Contents

List of Contributors *xvii*
Preface *xxiii*

Part One Fundamentals *1*

1 Overview of Magnetic Nanomaterials *3*
Ziyu Yang, Shuang Qiao, Shouheng Sun, and Yanglong Hou
1.1 Introduction *3*
1.1.1 Typical Magnetic Nanomaterials *4*
1.1.1.1 Magnetic Nanomaterials of Metal (Fe, Co, and Ni) *4*
1.1.1.2 Magnetic Nanomaterials of MN Alloys (M = Fe, Co, and Ni, N = Noble Metal) *7*
1.1.1.3 Magnetic Nanomaterials of M_1M_2 Alloys (M_1, M_2 = Fe, Co, and Ni) *9*
1.1.1.4 Magnetic Nanomaterials of Carbides and Nitrides M–C/N (M = Fe, Co, and Ni) *10*
1.1.1.5 Magnetic Nanomaterials of Metal Oxides *12*
1.1.1.6 Rare Earth-Based Permanent Magnets *13*
1.2 Typical Characterization of Magnetic Nanomaterials *14*
1.2.1 X-Ray Magnetic Circular Dichroism Spectroscopy *14*
1.2.2 Lorentz Transmission Electron Microscope *15*
1.2.3 Mössbauer Spectroscopy *18*
1.2.4 Magnetic Extended X-Ray Absorption Fine Structure *18*
1.2.5 Magnetic Force Microscopy *19*
1.2.6 Magnetic Analysis *21*
1.3 Conclusions *22*
References *22*

2 Magnetism of Nanomaterials *29*
Ralph Skomski, Balamurugan Balasubramanian, and David J. Sellmyer
2.1 Introduction *29*
2.1.1 Fundamental Considerations in Magnetism *32*
2.1.2 Exchange *34*
2.1.3 Itinerant Magnetism *35*
2.1.4 Classes of Magnetic Materials *38*

2.1.4.1 Permanent Magnets *39*
2.1.4.2 Other Applications *41*
2.1.5 Finite-Temperature Magnetism *42*
2.1.6 Magnetic Anisotropy *45*
2.1.6.1 Phenomenology of Anisotropy *45*
2.1.6.2 Microscopic Origin of Anisotropy *46*
2.1.6.3 Temperature Dependence of Anisotropy *48*
2.2 Nanomagnetic Phenomena of Atomic Origin *48*
2.2.1 RKKY Exchange *48*
2.2.2 Nanoparticle Magnetization *49*
2.2.3 Finite-Size Scaling *50*
2.2.4 Surface and Interface Anisotropy *51*
2.3 Micromagnetics *52*
2.3.1 Micromagnetic Free Energy *53*
2.3.2 Micromagnetic Scaling *54*
2.3.3 Magnetization Reversal *55*
2.3.3.1 Magnetization Curling *55*
2.3.3.2 Localized Nucleation *56*
2.3.3.3 Pinning *57*
2.3.4 Nanogeometry and Micromagnetism *58*
2.3.4.1 Hard-Soft Two-Phase Nanostructures *58*
2.3.4.2 Grain-Boundary Micromagnetism *60*
2.3.4.3 Micromagnetic Topological Protection *61*
2.3.5 Magnetization Dynamics *61*
2.3.5.1 Spin Waves and Ferromagnetic Resonance *62*
2.3.5.2 Nuclear Magnetic Resonance *63*
2.3.5.3 Magnetic Viscosity *63*
2.4 Spin-Dependent Transport *64*
2.4.1 Magnetoresistance *65*
2.4.1.1 Metallic Conductivity *65*
2.4.1.2 Magnetoresistance Mechanisms *67*
2.4.2 Anomalous Hall Effect *67*
2.4.3 Topological Orders *68*
2.4.4 Berry Phase *68*
Appendices *71*
Appendix 2.A: Functional Derivatives and Materials Equations *71*
Appendix 2.B: Relativistic Physics *72*
Appendix 2.C: Unit Conversion in Magnetism *74*
Acknowledgments *74*
References *74*

Part Two Synthesis *81*

3 Overview of Synthesis of Magnetic Nanomaterials *83*
Xin Chu and Yanglong Hou
3.1 Introduction *83*

3.2 General Synthesis Mechanism of Magnetic Nanoparticles *85*
3.2.1 Top-Down Approaches *85*
3.2.2 Bottom-Up Approaches *85*
3.3 Typical Methods and Equipment of Magnetic Nanomaterials Synthetic Techniques: Chemical Approaches *85*
3.3.1 Coprecipitation *85*
3.3.1.1 General Mechanism of Coprecipitation Method for Magnetic Nanoparticles Synthesis *85*
3.3.1.2 The Process and Influence Factors of Coprecipitation Method for Magnetic Nanoparticle Synthesis *86*
3.3.1.3 Characteristics of Typical Magnetic Nanoparticles Synthesized with Coprecipitation Method *87*
3.3.2 Hydrothermal and Solvent Thermal Synthesis *87*
3.3.2.1 General Mechanism of Hydrothermal and Solvent Thermal Method for Magnetic Nanoparticles Synthesis *87*
3.3.2.2 The Process and Influence Factor of Solvent Thermal Synthesis in Magnetic Nanoparticle Synthesis *87*
3.3.2.3 Characteristics of Typical Magnetic Nanoparticles Synthesized with Hydrothermal *88*
3.3.3 Thermal Decomposition *89*
3.3.3.1 General Mechanism of Thermal Decomposition Method for Magnetic Nanoparticles Synthesis *89*
3.3.3.2 The Influence Factors of Thermal Decomposition Method for Magnetic Nanoparticle Synthesis *89*
3.3.3.3 The Typical Magnetic Nanoparticles Synthesized with Thermal Decomposition *91*
3.3.4 Sol–Gel Method *91*
3.3.4.1 General Mechanism of Sol–Gel Method for Magnetic Nanoparticles Synthesis *91*
3.3.4.2 The Process and Influence Factors of Sol–Gel Method for Magnetic Nanoparticle Synthesis *92*
3.3.4.3 Characteristics of Typical Magnetic Nanoparticles Synthesized with Sol–Gel Method *93*
3.3.5 Ultrasonic Chemical Reactions *93*
3.3.5.1 General Mechanism of Ultrasonic Chemical Reactions for Magnetic Nanoparticles Synthesis *93*
3.3.5.2 The Process and Influence Factors of Ultrasonic Chemical Reactions for Magnetic Nanoparticle Synthesis *93*
3.3.5.3 Characteristics of Typical Magnetic Nanoparticles Synthesized with Ultrasonic Chemical Reaction *94*
3.3.6 Chemical Reduction *94*
3.3.6.1 General Mechanism of Chemical Reduction Method for Magnetic Nanoparticles Synthesis *94*
3.3.6.2 The Typical Reductive Agents Used in Chemical Reduction Method *95*
3.3.6.3 Characteristics of Typical Magnetic Nanoparticles Synthesized with Chemical Reduction *95*

3.3.7 Microemulsion Reactions *97*
3.3.7.1 General Mechanism of Microemulsion Reactions for Magnetic Nanoparticles Synthesis *97*
3.3.7.2 The Process and Influence Factors of Microemulsion Reactions for Magnetic Nanoparticle Synthesis *97*
3.3.7.3 Characteristics of Typical Magnetic Nanoparticles Synthesized with Microemulsion Reactions *99*
3.3.8 Microwave-Assisted Synthesis *100*
3.3.8.1 General Mechanism of Microwave-Assisted Synthesis for Magnetic Nanoparticles Synthesis *100*
3.3.8.2 The Process and Influence Factors of Microwave-Assisted Synthesis for Magnetic Nanoparticle Synthesis *100*
3.3.8.3 Characteristics of Typical Magnetic Nanoparticles Synthesized with Microwave-Assisted Synthesis *101*
3.3.9 Chemical Deposition *102*
3.3.9.1 General Mechanism of Chemical Deposition Method for Magnetic Nanoparticles Synthesis *102*
3.3.9.2 The Process and Influence Factors of Chemical Deposition Synthesis for Magnetic Nanoparticle Synthesis *102*
3.3.9.3 Characteristics of Typical Magnetic Nanoparticles Synthesized with Chemical Deposition Synthesis *102*
3.4 Typical Methods and Equipment of Magnetic Nanomaterials Synthetic Techniques: Physical Approaches *104*
3.4.1 Metal Evaporation Method *104*
3.4.1.1 General Mechanism of Metal Evaporation Method for Magnetic Nanoparticles Synthesis *104*
3.4.1.2 The Process and Influence Factors of Metal Evaporation Synthesis for Magnetic Nanoparticle Synthesis *104*
3.4.1.3 Characteristics of Typical Magnetic Nanoparticles Synthesized with Metal Evaporation Synthesis *105*
3.4.1.4 The Limitation of Metal Evaporation Synthesis in Magnetic Nanoparticle Synthesis *107*
3.4.2 High-Energy Ball Milling Method *108*
3.4.2.1 General Mechanism of High-Energy Ball Milling Method for Magnetic Nanoparticles Synthesis *108*
3.4.2.2 The Process and Influence Factors of High-Energy Ball Milling Method for Magnetic Nanoparticles Synthesis *108*
3.4.2.3 Characteristics of Typical Magnetic Nanoparticles Synthesized with High-Energy Ball Milling Method *108*
3.4.2.4 The Limitation of High-Energy Ball Milling Method in Magnetic Nanoparticle Synthesis *108*
3.4.3 Plasma Method *109*
3.4.3.1 General Mechanism of Plasma Method for Magnetic Nanoparticles Synthesis *109*
3.4.3.2 The Process and Influence Factors of Plasma Method for Magnetic Nanoparticle Synthesis *109*

3.4.3.3 Characteristics of Typical Magnetic Nanoparticles Synthesized with Plasma Method *110*
3.4.3.4 The Limitation of Plasma Method in Magnetic Nanoparticle Synthesis *113*
3.4.4 Other Methods *113*
3.5 Conclusions and Perspectives *113*
References *114*

4 Synthesis of Soft Magnetic Nanomaterials and Alloys *121*
Song Lan and Matthew A. Willard
4.1 Introduction *121*
4.2 Nanoparticles *123*
4.3 Nanorods *127*
4.4 Thin Films *134*
4.5 Ribbons *136*
4.5.1 Rapid Solidification *136*
4.5.2 Crystallization *137*
4.6 Conclusions *140*
References *141*

5 Synthesis of Nanostructured Rare-Earth Permanent Magnets *147*
Ming Yue and George C. Hadjipanayis
5.1 Introduction *147*
5.1.1 Development of Nanostructured Rare-Earth Permanent Magnets *147*
5.1.2 Techniques for Preparing Nanostructured REPM *149*
5.1.2.1 Nanostructured Powders and Low-Dimensional Materials *149*
5.1.2.2 Bulk Fully Dense Magnets *152*
5.2 RCo_x-Based (R = Sm, Pr, Y, La) Nanostructured Magnets *155*
5.2.1 RCo_x-Based Single-Phase Magnets *155*
5.2.1.1 Magnetically Isotropic Magnets *155*
5.2.1.2 Magnetically Anisotropic Magnets *156*
5.2.2 RCo_x-Based Nanocomposite Magnets *158*
5.2.2.1 Magnetically Isotropic Magnets *158*
5.2.2.2 Magnetically Anisotropic Magnets *160*
5.3 $R_2Fe_{14}B$-Based (R = Pr, Nd, Tb, Dy) Magnets *161*
5.3.1 $R_2Fe_{14}B$-Based Single-Phase Magnets *161*
5.3.1.1 Magnetically Isotropic Magnets *161*
5.3.1.2 Magnetically Anisotropic Magnets *162*
5.3.2 $R_2Fe_{14}B$-Based Nanocomposite Magnets *163*
5.3.2.1 Magnetically Isotropic Magnets *163*
5.3.2.2 Magnetically Anisotropic Magnets *164*
5.4 Conclusions and Perspectives *166*
References *166*

6 Synthesis of Rare Earth Free Permanent Magnets *175*
Shenqiang Ren and Jinbo Yang
6.1 Introduction *175*

6.2 Tetragonal $L1_0$ FeCo *175*
6.3 MnBi Low-Temperature Phase *179*
6.4 Conclusions and Perspective *186*
Acknowledgment *187*
References *187*

7 Synthesis and Properties of Magnetic Chalcogenide Nanostructures *191*
Karthik Ramasamy, Soubantika Palchoudhury, and Arunava Gupta
7.1 Introduction *191*
7.2 Synthesis Methods of Binary Magnetic Chalcogenide Nanostructures *192*
7.2.1 Iron Sulfide Nanocrystals *192*
7.2.2 Iron Selenide Nanocrystals *195*
7.2.3 Europium Chalcogenide Nanocrystals *196*
7.3 Synthesis Methods of Ternary and Higher Order Magnetic Chalcogenides Nanostructures *201*
7.4 Structural and Magnetic Characterizations of Magnetic Chalcogenide Nanostructures *206*
7.5 Potential Applications of Magnetic Chalcogenide Nanostructures *208*
7.5.1 Spintronics Applications *208*
7.5.2 Magnetocaloric Applications *209*
7.5.3 Magneto-Optic Applications *210*
7.5.4 Biomedical Applications *210*
7.6 Conclusions and Perspectives *211*
Acknowledgments *212*
References *212*

8 Magnetic Multicomponent Heterostructured Nanocrystals *217*
P. Davide Cozzoli, Concetta Nobile, Riccardo Scarfiello, Angela Fiore, and Luigi Carbone
8.1 Introduction *217*
8.2 Synthesis of Heterostructured Nanocrystals: Basic Concepts and Guiding Criteria *219*
8.2.1 Synthesis of Single-Material Nanocrystals *219*
8.2.2 Thermodynamics Underlying Heterostructure Formation *220*
8.2.3 Liquid-Phase Epitaxy via Seeded Growth *222*
8.3 Heterostructures with Core/Shell Geometries *223*
8.3.1 Direct Heterogeneous Deposition *224*
8.3.1.1 All-Metal Associations *226*
8.3.1.2 Semiconductor/Transition-Metal Associations *231*
8.3.1.3 Metal Oxide-Based Associations *231*
8.3.2 Silica Coating *235*
8.3.3 Shell Formation by Redox Replacement or Conversion Reactions *237*
8.3.4 Shell Transformation via Cation-Exchange Reactions *240*

8.3.5 Self-Controlled Nucleation-Growth, Thermally Induced Solid-State Atomic Diffusion and Phase Segregation *242*
8.3.5.1 Self-Controlled Nucleation Growth *242*
8.3.5.2 Thermally Induced Solid-State Diffusion and Phase Segregation *244*
8.4 Nanohetero-Oligomer Architectures *245*
8.4.1 Heterostructures Based on Nearly Isotropic-Shaped Material Domains *245*
8.4.1.1 Direct Heterogeneous Nucleation *246*
8.4.1.2 Postdeposition Coalescence-Crystallization and Solid-State Diffusion *254*
8.4.1.3 Reactions at Liquid/Liquid Interfaces *254*
8.4.1.4 Self-Regulated Homogeneous and Heterogeneous Nucleation *255*
8.4.1.5 Reactions Induced Between Preformed HNCs *256*
8.4.2 Heterostructures Based on Anisotropic-Shaped Material Sections *256*
8.4.2.1 Site-Specific Heterogeneous Nucleation *259*
8.4.2.2 Surfactant-Controlled Selective Heterogeneous Nucleation *264*
8.4.2.3 Strain-Driven Heterostructure Formation *266*
8.5 Conclusions *266*
Acknowledgment *267*
References *267*

9 Wet-Phase Synthesis of Typical Magnetic Nanoparticles with Controlled Morphologies *291*
Jiajia Liu, Jia Liu, Meng Xu, and Jiatao Zhang
9.1 Introduction *291*
9.1.1 Yolk–Shell Nanoparticles *292*
9.1.2 Dumbbell-Like Nanoparticles *297*
9.1.3 Nanowires and Nanorods *299*
9.1.3.1 Templating Synthesis Method *299*
9.1.3.2 Solvothermal Method *301*
9.2 Synthesis of Hollow/Porous Magnetic Nanoparticles *303*
9.2.1 Hollow Nanoparticles *303*
9.2.2 Porous Nanoparticles *310*
9.2.3 Nanorings and Nanodisks *312*
9.3 Conclusions and Perspectives *317*
Acknowledgment *317*
References *317*

10 Self-Assembly of Co Nanocrystals Self-Assembled in 2D and 3D Superlattices: Chemical and Physical Specific Properties *327*
Marie-Paule Pileni
10.1 Introduction *327*
10.2 Control of Crystalline Structure of Nanoparticles (Nanocrystallinity) and the Nanocrystal Size *328*
10.2.1 Synthesis of ε-Phase Co Nanocrystals *328*
10.2.2 Syntheses of Amorphous and hcp Phases *329*

10.2.3 Synthesis of fcc Phase *329*
10.3 Nano-Kirkendall Effect on Co Nanocrystals: Influence of Size and Nanocrystallinity [51–54] *329*
10.4 3D Self-Assemblies of Magnetic Supracrystals: Various Structures and Specific Behaviors *331*
10.4.1 Amorphous Cobalt (Co_A) Nanoparticles Used as Building Blocks *331*
10.4.2 Quasi Supracrystals Due to Magnetic Interactions between Nanocrystals [38] *331*
10.5 3D Self-Assemblies of Magnetic Supracrystals: Physical Properties *333*
10.5.1 Analogy between Supracrystals and Atomic Crystalline Structures [63] *333*
10.5.2 Magnetic Properties of Supracrystals of Single Domain ε-Phase Co Nanocrystals, Co_ε [68] *334*
10.5.3 Mechanical Properties of Co_ε Nanocrystals [73] *336*
10.6 Conclusions *337*
Acknowledgment *338*
References *338*

Part Three Applications *343*

11 Magnetic Nanoparticles for Bioseparation, Biosensing, and Regenerative Medicine *345*
Yiyuan Han, Min Wang, and Chenjie Xu
11.1 Introduction *345*
11.2 Synthesis and Modification of High-Moment Magnetic Nanoparticles *346*
11.3 Magnetic Nanomaterials for Bioseparation *347*
11.3.1 Protein Separation *347*
11.3.2 Bacteria Separation *350*
11.3.3 Removal of Pollutants from Water *353*
11.4 Magnetic Nanoparticles for Magnetic Biosensing *354*
11.4.1 Magnetometer-Based Biosensing *355*
11.4.2 Magnetic Resonance-Based Biosensing *356*
11.5 Magnetic Nanoparticles for Regenerative Medicine *358*
11.6 Challenges and Perspectives *360*
References *360*

12 Magnetic Nanomaterials for Diagnostics *365*
Zijian Zhou and Xiaoyuan Chen
12.1 Introduction *365*
12.2 Biocompatibility of Magnetic Nanoparticles *366*
12.2.1 Assessment of Biological Toxicity of Magnetic Nanoparticles *366*
12.2.2 General Toxicity of Magnetic Nanoparticles *367*
12.2.3 Design Considerations for Biocompatible Magnetic Nanoparticles *368*

12.3 Surface Functionalization of Magnetic Nanomaterials *368*
12.3.1 Tools and Rules of Surface Functionalization *368*
12.3.2 Surface Functionalization for Phase Transfer *369*
12.3.3 Surface Functionalization for Targeting *370*
12.4 Magnetic Resonance Imaging (MRI) *372*
12.4.1 Mechanism and Phenomenon of Magnetic Nanoparticles in MRI *372*
12.4.2 Engineered Magnetic Nanoparticles as Enhanced MRI Contrast Agents *374*
12.4.3 Portable microNMR Diagnostic Device *377*
12.5 Magnetoacoustic Tomography (MAT) *378*
12.5.1 Basic Principles of MAT *378*
12.5.2 Magnetic Nanoparticles as MAT Agents *380*
12.6 Magnetic Particle Imaging (MPI) *381*
12.6.1 Basic Principles of MPI *381*
12.6.2 Magnetic Nanoparticles as MPI Agents *383*
12.7 Multimodality Imaging *384*
12.7.1 Magnetic Nanoparticles for Multimodality Imaging *384*
12.7.2 Engineered Multifunctional Magnetic Nanoparticles *385*
12.8 Conclusions and Perspectives *386*
References *387*

13 Magnetic Nanomaterials for Therapy *393*
Daishun Ling and Taeghwan Hyeon
13.1 Introduction *393*
13.2 Imaging-Guided Therapy Using Magnetic Nanomaterials *393*
13.2.1 Imaging-Guided Chemotherapy *394*
13.2.2 Imaging-Guided Photodynamic Therapy *396*
13.2.3 Imaging-Guided Photothermal Therapy *397*
13.2.4 Imaging-Guided Multimodal Therapy *400*
13.2.5 Imaging-Guided Surgery *403*
13.2.6 Predicting Therapeutic Nanomedicine Efficacy *404*
13.3 Magnetic Hyperthermia *407*
13.3.1 Thermal Ablation *407*
13.3.2 Apoptotic Hyperthermia *410*
13.3.3 Hyperthermia-Controlled Drug Release *411*
13.3.4 Combining Magnetic Hyperthermia with Other Therapeutics *414*
13.4 Targeted Drug Delivery *416*
13.4.1 *In vitro* Magnetically Controlled Drug Delivery *416*
13.4.2 *In Vivo* Magnetically Controlled Drug Delivery *419*
13.5 Targeted Gene Delivery *419*
13.5.1 *In Vitro* Magnetofection *420*
13.5.2 *In Vivo* Gene Delivery Monitoring *425*
13.6 Manipulation of Cellular Functions *425*
13.7 Conclusions and Perspectives *429*
Acknowledgments *431*
References *431*

14 Magnetic Nanomaterials for Data Storage *439*
Jung-Wei Liao, Hong-Wei Zhang, and Chih-Huang Lai
14.1 Introduction: Magnetic Data Storage and its Requirements on Magnetic Nanomaterials *439*
14.2 Nanostructured Magnetic Thin Films for Data Storage: Overview of Perpendicular Recording (PMR) Media *442*
14.2.1.1 Overall Layer Structures of Co-Based Magnetic Thin Films *442*
14.2.1.2 Film Morphologies and Crystalline Structures of the Co-Based Recording Layer *442*
14.2.1.3 Intermediate Layers *445*
14.3 Nanostructured Magnetic Thin Films for Data Storage: Overview of FePt Media for Heat-Assisted Magnetic Recording (HAMR) *446*
14.3.1.1 Overview of $L1_0$ FePt for Heat-Assisted Magnetic Recording (HAMR) *447*
14.3.1.2 Development of $L1_0$ FePt Film for Magnetic Recording *447*
14.4 Monodisperse Magnetic Nanoparticles: Synthesis, Phase Transition, Orientation Control, and Nanocomposites *450*
14.4.1 Synthesis, Phase Transition, and Size Control of FePt Nanoparticles *451*
14.4.2 Orientation Control *453*
14.5 Patterned Magnetic Nanostructures for Bit Patterned Media Through Bottom-Up Approach: Self-Assembly and Guided Assembly of Block Copolymer *454*
14.5.1 Working Principles of Bit Patterned Media *454*
14.5.1.1 Self-Assembly and Guided Assembly of Block Copolymer (PCB) *455*
14.6 Patterned Magnetic Nanostructures for Bit Patterned Media Through Top-Down Approach: Lithograph *462*
14.6.1 Magnetic Materials for an Approach of an Etching Back Process *462*
14.6.2 Magnetic Materials for an Approach of a Prepatterned Substrate *463*
14.6.3 Magnetic Materials for Template Growth *464*
14.7 Conclusions and Perspectives *465*
References *467*

15 Magnetic Nanomaterials for Electromagnetic Wave Absorption *473*
Ling Bing Kong, Lie Liu, Zhihong Yang, Sean Li, and Tianshu Zhang
15.1 Introduction *473*
15.2 Magnetic Nanosized Powders and Composites *474*
15.2.1 Metallic Magnetic Nanosized Powders *474*
15.2.1.1 Chemical Routes *474*
15.2.1.2 DC Arc-Discharging Method *490*
15.2.1.3 High-Energy Ball Milling *493*
15.2.1.4 Physical Compaction *499*
15.2.2 Nonmetallic Magnetic Nanosized Powders *504*
15.3 Nanosized Carbon Materials with Magnetic Components *506*
15.4 Concluding Remarks *509*
References *510*

16 Magnetic Nanomaterials for Water Remediation *515*
Peirui Liu and Yu Hong
16.1 Introduction *515*
16.2 Magnetic Nanomaterials for Adsorption and Removal of Pollutants in Water *516*
16.2.1 Adsorption and Removal of Heavy Metals *516*
16.2.2 Adsorption and Removal of Dyes *521*
16.2.3 Adsorption and Removal of Other Pollutants *524*
16.3 Magnetic Nanomaterials for Catalytic Degradation of Wastewater *525*
16.3.1 Photochemical Catalysis *525*
16.3.2 Fenton Degradation *526*
16.3.3 Other Catalytic Degradation Methods *527*
16.4 Magnetic Nanomaterials for Wastewater Resources Recovery *529*
16.5 Magnetic Nanomaterials for Monitoring and Analysis Technologies *530*
16.5.1 Detection and Analysis of Trace Elements and Other Common Pollutants *531*
16.5.2 Detection and Analysis of Pathogen *533*
16.6 Conclusion and Perspectives *534*
Acknowledgment *535*
References *535*

Index *547*