Contents

List of Contributors   xi
Preface   xv

1  Emerging “Green” Materials and Technologies for Electronics   1
Melanie Baumgartner, Maria E. Coppola, Niyazi S. Sariciftci,
Eric D. Glowacki, Siegfried Bauer, and Mihai Irimia-Vladu
1.1  Introduction to “Green” Materials for Electronics   1
1.2  Paper   2
1.3  DNA and Nucleobases   8
1.4  Silk   13
1.5  Saccharides   16
1.6  Aloe Vera, Natural Waxes, and Gums   18
1.7  Cellulose and Cellulose Derivatives   22
1.8  Resins   25
1.9  Gelatine   28
1.10  Proteins, Peptides, Aminoacids   31
1.11  Natural and Nature-Inspired Semiconductors   34
1.12  Perspectives   45
References   45

2  Fabrication Approaches for Conducting Polymer Devices   55
Dimitrios A. Koutsouras, Eloïse Bihar, Jessamyn A. Fairfield,
Mohamed Saadaoui, and George G. Malliaras
2.1  Introduction   55
2.2  Photolithography   56
2.2.1  History   56
2.2.2  Basic Principles   57
2.2.3  Fabrication Steps   59
2.2.3.1  Substrate Cleaning   59
2.2.3.2  Deposition of the Photoresist   60
2.2.3.3  Post-apply Bake   61
2.2.3.4  Use of the Mask/Alignment/Exposure   62
2.2.3.5  Development   63
2.2.3.6  Descumming and Post-baking   64
3 Biocompatible Circuits for Human–Machine Interfacing 91

Erik O. Gabrielson, Daniel T. Simon, and Magnus Berggren

3.1 Introduction 91
3.2 Ion Transport Mechanisms 93
3.2.1 Ions and Types of Electrolytes 93
3.2.2 Ion Transport 93
3.2.2.1 Migration and Diffusion 93
3.2.2.2 Transport Number 94
3.2.3 Ion-Exchange Membranes 95
3.2.4 Bipolar Membranes 96
3.2.4.1 Forward Bias Regime 96
3.2.4.2 Reverse Bias Regime 97
3.2.5 Electrodes 98
3.3 Organic Electronic Ion Pump 99
3.3.1 Applications 100
3.3.2 Limitations 103
3.4 Ion Diodes, Transistors, and Circuits 103
3.4.1 Ion-Conducting Diodes 104
3.4.2 Transistors for Modulating Ion Flows 106
3.4.3 Applications 109
3.4.3.1 Modulating Neurotransmitter Flow 109
3.4.3.2 Diode Logics 109
3.4.3.3 Transistor Logics 109
3.4.3.4 Full-Wave Rectifier 111
3.5 Conclusions 113
References 115
4 Biocompatible Devices and Sustainable Processes for Green Electronics: Biocompatible Organic Electronic Devices for Sensing

Applications 119
Kyriaki Manoli, Mohammad Yusuf Mulla, Preethi Seshadri, Amber Tiwari, Mandeep Singh, Maria Magliulo, Gerardo Palazzo, and Luisa Torsi

4.1 Introduction 119
4.2 Fundamental Aspects of OTFT Sensors 120
4.3 OTFT: Sensing Applications 123
4.3.1 OTFTs: Chemical Sensors 123
4.3.1.1 Gas Sensors 123
4.3.1.2 Liquid Sensing 126
4.4 OTFTs: Biosensors 128
4.4.1 OTFTs with Solid Dielectric 129
4.4.2 Electrolyte-Gated OTFT Biosensors 132
4.4.2.1 EGOFET Biosensors 132
4.4.2.2 OECTs Biosensors 136
4.5 Conclusions 139
References 139

5 Biocompatible Materials for Transient Electronics 145
Suk-Won Hwang and John A. Rogers

5.1 Introduction 145
5.2 Mechanisms of Dissolution of Monocrystalline Silicon Nanomembranes (Si NMs) 146
5.3 Dissolution Mechanisms of Transient Conductors and Insulators 148
5.4 Tunable/Programmable Transience 150
5.5 Transient Electronic Systems 152
5.6 Functional Transformation via Transience 155
5.7 Biocompatibility and Bioresorption 157
5.8 Practical Applications in Medical Implants 158
5.9 Conclusions 160
References 160

6 Paper Electronics 163
Martti Toivakka, Jouko Peltonen, and Ronald Österbacka

6.1 Introduction 163
6.2 Paper as a Substrate for Electronics 164
6.3 Application Areas for Paper Electronics 169
6.4 Green Electronics on Paper 171
6.4.1 Diode Structures 171
6.4.2 Light-Emitting Paper 172
6.4.3 Solar Cells 173
6.4.4 TFTs on Paper 175
6.5 Paper-Based Analytical Devices and Test Platforms 175
6.5.1 Paper as a Sensor Substrate 175
6.5.2 Paper-Based Microplates, Patterning 177
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5.3</td>
<td>Paper-Based Microfluidics</td>
<td>178</td>
</tr>
<tr>
<td>6.5.4</td>
<td>Colorimetric (Optical) Indicators and Sensors</td>
<td>179</td>
</tr>
<tr>
<td>6.5.5</td>
<td>Electrical and Electro-Optical Sensors</td>
<td>179</td>
</tr>
<tr>
<td>6.5.6</td>
<td>Electrochemical Sensors, Assays</td>
<td>181</td>
</tr>
<tr>
<td>6.5.7</td>
<td>Wireless and Remote Sensing</td>
<td>181</td>
</tr>
<tr>
<td>6.6</td>
<td>Summary and Future Outlook</td>
<td>182</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td>183</td>
</tr>
<tr>
<td>7</td>
<td><strong>Engineering DNA and Nucleobases for Present and Future Device</strong></td>
<td>191</td>
</tr>
<tr>
<td></td>
<td><strong>Applications</strong></td>
<td></td>
</tr>
<tr>
<td>7.1</td>
<td>The Versatile World of Nucleic Acids</td>
<td>191</td>
</tr>
<tr>
<td>7.1.1</td>
<td>Introduction</td>
<td>191</td>
</tr>
<tr>
<td>7.1.2</td>
<td>Natural and Artificial Synthesis Sources of Nucleic Acids</td>
<td>193</td>
</tr>
<tr>
<td>7.2</td>
<td>Nucleic Acids in Electronics</td>
<td>195</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Introduction</td>
<td>195</td>
</tr>
<tr>
<td>7.2.2</td>
<td>Thin Film Properties</td>
<td>197</td>
</tr>
<tr>
<td>7.2.3</td>
<td>Nucleic Acids in Organic Electronic Devices</td>
<td>200</td>
</tr>
<tr>
<td>7.3</td>
<td>Nucleic Acids in Nanotechnology</td>
<td>206</td>
</tr>
<tr>
<td>7.3.1</td>
<td>Introduction</td>
<td>206</td>
</tr>
<tr>
<td>7.3.2</td>
<td>DNA Nanotechnology</td>
<td>209</td>
</tr>
<tr>
<td>7.3.3</td>
<td>Wet-to-Dry Transition</td>
<td>210</td>
</tr>
<tr>
<td>7.4</td>
<td>DNA Molecular Engineering</td>
<td>213</td>
</tr>
<tr>
<td>7.4.1</td>
<td>Introduction</td>
<td>213</td>
</tr>
<tr>
<td>7.4.2</td>
<td>Metal–Nucleobase Interaction and Self-assembly</td>
<td>214</td>
</tr>
<tr>
<td>7.4.3</td>
<td>DNA Biosensing</td>
<td>219</td>
</tr>
<tr>
<td>7.4.4</td>
<td>Electrode Self-assembly and Affinity in DNA Electronics</td>
<td>219</td>
</tr>
<tr>
<td>7.5</td>
<td>Summary and Future Outlook</td>
<td>223</td>
</tr>
<tr>
<td></td>
<td>Acknowledgments</td>
<td>224</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td>224</td>
</tr>
<tr>
<td>8</td>
<td><strong>Grotthuss Mechanisms: From Proton Transport in Ion Channels</strong></td>
<td>235</td>
</tr>
<tr>
<td></td>
<td><strong>to Bioprotonic Devices</strong></td>
<td></td>
</tr>
<tr>
<td>8.1</td>
<td>Introduction</td>
<td>235</td>
</tr>
<tr>
<td>8.2</td>
<td>Proton Wires: Chains of Hydrogen Bonds and Grotthuss Mechanisms</td>
<td>236</td>
</tr>
<tr>
<td>8.3</td>
<td>Proton Transport in Proton Channels</td>
<td>237</td>
</tr>
<tr>
<td>8.4</td>
<td>Proton Transport across Membranes and Oxidative Phosphorylation</td>
<td>238</td>
</tr>
<tr>
<td>8.5</td>
<td>Biopolymer Proton Conductors</td>
<td>239</td>
</tr>
<tr>
<td>8.6</td>
<td>Devices Based on Proton Conductors</td>
<td>240</td>
</tr>
<tr>
<td>8.7</td>
<td>Bioprotonic Devices: Diodes, Transistors, Memories, and Transducers</td>
<td>240</td>
</tr>
<tr>
<td>8.7.1</td>
<td>Protodes: PdH₂ for Efficient Proton Transport at the Contact Biopolymer Interface</td>
<td>241</td>
</tr>
</tbody>
</table>
Contents

8.7.2 Hydrogen Diffusion inside PdHx and Depletion: Synaptic Devices and Memories 243
8.7.3 A Phenomenological Description of Proton Transport and Acid and Base Doping 244
8.7.4 Complementary Bioprotonic Transistors 246
8.7.5 Enzyme Logic Transducer 248
8.8 Future Outlook 249
Acknowledgments 250
References 250

9 Emulating Natural Photosynthetic Apparatus by Employing Synthetic Membrane Proteins in Polymeric Membranes 255
Cherng-Wen Darren Tan and Eva-Kathrin Sinner
9.1 Introduction 255
9.2 Light-Harvesting Complex II 256
9.3 Natural Proteins in Natural Membrane Assemblies 257
9.3.1 The Need for Reliable Test Systems 259
9.3.2 Membrane Proteins in Artificial Membranes 260
9.3.3 Membrane Protein Production 260
9.3.4 Artificial Membranes 261
9.3.5 Integrating Protein and Membrane Production 261
9.3.6 LHCII in Artificial Lipid Membranes 263
9.3.7 LHCII in Artificial Polymer Membranes 263
9.4 Plant-Inspired Photovoltaics: The Twenty-First Century and Beyond 265
List of Abbreviations 265
References 265

10 Organic Optoelectronic Interfaces for Vision Restoration 269
Andrea Desii, Maria R. Antognazza, Fabio Benfenati, and Guglielmo Lanzani
10.1 Introduction 269
10.2 Retinal Implants for Vision Restoration 273
10.2.1 Toward an Organic Artificial Retina 275
10.2.2 Cellular Photostimulation Mediated by Molecular Materials 276
10.2.3 Optoelectronic Organic Membranes for Cell Stimulation 277
10.2.4 Photoelectrical Stimulation of Explanted Blind Retinas Mediated by Optoelectronic Thin Membranes 280
10.3 Perspectives 282
References 283

11 Nanostructured Silica from Diatoms Microalgae: Smart Materials for Photonics and Electronics 287
Roberta Ragni, Stefania R. Ciccio, Danilo Vona, and Gianluca M. Farinola
11.1 Diatoms: Living Cells in Glass Houses 287
11.2 Diatom Frustules in Photonics and Optics 291
11.2.1 Diatom Frustules as Photonic Crystals 291
11.2.2 Autofluorescence of Diatom Frustules 295
11.2.3 Functionalization of Diatom Frustules with Organic or Inorganic Emitters 298
11.3 Diatom Frustules in Electronics 302
11.3.1 Hybrid Metal or Metal Oxide Biosilica-Based Materials for Electronics 302
11.3.2 Diatom Frustules as Templates for Three-Dimensional Replication 304
11.4 Conclusions 308
   Acknowledgments 309
   References 309

Index 315