

Contents

Preface *xiii*

Foreword *xv*

1	Introduction to Ceramic Materials	1
	<i>Laura Treccani</i>	
1.1	Introduction: Ceramics for Biotechnological and Environmental Applications	1
1.2	What are Ceramic Materials?	4
1.2.1	Advanced and Traditional Ceramics	4
1.2.2	Properties of Advanced Ceramics	6
1.3	Oxide Ceramics	7
1.3.1	Alumina	7
1.3.1.1	Alumina Structure and Properties	8
1.3.1.2	Applications of Alumina: Some Examples	10
1.3.2	Titania	12
1.3.2.1	Titania Structure and Properties	12
1.3.2.2	Applications of Titania: Some Examples	14
1.3.3	Zirconia	16
1.3.3.1	Zirconia Structure and Properties	17
1.3.3.2	Applications of Zirconia: Some Examples	18
1.3.4	Silica	20
1.3.4.1	Properties of Silica	20
1.3.4.2	Application of Silica: Some Examples	23
1.3.5	Iron oxide	26
1.3.6	Barium Titanate	26
1.4	Nonoxide Ceramics	28
1.4.1	Nitrides	29
1.4.2	Carbides	29
1.5	Carbon-based Materials	30
1.6	Conclusions	32
	References	33

2	Processing Methods for Advanced Ceramics	47
	<i>Laura Treccani</i>	
2.1	Introduction	47
2.2	Powder Synthesis and Preparation	51
2.3	Shaping Methods	53
2.3.1	Pressing	53
2.3.2	Plastic Forming	54
2.3.2.1	Extrusion	54
2.3.2.2	Injection Molding	56
2.3.3	Colloidal Shaping	56
2.3.3.1	Slip Casting	57
2.3.3.2	Gel-casting	59
2.3.3.3	Freeze-casting	61
2.3.3.4	Sol-gel Process	65
2.3.3.5	Tape Casting	68
2.4	Additive Manufacturing	69
2.5	Conclusions	75
	References	75
3	Surface Modification of Ceramic Materials	85
	<i>Stephen Kroll</i>	
3.1	Introduction	85
3.2	Chemical Activation Strategies for Inert Ceramic Surfaces	87
3.2.1	Wet Chemical Hydroxylation: Acidic vs. Basic Hydroxylation	88
3.2.2	Hydrothermal Activation	90
3.2.3	Oxygen Plasma Treatment	90
3.3	Derivatization Strategies by Wet Chemistry Functionalization	92
3.3.1	Wet Chemical Silanization	93
3.3.2	Wet Chemical Nonsilane Functionalization	97
3.4	Ceramic Surface Decoration for Biotechnological and Environmental Applications	99
3.4.1	Biotechnological Applications	100
3.4.2	Environmental Applications	102
3.5	Summary and Outlook	104
	References	105
4	Atomic Force Microscopy for Imaging and Chemical Analysis of Ceramic Surfaces	119
	<i>Hannes C. Schniepp and Laura Treccani</i>	
4.1	Introduction	119
4.2	The Basic AFM Modes of Operation	121
4.2.1	Imaging modes	122
4.3	Dry AFM vs. Liquid-cell AFM	127
4.4	Technical Details About the AFM Imaging Process	128

- 4.4.1 Properties of Piezo Transducers and the Scanning Process 128
- 4.4.2 Properties of the Feedback Loops and Resulting Signals 130
- 4.4.3 Mechanical Stability and Tip Size Effects 130
- 4.4.4 Image Processing, Analysis and Interpretation 131
- 4.4.5 Secondary Contrasting Techniques 132
- 4.4.6 Suitability of Samples and Sample Preparation 133
- 4.5 Application of AFM for Biotechnological and Environmental Purposes 134
- 4.5.1 Testing the Surface Charges and Surface Chemistry of Functionalised Ceramics Surfaces 135
- 4.5.2 AFM for Environmental Applications 138
- 4.5.3 AFM Biofilm Formation – Microbiology 142
- 4.6 Conclusions 147
- References 147

5 Surface Chemical Analysis of Ceramics and Ceramic-Enhanced Analytics 159

Ivano Alessandri

- 5.1 Introduction 159
- 5.2 Methods for Surface Chemical Analysis of Ceramics: An Overview 160
- 5.2.1 Electron Spectroscopy (PES, Auger) 160
- 5.2.2 X-ray and UV Photoelectron Spectroscopy (XPS and UPS) 161
- 5.2.3 Auger Spectroscopy 162
- 5.2.4 Surface Chemical Analysis with XPS and Auger Spectroscopy 163
- 5.2.5 Secondary Ion Mass Spectrometry (SIMS) 165
- 5.2.6 Raman and Infrared Spectroscopy 166
- 5.3 Using Ceramic Colloids and Nanomaterials for Advanced Surface Chemical Analysis 169
- 5.3.1 Playing with Light Confinement, Morphology-dependent Resonances and Evanescent Fields: Opportunities for Optical Sensing and Vibrational Spectroscopy 169
- 5.3.2 Surface Sensing by Whispering Gallery Modes 171
- 5.3.3 Applications in Raman Microspectroscopy 173
- 5.3.3.1 Microlenses for Raman Microspectroscopy 173
- 5.3.3.2 SiO₂/TiO₂ and Hollow-shell Titania Resonators: Plasmon-free SERS 175
- 5.3.3.3 Probing Surface Chemical Reactions in Metal/Ceramic Composites 179
- 5.3.4 Ceramics for Matrix-assisted Laser Desorption Mass Spectrometry 180
- 5.4 Concluding Remarks and Outlook 182
- References 182

6 Methods for Electrokinetic Surface Characteristics 193

Zbigniew Adamczyk, Monika Wasilewska, and Maria Morga

- 6.1 Introduction 193
- 6.2 The Electric Double-layer 194
- 6.3 Electrokinetic Phenomena-theory 200

6.3.1	Electrophoresis	201
6.3.2	Streaming Current-streaming Potential	205
6.3.3	Particle Covered Surfaces	209
6.4	Experimental Evidences, Applications	212
6.4.1	Electrophoretic Characteristics of Surfaces	212
6.4.2	Nano and Microparticle Suspensions	212
6.4.3	Protein Covered Particles	219
6.4.4	Streaming Current/Streaming Potential Characteristics of Surfaces	224
6.4.5	Bare Substrates	225
6.4.6	Polyelectrolyte Modified Surfaces	229
6.4.7	Particle Covered Surfaces	234
6.4.8	Protein Covered Surfaces	245
6.5	Concluding Remarks	250
	Acknowledgments	251
	References	251
7	Functionalized Surfaces and Interactions with Biomolecules	259
	<i>Fabian Meder and Laura Treccani</i>	
7.1	Introduction	259
7.2	Fundamentals of Biomolecule Interactions with Functionalized Material Surfaces	261
7.2.1	Forces Between Biomolecules and Functionalized Surfaces	261
7.2.1.1	van der Waals forces	261
7.2.1.2	Electrostatic Interaction Forces	262
7.2.1.3	Hydrogen Bonds	263
7.2.1.4	Hydration and Hydrophobic Interaction Forces	264
7.2.1.5	Steric Interaction Forces	264
7.2.1.6	Specific Interaction Forces	264
7.2.1.7	Nonequilibrium Interaction Forces	265
7.2.1.8	Other Forces	265
7.2.2	Which Biomolecule, Media, and Material Properties Influence Biomolecule–Material Interactions?	265
7.2.2.1	Material Properties Influencing Biomolecule–Material Interactions	265
7.2.2.2	Biomolecule Properties Influencing Biomolecule–Material Interactions	266
7.2.2.3	Media Properties Influencing Biomolecule–Material Interactions	266
7.2.3	Events Occurring After Adsorption	267
7.3	Influence of Surface Functionality, Multifunctionality, and Heterogeneous Surface Chemistry	268
7.3.1	Charged and Zwitterionic Groups	268
7.3.2	Polymeric Surface Functionalization	271
7.3.3	Multifunctionality and Heterogeneity	273
7.3.4	Specific-Binding Surface Chemistries	275
7.4	Conclusions and Outlook	276
	Acknowledgments	276
	References	276

8	Interactions Between Surface Material and Bacteria: From Biofilm Formation to Suppression	283
	<i>Laura Treccani</i>	
8.1	Introduction	283
8.2	Biofilm Formation	284
8.3	Theoretical Models of Bacteria–Surface Interactions	289
8.3.1	The Thermodynamic Theory	289
8.3.2	DLVO Model	292
8.3.3	Extended DLVO-Theory	294
8.4	Detrimental Effects of Biofilms: Some Examples	295
8.5	Prevention of Biofilm Formation	299
8.5.1	Stimuli Responsive Coatings	306
8.5.2	Drug Release Antibacterial Materials	309
8.6	Characterization of Antimicrobial Materials and Coatings	311
8.6.1	Standards for Biofilm Growth and Analysis	316
8.7	Conclusions and Outlook	324
	References	324
9	Carbon Nanomaterials for Antibacterial Applications	337
	<i>Michael Maas and Julia Wehling</i>	
9.1	Introduction	337
9.1.1	Important Material Properties that Govern Antibacterial Activity	339
9.1.2	Effect of Nanomaterial Size on Bacterial Viability	339
9.1.3	Effect of Nanomaterial Surface Functionalities on Cellular Viability	340
9.1.4	Proposed Mechanisms for Antibacterial Activity	341
9.2	Inherent Antibacterial Properties of Carbon Nanomaterials	341
9.2.1	Graphene	343
9.2.2	Carbon Nanotubes	346
9.2.3	Fullerenes	348
9.2.4	Nanodiamonds	350
9.2.5	Diamond-Like Carbon, Diamond Thin Films	351
9.3	Functionalization of Carbon Nanomaterials for Tailoring Antibacterial Properties	353
9.3.1	Graphene	353
9.3.2	Carbon Nanotubes	354
9.3.3	Fullerenes	354
9.3.4	Nanodiamonds	355
9.3.5	Diamond-Like Carbon, Diamond Thin Films	355
9.4	Summary and Outlook	356
	References	357
10	Mesoporous Silica and Organosilica Biosensors for Water Quality and Environmental Monitoring	369
	<i>Madhappan S. Moorthy, Saravanan Nagappan, and Chang-Sik Ha</i>	
10.1	Introduction	369
10.2	Mesoporous Silica Materials for Biosensor Development	370

- 10.3 Functionalization of Mesoporous Silica and Organosilica-Based Biosensors 373
 - 10.3.1 Surface Functionalization 373
 - 10.3.2 Immobilization of Enzymes on Silica-Based Mesoporous Materials for Biosensors 375
 - 10.3.3 Electrochemical Biosensor 379
- 10.4 Applications of Mesoporous Silica and Organosilica-Based Biosensors 381
 - 10.4.1 Glucose Sensing 381
 - 10.4.2 Hemoglobin and Myoglobin Sensing Using Molecularly Imprinted Polymers 382
 - 10.4.3 Mesoporous Silica-Based Biosensors for Water Quality Monitoring 384
 - 10.4.4 Mesoporous Silica and Organosilica-Based Materials for Toxic Gas Sensing 386
 - 10.4.5 Mesoporous Silica and Organosilica-Based Immunosensors 389
- 10.5 Conclusions and Outlook 392
 - Acknowledgments 392
 - Abbreviations 393
 - References 394

11 Ceramic-Based Adsorbents in Bioproduct Recovery and Purification 407

Marcelo Fernández-Lahore, Vikas Yelemane, Tuhidul Islam, and María Laura Carbajal

- 11.1 Introduction 407
- 11.2 Chromatography and Chromatography Support 409
- 11.3 Functionalization of Ceramic-Based Adsorbents 412
 - 11.3.1 Chemobiological Functionalization 412
 - 11.3.2 Self-Assembled Systems 414
 - 11.3.3 Composite Structures 415
- 11.4 Characterization of Ceramic Adsorbent Particles 416
 - 11.4.1 Physicochemical Analysis 416
 - 11.4.2 Surface Energetics 417
- 11.5 Fundamentals of Bioproduct Adsorption onto Ceramic Beads 418
- 11.6 Application of Ceramic-Based Adsorbents 419
 - 11.6.1 General Chromatography 419
 - 11.6.2 Facilitated Protein Purification 424
 - 11.6.3 Integrated Downstream Bioprocessing 424
- 11.7 Conclusions and Outlook 426
 - References 426

Index 439