

Contents

Volume 1

SYNTHESIS

Chapter 1	Fluorinated Peroxides as Initiators of Fluorinated Polymers	3
	<i>Shohei Yamazaki and Hideo Sawada</i>	
1.1	Introduction	3
1.2	Computational Methods	5
1.3	Results and Discussion	6
1.3.1	Molecular Structure of Alkanoyl/Fluoroalkanoyl Peroxides	7
1.3.2	Molecular Structure of Alkanoyl/Fluoroalkanoyl Radicals	10
1.3.3	Bond Dissociation Energy of Alkanoyl/Fluoroalkanoyl Peroxides and Radicals	12
1.3.4	Thermal Decomposition of Alkanoyl/Fluoroalkanoyl Peroxides	17
1.4	Conclusion	20
	Acknowledgements	21
	References	21
Chapter 2	Fluoroalkylated Styrene Dimers: Synthesis, Properties, and Applications	22
	<i>Masato Yoshida</i>	
2.1	Introduction	22

RSC Polymer Chemistry Series No. 23

Fluorinated Polymers: Volume 1: Synthesis, Properties, Processing and Simulation
 Edited by Bruno Ameduri and Hideo Sawada

© The Royal Society of Chemistry 2017

Published by the Royal Society of Chemistry, www.rsc.org

2.2	General Aspects of the Addition of Perfluoroalkyl Radicals to Olefinic Compounds	23
2.3	Process for the Formation of Head-to-head Type Styrene Dimers Bearing Two Fluoroalkyl End-groups, as a Basic Principle for Reactions Between Two Radicals	25
2.4	Synthesis and Characteristic Properties of Styrene Dimers, as the Smallest Model Unit for Fluoroalkyl End-capped Oligomers and Polymers	29
2.5	Conclusion	37
	Acknowledgements	37
	References	37
Chapter 3	Anionic Polymerization of Fluorinated Vinyl Monomers	40
	<i>Tadashi Narita</i>	
3.1	Introduction	40
3.2	Anionic Polymerization Reactivity of Fluorinated Acrylates and Methacrylates	43
3.3	Anionic Polymerization Reactivity of Fluorinated 1,3-Butadiene	53
3.4	Anionic Polymerization Reactivity of Fluorinated Styrenes	67
3.5	Conclusion	69
	References	70
Chapter 4	Polyaddition of Fluorinated Vinyl Monomers	72
	<i>Tadashi Narita</i>	
4.1	Introduction	72
4.2	Anionic Polyaddition of Fluorinated Vinyl Monomers	73
4.3	Radical Polyaddition of Fluorinated Vinyl Monomers	79
4.4	Conclusion	101
	References	101
Chapter 5	Semifluorinated Aromatic Polymers and Their Properties	103
	<i>Susanta Banerjee and Anindita Ghosh</i>	
5.1	General Introduction to Aromatic Fluorinated Polymers	103
5.2	Fluorinated Poly(Arylene Ether)s	104
5.2.1	Preparation of Fluorinated Poly(Arylene Ether)s	105

5.2.2	Properties of Fluorinated Poly(Arylene Ether)s	108
5.2.3	Fluorinated Poly(Arylene Ether)s for Membrane-based Applications	111
5.3	Fluorinated Poly(Ether Imide)s	122
5.3.1	Preparation of Fluorinated Poly(Ether Imide)s	124
5.3.2	Properties of Fluorinated Poly(Ether Imide)s	125
5.3.3	Fluorinated Poly(Ether Imide)s for Membrane-based Applications	133
5.4	Fluorinated Poly(Ether Amide)s	141
5.4.1	Preparation of Fluorinated Poly(Ether Amide)s	141
5.4.2	Properties of Fluorinated Poly(Ether Amide)s	141
5.4.3	Fluorinated Poly(Ether Amide)s for Membrane-based Applications	146
5.5	Fluorinated Polyazoles	153
5.5.1	Preparation of Fluorinated Poly(Benzimidazole)s	153
5.5.2	Preparation of Fluorinated Poly(Benzoxazole)s	158
5.6	Miscellaneous Aromatic Fluorinated Polymers	163
5.6.1	Fluorinated Poly(Arylene)s	163
5.6.2	Fluorinated Hyperbranched Polymers	163
5.6.3	Fluorinated Dendrimers	168
5.6.4	Fluorinated Acrylate Polymers	168
5.6.5	Fluorinated Polymers with Perfluorocyclobutyl (PFCB) Units	168
5.6.6	Fluorinated Polymers with Octafluorocyclopentene Units	175
5.6.7	Fluorinated Phosphorus-containing Polymers	175
5.6.8	Fluorinated Microporous Copolymer as Gas Separation Membrane	175
5.6.9	Quaternized Fluorinated Copolymers as Anion-conductive Membranes	177
5.6.10	ETFE Film Grafted with Pentafluorostyrene as a Protein-exchange Membrane	178
5.7	Conclusion	181
	Abbreviations	182
	References	183

Chapter 6	Synthesis of Fluoro-functional Conjugated Polymers by Electrochemical Methods	190
	<i>Shinsuke Inagi</i>	
6.1	Introduction	190
6.2	Electropolymerization of Fluoro-aromatic Compounds	191
6.2.1	Electropolymerization of Aromatic Monomers	191
6.2.2	Electropolymerization of Fluoro-aromatic Monomers	193
6.2.3	Surface Morphology and Properties of Fluoro-functionalized Conjugated Polymers	194
6.2.4	Fluoro-functionalized Conjugated Polymers for Electronic Materials	196
6.3	Electrochemical Fluorination of Conjugated Polymers	197
6.3.1	Electrochemical Polymer Reactions	197
6.3.2	Anodic Fluorination of Polyfluorene Derivatives	198
6.3.3	Fluorination of Polyaniline by the CRS Method	201
6.4	Surface Modification of Conjugated Polymers with Fluoro-functional Groups by Electrochemical Methods	202
6.4.1	Conjugated Polymer Surface	202
6.4.2	Electro-click Reaction on Conjugated Polymer Surfaces	202
6.4.3	Gradient Surface Modification by the Electro-click Method	204
6.5	Conclusion	206
	References	207
Chapter 7	Supercritical Carbon Dioxide as Reaction Medium for Fluoropolymer Synthesis and Kinetic Investigations into Radical Polymerizations of VDF and HFP	211
	<i>Benjamin Hosemann, Rebekka Siegmann and Sabine Beuermann</i>	
7.1	Introduction	211
7.2	Supercritical Carbon Dioxide as Reaction Medium for Fluoropolymer Synthesis	214
7.3	In-line Monitoring of Vinylidene Fluoride Homo- and Copolymerizations in the Homogeneous Phase with Supercritical Carbon Dioxide	215

7.4	Kinetic Investigations for Vinylidene Fluoride Homo- and Copolymerizations in Supercritical Carbon Dioxide	216
7.4.1	Initiator Decomposition Kinetics	217
7.4.2	Propagation Rate Coefficients for VDF Homo- and Copolymerizations	219
7.4.3	Termination Kinetics of VDF-HFP copolymerizations	225
	References	229

PROPERTIES

Chapter 8	Structure–Property Relations in Semifluorinated Polymethacrylates	235
	<i>D. Pospiech, D. Jehnichen, P. Chunsod, P. Friedel, F. Simon and K. Grundke</i>	
8.1	Introduction	235
8.2	Experimental	239
8.2.1	Materials	239
8.2.2	Polymer Synthesis	239
8.2.3	Preparation of Thin Films	240
8.2.4	Characterization	241
8.2.5	Simulations	244
8.3	Results and Discussion	245
8.3.1	Synthesis Results	245
8.3.2	Solid-state Structure	246
8.3.3	Simulation Results	248
8.3.4	Temperature Behavior	250
8.4	Surface Properties	254
8.4.1	Surface Structure as Investigated by XRR and GISAXS	254
8.4.2	Surface Composition	256
8.4.3	Wetting Behavior	261
8.5	Conclusion	269
	Acknowledgements	270
	References	270
Chapter 9	Preparation and Self-assembly of Amphiphilic Fluoropolymers	276
	<i>Chun Feng and Xiaoyu Huang</i>	
9.1	Introduction	276
9.2	Preparation and Self-assembly of Linear Fluoropolymers	278

9.3	Preparation and Self-assembly of Non-linear Fluoropolymers	292
9.4	Conclusion	301
	Acknowledgements	303
	References	303

PROCESSING

Chapter 10	The Melt Viscosity Properties of Fluoroplastics – Correlations to Molecular Structure and Tailoring Principles	309
	<i>Harald Kaspar</i>	
10.1	Introduction	309
10.2	Terpolymers Under Investigation	312
10.3	Fundamentals of Melt Rheology	314
	10.3.1 Fluoropolymer Melts in Shear Flows	314
	10.3.2 Superposition Principles	317
10.4	Determining Molar Masses	320
	10.4.1 General Considerations on the Molar Mass Distribution	320
	10.4.2 Key Rheology Parameters and Dependence on the Average Molar Mass	321
	10.4.3 Diagnosing the Molar Mass Distribution of Insoluble Polymers	325
10.5	Customizing Concepts for Linear Chains	329
	10.5.1 Controlling the Average Molar Mass	329
	10.5.2 End-group Considerations in View of Chain Transfer	331
	10.5.3 Fine Tuning the Molar Mass Distribution	332
10.6	Tailoring the Polymer Topology by Long-chain Branching	335
	10.6.1 Evolution from Primary to Higher Order Populations	335
	10.6.2 Qualifying Complex Chain Architectures	339
	10.6.3 Long-chain Branched Fluoropolymers in Elongational Flows	343
	10.6.4 Benefits in Melt Processing	348
10.7	Conclusion	351
	Abbreviations and Symbols	353
	Abbreviations	353
	Symbols	354
	References	356

SIMULATION

Chapter 11 Molecular Simulation of Fluorinated Telomer and Polymers 361

*François Porzio, Étienne Cuierrier, Alexandre Fleury,
Bruno Améduri and Armand Soldera*

11.1	Introduction	361
11.2	Theory	363
	11.2.1 Arrhenius Equation	363
	11.2.2 Transition-state Theory	364
11.3	Quantum Chemistry	368
	11.3.1 Resolving the Schrödinger Equation	368
	11.3.2 Errors	370
11.4	Application	374
	11.4.1 Context	374
	11.4.2 The Molecular Structure	375
	11.4.3 The Symmetry Factor σ	377
	11.4.4 The TS Quasi-partition Function	378
	11.4.5 The Free Reactant Partition Function per Unit Volume	378
	11.4.6 The Activation Energy E_a	379
	11.4.7 The Rate Constants and the Chain Transfer Constant	380
	11.4.8 Intrinsic Reaction Coordinates (IRCs)	380
	11.4.9 Perspectives: Study of Regioselectivity for Iodine Transfer Polymerization	381
11.5	Conclusion	382
	References	383
	Subject Index	386

Volume 2

APPLICATIONS

Chapter 1 Industrial Aspects of Fluorinated Oligomers and Polymers 3

Rudy Dams and Klaus Hintzer

1.1	Introduction	3
1.2	Fluorinated Monomers and Building Blocks	4
	1.2.1 Fluorinated Monomers	4
	1.2.2 Perfluoroalkyl Building Blocks	7

1.3	Functionalized Oligomers and Their Applications	9
1.3.1	Synthesis	9
1.3.2	Derivatives of Functional Oligomers and Their Applications	11
1.4	Overview of Fluoropolymers	15
1.4.1	Fluoropolymer Production and Applications	15
1.4.2	Fluoropolymers with Functional Groups	17
1.4.3	Applications	18
1.5	Environmental Aspects	18
1.5.1	C ₈ Phase-out and Replacements	18
1.5.2	Fluoropolymer Recycling	21
1.5.3	Summary	25
	Abbreviations	26
	Monomers/Fluorochemicals	26
	Polymers	27
	References	27
Chapter 2	Fluoroalkyl Acrylate Polymers and Their Applications	32
	<i>Ikuo Yamamoto</i>	
2.1	Introduction	32
2.2	The PFOA Issue	33
2.3	Preparation	34
2.3.1	Monomers	34
2.3.2	Polymerizations	35
2.3.3	Polymer Composition	35
2.4	Expression Mechanism of Water Repellency of Fluoroalkyl Acrylate Polymers	36
2.4.1	Dynamic Contact Angle	37
2.4.2	Thermal Analysis	38
2.4.3	Molecular Aggregation States	38
2.4.4	Surface Reorganization	40
2.5	Molecular Design Concept for Short-chain Fluoroalkyl Acrylate Polymers	41
2.5.1	Comonomer	42
2.5.2	α -Substituent Group	43
2.5.3	Spacer	45
2.5.4	Perfluoroalkyl (R _f) Group	45
2.6	Applications	45
2.6.1	Textiles	45
2.6.2	Carpets	48

<i>Contents</i>	xvii
2.6.3 Paper	48
2.6.4 Non-woven Materials	48
2.6.5 Coatings	49
2.7 Outlook	49
Acknowledgements	49
References	50
Chapter 3 Structural Diversity in Fluorinated Polyphosphazenes: Exploring the Change from Crystalline Thermoplastics to High-performance Elastomers and Other New Materials	54
<i>Harry R. Allcock</i>	
3.1 Introduction	54
3.2 Synthesis Routes	55
3.3 Semicrystalline <i>Versus</i> Elastomeric or Gum-type Polyphosphazenes	59
3.4 Specific Fluoro-organophosphazenes	60
3.4.1 Poly[bis(trifluoroethoxy)phosphazene] (Compound 2)	60
3.4.2 Polymers with Longer Telomer Side-chains of Type $-\text{OCH}_2(\text{CF}_2)_x\text{CF}_2\text{H}$	60
3.4.3 Fluoroalkoxy Side-groups with CF_3 Terminal Units	61
3.4.4 Fluoroalkoxy Side-groups of the Type $-\text{OCH}_2\text{CH}_2(\text{CF}_2)_x\text{CF}_3$	62
3.4.5 Fluoroaryloxyphosphazenes	62
3.4.6 Trifluoroethylamino Side-groups	63
3.5 Mixed-substituent Elastomeric Polyphosphazenes	63
3.6 Interpenetrating Polymer Networks from PN-F and $[\text{NP}(\text{OCH}_2\text{CF}_3)_2]_n$	65
3.7 Elastomers Based on Non-covalent Interchain Interactions	66
3.8 Hybrid Fluoro-organophosphazene–Organosilicon Polymers	69
3.9 Fibers, Films and Surfaces from Polymer 2	72
3.10 Fire Resistance	73
3.11 Optical Properties: Controlled Refractive Index Polymers and Polymeric Dyes	73
3.12 Amphiphilic Polymer Membranes	73
3.13 Prospects for the Future	76
References	77

Chapter 4	Fluoroplastics and Fluoroelastomers – Basic Chemistry and High-performance Applications	80
	<i>Masahiro Ohkura and Yoshitomi Morizawa</i>	
4.1	Properties of Fluorine and Brief History of Fluoropolymers	80
4.2	Perfluoroplastics	83
4.2.1	Polytetrafluoroethylene (PTFE)	85
4.2.2	Tetrafluoroethylene–Hexafluoropropylene Copolymer (FEP)	87
4.2.3	Perfluoroalkoxy Copolymer (PFA)	88
4.2.4	Amorphous Perfluoroplastics	90
4.3	Partially Fluorinated Plastics	93
4.3.1	Poly(Chlorotrifluoroethylene) (PCTFE)	95
4.3.2	Poly(Vinylidene Fluoride) (PVdF)	95
4.3.3	Poly(Vinyl Fluoride) (PVF)	96
4.3.4	Ethylene–Tetrafluoroethylene Copolymer (ETFE)	96
4.3.5	Other Fluorine-containing Plastics	97
4.4	Fluoroelastomers	97
4.4.1	Vinylidene Fluoride Copolymer (FKM)	98
4.4.2	Tetrafluoroethylene–Propylene Copolymer (FEPM)	100
4.4.3	Perfluoroelastomer (FFKM)	100
4.4.4	Other Fluoroelastomers	101
4.5	Conclusion	103
	References	103
Chapter 5	Fluorinated Specialty Chemicals – Fluorinated Copolymers for Paints and Perfluoropolyethers for Coatings	110
	<i>Taiki Hoshino and Yoshitomi Morizawa</i>	
5.1	Synthesis and Coating Application of Partially Fluorinated Polymers	110
5.1.1	What Are Partially Fluorinated Polymers for Coatings?	111
5.1.2	Types and Characteristics of Partially Fluorinated Polymers for Coatings	112
5.1.3	Manufacturing Process for Partially Fluorinated Polymers	117
5.1.4	Examples of Coating Applications of Partially Fluorinated Polymers	118

<i>Contents</i>	xix
5.2 Synthesis and Application of Perfluoropolyethers	119
5.2.1 What Are Perfluoropolyethers?	119
5.2.2 Types and Characteristics of Perfluoropolyethers	120
5.2.3 Manufacturing Process for Perfluoropolyethers	121
5.2.4 Examples of Applications of Perfluoropolyethers	124
References	126
Chapter 6 Commercial Synthesis and Applications of Poly(Vinylidene Fluoride)	127
<i>James T. Goldbach, Ramin Amin-Sanayei, Wensheng He, James Henry, Walt Kosar, Amy Lefebvre, Gregory O'Brien, Diane Vaessen, Kurt Wood and Saeid Zerafati</i>	
6.1 Commercial Synthesis of PVDF	127
6.1.1 Properties of Vinylidene Fluoride	127
6.1.2 VDF Polymerization	128
6.1.3 Some Typical Polymerization Conditions	129
6.2 Industrial Applications of Poly(Vinylidene Fluoride)	131
6.2.1 History and Context	131
6.2.2 Key Properties of PVDF	132
6.2.3 Property Comparisons with Other Fluoropolymers	133
6.2.4 PVDF Producers	134
6.2.5 Chemical Process Industry (CPI) Applications	134
6.2.6 Wire and Cable Applications	135
6.2.7 Petrochemical Applications	137
6.2.8 PVDF Resins for Porous Membranes	139
6.2.9 PVDF in Photovoltaic Applications	140
6.2.10 PVDF in Lithium Ion Battery Applications	141
6.3 PVDF in Coatings Applications	145
6.3.1 Introduction	145
6.3.2 Types of PVDF Coatings	146
6.3.3 Performance of PVDF-based Coatings	151
6.4 Conclusion	153
References	154

Chapter 7	The Role of Perfluoropolyethers in the Development of Polymeric Proton Exchange Membrane Fuel Cells	158
	<i>M. Sansotera, M. Gola, G. Dotelli and W. Navarrini</i>	
7.1	Introduction	158
7.2	Interaction of PFPE Chains on Carbonaceous Materials	161
7.3	Effects of PFPE on Carbon Black and Carbon Fibers	163
7.3.1	PFPEs on Carbon Black	163
7.3.2	Effects of PFPE on Carbon Fibers	166
7.4	Effects of PFPE in PEMFC Gas Diffusion Layers	168
7.4.1	Macroporous Layer	168
7.4.2	Microporous Layer	172
	References	175
Chapter 8	Fluorinated Ionomers and Ionomer Membranes: Monomer and Polymer Synthesis and Applications	179
	<i>Takeshi Hirai and Yoshitomi Morizawa</i>	
8.1	Introduction and Brief History of Fluorinated Ionomer Membranes	179
8.2	Synthesis of Representative Ionomer Membranes	181
8.2.1	Sulfonic Acid-type Monomers	181
8.2.2	Carboxylic Acid-type Monomers	181
8.2.3	Polymerization	183
8.2.4	Hydrolysis, Cation Exchange and Fabrication	186
8.3	Development of Ionomer Functions in PEFC Applications	187
8.3.1	Fundamentals of PEFCs	187
8.3.2	Applications and Performance Requirements for Ionomers	191
8.3.3	Proton Exchange Membranes	192
8.3.4	Ionomers for Electrodes	202
8.4	Conclusion	203
	References	204
Chapter 9	Research and Non-major Commercial Co- and Terpolymers of Tetrafluoroethylene	206
	<i>Daniel A. Hercules, Cameron A. Parrish and Joseph S. Thrasher</i>	
9.1	Introduction and Scope	206

9.2	Co- and Terpolymers of Tetrafluoroethylene and Vinyl Ethers	209
9.2.1	Co- and Terpolymers of Tetrafluoroethylene and Alkyl Vinyl Ethers	209
9.2.2	Co- and Terpolymers of Tetrafluoroethylene and Alkyl Trifluorovinyl Ethers	215
9.2.3	Co- and Terpolymers of Tetrafluoroethylene and Perfluoroalkyl Trifluorovinyl Ethers	217
9.2.4	Co- and Terpolymers of Tetrafluoroethylene and Fluorinated Alkyl Vinyl Ethers Having Other Halogen Functionalities	218
9.2.5	Co- and Terpolymers of Tetrafluoroethylene and Fluorinated Alkyl Vinyl Ethers Having Multiple Ether Linkages on the Side-chain	219
9.2.6	Co- and Terpolymers of Tetrafluoroethylene and Fluorinated Alkyl Vinyl Ethers Having Sulfonyl Functionalities	220
9.2.7	Co- and Terpolymers of Tetrafluoroethylene and Fluorinated Alkyl Vinyl Ethers Having Amide Functionalities	221
9.2.8	Co- and Terpolymers of Tetrafluoroethylene and Fluorinated Alkyl Vinyl Ethers Having Carbonyl Functionalities	223
9.2.9	Co- and Terpolymers of Tetrafluoroethylene and Fluorinated Alkyl Vinyl Ethers Having Nitrile Functionalities (<i>e.g.</i> 8-CNVE)	224
9.2.10	Co- and Terpolymers of Tetrafluoroethylene and Fluorinated Alkyl Vinyl Ethers Having Multiple Vinyl Ether Functionalities	226
9.3	Co- and Terpolymers of Tetrafluoroethylene and Non-fluorine-containing Alkenes	228
9.4	Co- and Terpolymers of Tetrafluoroethylene and Polyfluoroalkenes	233
9.5	Co- and Terpolymers of Tetrafluoroethylene and Perfluoroalkenes	242
9.6	Co- and Terpolymers of Tetrafluoroethylene with Cyclic Monomers and Tetrafluoroethylene-based Photoresist Materials	245
9.7	Future Work and Conclusions	253
	References	254

Chapter 10 Chlorotrifluoroethylene Copolymers for Energy-applied Materials	265
<i>Bruno Ameduri</i>	
10.1 Introduction	265
10.2 Copolymers of Chlorotrifluoroethylene	266
10.2.1 Introduction	266
10.2.2 Kinetics of Radical Copolymerization of CTFE	268
10.2.3 Fluorinated Alternating Copolymers	268
10.3 CTFE Copolymers for Energy Material Applications	270
10.3.1 Polymer Electrolytes for Lithium Ion Batteries	270
10.3.2 Electroactive Devices	271
10.3.3 Fuel Cell Membranes	276
10.3.4 CTFE-containing Copolymers Bearing Phthalocyanines	294
10.4 Conclusion	294
Acknowledgements	295
References	295
Chapter 11 Fabrication of Flexible Transparent Nanohybrids with Heat-resistance Properties Using a Fluorinated Crystalline Polymer	301
<i>Atsuhiko Fujimori</i>	
11.1 Flexible Transparent Fluorinated Nanohybrids with Innovative Heat-resistance Properties: New Technology Proposal for the Fabrication of Transparent Materials Using a “Crystalline” Polymer	301
11.1.1 Introduction	301
11.1.2 Materials	305
11.1.3 Procedure	307
11.1.4 Formation and Thermal Behavior of “Crystalline” Transparent Nanohybrid	310
11.1.5 Fine Structural Analysis of “Crystalline” Transparent Nanohybrid	312
11.1.6 Improvement in Physical Properties of “Crystalline” Transparent Nanohybrid	318
11.1.7 Conclusion	325

11.2	Fabrication of Antibacterial Transparent Flexible Nanohybrid with Heat Resistance Using High-density Amorphous State Formation and Uniform Dispersion of Nanocarbons	325
11.2.1	Introduction	325
11.2.2	Materials	327
11.2.3	Procedure	332
11.2.4	Formation of Partially Fluorinated “Crystalline” Copolymer/Organo-modified Nanodiamond Hybrid with Uniform Dispersion	333
11.2.5	Fine Structural Analysis of “Crystalline” Transparent Nanohybrid with Nanodiamond	336
11.2.6	Improvement in the Behavior of the Physical Properties of “Crystalline” Transparent Nanohybrid with Nanodiamond	343
11.2.7	Conclusion	348
	References	348
Chapter 12	Creation of Superamphiphobic, Superhydrophobic/ Superoleophilic and Superhydrophilic/Superoleophobic Surfaces by Using Fluoroalkyl-endcapped Vinyltrimethoxysilane Oligomer as a Key Intermediate	353
	<i>Hideo Sawada</i>	
12.1	Introduction	353
12.2	Creation of a Superamphiphobic Surface	355
12.3	Creation of a Superhydrophilic/Superoleophobic Surface	356
12.4	Creation of Superhydrophobic/Superoleophilic Surface	359
12.5	Conclusion	363
	References	363
	Subject Index	366

