

Index

a

AAEM. *See* alkaline anion exchange membrane (AAEM)
 acetic acid 70
 acetylene black 34
 acidic PEM fuel cell 5
 acid polymerization catalysts 36
 activation energy 5, 6, 9, 25, 80
 AFCs. *See* alkaline fuel cells (AFCs)
 air-breathing cathode 201
 alkaline anion exchange membrane (AAEM) 19
 – alkaline fuel cell 11, 12, 17
 – fuel cell 16, 19–25
 – – alkaline membranes 17–19
 – – cathode and anode constituents 21
 – – performance 23
 – – polar curves and power densities, with Pt anodes/silver cathodes 22
 – – polarization curves 20, 21
 – – route to reduced costs and 3
 – nonplatinum cell 22
 – polar and power density curves, effect of CO₂ on 23
 – principles 16, 17
 – properties 19
 – resistance and polarization performance 24
 – – effect of temperature 24
 alkaline exchange membrane fuel cells 1
 alkaline fuel cells (AFCs) 11, 12, 26, 126
 – AAEM fuel cell 16
 – – alkaline membranes 17–19
 – – fuel cell examples 19–25
 – – principles 16, 17
 – aqueous electrolyte AFC 15, 16
 – HOR in alkaline 13, 15
 – ORR mechanism 12, 13
 alkaline membranes 26
 2-amino-3-carboxy-1,4-naphthoquinone 173

anion exchange membrane (AEM) 77, 156, 157
 anion exchange membrane-based direct ethanol fuel cells (AEM-DEFCs) 77, 78
 – anode catalysts for 78, 79
 – DFT calculations on model Pd clusters 79
 – EOR activity 78
 – vs. PEM-DEFCs 79
 anion exchange membranes (AEMs) 130
 anion exchange membranes, disadvantages 97
 anode catalysts
 – for direct ethanol fuel cells 73–79
 – for direct methanol fuel cells 71–73
 – for direct polyol fuel cells (ethylene glycol, glycerol) 79–84
 – future challenges and opportunities 96, 97
 anodic bioelectrocatalysis 169
 anodic mass transport losses 189
 anthraquinone-1,6-disulfonic acid 149
 Apollo Space Programme 3
 aqueous electrolyte AFC 15, 16
 – carbonation reaction 16
 – half reactions 16
 – overall redox reaction 16
 aqueous electrolyte-based fuel cells 3
 attenuated total reflectance surface-enhanced infrared absorption spectroscopy (ATR-SEIRAS) 178

b

benzene ring-free aliphatic polymers 137
 BES. *See* bioelectrochemical system (BES)
 biocathode 155
 biodiesel 69, 82
 bioelectrocatalysts 167
 – anodic 169
 – characterization of BESs and microbial 176
 – microbial characterization 176
 – nature of microbial 167–169

- operating conditions 169
 - types of 168
 - bioelectrocatalytic electricity generation, for autonomous robots 174
 - bioelectrochemical system (BES) 167, 175
 - application potential 175
 - characterization of 176
 - electrochemical methods
 - biological methods 178, 179
 - polarization curves 176
 - spectroelectrochemical 178
 - voltammetry 177
 - electrode materials 172
 - hydrogen gas 175
 - microbial systems 173–175
 - biofuel cells. *See also various fuel cells*
 - bipolar membrane (BPM) 156
 - block copolymers 117, 118
 - boron-doped diamond 39
 - Butler–Volmer equation 10, 189
 - Butler–Volmer kinetics 7, 8
- C**
- carbon aerogels (CAGs) 35, 39
 - carbonation effect 26
 - carbon blacks 34, 37, 39, 91, 92, 94, 152
 - based electrocatalyst support
 - problems 35
 - catalysts with surface-modified, enhanced proton and electron conduction 59
 - commercial (*See* Vulcan XC-72)
 - supported Pt electrocatalyst (Pt/C) 57, 91
 - carbon-coated anatase titania (CCT) 55
 - carbon dioxide (CO₂) 33, 112, 114, 126
 - carbonization 36, 95
 - carbon materials 34
 - ORR activity in alkaline solution 13
 - promising catalyst supports in fuel cells 34, 35 (*See also* carbon nanotubes; graphene; graphite nanofibers; mesoporous carbon)
 - carbon nanocoils (CNCs) 35, 49
 - carbon nanofibers (CNFs) 35, 42, 94
 - carbon nanohorns (CNHs) 35
 - carbon nanomaterials
 - as anode catalyst support 91
 - carbon nanofibers 94
 - carbon nanotubes 91–94
 - graphene sheets 95
 - ordered mesoporous carbons 94, 95
 - TEM images 92
 - carbon nanotubes (CNTs) 35, 43–45, 61, 91–94, 153
 - functionalization
 - with benzyl mercaptan and subsequent Pt deposition 46
 - and deposition of Pt nanoparticles 44
 - noncovalent 45
 - multilayer assembled, CNTs of PSS and PDDA as templates 45
 - nitrogen-doped carbon nanotubes (N-CNTs) 52
 - as support materials 42–49
 - carbon-supported catalysts 13
 - platinum catalysts 33
 - Carnot cycle limitation 69, 73
 - catalysts 3
 - binary and ternary 71
 - binders 151
 - ideal, properties 33, 34
 - Ir/C catalysts 234
 - Ir₃Sn/C catalysts 234
 - Pd/C catalysts 13
 - selection 2
 - with surface-modified carbon blacks 59
 - catastrophic effect 24
 - cathod
 - fouling 152
 - gas stream 24
 - kinetics of alkaline systems 4
 - as limiting factor of MFCs 159
 - mass transport losses 189
 - with non-Pt metal catalyst 153
 - cation exchange membrane (CEM) 156
 - cellulose 69, 73
 - charcoal 37
 - chemical bioelectrocatalysts 167
 - chemical energy 1, 3, 70
 - chemical vapor deposition (CVD) 38
 - chloralkali industry 1
 - Chlorella vulgaris* 155
 - cloth electrode assembly (CEA) 146
 - CMK-3 ordered carbon 37
 - cofeeding metal 37
 - colloidal crystal template 38
 - composite polymer membranes 118
 - conducting polymer, as support materials 57, 58
 - conducting polymer-grafted carbon materials 58, 59
 - conductive metal oxide, as support materials 54–56
 - conductive polyaniline (PANI) 57, 150, 155
 - conductivity 16, 17, 19, 23, 24, 36, 51, 60, 61, 92, 118, 126, 138, 188, 199
 - confocal laser scanning microscopy (CLSM) 179

- CO oxidation 49
- CO poisoning 40, 50
- corrosion 34, 44, 51, 54, 56, 59, 94, 210, 219
- covalent fictionalization strategies 44
- current collector 152
- current density 5–8, 11, 13, 22, 23, 53, 150, 154, 155, 199, 221, 227, 233
 - overall net 7
- cyclic voltammetry (CV) 219
- cycloalkyl ammonium cationic groups 132
- d**
- DABCO-based ammonium 132
- DAFC. *See* direct alcohol fuel cell (DAFC)
- DEFC. *See* direct ethanol fuel cell (DEFC)
- dehydrogenases 167
- density function theory (DFT) 50, 55, 71, 72, 76, 79, 80, 85, 222
- DFAFCs. *See* direct formic acid fuel cells (DFAFCs)
- differential electrochemical mass spectroscopy (DEMS) 76, 234
- diffusion–convection transport 190
- dimensional stability 137
- N,N*-dimethylacetamide (DMAc) 116
- direct alcohol fuel cell (DAFC)
 - electrocatalysts 215–235
 - electrocatalysts preparation 215, 216
 - carbon-supported platinum 216, 217
 - carbon-supported platinum–ruthenium 217, 218
- direct electron transfer (DET) 170, 171
 - via membrane-bound proteins 170
- direct ethanol fuel cell (DEFC) 74, 228
 - efficiency and fuel utilization. 74
 - polarization curves 235
 - with PtSn-1 as the anode catalyst 233
 - test 228
- direct formic acid fuel cells (DFAFCs) 51, 185
- direct methanol fuel cells (DMFCs) 38, 111, 185
 - basic principles of 111, 112
 - cell performances 223
 - focused research 118
 - membranes for 112
 - block copolymers 117, 118
 - composite polymer membranes 118
 - grafted polymer electrolyte membranes 117
 - perfluorosulfonic acid membranes 113, 114
 - poly(arylene ether)-type polymers 115
 - polybenzimidazoles (PBIs) 116
 - poly(ether ether) ketone (PEEK) 115
 - polyethersulfone (PES) 116, 117
 - polyimides 117
 - poly(styrene)-based electrolytes 114
 - polysulfone (PSU) 116, 117
 - properties 118–120
 - Pd₃Pt₁/C and Pt/C 221
 - single-cell polarization curves 220
 - single cell tests 222
 - direct methanol fuel cells, principles 71
 - disordered mesoporous carbon (DOMC) 35
 - disulfonated poly(arylene ether sulfone) copolymer 115
- DMFCs. *See* direct methanol fuel cells (DMFCs)
- e**
- electrical energy 1, 69, 74, 145, 175
- electrocatalysts
 - for direct alcohol fuel cells 215–235
 - for ethanol electrooxidation 227–235
 - for methanol oxidation reaction 222–226
 - for oxygen reduction reaction 218–222
- electrocatalytic activities, of Pt/CNT catalysts 46
- electrocatalytic reactions 33, 35, 191
- electrochemical active surface area (ECSA) 58
- electrochemical half reactions 4, 7, 26
- electrochemical reactions 3, 8, 33, 57, 96, 128, 145, 186, 188–190, 197, 201. *See also* electrocatalysts
- electrode–electrolyte interface 34
- electrodeposition 49, 194
- electrolyte ionic resistivity 189
- electron spin resonance (ESR) 34
- electron transfer pathway
 - direct transfer via membrane proteins 171
 - between microorganisms and electrodes 170
 - *Pseudomonas* sp. 173
- electrooxidation 70
 - electrocatalysts for ethanol 226
 - for ethanol, reaction mechanisms and catalysts 74–77
 - C–C breakage steps 76
 - decomposition on RhPt/SnO₂ 77
 - function of Sn 76
 - proposed mechanisms 75
 - ethylene glycol, reaction mechanisms and catalysts 81, 82
 - proposed mechanism 81
 - glycerol, reaction mechanisms and catalysts for 82–84
 - pathways using online collection and off-line HPLC analysis 85

- proposed mechanism on Pd catalysts 83
- IrSn/C for ethanol electrooxidation 234
- polyols 79–81
- products 70
- PtSn/C for ethanol electrooxidation 229
- of selected alcohols at standard conditions 70
- enzyme-based biofuel cells 155
- EOR. *See* ethanol, oxidation reaction (EOR)
- equilibrium kinetics 4
 - activation energies 6
 - current i 4, 6
 - rate constant 5
 - reaction rate 5
- ethanol
 - decomposition on RhPt/SnO₂ 77
 - oxidation reaction (EOR) 70, 75, 76, 79, 216, 229, 234
 - utilization 70
- ethanol electrooxidation. *See also*
 - electrooxidation
 - CV results of 227
 - electrocatalysts 227–235
 - residues 233
- ethanol fuel cell. *See* direct ethanol fuel cell
- ethylene glycol (EG) 69
- exopolymeric substances (EPS) 171
- extracellular electron transfer (EET) 167, 171, 173

f

- FePc-based cathode 154
- fermentations 69, 173
 - glucose 173
 - lignocellulose 152
 - microbial 174
- ferricyanide 154
- fluorescence in situ hybridization (FISH) 179
- formaldehyde 38, 216, 234, 235
- fuel cell polarization
 - and power curve 176
- fuel–oxidant configuration 188
- fuel–oxidant interface 191
- fuel utilization 190
- fullerene (C₆₀) film electrode 49
- furfuryl alcohol 37

g

- gas diffusion electrode (GDE) 15, 201, 203
- gas diffusion layer (GDL) 4
- gastrobots 174
- Gaussian distribution 198
- Geobacter* biofilms 177, 178

- OmcZ 179
- Geobacter sulfurreducens* 150, 168, 171
- Gibbs free energy 5, 222
- glycerol 69, 70, 79, 80, 83, 84
- GNFs. *See* graphite nanofibers (GNFs)
- GNS. *See* graphene, nanosheets (GNS)
- grafted polymer electrolyte membranes 117
- graphene 35
 - nanosheets (GNS) 49, 95
 - self-assembly of mixed Pt and Au nanoparticles
 - onto PDDA-functionalized graphene 52
 - sheets 95
 - as support materials for fuel cells 49–52
- graphite 198
 - electrode 147, 177, 193
 - fiber 40, 61
 - granular 148
- graphite nanofibers (GNFs)
 - Pt/GNF catalyst 42
 - Pt/GNF materials 40
 - Pt–Ru/GNF nanocomposite 40
 - as support materials 39–42, 61
 - surface reconstruction on 42
 - used to support metal nanoparticles 40
- graphitic mesoporous carbon (GMPC) 38, 39
- greenhouse gas emissions 3

h

- haloalkylation 128
- HCOOH oxidation 51
 - on a Pt1Au8/PDDA–G catalyst 51
- HEIs. *See* hydroxide exchange ionomers (HEIs)
- HEMFCs. *See* hydroxide exchange membrane fuel cells (HEMFCs)
- HEMs. *See* hydroxide exchange membranes (HEMs)
- heterogeneous hydrogenation 69
- Heyrovsky–Volmer mechanism 9
- high-electron-density polymer matrix 134
- high-performance polymer membranes 1
- Hoffmann elimination mechanism 131
- H₂/O₂ fuel cells 15
- HOR. *See* hydrogen oxidation reaction (HOR)
- HR-EDS analysis 224, 226, 230, 233
 - Pt₃Sn/C nanoparticles 229, 230
- humidification 24
 - effect of 25
 - effect on Tokuyama AAEM 25
 - for membrane 25
- hydrogen oxidation reaction (HOR) 4, 8, 9, 14, 16, 24, 26, 208
 - in alkaline 13–15

- anode 24
- exchange current density for 15
- mechanism 14
- nonbulk metal 15
- hydroperoxide oxidation decomposition
 - method 216
- hydroxide-conducting membrane 3
- hydroxide-conducting polymer
 - electrolytes 125
- hydroxide conductivity 125
- hydroxide exchange ionomers (HEIs) 125
 - definition 125
 - functions 125, 126
 - requirements 126
 - – controlled solubility 128
- hydroxide exchange membrane fuel cells (HEMFCs) 125–128, 133, 140
- hydroxide exchange membranes (HEMs) 125
 - block polymers 138
 - cationic functional group 130
 - cationic functional group, structure/properties of 130
 - – cycloalkyl ammonium 132
 - – guanidinium 133
 - – imidazolium 133
 - – pyridinium 133
 - – quaternary nitrogen-based cationic functional groups 130
 - – tetraalkyl ammonium 130–132
 - chemical cross-linking, structure/properties 138
 - – chemical structure 138–140
 - – physical structure 140
 - definition 125
 - features 126
 - functions 125, 126
 - high fuel crossover/gas permeability 129
 - high solvent resistance 128
 - low fuel crossover/gas permeability 128
 - phosphonium 134
 - polymer main chain, structure/properties 134
 - – aliphatic main-chain polymers 137
 - – aromatic main-chain polymers 137
 - – chemical structure 134–137
 - – sequential structure 138
 - properties of
 - – fabrications and categories 128
 - – membrane radiation grafting 129
 - – monomer polymerization 129
 - – polymer functionalization 128, 129
 - – reinforcement methods 130

- quaternary phosphorus-based cationic functional groups 134
- requirements 126
- – controlled solubility 128
- – excellent chemical stability 127
- – high hydroxide conductivity 126, 127
- – sufficient physical stability 127
- hydroxide ions 2

i

- imidazolium-functionalized polymers 133
- imidazolium systems 133
- impregnation–reduction method 216
- indium tin oxide (ITO) nanocrystals 50
- ion exchange capacity (IEC) 130
- ionomer 3, 19, 22, 23, 79, 133, 134
- iron ethylenediaminetetraacetic acid (Fe-EDTA) catholyte 154
- ITO–graphene hybrid 50

k

- Ketjen Black-supported catalysts 34
- KOH-doped membrane 22

l

- laminar flow-based fuel cells (LLFCs)
 - alkaline cathode stream 209
 - carrier substrate with configuration of 198
 - flow-over designs 187
 - flow-through design
 - – multiple inlets 201
 - formic acid concentration 199
 - formic acid/methanol 204, 205
 - hydrazine fuel cells 207
 - membraneless
 - – air-breathing cathodes 202
 - – power density 203
 - – radial flow architecture 201
 - microfluidics, advantages 190
 - vanadium redox couples 206
 - vanadium redox fuel cell, energy density of 207
- Levich–Koutecky equation 14
- lignocellulose 152
- lithium batteries, in electronic devices 116
- LLFCs. *See* laminar flow-based fuel cells (LLFCs)
- low-temperature
 - direct alcohol fuel cells (DAFCs) 69, 70
 - fuel cells 1
 - – conventional 2
 - polymer electrolyte fuel cells 69

m

- mass conservation equation 190
- mass transport limitation 34, 35
- MEA. *See* membrane electrode assembly (MEA)
- mediated electron transfer (MET) 170, 172
- membrane electrode assembly (MEA) 3, 127, 146, 175, 186, 222
 - constructed with Pt/N–graphene as ORR catalyst 53
 - polarization and power density curves on 53, 54
 - preparation 222
 - Pt/MWNTs thin-film electrode-based MEA 94
 - Pt supports in MEA cathode 39
- membraneless microfluidic fuel cells 185
- membrane proton conductivity 119
- membrane radiation grafting 129
- mesoporous carbon as support materials 35–39
- metal carbides and metal nitrides, as catalyst supports 56
- metal content, designing electrocatalyst 33
 - DOE target 33
 - loading in electrode 33
- metal electrocatalysts, synthetic methods of 84–86
 - colloidal method 87
 - organic-phase method 89, 90
 - polyol method 87–89
 - impregnation method 86, 87
 - microemulsion method 90
 - spray conversion reaction process 91
- metal–metal oxide catalyst 50, 51, 54
- metal nanoparticles 45
 - on graphene 50
- metal oxides 50, 51, 54
- methanol 69
 - crossover 112
 - oxidation 37
 - oxidation as a catalyst support 38
- methanol electrooxidation 47
 - PtRu model catalyst for 226
 - reaction mechanisms and catalysts for 71–73
- methanol oxidation catalyst 215
- methanol oxidation reaction (MOR) 53, 215
 - carbon-supported platinum–ruthenium for 223
 - competitive MOR activity compared with commercial PtRu/C (E-TEK) 92
 - electrocatalysts 222–226
 - carbon-supported platinum–ruthenium 223–226
 - composition screening 222, 223, 227–229
 - IrSn/C for ethanol electrooxidation 234, 235
 - PtSn/C for ethanol electrooxidation 229–234
 - electrocatalysts for 222
 - enhancement of MOR activity to the synergistic effects of Ru 73
 - involving oxophilic C–N defects near C/Pt catalyst particle interface 53
 - promoters adopted to enhance activity of Pt toward 93
 - PtRu/DWNTs, MOR activity 93
- methanol permeability performance data 119
- methanol-tolerant cathode 222
- 1-methyl-2-pyrrolidone (NMP) 116
- MFC. *See* microbial fuel cell (MFC)
- microbial bioanode, polarization curve 169
- microbial bioelectrocatalysts 167, 168
 - for low-temperature fuel cell 169
- microbial bioelectrochemical systems 174
- microbial electron transfer mechanisms 169
 - direct electron transfer 170–172
 - mediated electron transfer (MET) 172, 173
 - on primary metabolites 173
 - secondary metabolites 173
- microbial electrosynthesis cell 174
- microbial fuel cell (MFC) 2, 145, 173
 - with an algae-grown cathode 155
 - anode materials 147, 173
 - with biofilm on surface 146
 - fiber carbon materials 148, 149
 - granular carbon materials 148
 - modification of anode materials 149, 150
 - porous carbon materials 149
 - solid carbon materials 147, 148
 - cathode 150
 - catalyst binders 151
 - cathode fouling 152, 153
 - current collector 152
 - diffusion layers 152
 - cathode catalysts 153
 - biocathodes 155
 - carbon cathodes 154
 - cathode with non-Pt metal catalyst 153, 154
 - conductive polymers 155
 - Pt cathode modified with nanomaterials 153
 - configuration 146, 147
 - separators 156

- anion exchange membranes 157
- bipolar membranes 157
- cation exchange membranes 156, 157
- filtration membranes 157, 158
- porous fabrics 158
- sketches of 174
- microelectromechanical systems (MEMS)-based approaches 186
- microfiltration (MF) membrane 156
- microfluidic fuel cells 2, 185
 - devices 192–196
 - electrolyte types 208–210
 - flow-over designs 187
 - fuel types 203–207
 - fundamentals 187–189
 - hybrid system, implementation 185
 - maximum power density 206
 - membraneless LFFC designs 190–203
 - air-breathing cathode, flow architecture/fabrication 201, 202
 - flow-over design, flow architecture/fabrication of 197–200
 - flow-through design, flow architecture/fabrication of 200, 201
 - performance comparison 203
 - microchannel 186
 - microelectromechanical systems (MEMS)-based approaches 186
 - oxidant streams flow 186
 - oxidant types 207, 208
- microfluidic systems 188
- micro fuel cells 185
- mitochondria 167
- 3M nanostructured thin film (NSTF) catalyst 59, 60
- MOR. *See* methanol oxidation reaction (MOR)
- MWCNTs
 - adsorption of 1-aminopyrene (1-AP) molecules 47
 - functionalization method 44
 - functionalization method of 44
 - with thiol groups 45
 - functionalized MWCNTs with thiol groups 45
 - intrinsic properties 46
 - positive surface charge on 46
 - Pt/MWCNT composite 45
- n**
- Nafion 113, 189
 - membranes 3
- nanoparticle aggregates 45
- NanoSIMS 178
- nanowires 89, 170, 171, 179
- 1,4-naphthoquinone (NQ) 149
- Navier–Stokes equations 188
- Nernst equation 7, 188
- nitrogen-doped carbon materials 39, 52–54
- nitrogen-doped graphene nanoplatelets 53
- nitrogen-rich ethylenediamine (ED) precursor 53
- noble metal-free electrode electrocatalysts 173
- nonhumidified operation 25
- nucleophilic addition–elimination mechanism 133
- NWs/carbon paper composite 56
- o**
- OCV. *See* open-circuit voltage (OCV)
- ohmic resistance 34, 189
- OMC. *See* ordered mesoporous carbon (OMC)
- open-circuit voltage (OCV) 15, 22, 23, 222, 223, 228, 229
- ordered mesoporous carbon (OMC) 35, 87, 94, 95
 - supported electrocatalysts 35
 - supported Pt catalysts 39
 - synthesis procedures from an OMS template 36
- ordered nanoporous carbons
 - obtained by template synthesis using ordered mesoporous silica SBA-15 37
- ORR. *See* oxygen reduction reaction (ORR)
- oxametallacyclic conformation 77
- oxidants 145
- oxygen-containing species 47
- oxygen reduction reaction (ORR) 4, 8–10, 12, 13, 16, 20, 37, 39, 52–54, 78, 207, 216
 - bifunctional mechanism involving oxophilic C–N defects 53
 - catalyst support of Pt for 53
 - electrocatalysts 218–222
 - highly active PtFe 218, 219
 - methanol-tolerant PtPd 219–222
 - PtFe/C300 exhibits 219
 - highly active PtFe electrocatalysts for 218, 219
 - mechanism 12
 - direct four-electron pathway 12
 - serial four-electron pathway 12
 - methanol-tolerant PtPd electrocatalysts for 219–222
 - of Pd₃Pt₁/C 221
 - pH effect 13
 - polarization curves for 221
 - PtFe/C300 exhibits 219

- superior ORR kinetics of AFC 15
- volcano plot of activity of transition metals for 10

P

- palladium–cobalt (Pd–Co) alloy 202
- PaniNF-supported Pt electrocatalyst 57
- particle size 37, 41, 43, 85, 86, 93, 216, 219, 229, 235
 - distribution 90
- PEMFC. *See* proton exchange membrane fuel cell (PEMFC)
- PEM fuel cells 3
 - catalyst layer, illustration of three-phase boundary *vs.* two-phase boundary 58
 - common acidic 3
 - principles 4
 - Butler–Volmer Kinetics 7, 8
 - equilibrium kinetics 4–7
 - exchange current density 8–10
 - fuel cell polarization curve 10, 11
 - PEM-direct ethanol fuel cells 74
 - *vs.* AEMFCs 78
- perfluorosulfonic acid membranes 113, 114
- phenol 38, 129
- photolithography process, rigid
 - microchannels 199
- photomask 197
- platinum nanoparticles 50
- polar curves 22, 23
- polarization 4, 8, 20, 21, 53, 151
 - curves 176, 221
- poly(acrylic acid sodium) (PAA) 47
- polyaniline nanofibers (PaniNFs) 57
- polyanions (poly(styrenesulfonic acid) (PSS) 46, 47
- poly(aryl benzimidazoles) 137
- poly(arylene ether ether ketones) 115
- poly(arylene ether sulfones) 115
- poly(arylene ether)-type polymers, direct
 - methanol fuel cells 115
- poly(aryl ether ketones) 137
- poly(aryl ethers) 137
- poly(aryl imides) 137
- polybenzimidazole 1, 116
- polybenzimidazoles (PBIs) 116
 - direct methanol fuel cells 116
- poly(dimethylsiloxane) (PDMS) 152, 197
- polyelectrolytes 45
- poly(ether ether) ketone (PEEK) 115
- poly(ether ether ketone ketone) (PEEKK) 115
- polyethersulfone (PES) 116, 117
- polyimides 117
- polymer electrolyte membrane (PEM) fuel 3
- polymerization processes 38
- polymer membranes 1
- polymethylmethacrylate (PMMA) 198, 199
- poly(methyl vinyl ether-alt-maleic anhydride) (PMVMA) membrane 24
- poly(*N*-acetylaniline) (PAANI) 58
- poly(*N*-vinyl carbazole) (PVK) 58
- polyol method 216, 218
- poly (diallyldimethylammonium chloride) (PDDA) 45, 51
- poly(phenylenes) 137
- polypyrrole/anthraquinone-2-sulfonate (PPy/AQS) conductive polymer 155
- poly(sodium 4-styrenesulfonate) (PSS) 45
- poly(styrene)-based electrolytes 114
- polysulfone 130
- polysulfone (PSU) 116, 117, 132
- polytetrafluoroethylene (PTFE) 151
- poly(9-(4-vinyl-phenyl)carbazole) (P4VPCz) 58
- pore topology 36
- porous materials 156
- postpolymerization approach 115
- potential efficiency 74
- PPy/anthraquinone-2,6-disulfonate (AQDS)
 - composite 155
- proton conductivity 116
- proton exchange membrane (PEM)-based
 - direct methanol fuel cell 71
 - principles 71
- proton exchange membrane fuel cell (PEMFC) 33, 35, 54, 60, 126, 185, 201, 215
 - performance 33
- proton exchange membranes (PEMs) 126
- Pt agglomeration 91
- Pt–Au/PDDA–G electrocatalysts 51
- Pt-based electrocatalysts 218
- Pt-bimetallic catalysts, XRD and TEM
 - results 229
- Pt cathode modified with nanomaterials 153
- Pt/C (E-TEK) catalyst 38
- Pt/C catalysts ethanol oxidation, linear sweep
 - voltammograms 234
- Pt/C–HCHO, TEM images for 217
- Pt-containing gas diffusion electrode (GDE) 15
- Pt electrocatalyst carbon-supported 34
- Pt/GNS electrocatalyst 40, 49
- Pt–ITO–graphene 50
 - nanocomposites 50
- Pt–M alloys 72
- Pt/MWCNT composite 45
- Pt nanoparticles 46, 49

- on mesoporous carbon 38
- possible effect of charged functional groups 47
- Pt particle size 33, 34
- Pt nanoparticles supported on both OMCs 39
- Pt/PaniNFs catalyst 57
- PtPd carbon-supported 227
- Pt–Ru alloy catalyst 39, 49
- Pt/Ru atomic ratio 40
- PtRu carbon-supported 217, 227
 - for methanol electrooxidation 225
 - vs. SCE 227
 - XRD and TEM characterization 218
- Pt–Ru catalysts 58
- PtRu/C-EG catalyst 224
- PtRu/C-EG DMFC single cell
 - performance 225
- Pt–Ru/GNF nanocomposite 40
- Pt–Ru nanoparticles 37, 47
 - on 1-AP-MWCNTs 48
- Pt–Ru/PVK composite 58
- Pt–S bonds 45
- PtSn carbon-supported 227
- PtSn catalysts 70
- PtSn/C catalysts 223
 - for ethanol fuel cells 230
- Pt₃Sn/C catalysts
 - ethanol oxidation, linear sweep voltammograms of 234
- Pt/TiO₂ catalyst 55
- PtW carbon-supported 227
- Pt/WO₃-based electrode 56
- pyrene-containing molecules 45
- pyrenyl group 47
- pyridinium hydroxide 133
- pyrolysis process 36
- pyrolyzing carbon mixed iron-chelated ethylenediaminetetraacetic acid (PFeEDTA/C) 154

q

- quaternary ammonium-containing membranes 24
- quaternary ammonium hydroxide (QAOH) polymers 78
- quaternary phosphonium 130
- quaternization reaction 129

r

- reverse electrolysis 3
- Rhodferax* 171
- rotating ring disk electrode (RRDE) 13
- ruthenium acetylacetonates 37

s

- SBA-15 mesoporous silica 37
- selectively transport 1
- self-purging effect 24
- semiconductor 45
- SEM image of PtRu/DWNTs thin film 93
- Shewanella oneidensis* 171
- Shewanella putrefaciens* 150
- silica–carbon composite 36
- sintering, of platinum particles 59
- small organic molecules (SOMs) 33
- SNIFTIRS spectrum 75
- soft lithography 197
- styrene-based electrolytes 114
- sulfonated PEEK (SPEEK) 115
 - repeat unit of 115
- sulfonated poly(styrene) 114
- sulfonated polystyrene-block-poly(ethylene-ran-butylene)-block-polystyrene (SSEBS) copolymers 118
- sulfonated styrene-based monomers 114
- support materials, for fuel cells
 - carbon nanotubes 42–49
 - conducting polymer 57, 58
 - grafted carbon materials 58, 59
 - conductive metal oxide 54–56
 - graphene as support materials 49–52
 - graphite nanofibers 39–42
 - mesoporous carbon 35–39
 - metal carbides and metal nitrides 56
 - 3M nanostructured thin film 59, 60
 - nitrogen-doped carbon materials 52–54
- surface-enhanced Raman resonance scattering (SERRS) 178
- surface oxidation 44

t

- Tafel plots 178
- Tafel–Volmer mechanism 15
- TEM images
 - distribution histograms of Pt–Ru nanoparticles
 - AO-MWCNTs 48
 - 1-AP-MWCNTs 48
 - Pt–Ru loading 48
 - GNFs 42
 - HR-EDS analysis 230
 - Pt/C 217
 - Pt/C-EG 216, 217
 - Pt/C-HCHO 217
 - Pt ITO graphene 51
 - Pt nanoparticles deposited on 45
 - PtRu/C-EG 218, 224, 225

- PtRu/C-IM 224
 - Pt–Ru–CMMs 37, 38
 - PtRu/CNT 92
 - PtRu/DWNTs 93
 - PtRu-EG 224
 - Pt–Ru/GNF nanocomposite 41
 - PtRu-IM 224
 - PtSn-1 232
 - PtSn-2 232
 - Pt₃Sn/C nanoparticles 229, 230
 - tetramethoxyphenylporphyrin (TMPP) 153
 - thermodynamic energy conversion
 - efficiencies 69, 70
 - thermodynamics 3
 - TiO₂ nanotube-supported Pt
 - catalysts 54, 55
 - removal of CO poisoning intermediates during methanol oxidation over 55
 - titanium diboride (TiB₂) 56
 - titanium oxide 55
 - trimethyl ammonium- functionalized polymer
 - IEC-normalized hydroxide conductivity of 131
 - trimethylbenzene 37
 - triple-phase boundary (TPB) 35
 - tris(2,4,6-trimethoxyphenyl) benzyl phosphonium hydroxide functional group 134
 - tungsten carbides 56
 - tungsten oxides 56
- u**
- ultrafiltration (UF) membrane 156
 - unmanned aerial vehicles (UAVs) 185
- v**
- Vegard's law 231
 - Vulcan carbon (XC-72) 34, 35, 39, 40, 49, 51, 216
 - supported Pt catalyst 54
- w**
- water management 26
- x**
- x-ray absorption spectroscopy 37
 - x-ray diffraction (XRD) 218
 - calculation results of PtRu/C-EG electrocatalyst 225
 - carbon-supported Pt and Pt-bimetallic catalysts 229
 - characterization results of PtRu/C prepared by 218
 - patterns of Pt–Fe/C catalysts 219
 - patterns of PtSn-1 and PtSn-2 231
 - Pt–Ru/GNF nanocomposite 41
 - x-ray photoelectron spectroscopy (XPS) 34, 47