare high quality multilayered and single layer thin films to investigate the fundamental transport properties of magnetic single layers and multilayers. In particular the relation between the giant magnetoresistance phenomenon and the anisotropic magnetoresistance were investigated. The experimental investigative tools include low and high angle X-ray analysis for film characterization and magnetotransport and SQUID magnetometry for the transport studies. This grant is an AASERT grant and the funds covered the salary and research expenses of Brad Miller.

**II. Accomplished Research**

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.

A. "A Method of Separating the Giant Magnetoresistance and the Anisotropic Magnetoresistance in Multilayers," by Y-J. Chen, B.H. Miller, and E. Dan Dahlberg, *J. Appl. Phys.* **73**, 6384 (1993).

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.

B. "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. (a paper which obtained similar findings was published shortly after we submitted this work and we felt it appropriate to withdraw this from further consideration).

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.

C. "The effect of ion implant damage on the exchange coupling and magnetotransport in magnetic multilayers," M. Tondra, B. Miller, and E. Dan Dahlberg, manuscript in preparation.

For the purpose of developing practical devices and as a mechanism to alter the giant magnetoresistance effect and the exchange coupling in magnetic multilayers, inert gas ions were implanted for controlled damage. With complete magnetic, structural, and magnetotransport measurements between increasing the ion doses, the systematics of many of the interesting phenomena occurring in magnetic multilayers has been investigated. Included in this study is the resistivity, the anisotropic magnetoresistance, the giant magnetoresistance, the Hall effect, the extraordinary Hall effect, the exchange coupling between the layers, the coercivity, and the value of the saturation magnetization.

D. "Accurate determination of the exchange coupling between Co and CoO," B. Miller, M. Tondra, and E. Dan Dahlberg, manuscript in preparation.

The usual technique for determination of the antiferromagnetic/ferromagnetic (AF/F) exchange coupling is to measure the reverse coercivity of the pinned film. In this work, we found this measures only a lower limit for the pinning field. A more accurate measurement of the exchange coupling is measurements of the low field dependent small rotation of the pinned layer. Simply put, the reverse field coercivity measures a threshold a complex wall nucleation process, not the actual pinning. Our technique accurately determines the exchange and not the nucleation process. In addition, we have found an effective stiffness of the films by correlating a spiral length scale for a magnetization rotation as a function of the thickness of the films.

E. "Effect of the anisotropic magnetoresistance state on the measurement of the giant magnetoresistance: A critical testing of GMR models," B. Miller, M. Tondra, E. Chen, and E. Dan Dahlberg, manuscript in preparation.

Accurate measurements of the giant magnetoresistance states in each of the two anisotropic magnetoresistance states allows a determination of the effect of a small change in the resistivity on the GMR. This provides a simple but controlled mechanism to alter the GMR in various systems. Using this data, we have been able to fit to models for the GMR. Being consistent with the models does not prove them, but does allow us to discard other models. In addition, the use of the models for interpretation of the data implies the interfacial scattering model GMR scattering must occur on a much shorter length scale than previously believed.

### III. Personnel

A.. Miller, B., Ph.D. received 1995, working for Seagate.

# UNIVERSITY OF MINNESOTA

Grants and Contracts  
Office of Research and  
Technology Transfer

Suite 201  
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Fax: 612-624-4843

DATE: 10/24/95

TO: E. DAN Dahlberg Physics

FROM: Ginny Olson  
ORTTA

RE: AFOSR- F49620-92-J-0353  
CUFS # 533-6233

Attached is a copy of a delinquent report list we received from AFOSR regarding the above-reference Technical Report which was due on August 31, 1995.

Would you please complete the report and send the originals to AFOSR at the address shown on the letter? Also please send us a copy of your transmittal letter and the first page of your report for our files.

If you have already completed this report, please send me a copy so I can get it removed from this list. Please note that these overdue reports delay all AFOSR grants to the University not just your own.

VSO/mk

Enc.



DEPARTMENT OF THE AIR FORCE  
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (AFMC)  
BOLLING AIR FORCE BASE, DC

16 Oct 95

AFOSR/PKA  
110 Duncan Avenue Room B115  
Bolling AFB DC 20332-8080

University of Minnesota  
Attn: Virginia Olson  
Office of Research & Technology Transfer Admin.  
1100 Washington South Suite 201  
Minneapolis MN 55415-1226

Dear Ms. Olson

The attached list shows reports that are either delinquent or will soon be due. It is the responsibility of each awardee to ensure that all reports are received by the due dates shown in the contracts and grants. Failure to submit any report by the due date will be justification for withholding of future awards to the recipient.

We are working with Finance to ensure that all grant payments are made. If you have notified us of a missing payment, please let us know when it is received so we can clear our records. It is easier to correct when you inform us shortly after a payment is missed rather than after the grant has expired. In addition to the amount, Finance must know which payment is in question.

Some Grantees are failing to return unobligated funds. When the Final Fiscal Report (SF 269) reflects an unobligated balance, that amount is to be returned to the Government in conjunction with the final report. Please note that if it is not mailed with the report, it must be received by this office within 10 days. Otherwise, the final report will be considered delinquent which may result in the withholding of awards. Grantees with outstanding unobligated balances can expect the report(s) to appear on the November Delinquent Awardee List.

When cost sharing is negotiated, the amounts shown on the SF 269 should represent the negotiated Government/Grantee ratio. This is based on the total grant amount--not on individual cost categories. If the Grantee contributes less than the amount shown in the grant document, the Government's share is to be reduced proportionately.

Remember that requests for no cost extensions must be received by AFOSR/PKA prior to the grant or contract expiration. If such requests are sent to the program manager, they run the risk of not being forwarded to this office prior to the expiration date. Please allow sufficient processing time, and always ensure that each request is coordinated through the Contracts & Grants Office.

Due to a recent reorganization of workload assignments, some institutions have new administrators. The administrator for all awardees in the State of Minnesota is Jennifer Bell, (202)767-6836.

If any of the information on the attached list conflicts with your records, please contact me at telephone (202)767-4949, fax (202)404-7951, or e-mail [marilyn.mckee@afosr.af.mil](mailto:marilyn.mckee@afosr.af.mil).

Sincerely,



MARILYN J MCKEE  
Chief, Contract and Grant  
Administration Division

1 Attachment  
Delinquency/Reminder List

cc:  
Each PM and PI