

HANDBOOK OF
Magnetism
AND ADVANCED MAGNETIC MATERIALS

1

Fundamentals and Theory

Micromagnetism

Novel Techniques for Characterizing
and Preparing Samples

Novel Materials

Spintronics and Magnetoelectronics

Editors-in-Chief

HELMUT KRONMÜLLER

STUART PARKIN

 **WILEY**

Contents

VOLUME 1: FUNDAMENTALS AND THEORY

Contributors to Volume 1

Foreword

Preface to Volume 1

Abbreviations and Acronyms

Electron Theory of Magnetism

Density-functional Theory of Magnetism

Gustav Bihlmayer

Multiband Hubbard Models and the Transition Metals

Gernot Stollhoff

Dynamical Mean-field Theory of Itinerant Electron Magnetism

Alexander I. Lichtenstein/Mikhail I. Katsnelson

Quantum Monte Carlo Methods

Fakher F. Assaad/Matthias Troyer

Strongly Correlated Electronic Systems

Heavy Fermions: Electrons at the Edge of Magnetism

Piers Coleman

The Kondo Effect

Barbara A. Jones

Orbital Physics in Transition-metal Oxides: Magnetism and Optics

Peter Horsch

Theory of Magnetic Spectroscopy and Scattering

Magnetic Spectroscopy

H. Ebert

X-ray and Neutron Scattering by Magnetic Materials

S.W. Lovesey/Y. Tanaka

Spin Dynamics and Relaxation

Spin Waves: History and a Summary of Recent Developments

D.L. Mills

Dissipative Magnetization Dynamics Close to the Adiabatic Regime

Manfred Fähnle/Daniel Steiauf

Phase Transitions and Finite Temperature Magnetism

303

Phase Transitions and Finite Temperature Magnetism: Experiment and Analysis

305

Sharika Nandan Kaul Electron Theory of Finite Temperature Magnetism

334

Jürgen Kübler

Theory of Magnetic Phase Transitions

367

David P. Landau Disordered and Frustrated Spin Systems

398

Kurt Binder/A. Peter Young Quantum Phase Transitions

413

Subir Sachdev

29

Theory of Magnetocrystalline Anisotropy and Magnetoelasticity

423

Theory of Magnetocrystalline Anisotropy and Magnetoelasticity in Transition-metal Systems

425

Ruqian Wu

Theory of Magnetocrystalline Anisotropy and Magnetoelasticity in 4f and 5f Metals

435

Børje Johansson/Michael S.S. Brooks

Magnetostriction and Magnetoelasticity Theory: A Modern View

453

A. del Moral

164

Theory of Transport and Exchange Phenomena in Thin Film Systems

485

Exchange Coupling in Magnetic Multilayers

David M. Edwards/Andrey Umerski

487

Enhanced Magnetoresistance

Peter Zahn/Ingrid Mertig

513

The Berry Phase in Magnetism and the Anomalous Hall Effect

Patrick Bruno

540

Theory of Spin-dependent Tunneling

Hiroshi Imamura/Sadamichi Maekawa

559

245

247

Magnetism of Low Dimensions

575

Magnetism of Low-dimensional Metallic Structures

Axel Enders/Pietro Gambardella/Klaus Kern

577

Magnetism of Low-dimensional Systems: Theory <i>Stefan Blügel/Gustav Bihlmayer</i>	598	Magnetism and Superconductivity	659
Molecular Magnets: Phenomenology and Theory	641	Interplay of Superconductivity and Magnetism <i>Saburo Takahashi/Sadamichi Maekawa</i>	661
Molecular Magnets: Phenomenology and Theory <i>Mark R. Pederson/Tunna Baruah</i>	643	Magnetic Superconductors <i>A. Buzdin/J. Flouquet</i>	678

VOLUME 2: MICROMAGNETISM

Contributors to Volume 2

Foreword

Preface to Volume 2

Abbreviations and Acronyms

Fundamentals of Micromagnetism and Discrete Computational Models

General Micromagnetic Theory <i>Helmut Kronmüller</i>	703
Numerical Micromagnetics: Finite Difference Methods <i>Jacques E. Militat/Michael J. Donahue</i>	742
Numerical Methods in Micromagnetics (Finite Element Method) <i>Thomas Schrefl/Gino Hrkac/Simon Bance/Dieter Suess/ Otmar Ertl/Josef Fidler</i>	765
Magnetization Dynamics Including Thermal Fluctuations: Basic Phenomenology, Fast Remagnetization Processes and Transitions Over High-energy Barriers <i>Dmitri V. Berkov</i>	795
Nonlinear Magnetization Dynamics in Nanomagnets <i>Claudio Serpico/Giorgio Bertotti/Isaak D. Mayergoyz/ Massimiliano d'Aquino</i>	824
Classical Spin Models <i>Ulrich Nowak</i>	858

Magnetic Configurations in Small Elements, Magnetization Processes and Hysteretic Properties

Magnetization Configurations and Reversal in Small Magnetic Elements <i>Mathias Kläui/Carlos António Fernandes Vaz</i>	877
Magnetic Properties of Systems of Low Dimensions <i>Rolf Allenspach</i>	899

xii	Domain Wall Propagation in Magnetic Wires <i>Teruo Ono</i>	933
xiii	Current Induced Domain-wall Motion in Magnetic Nanowires <i>Luc Thomas/Stuart Parkin</i>	942
xv	The Motion of Domain Walls in Nanocircuits and its Application to Digital Logic <i>Russell P. Cowburn</i>	983
xix	Guided Spin Waves <i>Riccardo Hertel</i>	1003

701	Magnetization Processes and the Microstructure	1021
703	Micromagnetism–Microstructure Relations and the Hysteresis Loop <i>Dagmar Goll</i>	1023
742	Modeling of Nonlinear Behavior and Hysteresis in Magnetic Materials <i>David C. Jiles/Yevgen Melikhov</i>	1059

Magnetization Dynamics, Solitons, Modes and Thermal Excitations

1081	Magnetization Dynamics, Solitons, Modes and Thermal Excitations	1081
1083	Magnetization Dynamics: Thermal-driven Noise in Magnetoresistive Sensors <i>Jian-Gang Zhu</i>	1083
1092	Magnetic Modes in Circular Thin Film Elements, Experiment and Theory <i>Christian H. Back/Matthias Buess</i>	1092
1114	Nonlinear Multidimensional Spin-wave Excitations in Magnetic Films <i>Sergej O. Demokritov/Andrei N. Slavin</i>	1114

Micromagnetics of Spin Angular Momentum Transfer

1145	Micromagnetics of Spin Angular Momentum Transfer	1145
1147	Theory of Spin-transfer Torque <i>Mark D. Stiles</i>	1147
1167	Microwave Generation in Magnetic Multilayers and Nanostructures <i>William H. Rippard/Matthew R. Pufall</i>	1167

VOLUME 3: NOVEL TECHNIQUES FOR CHARACTERIZING AND PREPARING SAMPLES

Contributors to Volume 3	xi	Magneto-optical Techniques	1511
Foreword	xiii	Investigation of Domains and Dynamics of Domain Walls by the Magneto-optical Kerr-effect <i>Rudolf Schäfer</i>	1513
Preface to Volume 3	xv	Magnetization-induced Second Harmonic Generation <i>Andrei Kirilyuk/Theo Rasing</i>	1542
Abbreviations and Acronyms	xix	Investigation of Spin Waves and Spin Dynamics by Optical Techniques <i>Burkard Hillebrands/Jaroslav Hamrle</i>	1566
X-Ray and Neutron Diffraction Techniques	1193	Time-resolved Kerr-effect and Spin Dynamics in Itinerant Ferromagnets <i>Bert Koopmans</i>	1589
Spin Structures and Spin Wave Excitations <i>Igor A. Zaliznyak</i>	1195		
Domain States Determined by Neutron Refraction and Scattering <i>Axel Hoffmann/Gian P. Felcher</i>	1211		
Polarized Neutron Reflectivity and Scattering from Magnetic Nanostructures and Spintronic Materials <i>Hartmut Zabel/Katharina Theis-Bröhl/Boris P. Toperverg</i>	1237		
Synchrotron Radiation Techniques	1309	Spin-polarized Electron Spectroscopies	1615
Synchrotron Radiation Techniques Based on X-ray Magnetic Circular Dichroism <i>Gisela Schütz/Eberhard Goering/Hermann Stoll</i>	1311	Investigation of Ultrathin Ferromagnetic Films by Magnetic Resonance <i>Klaus Baberschke</i>	1617
Time and Space Resolved Magnetization Dynamics	1365	Spin-polarized Photoelectron Spectroscopy as a Probe of Magnetic Systems <i>Peter David Johnson/Gernot Güntherodt</i>	1635
Ultrafast Magnetodynamics with Lateral Resolution: A View by Photoemission Microscopy <i>Hermann A. Dürr/Claus M. Schneider</i>	1367	High-energy Surface Spin Waves Studied by Spin-polarized Electron Energy Loss Spectroscopy <i>Markus Etzkorn/Parameswaran Sarala Anil Kumar/Jürgen Kirschner</i>	1658
Electron Microscopy and Electron Holography	1391	Nanomagnetism – Application and Characterization	1685
Lorentz Microscopy of Thin-film Systems <i>Josef Zweck/Thomas Uhlig</i>	1393	Scanning Probe Techniques: MFM and SP-STM <i>Alexander Schwarz/Matthias Bode/Roland Wiesendanger</i>	1687
Electron Holography of Ferromagnetic Materials <i>Martha R. McCartney/David J. Smith</i>	1428	Alternative Patterning Techniques: Magnetic Interactions in Nanomagnet Arrays <i>Jacques Ferré/Jean Pierre Jamet</i>	1710
Spin-polarized Low Energy Electron Diffraction <i>Hans-Joachim Elmers</i>	1444	Chemical Synthesis of Monodisperse Magnetic Nanoparticles <i>Chao Wang/Shouheng Sun</i>	1736
Spin-polarized Low Energy Electron Microscopy <i>Ernst Bauer</i>	1470	Nanoimprint Technology for Patterned Magnetic Nanostructures <i>Stephen Y. Chou</i>	1748
Scanning Electron Microscopy with Polarization Analysis <i>Hans Peter Oepen/Robert Frömter</i>	1488	Growth Techniques	1773
		Growth of Magnetic Materials using Molecular Beam Epitaxy <i>James N. Eckstein</i>	1775
		Epitaxial Heusler Alloys on III–V Semiconductors <i>Thorsten Hesjedal/Klaus H. Ploog</i>	1796
		Crystal Growth of Magnetic Materials <i>Günter Behr/Wolfgang Löser</i>	1821

VOLUME 4: NOVEL MATERIALS

Contributors to Volume 4

Foreword

Preface to Volume 4

Abbreviations and Acronyms

Soft Magnetic Materials

Amorphous Alloys

Hywel A. Davies/Michael R.J. Gibbs

Soft Magnetic Materials – Nanocrystalline Alloys

Giselher Herzer

Soft Magnetic Bulk Glassy and Bulk Nanocrystalline Alloys

Akihisa Inoue/Akihiro Makino/Teruo Bitoh

Advanced Soft Magnetic Materials for Power Applications

Anthony J. Moses

Hard Magnetic Materials

Rare-earth Intermetallics for Permanent Magnet Applications

Josef Fidler/Dieter Suess/Thomas Schrefl

Rare-earth Transition-metal Magnets

Werner Rodewald

Rare-earth Nanocrystalline and Nanostructured Magnets

Melania Marinescu/Alexander Gabay/George C. Hadjipanayis

Current Status and Future Development of the Magnetic Materials Industry in China

Yang Luo

Ferro- and Ferrimagnetic Oxides and Alloys

Ferrimagnetic Insulators

Victor A.M. Brabers

Crystallography and Chemistry of Perovskites

Mats Johnsson/Peter Lemmens

Dilute Magnetic Oxides and Nitrides

John Michael David Coey/Karsten Rode

Heusler Alloys

Robert A. de Groot

Half-metals

M. Venkatesan

Ferro-, Ferri-, and Antiferrimagnetic Nanoparticles

Superparamagnetic Particles

Steen Mørup/Mikkel Fougt Hansen

xii	Novel Nanoparticulate Magnetic Materials and Structures <i>David J. Sellmyer/Yingfan Xu/Yucheng Sui/ Ralph Skomski</i>	2177
xiii		
xv	Micro- and Nanowires	2191
xix	Advanced Magnetic Microwires <i>Manuel Vázquez</i>	2193
1859	Template-based Synthesis and Characterization of High-density Ferromagnetic Nanowire Arrays <i>Kornelius Nielsch/Bethanie J.H. Stadler</i>	2227
1861	Magnetic Carbon <i>Pablo Esquinazi</i>	2256
1882		
1909		
1926	Magnetic Thin Films	2283
1943	Magnetic Ultrathin Films <i>Bretislav Heinrich/John Francis Cochran</i>	2285
1945	Hard Magnetic Films <i>Toshiyuki Shima/Koki Takanashi</i>	2306
1969		
2005		
2035	Magnetic Materials with Outstanding Properties	2325
2079	Magneto-optical Materials <i>Wolfgang Kleemann</i>	2327
2098	Magnetocaloric Materials <i>Vitalij K. Pecharsky/Karl A. Gschneidner, Jr.</i>	2363
2107	Chalcogenides and Pnictides <i>Daniel Fruchart/Pierre Wolfers</i>	2378
2121	Magnetostrictive Materials and Magnetic Shape Memory Materials <i>Robert C. O'Handley</i>	2401
2133	Ferroelectricity in Incommensurate Magnets <i>A. Brooks Harris/Gavin Lawes</i>	2428
2157	Magnetism and Quantum Criticality in Heavy-Fermion Compounds: Interplay with Superconductivity <i>Oliver Stockert/Michael Nicklas/Peter Thalmeier/ Philipp Gegenwart/Frank Steglich</i>	2461
2159	Molecular Nanomagnets <i>Wolfgang Wernsdorfer</i>	2481
	Biomagnetic Materials	2505
	Spintronic Biochips for Biomolecular Recognition <i>Paulo P. Freitas/Hugo A. Ferreira</i>	2507
	Application of Magnetic Particles in Medicine and Biology <i>Wilfried Andrä/Urs Häfeli/Rudolf Hergt/ Ripen Misri</i>	2536

VOLUME 5: SPINTRONICS AND MAGNETOELECTRONICS

Contributors to Volume 5	xi	Ferromagnetic Semiconductors <i>Fumihiro Matsukura/Hideo Ohno</i>	2756
Foreword	xiii	Diluted Ferromagnetic Semiconductors – Theoretical Aspects <i>Tomasz Dietl</i>	2774
Preface to Volume 5	xv		
Abbreviations and Acronyms	xix	Semiconductor Spintronics	2791
Metal Spintronics	2569	Spin Engineering in Quantum Well Structures <i>Roberto C. Myers/Arthur C. Gossard</i>	2793
Magnetic Tunnel Junctions	2571	Hot Electron Spintronics <i>Xin Jiang/Sebastiaan van Dijken/Stuart Parkin</i>	2812
		Spin-dependent Transport of Carriers in Semiconductors <i>Roland Winkler</i>	2830
Spin Angular Momentum Transfer in Magnetoresistive Nanojunctions	2592	Semiconductor Spintronic Devices <i>Michael E. Flatté</i>	2844
		Theory of Spin Hall Effects in Semiconductors <i>Hans-Andreas Engel/Emmanuel I. Rashba/Bertrand I. Halperin</i>	2858
Spin-transfer in High Magnetic Fields and Single Magnetic Layer Nanopillars	2611	Manipulation of Spins and Coherence in Semiconductors <i>Nathaniel P. Stern/Jesse Berezovsky/Sayantani Ghosh/ David D. Awschalom</i>	2878
		Quantum Computing with Spins in Solids <i>William A. Coish/Daniel Loss</i>	2895
Microwave Excitations in Spin Momentum Transfer Devices	2630	The Magnetic Resonance Force Microscope <i>P. Chris Hammel/Denis V. Pelekhov</i>	2916
Theory of Spin-polarized Current and Spin-transfer Torque in Magnetic Multilayers	2648		
Exotic Materials	2669	Magnetoresistance	2941
High-temperature Superconductivity – Magnetic Mechanisms	2671	Tunneling Magnetoresistance in Semiconductors <i>Shinobu Ohya/Masaaki Tanaka</i>	2943
		Spin-dependent Tunneling: Role of Evanescent and Resonant States <i>Evgeny Y. Tsymbal</i>	2963
Magnetic Polaron	2689	Geometry-driven Magnetoresistance <i>Stuart A. Solin/L. Ramdas Ram-Mohan</i>	2979
The Kondo Effect in Mesoscopic Quantum Dots	2703		
Ferromagnetic Manganite Films	2725	Subject Index	3001
	2727		