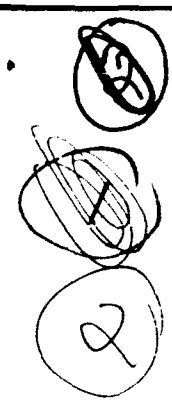


PREFACE

Apr 91

Nanostructured Magnetic Materials

In the last twenty years a great amount of progress has been made in the development of new magnetic materials. Permanent magnets have progressed from the AlNiCo's (with $(BH)_m$~8 MGOe) to the strong rare-earth magnets of $SmCo_5$ ($(BH)_m$~20 MGOe), $Sm_2(Co,Fe,Cu,Zr)_{17}$ ($(BH)_m$~30 MGOe) and the recently discovered Nd-Fe-B super-magnets with $(BH)_m$~50 MGOe. For years the magnetic storage industry has employed Fe_2O_3 and CrO_2 for storage media and permalloys and ferrites for recording heads. The recent development of thin film heads, the demand of higher density of information storage and the emergence of completely new technologies, like magneto-optics, call for entirely new types of magnetic materials. Another area in which new techniques of materials preparation have made a dramatic impact is the epitaxial growth of magnetic films. Recent work has shown that this process can be controlled on the scale of atomic monolayers permitting the growth of totally artificial structures, such as artificial superlattices with a resolution on this scale. Epitaxial growth has also permitted the stabilization of metastable phases in thin film form. These new phases often possess striking properties, such as strong perpendicular anisotropies, which may prove useful for technological applications such as recording. Research on magnetic multilayers and superlattices is increasing at an accelerating pace. Complex couplings between different magnetic layers lead to new properties not seen in bulk materials. Magnetic surfaces and interfaces show large magnetic anisotropy (surface anisotropy), coercivity, galvano-magnetic and magneto-optic effects that can lead to future storage technologies. Ultrafine particles also show interesting and unique properties ranging from superparamagnetism to strong magnetic hysteresis in particles with a size close to that of single domain particle. The investigation of these new materials is shedding new light on magnetism in general, and yields unusual materials in powder form which have potential use in magnetic tapes as well as in many other technological areas.

The remarkable progress made in magnetic materials has been aided by an interplay between experimental measurements and theoretical models. The Stoner and Wohlfarth model of single domain particles helped significantly in understanding the origin of magnetic hysteresis in permanent magnets. However, this oversimplified theory is often used incorrectly to describe the hysteresis

behavior of complex magnetic materials where a "domain wall pinning" or a "nucleation of reversed domains" process is rather more appropriate. The origin of surface anisotropy in thin films and ultrafine particles is not yet clear, and the effects of film thickness and interfaces on the intrinsic and extrinsic magnetic properties are not well understood. In superlattices, it is now found that strong coupling between two ferromagnetic layers can be carried through an intervening layer which is not ferromagnetic. Transport measurements in these structures show giant magneto-resistance effects. The progress in band theory of magnetic materials has also been remarkable. Using novel statistical techniques of Monte Carlo calculation the Curie temperature of Fe has been calculated accurately. This progress has now paved the way for addressing the important "secondary" phenomena such as magnetic anisotropy, galvano-magnetism and magneto-optic rotations which are due to "spin-orbit coupling." All of these properties have been poorly understood in the past and are decisive for many application.

The NATO Advanced Study Institute (ASI) on the Science and Technology of Nanostructured Magnetic Materials which was held June 24 - July 6, 1990 in Aghia Pelaghia, Crete, Greece, reviewed the remarkable progress made in magnetic materials over the last few years and addressed the current state-of-the-art research and its impact on technological applications. The subject matter fell into a number of broad areas including thin films, multilayers, disordered systems, ultrafine particles, intermetallic compounds, permanent magnets and magnetic imaging techniques. The present volume contains the invited lectures as well as a number of contributed papers. The book is divided into seven chapters representing the various topics discussed at the meeting. We hope that this book will serve as a reference to all researchers in magnetic materials and other related fields.

The workshop was made possible due to the generous support by NATO Scientific Affairs Division, Brussels, Belgium. The directors wish also to express their gratitude for the additional support by the Office of Naval Research, European U. S. Army, IBM, General Electric, Philips Hamburg and Du Pont. We also thank Mrs. Helen Long for her efficient assistance with many aspects of the workshop and Mrs. Voula Hadjipanayis for her enthusiastic support during the time of the meeting.

George C. Hadjipanayis

Gary Prinz

CHAPTERS

I. Thin Films, Surfaces and Interfaces

II. Multilayers

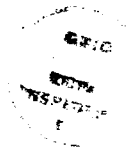
III. Domain Walls, Magnetic Domains and Techniques for Their Observation

IV. Magnetic Anisotropy and Random Magnets

V. Magnetic Semiconductors and Intermetallic Compounds

VI. Fine Particles

VII. Magnetic Hysteresis and Permanent Magnets



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A-1

I. THIN FILMS, SURFACES AND INTERFACES

1.	Electronic Structure and Magnetism of Metal Surfaces, Overlayers & Interfaces	Freeman
*2.	Metastable Phases Via MBE	G. Prinz
3.	Spin Resolved Photoemmision	Kirschner
4.	Growth and Magnetic Properties of Metastable Structures	Heinrich
5.	Correlation of Crystalline and Electronic Structure in Epitaxial FCC-Cobalt Monolayers on Cu(100)	Schneider
6.	Mössbauer Studies of Ultrathin Magnetic Films of Fe/Ag(100)	Koon
7.	Spin-Dependence of Absorbed and Reflected Current on Fe(110)	Hammond
8.	MBE Growth of Metal/Semiconductor Interfaces	Slaughter
9.	Surface and Interface Magnetism	Meier
10.	Ferromagnetic Resonance Studies of Epitaxial Ultrathin Fe(001)/Cu(001) Bilayers and Fe(001)/Cu(001)/Fe(001) Trilayers	Celinski
11.	Laser Ablation Deposition of Metallic Thin Films	Gavigan
12.	Exchange Coupled Films for Magneto-Optic Applications	Gambino
13.	Temperature Dependence of Micromagnetic Domain Structure in Cobalt Films	McFadyen
14.	Hyperfine Interaction Techniques Applied to the Study of Surfaces and Interfaces	Rots
15.	Surface Magnetostriction	O'Handley

* to be sent directly to Plennum Publishing Company

II. MULTILAYERS

1.	Magnetic Rare-Earth Artificial Metallic Superlattices	Rhyne
2.	X-Ray Characterization of Magnetic Multilayers and Superlattices	Falco
3.	The Characterization of Interface Roughness and Other Defects in Multilayers by X-Ray Scattering	Sinha
4.	Magnetism of Nanostructured Rare-Earth Multilayers	Sellmyer
5.	FMR Studies of Metallic Magnetic Thin Films in Layered Structures	Hurdequint
6.	Compositionally Modulated Magnetic Multilayers: Temperature and Modulation Dependent Properties	Flevaris
7.	Structural and Magnetic Properties of Epitaxial Co/Pd Superlattices	Engel
8.	First Principle Calculation of the Magnetocrystalline Anisotropy Energy of Co_nPd_m Multilayers	Daalderop
9.	Structural and Magnetic Studies in Co-Pt Multilayers	Krishnan
10.	Magnetic Properties of Hexagonal Fe/Ru Superlattice With Short Periodicities	Piecuch
11.	Magnetic Studies of Fe-Si Compositionally Modulated Thin Films	Tejada
12.	Mössbauer Spectroscopy of the Fe/Ni Interface	Donzelli
13.	Analysis of Amorphous Dysprosium - Transition Metal Nanoscale Magnetic Multilayers	Shan
14.	Transport Properties of Metallic Thin Films and Multilayers	Fert

III. DOMAIN WALLS, MAGNETIC DOMAINS AND TECHNIQUES FOR THEIR OBSERVATION

1.	Micromagnetics of Longitudinal Recording Media	Alexopoulos
2.	MO-Recording: The Switching Process and Its Relation to the Magnetic Properties of Thin Films	Mergel
3.	Micromagnetic Computations of Magnetization Configurations	Jakubovics
4.	Domain Walls and Domain Wall Structure	Humphrey
5.	Domain Wall Multiplication in Amorphous Ferromagnetic Alloys	Beatrice
6.	Electron Microscope Methods for Imaging Internal Magnetic Fields at High Spatial Resolution	Spence
7.	Scanning Tunneling Microscopy and Force Microscopy Applied to Magnetic Materials	Garcia
8.	Special Session on Spin-Polarized Vacuum Tunneling	Notes by Hathaway
9.	Magnetic Imaging Via Scanning Electron Microscopy with Polarization Analysis	Celotta
10.	Atomic Scale Probe Into High-Tc Superconductors Using Scanning Tunneling Microscopy	Rao

IV. MAGNETIC ANISOTROPY AND RANDOM MAGNETS

1.	Magnetic Anisotropy	Jansen
2.	Random Anisotropy in Magnetic Materials	Cullen
3.	Perpendicular and In-Plane Anisotropy in Amorphous Tb-Fe	O'Shea
4.	Magnetostriction in Amorphous Magnets	Hernando
5.	Anderson Localization in 3-Dimensional Amorphous Alloys: Evolution with the Content of Magnetic Ions	Filippi
6.	On the Law of Approach to Saturation in the Series of Amorphous Alloys α-$Dy_xGd_{1-x}Ni$	Amaral
7.	Magnetoresistance of Amorphous $U_{1-x}Sb_x$ Films	Freitas
8.	Absence of Temperature-Driven First Order Phase Transitions in Systems with Random Bonds	Berker

V. MAGNETIC SEMICONDUCTORS AND INTERMETALLIC COMPOUNDS

1.	Magnetic Behavior of Diluted Magnetic Semiconductors	de Jonge
2.	Intermetallic Compounds and Crystal Field Interactions	Coey
3.	Crystal Field and Exchange Interactions in Hard Magnetic Materials	Franse
4.	First Order Magnetization Processes	Asti
5.	Structure and Properties of Novel Ternary Fe-Rich Rare-Earth Carbides	Jacobs

VI. FINE PARTICLES

1.	Granular Solids	Chien
2.	Ultrafine Magnetic Particles	Hadjipanayis
3.	Magnetic Nanometer Systems and Mössbauer Spectroscopy	Morrish
4.	Some Topics in Fine Particle Magnetism	Berkowitz
5.	Mössbauer Studies of Fine Fe-Based Particles	Morup
6.	Mössbauer Studies of Fine Particles of Fe-Cr-B	Kostikas
7.	Chemical Preparation of Fe-Cr-B Particles	Koch
8.	Composition and Structure of Fe-Ni-B Alloy Particles Prepared by Chemical Reductions with $NaBH_4$	Linderoth
9.	Quantum Effects in Ultrafine Nd-Fe-B Particles	Quintela
10.	Magnetization Reversal in Clusters of Magnetic Particles	Hendriksen
11.	Electric and Magnetic Properties of Small Systems	Arajs
12.	Existence of Frequency Cut-Off in the Spin Wave Spectrum of Small Magnetic Particles	Garcia

VII. MAGNETIC HYSTERESIS AND PERMANENT MAGNETS

1.	Mechanically Alloyed Permanent Magnets	Schultz
2.	Melt-Spun Magnets	Pinkerton
3.	Solid NdFeB Magnets Made by Gas Atomization and Extrusion	Dulis
4.	The Role of Microstructure in Permanent Magnets	Hadjipanayis
5.	Lorentz Microscopy in Permanent Magnets	Fidler
6.	Coercivity in Hard Magnetic Materials	Givord
7.	Micromagnetism and Magnetization Processes in Modern Magnetic Materials	Kronmüller
8.	Micromagnetic Approach to Magnetic Hysteresis	Victora
9.	Magnetic Hysteresis in Disordered Magnets	Soukoulis
10.	Coercivity of Nanostructured Materials	Otani
11.	Magnetic Hysteresis of Co-Pt Films	Tsoukatos
12.	Technology and Application of Permanent Magnets	Narasimhan

Issued April 1988

ASI no. [ ]

NATO International Scientific Exchange Programmes

ADVANCED STUDY INSTITUTE

Scientific Affairs Division - NATO - B-1110 Brussels Belgium - Telephone 02/241 00 40 - Telex 23-867 (NATOHQ)

GENERAL REPORT

Note

This report should be sent within 30 days of the meeting. The financial report (pink form) may be sent later after consolidation of the accounts ; however it must be with NATO by not later than 120 days from the end of the meeting. It should be recalled that only after acceptance by NATO of the financial report as well as the present report can any final supplementary award be authorized.

1. Advanced Study Institute

Title : Science and Technology of Nanostructured Magnetic Materials

Location : Aghia Pelaghia
(site and country) Crete, GREECE

Dates : June 25 - July 6, 1990
Number of working days : 10

2. Director :
(name, position, official address, telephone no., telex no.)

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Dr. Luigi Paretti, MASPEC, Parma, ITALY

4. Scientific Codes and percentages of discipline content (see NATO classification of scientific subjects)

Code	%	Code	%	Code	%
4 2 04	6 0	2 7 1 2	4 0		

5. General Comments

The Director is asked to give here general comments on the meeting; comments on the application process, the planning and execution of the meeting itself and follow-up are also useful for the maintenance and improvement of the ASI Programme and are welcome. Specifically financial comments should not be given here but may be made in the accompanying financial report. A short scientific summary of the meeting should be prepared on the attached camera ready copy sheets for publication in the NATO Science Committee Yearbook.

The idea for a NATO Advanced Study Institute on Nanostructured Magnetic Materials arose in a 3M Conference where [illegible]y Prinz suggested to me that we should hold this Institute in Greece. Soon after this we planned a tentative program, made a list of possible lecturers and wrote to them asking if they wanted to participate in the Institute. After we received their answer we applied to NATO for funding of the Institute.

When we learned that the proposed Institute was approved we wrote again to the lecturers, reminded them of their duties and asked them to provide us with names of good students who would greatly benefit from this Institute. We also sent letters and posters to many laboratories doing research in magnetic materials and encouraged researchers and students to apply for the Institute. In addition we advertised the Institute in the Physics Today and
A large number of students and researchers applied to come to the Institute. At this time we decided to include additional short talks to cover the state-of-the art current research in magnetic materials. We have chosen several speakers from the people who applied and asked them to give "invited talks" on topics of their expertise. These speakers were treated the same way as the other participants. We also advertised the idea of poster presentations.

Several times before the meeting we sent letters to the lecturers and speakers and ask them to have their manuscripts ready at the time of the Institute and also copies and summaries of the talks for the rest of the participants. Tentative lists of participants were sent to Plenum Publishing Company, who provided camera ready sheets and instructions for manuscript preparation to all applicants. The daily program consisted of talks from 8:45 a.m. to 10:45 a.m. followed by a coffee break at 11:15. The talks continued until 1:15 p.m. followed by a siesta to 5:00 p.m. The talks resumed again at 5:00 to 7:00 p.m. after which the group got together for dinner. During the time of the meeting it was evident that some topics needed additional time for questions to be answered and differences to be resolved. To handle this we introduced special sessions, for those interested, in the afternoon at 4 p.m., one hour before the afternoon session.

Wednesday afternoon we visited Knossos and on the first Sunday we organized an excursion to Samaria Gorge. Our social events included a welcome cocktail party, a Greek night and a banquet Cretan night.

6. National distribution of Lecturers (L) and ASI Students (S)

	L	S		L	S		L	S		L	S
Belgium			Iceland			Spain	1		Other Countries		
Canada	1		Italy			Turkey			*(specify)*		
Denmark			Luxembourg			UK	1		Ireland	1	
France	2		Netherlands	2		USA	5				
Germany	2		Norway								
Greece	1		Portugal						TOTALS		

7. Book to be published as a product of the ASI

Title of Book : SCIENCE AND TECHNOLOGY OF NANOSTRUCTURED MAGNETIC MATERIALS

Editor(s) : (a) George C. Hadjipanayis

(b) Gary Prinz

(c) Luigi Pareti

Publisher : Plenum Publishing Company

Expected Date of Publication : April 1991

Editor's Comments

Date : Jan 6, 1991

Signature George Hadjipan

Attachments

1. Annex - List of Director(s), Lecturers and ASI Students
2. Scientific summary : camera ready

June 25 - July 6, 1990
Heraklion (Aghia Pelayia) Crete, Greece

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The Institute reviewed the remarkable progress made in magnetic materials over the last few years and addressed the current state-of-the-art research and its impact on technological applications. The subject matter fell into a number of broad areas including thin films, multilayers, disordered systems, ultrafine particles, intermetallic compounds, permanent magnets and magnetic imaging techniques.

The development of new techniques for materials preparation has made a dramatic impact in the area of epitaxial growth of magnetic films. Several presentations have shown that this process can be controlled on the scale of atomic layers permitting the growth of artificial structures such as artificial superlattices with nearly atomic resolution. Epitaxial growth has also permitted the stabilization of metastable phases in thin films which often possess a strong perpendicular anisotropy which may prove useful for technological applications. In magnetic multilayers and superlattices the complex coupling between different magnetic layers was discussed both experimentally and theoretically. In superlattices it was proposed that a strong coupling between two ferromagnetic layers can be carried out through an intervening layer which is not ferromagnetic. This coupling leads to new properties not seen in the past. Magnetic surfaces and interfaces show large magnetic anisotropy (surface anistropy), coercivity, magnetoresistance, galvanomagnetic and magnetooptic effects that can lead to future storage technologies. Band structure studies using statistical techniques of Monte Carlo calculations, led to accurate calculations of the Curie temperature of Fe, Co, Ni films. The solution of this problem opened the door for other important phenomena which are due to "spin orbit" coupling. Several contributions discussed the physics of ultrafine particles and granular solids with interesting and unique properties from superparamagnetism to strong magnetic hysteresis. The magnetic properties of rare-earth intermetallic compounds with potential applications in permanent magnets have been discussed including the crystal field effects and the origin of magnetic anisotropy. The magnetic hysteresis behavior of fine particles, permanent magnets, melt-spun ribbons and mechanically alloyed magnets have been discussed. The magnetic hysteresis models of "domain wall pinning" and "nucleation of reversed domains" have been reviewed and their applicability in different magnetic materials was discussed. The micromagnetic approach using the Landau-Lifshitz-Gilbert equation was also presented to explain the hysteresis behavior of thin films.

The magnetic properties of all of these materials are strongly influenced by their microstructure and several methods to evaluate their growth, lattice structure and sample integrity were discussed. These included spin-polarized electron spectroscopy, DPC and RHEED/RE Microscopy and Lorentz microscopy.

Finally the applications of magnetic materials in magnetic recording, magneto-optic recording and permanent magnets have been discussed with more emphasis given to the improvement of material properties for these applications.

Granular Solids, Prof. C. Chien, Johns Hopkins University, Baltimore, Maryland
Intermetallic Compounds and Crystal Field Interactions, Prof. T. Coey, Trinity College, Dublin, Ireland
Random Anisotropy in Magnetic Materials, Prof. J. Cullen, Naval Surface Weapons Center, Silver Springs, MD
Magnetic Behavior of Diluted Magnetic Semiconductors, Prof. W. de Jonge, Eindhoven University of Technology, The Netherlands
Transport Properties of Metallic Thin Films and Multilayers, Prof. A. Fert, Universite Paris Sud, Orsay, France
Scanning Tunneling Microscopy and Force Microscopy Applied to Magnetic Materials, Prof. N. Garcia, Autonouous University of Madrid, Madrid, Spain
Coercivity in Hard Magnetic Materials, Prof. D. Givord, Neel Laboratory, Grenoble, France
Ultrafine Magnetic Particles, Prof. G. C. Hadjipanayis, University of Delaware, Newark, Delaware
The Role of Microstructure in Permanent Magnets, Prof. G. C. Hadjipanayis, University of Delaware, Newark, Delaware
Micromagnetism and Magnetization Processes in Modern Magnetic Materials, Prof. K. Kronmüller, Max-Planck Institute fur Metallforschung, Stuttgard, Germany
Magnetic Nanometer Systems and Mössbauer Spectroscopy, Prof. A. Morrish, University of Manitoba, Winnepeg, Canada
Metastable Phases Via MBE, Dr. G. Prinz, Naval Research Laboratory, Washington, D. C.
Magnetic Rare-Earth Artificial Metallic Superlattices, Prof. J. Rhyne, National Bureau of Standards, Gaithersburg, Maryland
Spin Resolved Photoemmision, Prof. J. Kirschner, Institut fur Grenzflachenforschung and Vakuumphysik, Julich, Germany
Magnetism of Nanostructured Rare-Earth Multilayers, Prof. D. Sellmyer, University of Nebraska, Lincoln, Nebraska
Electron Microscope Methods for Imaging Internal Magnetic Fields at High Spatial Resolution, Prof. J. Spence, Arizona State University, Tempe, Arizona

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