ASM Handbook®

Volume 10
Materials Characterization

Prepared under the direction of the
ASM International Handbook Committee

Division Editors
Thomas J. Bruno, National Institute of Standards and Technology
Ryan Deacon, United Technologies Research Center
Jeffrey A. Jansen, The Madison Group
Neal Magdefrau, Electron Microscopy Innovative Technologies
Erik Mueller, National Transportation Safety Board
George F. Vander Voort, Vander Voort Consulting L.L.C
Dehua Yang, Ebatco

ASM International Staff
Victoria Burt, Content Developer
Steve Lampman, Senior Content Developer
Amy Nolan, Content Developer
Susan Sellers, Content Developer
Madrid Tramble, Manager of Production
Vincent Katona, Production Coordinator
Jennifer Kelly, Production Coordinator
Karen Marken, Senior Managing Editor
Scott D. Henry, Senior Content Engineer

Editorial Assistance
Elizabeth Marquard
Lilla Ryan

ASM International®
Materials Park, Ohio 44073-0002
www.asminternational.org

Copyright © 2019 ASM International®
All rights reserved
www.asminternational.org

Contents

Introduction to Materials Analysis Methods 1

Introduction to Materials Characterization 3
Introduction to Characterization of Metals 5
Semiconductor Characterization
David T. Schoen, Meredith S. Nevius, and Sumit Chaudhary 11
Characterization of Ceramics and Glasses 29
Introduction to Characterization of Organic Solids and Organic Liquids
Richard Rucker 35
Introduction to Characterization of Powders
Bo Hu 39

Spectroscopy **49**

Optical Emission Spectroscopy
Arne Bengtson 51
Atomic Absorption Spectroscopy
Gary D. Rayson 64
Inductively Coupled Plasma Optical Emission Spectroscopy
Oumaïma Gharbi, Odile Hirsch, Patrick Chapon, and Alice Stankova 71
Infrared Spectroscopy
Curtis Marcott 84
Raman Spectroscopy 101
Nuclear Magnetic Resonance
Randall E. Youngman 113

Mass and Ion Spectrometry **129**

Solid Analysis by Mass Spectrometry
Jessica Román-Kustas, Raymond S. Fuentes, and Curtis D. Mowry 131
Gas Analysis by Mass Spectrometry
Curtis D. Mowry, Russell L. Jarek, Jessica Román-Kustas, Amber C. Telles, and Adam S. Pimentel 143
Glow Discharge Mass Spectrometry
Cristina Gonzalez-Gago, Nerea Bordel, and Jorge Pisonero 153
Inductively Coupled Plasma Mass Spectrometry
Fuhe Li and Hugh E. Gotts 162
Rutherford Backscattering Spectrometry
Lin Shao and Wei-Kan Chu 173
Low-Energy Ion-Scattering Spectroscopy
Kenji Umezawa 185

Chemical Analysis and Separation Techniques
Thomas J. Bruno, National Institute of Standards and Technology 193

Calibration and Experimental Uncertainty
Thomas J. Bruno 195
Chemical Spot Tests and Presumptive Tests
April A. Hill 201
Classical Wet Analytical Chemistry
Lisa S. Ott 217
Gas Chromatography
Tara M. Lovestead 229
Gas Chromatography/Mass Spectrometry
Tara M. Lovestead and Kimberly N. Urness 235
Liquid Chromatography
Kavita M. Jeerage and Gregory P. Dooley 242
Ion Chromatography
Christopher A. Pohl 254
Electrochemical Methods
Paris Svoronos 266
Neutron Activation Analysis
Revised by Bryan E. Tomlin 292

Thermal Analysis
Jeffrey A. Jansen, The Madison Group **303**

Differential Scanning Calorimetry
Adapted by Victoria Burt 305
Thermogravimetric Analysis 312
Dynamic Mechanical Analysis
Victoria Burt 319
Thermomechanical Analysis
Richard E. Chinn 324

X-Ray Analysis **335**

X-Ray Spectroscopy
Revised by S. Lampman 337
Extended X-Ray Absorption Fine Structure 362
Particle-Induced X-Ray Emission 372
Mössbauer Spectroscopy 378

X-Ray and Neutron Diffraction
Erik Mueller, National Transportation Safety Board **387**

Introduction to Diffraction Methods
Matteo Leoni 389
X-Ray Powder Diffraction
Matteo Leoni 399
Single-Crystal X-Ray Diffraction
Vladislav V. Gurzhiy 414
Micro X-Ray Diffraction
Thomas N. Blanton and Gregory Schmidt 427
X-Ray Diffraction Residual-Stress Techniques
Paul S. Prevéy and Douglas J. Hornbach 440
X-Ray Topography
Balaji Raghothamachar and Michael Dudley 459
Synchrotron X-Ray Diffraction Applications
Wenqian Xu, Saul H. Lapidus, Andrey Y. Yakovenko, Youngchang Kim, Olaf J. Borkiewicz, Kamila M. Wiaderek, Yu-Sheng Chen and Tiffany L. Kinnibrugh 478
Neutron Diffraction
António M. dos Santos, Melanie Kirkham, and Christina Hoffmann 492

Light Optical Metallography
George F. Vander Voort, Vander Voort Consulting L.L.C **509**

Light Optical Metallography
George F. Vander Voort 511
Quantitative Metallography
George F. Vander Voort 528

Microscopy and Microanalysis
Ryan Deacon, United Technologies Research Center
Neal Magdefrau, Electron Microscopy Innovative Technologies **541**

Scanning Electron Microscopy
Yoosuf N. Picard 543
Crystallographic Analysis by Electron Backscatter Diffraction in the Scanning Electron Microscope
Joseph R. Michael 576
Transmission Electron Microscopy
Masashi Watanabe 592
Electron Probe X-Ray Microanalysis
Dale E. Newbury and Nicholas W. M. Ritchie 614
Focused Ion Beam Instruments
Nabil Bassim and John Notte 635

Surface Analysis
Dehua Yang, Ebatco **671**

Introduction to Surface Analysis
Dehua Yang 673
Auger Electron Spectroscopy
A. Joshi and D.F. Paul 675
Low-Energy Electron Diffraction
Revised by Amirali Zangiabadi 699
Introduction to Scanning Probe Microscopy
Bharat Bhushan 709
Atomic Force Microscopy
Paul West 725
Secondary Ion Mass Spectroscopy 739
X-Ray Photoelectron Spectroscopy
Binayak Panda 757
Thermal Desorption Spectroscopy
Gary L. Doll and Paul J. Shiller 772

Reference Information **781**

Glossary of Terms 783
Index 801