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-ethylenedioxythiopene) Polymer – Based ECD *102*
4.3.5 Other Solid-State Viologens *103*
4.4 Other Metal Hexacyanometallate-Viologen-Based ECDs *104*

4.5 Prospects for Metal Hexacyanometallate-Viologen-Based ECDs *105*
References *106*

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(triarylamine)s *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*

12 Layer-by-Layer Assembly of Electrochromic Materials: On the Efficient Method for Immobilisation of Nanomaterials *337*
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 Intervalence 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 Llordes, 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*

15.6.13 Additional Heat Transfer *451*
15.6.14 Number of Glass Layers in a Window Pane *452*
15.6.15 General Calculation Procedures *452*
15.7 Spectroscopic Measurement and Calculation of Solar Radiation Glazing Factors *452*
15.7.1 Spectroscopic Data for Float Glass and Low Emittance Glass *453*
15.7.2 Spectroscopic Data for Dark Silver Coated Glass *455*
15.7.3 Spectroscopic Data for Electrochromic Windows *456*
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 *461*
15.7.5 Solar Radiation Glazing Factors for Electrochromic Windows *465*
15.7.6 Miscellaneous Other Electrochromic Properties *470*
15.7.6.1 General *470*
15.7.6.2 Colour Coordinates *470*
15.7.6.3 Electrochromic Efficiency *471*
15.7.6.4 Energy Consumption, Memory and Switching Time *472*
15.7.6.5 Durability *472*
15.7.6.6 Electrochromic Window Configuration *473*
15.7.6.7 Reflectance-Induced Limitations *474*
15.8 Commercial Electrochromic Windows and the Path Ahead *475*
15.9 Increased Application of Solar Radiation Glazing Factors *476*
15.10 Conclusions *476*
Acknowledgements *477*
15.A Appendix: Tables for Calculation of Solar Radiation Glazing Factors *477*
15.B Appendix: Tables for Calculation of Thermal Conductance *488*
References *492*

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 TiO_2 Layer is Separated from the Electrochromic Layer *594*
20.2.1.1 Inorganic Materials as EC Layers *599*
20.2.1.2 Conjugated Conducting Polymer Materials as EC Layers *604*
20.2.2 Combined-Type PECD (Type II): The Dye-Sensitised TiO_2 Layer is Combined with the Electrochromic Layer *610*
20.2.3 Non-Symmetric-Type PECDs (Type III): The Active Area of the Dye-Sensitised TiO_2 Layer is Non-Symmetric to the Electrochromic Layer *613*
20.2.4 Parallel-Type PECDs: Where the Dye-Sensitised TiO_2 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*