Contents

Preface XIX
Acknowledgements XXI
List of Contributors XXIII

Part I Electrochromic Materials and Processing 1

1 Electrochromic Metal Oxides: An Introduction to Materials and Devices 3
   Claes-Göran Granqvist
   1.1 Introduction 3
   1.2 Some Notes on History and Early Applications 5
   1.3 Overview of Electrochromic Oxides 6
   1.3.1 Recent Work on Electrochromic Oxide Thin Films 7
   1.3.2 Optical and Electronic Effects 9
   1.3.3 Charge Transfer Absorption in Tungsten Oxide 11
   1.3.4 Ionic Effects 14
   1.3.5 On the Importance of Thin-Film Deposition Parameters 18
   1.3.6 Electrochromism in Films of Mixed Oxide: The W–Ni-Oxide System 21
   1.4 Transparent Electrical Conductors and Electrolytes 23
   1.4.1 Transparent Electrical Conductors: Oxide Films 25
   1.4.2 Transparent Electrical Conductors: Metal-Based Films 26
   1.4.3 Transparent Electrical Conductors: Nanowire-Based Coatings and Other Alternatives 27
   1.4.4 Electrolytes: Some Examples 29
   1.5 Towards Devices 30
   1.5.1 Six Hurdles for Device Manufacturing 31
   1.5.2 Practical Constructions of Electrochromic Devices 32
   1.6 Conclusions 33
   Acknowledgement 33
   References 33
2 Electrochromic Materials Based on Prussian Blue and Other Metal Metallohexacyanates 41

David R. Rosseinsky and Roger J. Mortimer

2.1 The Electrochromism of Prussian Blue 41

2.1.1 Introduction 41

2.1.2 Electrodeposited PB Film and Comparisons with Bulk PB 42

2.1.3 PB Prepared from Direct Cell Reaction, with No Applied Potential 45

2.1.4 Layer-by-Layer Deposition of PB 46

2.1.5 PB on Graphene 46

2.1.6 Alternative Preparations of PB: PB from Colloid and Similar Origins 46

2.1.7 Alternative Electrolytes Including Polymeric for PB Electrochromism 47

2.2 Metal Metallohexacyanates akin to Prussian Blue 48

2.2.1 Ruthenium Purple RP 48

2.2.2 Vanadium Hexacyanoferrate 48

2.2.3 Nickel Hexacyanoferrate 48

2.3 Copper Hexacyanoferrate 49

2.3.1 Palladium Hexacyanoferrate 49

2.3.2 Indium Hexacyanoferrate and Gallium Hexacyanoferrate 49

2.3.3 Miscellaneous PB Analogues as Hexacyanoferrates 49

2.3.4 Mixed-Metal and Mixed-Ligand PB Analogues Listed 50

References 50

3 Electrochromic Materials and Devices Based on Viologens 57

Paul M. S. Monk, David R. Rosseinsky, and Roger J. Mortimer

3.1 Introduction, Naming and Previous Studies 57

3.2 Redox Chemistry of Bipyridilium Electrochromes 58

3.3 Physicochemical Considerations for Including Bipyridilium Species in ECDs 61

3.3.1 Type-1 Viologen Electrochromes 61

3.3.2 Type-2 Viologen Electrochromes 61

3.3.2.1 The Effect of the Bipyridilium-N Substituent 62

3.3.2.2 The Effect of Micellar Viologen Species 62

3.3.2.3 The Effect of Film Morphology 64

3.3.2.4 The Effect of the Counter Anion 64

3.3.2.5 The Use of Electron Mediators and the Formation of Electro-Inactive Oils 65

3.3.2.6 The Effect of Dimerised Radical Cations 67

3.3.3 Type-3 Viologen Electrochromes 68

3.3.3.1 Immobilising Viologen Electrochromes 69

3.3.3.2 Derivatised Electrodes 69

3.4 Exemplar Bipyridilium ECDs 72

3.4.1 The Philips Device 72
3.4.2 The ICI Device  72
3.4.3 The IBM Device  74
3.4.4 The Gentex Device  74
3.4.5 The NTERA Device  76
3.4.6 The NanoChromics Cell  76
3.4.7 The Grätzel Device  78
3.5 Elaborations  78
3.5.1 The Use of Pulsed Potentials  79
3.5.2 Electropolychromism  79
3.5.3 Viologen Electrochemiluminescence  79
3.5.4 Viologens Incorporated within Paper  80
References  81

4 Electrochromic Devices Based on Metal Hexacyanometallate/Viologen Pairings  91
Kuo-Chuan Ho, Chih-Wei Hu, and Thomas S. Varley
4.1 Introduction  91
4.1.1 Overview of Prussian Blue and Viologen Electrochromic Devices  92
4.2 Hybrid (Solid-with-Solution) Electrochromic Devices  93
4.2.1 Prussian Blue and Heptyl Viologen Solid-with-Solution-Type ECD  93
4.2.1.1 Preparation and Characterisation of PB Thin Film and HV(BF$_4$)$_2$  94
4.2.1.2 Redox Behaviours and Visible Spectra of the PB Film and HV(BF$_4$)$_2$ Solution  94
4.2.1.3 Operating Parameters and Properties of PHECD  95
4.2.1.4 Analogous Devices  96
4.2.2 PB Thin Film and Viologen in Ionic Liquid–Based ECD  97
4.3 All-Solid Electrochromic Devices  97
4.3.1 Prussian Blue and Poly(butyl viologen) Thin-Film ECD  97
4.3.1.1 Preparation of Poly(butyl viologen) Thin Film  97
4.3.1.2 Electrochemical and Optical Properties of Poly(butyl viologen) Thin Films  98
4.3.1.3 Electrochromic Performance of PBV-PB ECD  99
4.3.2 Prussian Blue and Viologen Anchored TiO$_2$–Based ECD  99
4.3.3 Polypyrrole-Prussian Blue Composite Film and Benzylviologen Polymer–Based Thin-Film-Type ECD  100
4.3.3.1 Preparation of PP-PB Thin-Film  101
4.3.3.2 Performance of the PP-PB Thin-Film and pBPQ-Based Electrochromic Device  101
4.3.4 PB Thin-Film and Viologen-Doped Poly(3,4-ethylenedioxythiophene) Polymer–Based ECD  102
4.3.5 Other Solid-State Viologens  103
4.4 Other Metal Hexacyanometallate-Viologen-Based ECDs  104
5 Conjugated Electrochromic Polymers: Structure-Driven Colour and Processing Control 113
Aubrey L. Dyer, Anna M. Österholm, D. Eric Shen, Keith E. Johnson, and John R. Reynolds

5.1 Introduction and Background 113
5.1.1 Source of Electrochromism in Conjugated Polymers 113
5.1.1.1 Common Polyheterocycles 116
5.1.1.2 Donor–Acceptor Approach – The Push–Pull of Electrons 118
5.1.1.3 Steric Interactions 120
5.1.1.4 Fused Aromatics 122
5.2 Representative Systems 123
5.2.1 Coloured-to-Transmissive Polymers 123
5.2.1.1 Yellow 124
5.2.1.2 Orange and Red 125
5.2.1.3 Blue and Purple 127
5.2.1.4 Cyan/Green 133
5.2.1.5 Black 135
5.2.2 Anodically Colouring 139
5.2.3 Inducing Multicoloured States in ECPs 143
5.2.3.1 Polyaniline: A Model ECP with Multiple Redox States 146
5.2.3.2 Colour Control via Copolymerisation 147
5.2.3.3 Appended Electrochromes on ECPs 148
5.2.3.4 Surface-Confined Polymerisation 149
5.2.3.5 Combining Redox States – Oxidation and Reduction in a Single Material 150
5.2.3.6 Composite Formation with Electrochrome Dopants 151
5.3 Processability of Electrochromic Polymers 152
5.3.1 Electrochemical Polymerisation 152
5.3.2 Functionalisation of ECPs for Achieving Organic Solubility 156
5.3.3 Aqueous Processability and Compatibility 158
5.3.3.1 Use of Charged Polymers 159
5.3.3.2 Ion Functionalised Polymers 161
5.3.3.3 Organic Processing to Achieve Water Solubility and Water Switchability 163
5.3.4 Methods for Patterning 165
5.4 Summary and Perspective 168
Acknowledgements 169
References 169
6 Electrochromism within Transition-Metal Coordination Complexes and Polymers 185
   Yu-Wu Zhong
6.1 Electronic Transitions and Redox Properties of Transition-Metal Complexes 185
6.2 Electrochromism in Reductively Electropolymerised Films of Polypyridyl Complexes 187
6.3 Electrochromism in Oxidatively Electropolymerised Films of Transition-Metal Complexes 192
6.4 Electrochromism in Self-Assembled or Self-Adsorbed Multilayer Films of Transition-Metal Complexes 196
6.5 Electrochromism in Spin-Coated or Drop-Cast Thin Films of Transition-Metal Complexes 200
6.6 Conclusion and Outlook 204
Acknowledgements 205
References 205

7 Organic Near-Infrared Electrochromic Materials 211
   Bin Yao, Jie Zhang, and Xinhua Wan
7.1 Introduction 211
7.2 Aromatic Quinones 212
7.3 Aromatic Imides 216
7.4 Anthraquinone Imides 218
7.5 Poly(triarylamines) 221
7.6 Conjugated Polymers 228
7.7 Other NIR Electrochromic Materials 235
7.8 Conclusion 236
References 237

8 Metal Hydrides for Smart-Window Applications 241
   Kazuki Yoshimura
8.1 Switchable-Mirror Thin Films 241
8.2 Optical Switching Property 242
8.3 Switching Durability 243
8.4 Colour in the Transparent State 244
8.5 Electrochromic Switchable Mirror 245
8.6 Smart-Window Application 246
References 247

Part II Nanostructured Electrochromic Materials and Device Fabrication 249

9 Nanostructures in Electrochromic Materials 251
   Shanxin Xiong, Pooi See Lee, and Xuehong Lu
9.1 Introduction 251
9.1.1 Why Nanostructures? 251
9.1.2 Classification of Nanostructural Electrochromic Materials 252
9.1.3 Preparation Method 253
9.2 Nanostructures of Transition Metal Oxides (TMOs) 253
9.2.1 Introduction 253
9.2.2 Single TMO Systems 257
9.2.3 Binary TMO Systems 261
9.3 Nanostructures of Conjugated Polymers 262
9.3.1 Introduction 262
9.3.2 Polythiophene and Its Derivatives 263
9.3.3 Polyaniline 264
9.3.4 Polypyrrole 266
9.4 Nanostructures of Organic-Metal Complexes and Viologen 267
9.4.1 Introduction 267
9.4.2 Organic-Metal Complexes 267
9.4.3 Viologens 268
9.5 Electrochromic Nanocomposites and Nanohybrids 268
9.5.1 Introduction 268
9.5.2 Nanocomposites of Electrochromic Materials 269
9.5.2.1 Conjugated Polymer/TMO and TMO/TMO Nanocomposites 269
9.5.2.2 Conjugated Polymer/Organic Small-Molecule Nanocomposites 272
9.5.3 Nanocomposites of Electrochromic/Non-Electrochromic Active Materials 274
9.5.3.1 Conjugated Polymers as Electrochromic Materials 274
9.5.3.2 TMOs as Electrochromic Materials 275
9.5.3.3 Organic Small Molecules as Electrochromic Materials 277.
9.5.3.4 Electrochromic Nanohybrids with Covalent Bonds 278
9.6 Conclusions and Perspective 281
References 282

10 Advances in Polymer Electrolytes for Electrochromic Applications 289
Alice Lee-Sie Eh, Xuehong Lu, and Pooi See Lee
10.1 Introduction 289
10.2 Requirements of Polymer Electrolytes in Electrochromic Applications 290
10.3 Types of Polymer Electrolytes 291
10.3.1 Solid Polymer Electrolytes (SPEs) 292
10.3.2 Gel Polymer Electrolytes (GPEs) 292
10.3.3 Polyelectrolytes 293
10.3.4 Composite Polymer Electrolytes (CPEs) 294
10.4 Polymer Hosts of Interest in Electrochromic Devices 294
10.4.1 PEO/PEG-Based Polymer Electrolytes 295
10.4.2 PMMA-Based Polymer Electrolytes 296
10.4.3 PVDF-Based Polymer Electrolytes 297
10.4.4 Ionic Liquid–Based Polymer Electrolytes 300
10.4.5 Poly(propylene carbonate) (PPC)-Based Polymer Electrolytes 302
10.5 Recent Trends in Polymer Electrolytes 303
10.5.1 Flexible, Imprintable, Bendable and Shape-Conformable Polymer Electrolytes 303
10.5.2 Potentially ‘Green’ Biodegradable Polymer Electrolytes Using Naturally Available Polymer Host 303
10.6 Future Outlook 305
10.6.1 Recent Trends in Electrochromic Devices 305
10.6.2 Challenges in Creating Versatile Polymer Electrolytes for EC Devices 307
References 307

11 Gyroid-Structured Electrodes for Electrochromic and Supercapacitor Applications 311
Maik R.J. Scherer and Ullrich Steiner
11.1 Introduction to Nanostructured Electrochromic Electrodes 311
11.1.1 Three-Dimensional Nanostructuring Strategies 313
11.2 Polymer Self-Assembly and the Gyroid Nanomorphology 315
11.2.1 Copolymer Microphase Separation 315
11.2.2 Double-Gyroid 316
11.2.3 Synthesis of Mesoporous DG Templates 318
11.3 Gyroid-Structured Vanadium Pentoxide 320
11.3.1 Electrochemical Characterisation of V_2O_5 Electrodes 322
11.3.2 Electrochromic Displays Based on V_2O_5 Electrodes 322
11.3.3 Electrochromic V_2O_5 Supercapacitors 324
11.4 Gyroid-Structured Nickel Oxide 326
11.4.1 Electrochromic Displays Based on NiO Electrodes 328
11.5 Concluding Remarks 329
References 331

Susana I. Córdoba de Torresi, Jose R. Martins Neto, Marcio Vidotti, and Fritz Huguenin
12.1 Introduction to the Layer-by-Layer Deposition Technique 337
12.2 Layer-by-Layer Assembly in Electrochromic Materials 337
12.2.1 Layer-by-Layer Assembly of Conjugated Conducting Polymers 338
12.2.2 Layer-by-Layer Assembly of Intercalation Charge Transfer Coloration Materials 340
12.3 Layer-by-Layer Assembly of Metal Oxides 342
12.3.1 Tungsten Oxide 344
12.3.2 Hexaniobate 346
12.3.3 Vanadium Oxide 346
12.3.4 Titanium Oxide 348
12.3.5 Nickel Hydroxide 349
12.4 Layer-by-Layer and Electrophoretic Deposition for Nanoparticles Immobilisation 351
12.4.1 Comparing Layer-by-Layer and Electrophoretic Deposition 351
Acknowledgements 357
References 357

13 Plasmonic Electrochromism of Metal Oxide Nanocrystals 363
Anna Lloderes, Evan L. Runnerstrom, Sebastien D. Lounis, and Delia J. Milliron
13.1 Introduction to Plasmonic Electrochromic Nanocrystals 363
13.2 History of Electrochromism in Metal and Semiconductor Nanocrystals 368
13.3 Doped Metal Oxide Colloidal Nanocrystals as Plasmonic Electrochromic Materials 377
13.3.1 Colloidal Synthesis of Doped Metal Oxide Nanocrystals 377
13.3.2 Plasmonic Electrochromic Electrodes Based on Colloidal ITO and AZO Nanocrystals 379
13.3.3 Design Principles for Nanocrystal-Based Plasmonic Electrochromics 382
13.4 Advanced Electrochromic Electrodes Constructed from Colloidal Plasmonic NCs 383
13.4.1 NIR-Selective Mesoporous Architectured Electrodes Based on Plasmonic Colloidal Nanocrystals 384
13.4.2 Dual-Band Nanocrystal-in-Glass Composite Electrodes Based on Plasmonic Colloidal Nanocrystals and Conventional Electrochromic Materials 385
13.4.3 Other Advanced Composite Electrochromic Electrodes Obtained from Non-Colloidal Approaches 391
13.4.3.1 Hybrid Electrochromic Nanocomposites 391
13.4.3.2 Inorganic Nanocomposites for Advanced Counter Electrodes 392
13.5 Conclusions and Outlook 393
References 394

Part III Applications of Electrochromic Materials 399

14 Solution-Phase Electrochromic Devices and Systems 401
Harlan J. Byker
14.1 Introduction 401
14.2 Early History of Solution-Phase EC 402
14.3 The World’s Most Widely Used Electrochromic Material 405
14.4 Commercialisation of EC Devices 406
14.5 Reversibility and Stability in Solution-Phase EC Systems 409
14.6 Thickened and Gelled Solution-Phase Systems 411
14.7 Nernst Equilibrium, Disproportionation and Stability 413
14.8 Closing Remarks 415
References 416

15 Electrochromic Smart Windows for Dynamic Daylight and Solar Energy Control in Buildings 419
Bjørn Petter Jelle
15.1 Introduction 419
15.2 Solar Radiation 421
15.3 Solar Radiation through Window Panes and Glass Structures 421
15.4 Solar Radiation Modulation by Electrochromic Windows 425
15.5 Experimental 427
15.5.1 Glass Samples and Window Pane Configurations 427
15.5.2 UV-VIS-NIR Spectrophotometry 428
15.5.3 Emissivity Determination by Specular IR Reflectance 428
15.5.4 Emissivity Determination by Heat Flow Meter 428
15.5.5 Emissivity Determination by Hemispherical Reflectance 429
15.5.6 Actual Emissivity Determinations in This Study 430
15.6 Measurement and Calculation Method of Solar Radiation Glazing Factors 430
15.6.1 Ultraviolet Solar Transmittance 430
15.6.2 Visible Solar Transmittance 431
15.6.3 Solar Transmittance 431
15.6.4 Solar Material Protection Factor (SMPF) 432
15.6.5 Solar Skin Protection Factor (SSPF) 433
15.6.6 External Visible Solar Reflectance 434
15.6.7 Internal Visible Solar Reflectance 434
15.6.8 Solar Reflectance 435
15.6.9 Solar Absorbance 436
15.6.10 Emissivity 436
15.6.10.1 Emissivity in General 436
15.6.10.2 Emissivity by Specular IR Reflectance Measurements 437
15.6.10.3 Emissivity by Heat Flow Meter Apparatus 437
15.6.10.4 Emissivity by Hemispherical Reflectance 440
15.6.11 Solar Factor (SF) 440
15.6.11.1 Solar Factor in General 440
15.6.11.2 Heat Transfer Coefficients of Glazing towards the Outside and Inside 441
15.6.11.3 Secondary Heat Transfer Factor towards the Inside for Multiple Glazing 441
15.6.11.4 Thermal Conductance 442
15.6.11.5 Solar Factor for Single Glazing 445
15.6.11.6 Solar Factor for Double Glazing 446
15.6.11.7 Solar Factor for Triple Glazing 447
15.6.12 Colour Rendering Factor (CRF) 449
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.6.13 Additional Heat Transfer</td>
<td>451</td>
</tr>
<tr>
<td>15.6.14 Number of Glass Layers in a Window Pane</td>
<td>452</td>
</tr>
<tr>
<td>15.6.15 General Calculation Procedures</td>
<td>452</td>
</tr>
<tr>
<td>15.7 Spectroscopic Measurement and Calculation of Solar Radiation Glazing Factors</td>
<td>452</td>
</tr>
<tr>
<td>15.7.1 Spectroscopic Data for Float Glass and Low Emittance Glass</td>
<td>453</td>
</tr>
<tr>
<td>15.7.2 Spectroscopic Data for Dark Silver Coated Glass</td>
<td>455</td>
</tr>
<tr>
<td>15.7.3 Spectroscopic Data for Electrochromic Windows</td>
<td>456</td>
</tr>
<tr>
<td>15.7.4 Solar Radiation Glazing Factors for Float Glass, Low Emittance Glass, Dark Silver Coated Glass and Two-Layer and Three-Layer Window Pane Configurations</td>
<td>461</td>
</tr>
<tr>
<td>15.7.5 Solar Radiation Glazing Factors for Electrochromic Windows</td>
<td>465</td>
</tr>
<tr>
<td>15.7.6 Miscellaneous Other Electrochromic Properties</td>
<td>470</td>
</tr>
<tr>
<td>15.7.6.1 General</td>
<td>470</td>
</tr>
<tr>
<td>15.7.6.2 Colour Coordinates</td>
<td>470</td>
</tr>
<tr>
<td>15.7.6.3 Electrochromic Efficiency</td>
<td>471</td>
</tr>
<tr>
<td>15.7.6.4 Energy Consumption, Memory and Switching Time</td>
<td>472</td>
</tr>
<tr>
<td>15.7.6.5 Durability</td>
<td>472</td>
</tr>
<tr>
<td>15.7.6.6 Electrochromic Window Configuration</td>
<td>473</td>
</tr>
<tr>
<td>15.7.6.7 Reflectance-Induced Limitations</td>
<td>474</td>
</tr>
<tr>
<td>15.8 Commercial Electrochromic Windows and the Path Ahead</td>
<td>475</td>
</tr>
<tr>
<td>15.9 Increased Application of Solar Radiation Glazing Factors</td>
<td>476</td>
</tr>
<tr>
<td>15.10 Conclusions</td>
<td>476</td>
</tr>
<tr>
<td>15.A Appendix: Tables for Calculation of Solar Radiation Glazing Factors</td>
<td>477</td>
</tr>
<tr>
<td>15.B Appendix: Tables for Calculation of Thermal Conductance</td>
<td>488</td>
</tr>
<tr>
<td>References</td>
<td>492</td>
</tr>
</tbody>
</table>

16 Fabric Electrochromic Displays for Adaptive Camouflage, Biomimicry, Wearable Displays and Fashion 503

*Michael T. Otley, Michael A. Invernale, and Gregory A. Sotzing*

16.1 Introduction 503
16.1.1 Colour-Changing Technologies Background 504
16.1.2 Previous Work 505
16.1.3 Conductivity Trends of PEDOT-PSS Impregnated Fabric and the Effect of Conductivity on Electrochromic Textile 510
16.1.4 The Effects of Coloured-Based Fabric on Electrochromic Textile 513
16.1.5 Other Electrochromic Fabric 514
16.2 Non-Electrochromic Colour-Changing Fabric 517
16.2.1 Thermochromic Fabric 517
16.2.2 Photochromic Fabric 517
16.2.3 LED and LCD Technology 518
16.3 Conclusion 519
References 521

Part IV Device Case Studies, Environmental Impact Issues and Elaborations 525

17 Electrochromic Foil: A Case Study 527
Claes-Göran Granqvist
17.1 Introduction 527
17.2 Device Design and Optical Properties of Electrochromic Foil 528
17.3 Comments on Lifetime and Durability 532
17.4 Electrolyte Functionalisation by Nanoparticles 538
17.5 Comments and Conclusion 541
Acknowledgements 542
References 542

18 Life Cycle Analysis (LCA) of Electrochromic Smart Windows 545
Uwe Posset and Matthias Harsch
18.1 Life Cycle Analysis 545
18.2 Application of LCA to Electrochromic Smart Windows 549
18.3 LCA of Novel Plastic-Film-Based Electrochromic Devices 560
18.4 LCA for EC Target Applications 564
18.4.1 Automotive Sunroof Case 564
18.4.2 Appliance Example: Window Case for a House-Hold Oven 566
18.4.3 Aircraft Cabin Window Case 567
18.5 Conclusion 568
References 568

19 Electrochromic Glazing in Buildings: A Case Study 571
John Mardaljevic, Ruth Kelly Waskett, and Birgit Painter
19.1 Introduction 571
19.1.1 Daylight in Buildings 572
19.1.2 The Importance of View 572
19.2 Variable Transmission Glazing for Use in Buildings 573
19.2.1 Chromogenic Glass 573
19.2.2 VTG Performance Characteristics 574
19.2.3 EC Product Details and Practicalities 577
19.2.4 Operational Factors 578
19.2.5 Zoning of EC Glazing 580
19.2.6 Performance Prediction Using Building Simulation Tools 582
19.2.7 Occupant-Based Studies 583
19.3 Case Study: The De Montfort EC Office Installation 584
19.3.1 Background 584
19.3.2 Installation of the EC Glazing 585
19.3.3 Subjective Data Collection 587
19.3.4 Measurement of Physical Quantities 587
19.3.5 The Daylight Illumination Spectrum with EC Glazing 588
19.4 Summary 591
References 591

20 Photoelectrochromic Materials and Devices 593
Kuo-Chuan Ho, Hsin-Wei Chen, and Chih-Yu Hsu
20.1 Introduction 593
20.2 Structure Design of the PECDs 594
20.2.1 Separated-Type PECD (Type I): The Dye-Sensitised TiO₂ Layer is
Separated from the Electrochromic Layer 594
20.2.1.1 Inorganic Materials as EC Layers 599
20.2.2 Combined-Type PECD (Type II): The Dye-Sensitised TiO₂ Layer is
Combined with the Electrochromic Layer 610
20.2.3 Non-Symmetric-Type PECDs (Type III): The Active Area of the
Dye-Sensitised TiO₂ Layer is Non-Symmetric to the Electrochromic
Layer 613
20.2.4 Parallel-Type PECDs: Where the Dye-Sensitised TiO₂ Layer is
Parallel and Separated with the Electrochromic Layer. The
Electrolytes for Both Layers are Different for Their Optimal
Performance 616
20.2.5 Prospects 619
References 620

Appendix Definitions of Electrochromic Materials and Device Performance
Parameters 623
Roger J. Mortimer, Paul M. S. Monk, and David R. Rosseinsky
A.1 Contrast Ratio CR 623
A.2 Response Time τ 624
A.3 Write–Erase Efficiency 624
A.4 Cycle Life 624
A.5 Coloration Efficiency η 625
References 625

Index 627