
CONTENTS

| | |
|--|------------|
| Preface | xii |
| 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 Bonds 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 | |

| | |
|--|---|
| <p>3.2.3 Particle Size Determination 42 3.2.4 Surface Structure 45</p> <p>3.3 Microscopy 46 3.3.1 Transmission Electron Microscopy 46 3.3.2 Field Ion Microscopy 51 3.3.3 Scanning Microscopy 51</p> <p>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</p> <p>4 Properties of Individual Nanoparticles 72</p> <p>4.1 Introduction 72</p> <p>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</p> <p>4.3 Semiconducting Nanoparticles 90 4.3.1 Optical Properties 90 4.3.2 Photofragmentation 92 4.3.3 Coulombic Explosion 93</p> <p>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</p> <p>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</p> <p>4.6 Conclusion 101</p> <p>5 Carbon Nanostructures 103 5.1 Introduction 103</p> | <p>5.2 Carbon Molecules 103 5.2.1 Nature of the Carbon Bond 103 5.2.2 New Carbon Structures 105</p> <p>5.3 Carbon Clusters 106 5.3.1 Small Carbon Clusters 106 5.3.2 Discovery of C₆₀ 107 5.3.3 Structure of C₆₀ and Its Crystal 110 5.3.4 Alkali-Doped C₆₀ 110 5.3.5 Superconductivity in C₆₀ 112 5.3.6 Larger and Smaller Fullerenes 113 5.3.7 Other Buckyballs 113</p> <p>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</p> <p>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</p> <p>6 Bulk Nanostructured Materials 133</p> <p>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</p> <p>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</p> |
|--|---|

| | |
|---|------------|
| 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 |