

---

# Magnetic Characterization Techniques for Nanomaterials

---

Challa S.S.R. Kumar  
Editor

# Magnetic Characterization Techniques for Nanomaterials

 Springer

*Editor*

Challa S.S.R. Kumar  
Integrated Mesoscale Architectures for Sustainable Catalysis (IMASC)  
Rowland Institute of Science  
Harvard University  
Cambridge, MA, USA

ISBN 978-3-662-52779-5                      ISBN 978-3-662-52780-1 (eBook)  
DOI 10.1007/978-3-662-52780-1

Library of Congress Control Number: 2016953107

© Springer-Verlag Berlin Heidelberg 2017

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

This Springer imprint is published by Springer Nature  
The registered company is Springer-Verlag GmbH Germany  
The registered company address is: Heidelberger Platz 3, 14197 Berlin, Germany

---

# Contents

<b>1 Rotational Anisotropy Nonlinear Harmonic Generation</b> . . . . .	1
Darius H. Torchinsky and David Hsieh	
<b>2 Magnetic Rotational Spectroscopy for Probing Rheology of Nanoliter Droplets and Thin Films</b> . . . . .	51
Konstantin G. Kornev, Yu Gu, Pavel Aprelev, and Alexander Tokarev	
<b>3 Iron Oxide Nanoparticle-Based MRI Contrast Agents: Characterization and In Vivo Use</b> . . . . .	85
F. Herranz, M. P. Morales, I. Rodríguez, and J. Ruiz-Cabello	
<b>4 Nonlinear Nonequilibrium Simulations of Magnetic Nanoparticles</b> . . . . .	121
Daniel B. Reeves	
<b>5 Magnetic Force Microscopy Characterization of Magnetic Nanowires and Nanotubes</b> . . . . .	157
Muhammad Ramzan Tabasum, Fatih Zighem, Luc Piraux, and Bernard Nysten	
<b>6 Characterization of Magnetism in Gold Nanoparticles</b> . . . . .	191
B. Donnio, J. L. Gallani, and M. V. Rastei	
<b>7 Magnetic Force Microscopy</b> . . . . .	209
Daniele Passeri, Livia Angeloni, Melania Reggente, and Marco Rossi	
<b>8 Characterization of Magnetic Hyperthermia in Magnetic Nanoparticles</b> . . . . .	261
Eva Natividad and Irene Andreu	
<b>9 In Situ Lorentz Microscopy and Electron Holography Magnetization Studies of Ferromagnetic Focused Electron Beam Induced Nanodeposits</b> . . . . .	305
César Magén, Luis A. Rodríguez, Luis E. Serrano-Ramón, Christophe Gatel, Etienne Snoeck, and José M. De Teresa	

---

<b>10 Neutron Reflectivity to Characterize Nanostructured Films</b> . . . . .	339
Sirshendu Gayen, Milan K. Sanyal, and Max Wolff	
<b>11 Characterization of Magnetism in Core–Shell Nanoparticles</b> . . . . .	375
Elizabeth Skoropata and Johan van Lierop	
<b>12 Characterization of Ferromagnetic Bimetallic Nanomaterials Using Electron Microscopy</b> . . . . .	413
Nabraj Bhattarai	
<b>13 Magnetic Characterization of Nanodendritic Platinum</b> . . . . .	431
Wenxian Li, Ziqi Sun, and Shi-Xue Dou	
<b>14 Magneto-Optical (MO) Characterization Tools for Chemically Prepared Magnetic Nanomaterials</b> . . . . .	457
Francesco Pineider and Claudio Sangregorio	
<b>15 Magnetic Nanoparticles Used as Contrast Agents in MRI: Relaxometric Characterisation</b> . . . . .	511
Marc-André Fortin	
<b>Index</b> . . . . .	557

---

## Contributors

**Irene Andreu** Instituto de Ciencia de Materiales de Aragón (ICMA), CSIC - Universidad de Zaragoza, Zaragoza, Spain

**Livia Angeloni** Department of Basic and Applied Sciences for Engineering, SAPIENZA University of Rome, Rome, Italy

**Pavel Aprelev** Department of Materials Science and Engineering, Clemson University, Clemson, SC, USA

**Nabraj Bhattarai** Emergent Atomic and Magnetic Structures, Division of Materials Sciences and Engineering, Ames Laboratory, Ames, IA, USA

**José M. De Teresa** Laboratorio de Microscopias Avanzadas (LMA), Instituto de Nanociencia de Aragón (INA), Zaragoza, Spain

Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales de Aragón (ICMA), Universidad de Zaragoza-CSIC, Zaragoza, Spain

Transpyrenean Associated Laboratory for Electron Microscopy (TALEM), CEMES-INA, CNRS-Universidad de Zaragoza, Zaragoza, Spain

**B. Donnio** IPCMS-DMO, CNRS – University of Strasbourg, Strasbourg, France

**Shi-Xue Dou** Institute for Superconducting and Electronic Materials, University of Wollongong, Wollongong, NSW, Australia

**Marc-André Fortin** Laboratory for Biomaterials in Imaging, Axe médecine régénératrice, Centre de recherche du Centre hospitalier universitaire de Québec (CR-CHUQ), Québec City, QC, Canada

Département de génie des mines, de la métallurgie et des matériaux and Centre de recherche sur les matériaux avancés (CERMA), Université Laval, Québec City, QC, Canada

**J. L. Gallani** IPCMS-DMO, CNRS – University of Strasbourg, Strasbourg, France

**Christophe Gatel** Centre d'Élaboration de Matériaux et des Etudes Structurales (CEMES-CNRS), Toulouse, France

Transpyrenean Associated Laboratory for Electron Microscopy (TALEM), CEMES-INA, CNRS-Universidad de Zaragoza, Zaragoza, Spain

**Sirshendu Gayen** Surface Physics and Material Science Division, Saha Institute of Nuclear Physics, Kolkata, India

**Yu Gu** Department of Materials Science and Engineering, Clemson University, Clemson, SC, USA

**F. Herranz** Advanced Imaging Unit, Centro Nacional de Investigaciones Cardiovasculares Carlos III (CNIC) and CIBERES, Madrid, Spain

**David Hsieh** Department of Physics, California Institute of Technology, Pasadena, CA, USA

**Konstantin G. Kornev** Department of Materials Science and Engineering, Clemson University, Clemson, SC, USA

**Wenxian Li** School of Materials Science and Engineering, Shanghai University, Shanghai, People's Republic of China

Institute for Superconducting and Electronic Materials, University of Wollongong, Wollongong, NSW, Australia

**César Magén** Laboratorio de Microscopias Avanzadas (LMA), Instituto de Nanociencia de Aragón (INA), Zaragoza, Spain

Departamento de Física de la Materia Condensada, Universidad de Zaragoza, Zaragoza, Spain

Fundación ARAID, Zaragoza, Spain

Transpyrenean Associated Laboratory for Electron Microscopy (TALEM), CEMES-INA, CNRS-Universidad de Zaragoza, Zaragoza, Spain

Departamento de Física, Universidad del Valle, Cali, Colombia

**M. P. Morales** Instituto de Ciencia de Materiales de Madrid (ICMM)/CSIC, Cantoblanco, Spain

**Eva Natividad** Instituto de Ciencia de Materiales de Aragón (ICMA), CSIC - Universidad de Zaragoza, Zaragoza, Spain

**Bernard Nysten** Institute of Condensed Matter and Nanosciences, Bio and Soft Matter (IMCN/BSMA), Université catholique de Louvain, Louvain La Neuve, Belgium

**Daniele Passeri** Department of Basic and Applied Sciences for Engineering, SAPIENZA University of Rome, Rome, Italy

**Francesco Pineider** INSTM and Department of Chemistry and Industrial Chemistry, University of Pisa, Pisa, Italy

**Luc Piraux** Institute of Condensed Matter and Nanosciences, Bio and Soft Matter (IMCN/BSMA), Université catholique de Louvain, Louvain La Neuve, Belgium

**M. V. Rastei** IPCMS-DMO, CNRS – University of Strasbourg, Strasbourg, France

**Daniel B. Reeves** Department of Physics and Astronomy, Dartmouth College, Hanover, NH, USA

Vaccine and Infectious Disease Division, Fred Hutchinson Cancer Research Center, Seattle, WA, USA

**Melania Reggente** Department of Basic and Applied Sciences for Engineering, SAPIENZA University of Rome, Rome, Italy

**Luis A. Rodríguez** Laboratorio de Microscopias Avanzadas (LMA), Instituto de Nanociencia de Aragón (INA), Zaragoza, Spain

Departamento de Física de la Materia Condensada, Universidad de Zaragoza, Zaragoza, Spain

Centre d'Élaboration de Matériaux et des Etudes Structurales (CEMES-CNRS), Toulouse, France

Transpyrenean Associated Laboratory for Electron Microscopy (TALEM), CEMES-INA, CNRS-Universidad de Zaragoza, Zaragoza, Spain

**I. Rodríguez** Department of Physical Chemistry, Faculty of Pharmacy, Complutense University, Madrid, Spain

Advanced Imaging Unit, Centro Nacional de Investigaciones Cardiovasculares Carlos III (CNIC) and CIBERES, Madrid, Spain

**Marco Rossi** Department of Basic and Applied Sciences for Engineering, SAPIENZA University of Rome, Rome, Italy

Centro di Ricerca per le Nanotecnologie Applicate all'Ingegneria della Sapienza (CNIS), SAPIENZA University of Rome, Rome, Italy

**J. Ruiz-Cabello** Department of Physical Chemistry, Faculty of Pharmacy, Complutense University, Madrid, Spain

Advanced Imaging Unit, Centro Nacional de Investigaciones Cardiovasculares Carlos III (CNIC) and CIBERES, Madrid, Spain

**Claudio Sangregorio** INSTM and ICCOM-CNR, Sesto Fiorentino (FI), Italy

**Milan K. Sanyal** Surface Physics and Material Science Division, Saha Institute of Nuclear Physics, Kolkata, India

**Luis E. Serrano-Ramón** Centre d'Élaboration de Matériaux et des Etudes Structurales (CEMES-CNRS), Toulouse, France

Transpyrenean Associated Laboratory for Electron Microscopy (TALEM), CEMES-INA, CNRS-Universidad de Zaragoza, Zaragoza, Spain



---

**Elizabeth Skoropata** Department of Physics and Astronomy, University of Manitoba, Winnipeg, MB, Canada

**Etienne Snoeck** Centre d'Élaboration de Matériaux et des Etudes Structurales (CEMES-CNRS), Toulouse, France

Transpyrenean Associated Laboratory for Electron Microscopy (TALEM), CEMES-INA, CNRS-Universidad de Zaragoza, Zaragoza, Spain

**Ziqi Sun** Institute for Superconducting and Electronic Materials, University of Wollongong, Wollongong, NSW, Australia

School of Chemistry, Physics and Mechanical Engineering, Queensland University of Technology Gardens Point, Brisbane, QLD, Australia

**Muhammad Ramzan Tabasum** Institute of Condensed Matter and Nanosciences, Bio and Soft Matter (IMCN/BSMA), Université catholique de Louvain, Louvain La Neuve, Belgium

**Alexander Tokarev** Department of Materials Science and Engineering, Clemson University, Clemson, SC, USA

**Darius H. Torchinsky** Department of Physics, California Institute of Technology, Pasadena, CA, USA

Temple University Department of Physics and Temple Materials Institute, Temple University, Philadelphia, PA, USA

**Johan van Lierop** Department of Physics and Astronomy, University of Manitoba, Winnipeg, MB, Canada

**Max Wolff** Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden

**Fatih Zighem** LSPM, CNRS-Université Paris 13, Sorbonne Paris Cité, Villetaneuse, France