
CONTENTS

| | |
|--|-----------|
| Preface | xi |
| 1 Introduction | 1 |
| 2 Introduction to Physics of the Solid State | 8 |
| 2.1 Structure 8 | |
| 2.1.1 Size Dependence of Properties 8 | |
| 2.1.2 Crystal Structures 9 | |
| 2.1.3 Face-Centered Cubic Nanoparticles 12 | |
| 2.1.4 Tetrahedrally Bonded Semiconductor Structures 15 | |
| 2.1.5 Lattice Vibrations 18 | |
| 2.2 Energy Bands 20 | |
| 2.2.1 Insulators, Semiconductors, and Conductors 20 | |
| 2.2.2 Reciprocal Space 22 | |
| 2.2.3 Energy Bands and Gaps of Semiconductors 23 | |
| 2.2.4 Effective Masses 28 | |
| 2.2.5 Fermi Surfaces 29 | |
| 2.3 Localized Particles 30 | |
| 2.3.1 Donors, Acceptors, and Deep Traps 30 | |
| 2.3.2 Mobility 31 | |
| 2.3.3 Excitons 32 | |
| 3 Methods of Measuring Properties | 35 |
| 3.1 Introduction 35 | |
| 3.2 Structure 36 | |
| 3.2.1 Atomic Structures 36 | |
| 3.2.2 Crystallography 37 | |

- 3.2.3 Particle Size Determination 42
- 3.2.4 Surface Structure 45
- 3.3 Microscopy 46
 - 3.3.1 Transmission Electron Microscopy 46
 - 3.3.2 Field Ion Microscopy 51
 - 3.3.3 Scanning Microscopy 51
- 3.4 Spectroscopy 58
 - 3.4.1 Infrared and Raman Spectroscopy 58
 - 3.4.2 Photoemission and X-Ray Spectroscopy 62
 - 3.4.3 Magnetic Resonance 68

4 Properties of Individual Nanoparticles

72

- 4.1 Introduction 72
- 4.2 Metal Nanoclusters 74
 - 4.2.1 Magic Numbers 74
 - 4.2.2 Theoretical Modeling of Nanoparticles 75
 - 4.2.3 Geometric Structure 78
 - 4.2.4 Electronic Structure 81
 - 4.2.5 Reactivity 83
 - 4.2.6 Fluctuations 86
 - 4.2.7 Magnetic Clusters 86
 - 4.2.8 Bulk to Nanotransition 88
- 4.3 Semiconducting Nanoparticles 90
 - 4.3.1 Optical Properties 90
 - 4.3.2 Photofragmentation 92
 - 4.3.3 Coulombic Explosion 93
- 4.4 Rare Gas and Molecular Clusters 94
 - 4.4.1 Inert-Gas Clusters 94
 - 4.4.2 Superfluid Clusters 95
 - 4.4.3 Molecular Clusters 96
- 4.5 Methods of Synthesis 97
 - 4.5.1 RF Plasma 97
 - 4.5.2 Chemical Methods 98
 - 4.5.3 Thermolysis 99
 - 4.5.4 Pulsed Laser Methods 100
- 4.6 Conclusion 101

5 Carbon Nanostructures

103

- 5.1 Introduction 103

- 5.2 Carbon Molecules 103
 - 5.2.1 Nature of the Carbon Bond 103
 - 5.2.2 New Carbon Structures 105
- 5.3 Carbon Clusters 106
 - 5.3.1 Small Carbon Clusters 106
 - 5.3.2 Discovery of C_{60} 107
 - 5.3.3 Structure of C_{60} and Its Crystal 110
 - 5.3.4 Alkali-Doped C_{60} 110
 - 5.3.5 Superconductivity in C_{60} 112
 - 5.3.6 Larger and Smaller Fullerenes 113
 - 5.3.7 Other Buckyballs 113
- 5.4 Carbon Nanotubes 114
 - 5.4.1 Fabrication 114
 - 5.4.2 Structure 117
 - 5.4.3 Electrical Properties 118
 - 5.4.4 Vibrational Properties 122
 - 5.4.5 Mechanical Properties 123
- 5.5 Applications of Carbon Nanotubes 125
 - 5.5.1 Field Emission and Shielding 125
 - 5.5.2 Computers 126
 - 5.5.3 Fuel Cells 127
 - 5.5.4 Chemical Sensors 128
 - 5.5.5 Catalysis 129
 - 5.5.6 Mechanical Reinforcement 130

6 Bulk Nanostructured Materials

133

- 6.1 Solid Disordered Nanostructures 133
 - 6.1.1 Methods of Synthesis 133
 - 6.1.2 Failure Mechanisms of Conventional Grain-Sized Materials 137
 - 6.1.3 Mechanical Properties 139
 - 6.1.4 Nanostructured Multilayers 141
 - 6.1.5 Electrical Properties 142
 - 6.1.6 Other Properties 147
 - 6.1.7 Metal Nanocluster Composite Glasses 148
 - 6.1.8 Porous Silicon 150
- 6.2 Nanostructured Crystals 153
 - 6.2.1 Natural Nanocrystals 153
 - 6.2.2 Computational Prediction of Cluster Lattices 153
 - 6.2.3 Arrays of Nanoparticles in Zeolites 154
 - 6.2.4 Crystals of Metal Nanoparticles 157

- 6.2.5 Nanoparticle Lattices in Colloidal Suspensions 158
- 6.2.6 Photonic Crystals 159

7 Nanostructured Ferromagnetism 165

- 7.1 Basics of Ferromagnetism 165
- 7.2 Effect of Bulk Nanostructuring of Magnetic Properties 170
- 7.3 Dynamics of Nanomagnets 172
- 7.4 Nanopore Containment of Magnetic Particles 176
- 7.5 Nanocarbon Ferromagnets 177
- 7.6 Giant and Colossal Magnetoresistance 181
- 7.7 Ferrofluids 186

8 Optical and Vibrational Spectroscopy 194

- 8.1 Introduction 194
- 8.2 Infrared Frequency Range 196
 - 8.2.1 Spectroscopy of Semiconductors; Excitons 196
 - 8.2.2 Infrared Surface Spectroscopy 198
 - 8.2.3 Raman Spectroscopy 203
 - 8.2.4 Brillouin Spectroscopy 210
- 8.3 Luminescence 213
 - 8.3.1 Photoluminescence 213
 - 8.3.2 Surface States 215
 - 8.3.3 Thermoluminescence 221
- 8.4 Nanostructures in Zeolite Cages 222

9 Quantum Wells, Wires, and Dots 226

- 9.1 Introduction 226
- 9.2 Preparation of Quantum Nanostructures 227
- 9.3 Size and Dimensionality Effects 231
 - 9.3.1 Size Effects 231
 - 9.3.2 Conduction Electrons and Dimensionality 233
 - 9.3.3 Fermi Gas and Density of States 234
 - 9.3.4 Potential Wells 236
 - 9.3.5 Partial Confinement 241
 - 9.3.6 Properties Dependent on Density of States 242

- 9.4 Excitons 244
- 9.5 Single-Electron Tunneling 245
- 9.6 Applications 248
 - 9.6.1 Infrared Detectors 248
 - 9.6.2 Quantum Dot Lasers 251
- 9.7 Superconductivity 253

10 Self-Assembly and Catalysis 257

- 10.1 Self-Assembly 257
 - 10.1.1 Process of Self-Assembly 257
 - 10.1.2 Semiconductor Islands 258
 - 10.1.3 Monolayers 260
- 10.2 Catalysis 264
 - 10.2.1 Nature of Catalysis 264
 - 10.2.2 Surface Area of Nanoparticles 264
 - 10.2.3 Porous Materials 268
 - 10.2.4 Pillared Clays 273
 - 10.2.5 Colloids 277

11 Organic Compounds and Polymers 281

- 11.1 Introduction 281
- 11.2 Forming and Characterizing Polymers 283
 - 11.2.1 Polymerization 283
 - 11.2.2 Sizes of Polymers 284
- 11.3 Nanocrystals 285
 - 11.3.1 Condensed Ring Types 285
 - 11.3.2 Polydiacetylene Types 289
- 11.4 Polymers 292
 - 11.4.1 Conductive Polymers 292
 - 11.4.2 Block Copolymers 293
- 11.5 Supramolecular Structures 295
 - 11.5.1 Transition-Metal-Mediated Types 295
 - 11.5.2 Dendritic Molecules 296
 - 11.5.3 Supramolecular Dendrimers 302
 - 11.5.4 Micelles 305

| | | |
|-----------|--|------------|
| 12 | Biological Materials | 310 |
| 12.1 | Introduction | 310 |
| 12.2 | Biological Building Blocks | 311 |
| 12.2.1 | Sizes of Building Blocks and Nanostructures | 311 |
| 12.2.2 | Polypeptide Nanowire and Protein Nanoparticle | 314 |
| 12.3 | Nucleic Acids | 316 |
| 12.3.1 | DNA Double Nanowire | 316 |
| 12.3.2 | Genetic Code and Protein Synthesis | 322 |
| 12.4 | Biological Nanostructures | 324 |
| 12.4.1 | Examples of Proteins | 324 |
| 12.4.2 | Micelles and Vesicles | 326 |
| 12.4.3 | Multilayer Films | 329 |
| 13 | Nanomachines and Nanodevices | 332 |
| 13.1 | Microelectromechanical Systems (MEMSs) | 332 |
| 13.2 | Nanoelectromechanical Systems (NEMSs) | 335 |
| 13.2.1 | Fabrication | 335 |
| 13.2.2 | Nanodevices and Nanomachines | 339 |
| 13.3 | Molecular and Supramolecular Switches | 345 |
| A | Formulas for Dimensionality | 357 |
| A.1 | Introduction | 357 |
| A.2 | Delocalization | 357 |
| A.3 | Partial Confinement | 358 |
| B | Tabulations of Semiconducting Material Properties | 361 |
| | Index | 371 |