Contents

Preface xi
Acknowledgements xv
Contributors xvii

1 A Fundamental Review of the Relationships between Nanotechnology and Lignocellulosic Biomass 1
Theodore H. Wegner and E. Philip Jones

1.1 Introduction 1
1.2 Use of Lignocellulosic-based Materials 3
1.3 Green Chemistry and Green Engineering 4
1.4 Nanotechnology 6
1.5 Nanotechnology-enabled Product Possibilities 8
1.6 Wood Nanodimensional Structure and Composition 10
1.7 Nanomanufacturing 11
1.8 Nanotechnology Health and Safety Issues 15
1.9 Instrumentation, Metrology, and Standards for Nanotechnology 16
1.10 A Nanotechnology Agenda for the Forest Products Industry 17
1.11 Forest Products Industry Technology Priorities 21
1.12 Nanotechnology Priority Areas to Meet the Needs of the Forest Products Industry 23
1.12.1 Achieving Lighter Weight, Higher Strength Materials 23
1.12.2 Production of Nanocryrstalline Cellulose and Nanofibrils from Wood 25
1.12.3 Controlling Water/Moisture Interactions with Cellulose 26
1.12.4 Producing Hyperperformance Nanocomposites from Nanocrystalline Cellulose 29
1.12.5 Capturing the Photonic and Piezoelectric Properties of Lignocelluloses 30
1.12.6 Reducing Energy Usage and Reducing Capital Costs in Processing Wood to Products 33
1.13 Summary 37
References 38

2 Biogenesis of Cellulose Nanofibrils by a Biological Nanomachine 43
Candace H. Haigler and Alison W. Roberts
Contents

2.1 Introduction 43
2.2 Background 44
2.3 CesA Protein is a Major Component of the Plant CSC 45
2.4 The Functional Operation of the CSC 47
  2.4.1 Assemble with Genetically Determined Morphology 48
  2.4.2 Stabilize in Operational Form in the Plasma Membrane 50
  2.4.3 Acquire UDP-Glucose Substrate 50
  2.4.4 Polymerize Glucose with β-1,4-Linkage 51
  2.4.5 Operate so that Fibrils Emerge Outside the Plasma Membrane 51
  2.4.6 Control Cellulose Chain Length 51
  2.4.7 Control Cellulose Nanofibril Diameter 52
  2.4.8 Control Crystallization? 53
  2.4.9 Move in the Plasma Membrane as it Spins out Cellulose Nanofibrils 53
2.5 Phylogenetic Analysis 53
  2.5.1 Possible Functional Diversification of CS Proteins 53
2.6 Conclusion 55
References 55

3 Tools for the Characterization of Biomass at the Nanometer Scale 61
James F. Beecher, Christopher G. Hunt and J.Y. Zhu

3.1 Introduction 61
3.2 Water in Biomass 61
3.3 Measurement of Specific Biomass Properties 62
  3.3.1 Pore Structure and Accessibility 62
  3.3.2 Cellulose Crystallinity 66
3.4 Microscopy and Spectroscopy 68
  3.4.1 Specimen Preparation 68
  3.4.2 Scanning Probe Microscopies 71
  3.4.3 Focused Beam Microscopies 75
  3.4.4 Transmission Electron Microscopy 78
3.5 Summary 80
References 80

4 Tools to Probe Nanoscale Surface Phenomena in Cellulose Thin Films: Applications in the Area of Adsorption and Friction 91
Junlong Song, Yan Li, Juan P. Hinestroza and Orlando J. Rojas

4.1 Introduction 91
4.2 Polyampholytes Applications in Fiber Modification 92
4.3 Cellulose Thin Films 95
4.4 Friction Phenomena in Cellulose Systems 97
4.5 Lubrication 98
4.6 Boundary Layer Lubrication 99
4.6.1 Thin Films: Property Changes and Transitions 99
4.6.2 Orientation of Lubricant Films 101
4.7 Techniques to Study Adsorption and Friction Phenomena 102
4.8 Surface Plasmon Resonance (SPR) 103
4.9 Quartz Crystal Microbalance with Dissipation (QCM) 105
4.10 Application of SPR and QCM to Probe Adsorbed Films 107
4.10.1 Monitoring Adsorption and Desorption of Macromolecules 107
4.10.2 Conformation of Adsorbate Layers Revealed by the QCM-D 108
4.10.3 Coupling QCM and SPR Data 109
4.11 Lateral Force Microscopy 112
4.12 Summary 115

Acknowledgements 116
References 116

5 Polyelectrolyte Multilayers for Fibre Engineering 123
Rikard Lingström, Erik Johansson and Lars Wågberg
5.1 Background 123
5.2 The Formation of PEM on Wood Fibres 125
5.3 Formation of PEM with Different Polyelectrolytes and the Properties of the Layers Formed 129
5.4 Formation of PEM on Fibres 132
5.5 Influence of PEM on Properties of Fibre Networks 139
5.6 Influence of PEM on Adhesion between Surfaces 141
5.7 Concluding Remarks 144
Acknowledgements 145
References 145

6 Hemicelluloses at Interfaces: Some Aspects of the Interactions 149
Tekla Tammelin, Arja Paananen and Monika Österberg
6.1 Overview 149
6.2 Introduction 150
6.3 Theoretical Basis for Interpreting QCM-D and AFM Data 152
6.3.1 QCM-D Data 152
6.3.2 Measuring Interaction Forces with AFM 153
6.4 Experimental 154
6.4.1 Materials 154
6.4.2 Methods 155
6.5 Results 158
6.5.1 Adsorption of Hemicelluloses on Cellulose 158
6.5.2 Viscoelastic Properties of the Hemicellulose Layers 160
6.5.3 Effect of Xylan Adsorption on the Interaction between Cellulose Beads 163
6.5.4 Effect of Electrolyte on the Interaction between Xylan-coated Cellulose Surfaces 164
6.6 Discussion 164
   6.6.1 Adsorption of Dissolved Hemicelluloses on Cellulose 164
   6.6.2 Adsorption Behavior and Interaction Forces between Xylan and Cellulose 166
6.7 Conclusions 168
Acknowledgements 168
References 168

7 Lignin: Functional Biomaterial with Potential in Surface Chemistry and Nanoscience 173
Shannon M. Notley and Magnus Norgren
7.1 Introduction 173
7.2 Lignin Synthesis and Structural Aspects 174
7.3 Isolation of Lignin from Wood, Pulp and Pulping Liquors 177
   7.3.1 Isolation of Lignin from Wood and Pulp Fibres 178
   7.3.2 Isolation of Lignin from Spent Pulping Liquors 180
7.4 Solution Properties of Kraft Lignin 181
7.5 Surface Chemistry of Solid State Lignin 187
   7.5.1 Preparation and Properties of Lignin Thin Films 188
   7.5.2 Use of Lignin Thin Films for the Investigation of Surface Chemical Properties 191
7.6 Lignin: Current and Future Uses 196
7.7 Concluding Remarks 198
References 198

8 Cellulose and Chitin as Nanoscopic Biomaterials 207
Jacob D. Goodrich, Deepanjan Bhattacharya and William T. Winter
8.1 Overview 207
8.2 Introduction 207
8.3 Preparation and Microscopic Characterization of Cellulose and Chitin Nanoparticles 210
8.4 NMR Characterization of Cellulose and Chitin Nanoparticles 214
8.5 Chemical Modification of Cellulose and Chitin Nanoparticles 220
8.6 Nanocomposite Properties 225
8.7 Conclusions 227
Acknowledgements 228
References 228

9 Bacterial Cellulose and Its Polymeric Nanocomposites 231
Marie-Pierre G. Laborie
9.1 Introduction 231
9.2 Bacterial Cellulose: Biosynthesis and Basic Physical and Mechanical Properties 232
9.2.1 Synthesis and Properties of BC 232
9.2.2 Performance of BC Mats 232
9.3 BC Nanocomposites by in situ Polymerization 234
  9.3.1 BC Nanocomposites with Thermosetting Phenolic and Epoxy Resins 234
  9.3.2 BC Nanocomposites with Acrylic Resins 235
9.4 BC Nanocomposites by Polymer Impregnation and Solution Casting 242
  9.4.1 BC/Biopolymer Nanocomposites 243
  9.4.2 BC/Synthetic Polymer Nanocomposites 247
9.5 BC Nanocomposites via Biomimetic Approaches 248
  9.5.1 BC/Xyloglucan Nanocomposites 250
  9.5.2 BC/Mannan Nanocomposites 255
  9.5.3 BC/Pectin Nanocomposites 257
  9.5.4 BC/Xyoglucan/Pectin Nanocomposites 258
  9.5.5 BC/Lignin Nanocomposites 259
  9.5.6 BC/Synthetic Polymer Nanocomposites 261
9.6 BC/Polymer Nanocomposites Based on Bacterial Cellulose Nanocrystals 263
9.7 Conclusions and Prospects 266
References 267

10 Cellulose Nanocrystals in Polymer Matrices 273
  John Simonsen and Youssef Habibi
  10.1 Introduction 273
  10.2 Background on CNXL Material Science 273
  10.3 Polymer Nanocomposite Systems 277
  10.4 Thermal Properties 278
  10.5 Mechanical Properties 279
  10.6 Transport Properties 283
References 287

11 Development and Application of Naturally Renewable Scaffold Materials for Bone Tissue Engineering 293
  Seth D. McCullen, Ariel D. Hanson, Lucian A. Lucia and Elizabeth G. Loboa
  11.1 Introduction 293
  11.2 Natural Renewable Materials for Bone Tissue Engineering (BTE) 295
  11.3 Bone Background 296
    11.3.1 Progenitor Cells for Tissue Engineering Bone 297
    11.3.2 Natural Renewable Materials Used for Bone Tissue Engineering 298
    11.3.3 Naturally Occurring Polysaccharide Materials in BTE 298
    11.3.4 Naturally Occurring Fibrous Protein Materials in BTE 301
12 Template Synthesis of Nanostructured Metals Using Cellulose Nanocrystal

Yongsoo Shin and Gregory J. Exarhos

12.1 Overview 315
12.2 Introduction 316
12.3 Metal Oxide and Metal Carbides 317
  12.3.1 Porous Anatase 317
  12.3.2 SiC Nanorods 320
12.4 Metal Nanoparticles on CNXL 321
  12.4.1 Transition Metal Nanoparticles 321
  12.4.2 Precious Metal Nanoparticles: Ag, Au, Pd, Pt 324
  12.4.3 Nanocrystalline Se 326
12.5 Conclusion 330

Acknowledgements 331
References 331

Index 337