

NANO SCIENCE
AND TECHNOLOGY

B. Bhushan
H. Fuchs (Eds.)

Applied Scanning Probe Methods XII

Characterization



Springer

NANO SCIENCE AND TECHNOLOGY

NANO SCIENCE AND TECHNOLOGY

Series Editors:

P. Avouris B. Bhushan D. Bimberg K. von Klitzing H. Sakaki R. Wiesendanger

The series NanoScience and Technology is focused on the fascinating nano-world, mesoscopic physics, analysis with atomic resolution, nano and quantum-effect devices, nanomechanics and atomic-scale processes. All the basic aspects and technology-oriented developments in this emerging discipline are covered by comprehensive and timely books. The series constitutes a survey of the relevant special topics, which are presented by leading experts in the field. These books will appeal to researchers, engineers, and advanced students.

Multiscale Dissipative Mechanisms and Hierarchical Surfaces

Friction, Superhydrophobicity, and Biomimetics

Editors: M. Nosonovsky, B. Bhushan

Applied Scanning Probe Methods I

Editors: B. Bhushan, H. Fuchs, S. Hosaka

Applied Scanning Probe Methods II

Scanning Probe Microscopy Techniques

Editors: B. Bhushan, H. Fuchs

Applied Scanning Probe Methods III

Characterization

Editors: B. Bhushan, H. Fuchs

Applied Scanning Probe Methods IV

Industrial Application

Editors: B. Bhushan, H. Fuchs

Applied Scanning Probe Methods V

Scanning Probe Microscopy Techniques

Editors: B. Bhushan, H. Fuchs, S. Kawata

Applied Scanning Probe Methods VI

Characterization

Editors: B. Bhushan, S. Kawata

Applied Scanning Probe Methods VII

Biomimetics and Industrial Applications

Editors: B. Bhushan, H. Fuchs

Applied Scanning Probe Methods VIII

Scanning Probe Microscopy Techniques

Editors: B. Bhushan, H. Fuchs, M. Tomitori

Applied Scanning Probe Methods IX

Characterization

Editors: B. Bhushan, H. Fuchs, M. Tomitori

Applied Scanning Probe Methods X

Biomimetics and Industrial Applications

Editors: B. Bhushan, H. Fuchs, M. Tomitori

Applied Scanning Probe Methods XI

Scanning Probe Microscopy

Techniques

Editors: B. Bhushan, H. Fuchs

Applied Scanning Probe Methods XII

Characterization

Editors: B. Bhushan, H. Fuchs

Applied Scanning Probe Methods XIII

Biomimetics and Industrial Applications

Editors: B. Bhushan, H. Fuchs

Magnetic Microscopy

of Nanostructures

Editors: H. Hopster and H.P. Oepen

The Physics of Nanotubes

Fundamentals of Theory, Optics and Transport Devices

Editors: S.V. Rotkin and S. Subramoney

Atomic Force Microscopy, Scanning

Nearfield Optical Microscopy

and Nanoscratching

Application to Rough

and Natural Surfaces

By G. Kaupp

Nanocatalysis

Editors: U. Heiz, U. Landman

Roadmap

of Scanning Probe Microscopy

Editors: S. Morita

Nanostructures –

Fabrication and Analysis

Editor: H. Nejo

Bharat Bhushan
Harald Fuchs

Applied Scanning Probe Methods XII

Characterization

With 101 Figures and 14 Tables
Including 70 Color Figures

 **Springer**

Editors

Prof. Dr. Bharat Bhushan
Ohio State University
Nanoprobe Laboratory for Bio- & Nanotechnology
& Biomimetics (NLB²)
201 W. 19th Ave
Columbus, Ohio 43210-1142
USA
bhushan.2@osu.edu

Prof. Dr. Harald Fuchs
Universität Münster
FB 16
Physikalisches Institut
Wilhelm-Klemm-Str. 10
48149 Münster
Germany
fuchsh@uni-muenster.de

Series Editors

Professor Dr. Phaedon Avouris
IBM Research Division
Nanometer Scale Science & Technology
Thomas J. Watson Research Center, P.O. Box 218
Yorktown Heights, NY 10598, USA

Professor Bharat Bhushan
Nanoprobe Laboratory for Bio- & Nanotechnology
and Biomimetics (NLB²) 201 W. 19th Avenue
The Ohio State University
Columbus, Ohio 43210-1142, USA

Professor Dr. Dieter Bimberg
TU Berlin, Fakultät Mathematik,
Naturwissenschaften,
Institut für Festkörperphysik
Hardenbergstr. 36, 10623 Berlin, Germany

Professor Dr., Dres. h. c. Klaus von Klitzing
Max-Planck-Institut für Festkörperforschung
Heisenbergstrasse 1, 70569 Stuttgart, Germany

Professor Hiroyuki Sakaki
University of Tokyo
Institute of Industrial Science,
4-6-1 Komaba, Meguro-ku, Tokyo 153-8505
Japan

Professor Dr. Roland Wiesendanger
Institut für Angewandte Physik
Universität Hamburg
Jungiusstrasse 11, 20355 Hamburg, Germany

ISBN: 978-3-540-85038-0

e-ISBN: 978-3-540-85039-7

NanoScience and Technology ISSN 1434-4904

Library of Congress Control Number: 2008933866

© Springer-Verlag Berlin Heidelberg 2009

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer. Violations are liable to prosecution under the German Copyright Law.

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Cover design: WMXDesign GmbH, Heidelberg

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

Preface for Applied Scanning Probe Methods Vol. XI–XIII

The extremely positive response by the advanced community to the Springer series on Applied Scanning Probe Methods I–X as well as intense engagement of the researchers working in the field of applied scanning probe techniques have led to three more volumes of this series. Following the previous concept, the chapters were focused on development of novel scanning probe microscopy techniques in Vol. XI, characterization, i.e. the application of scanning probes on various surfaces in Vol. XII, and the application of SPM probe to biomimetics and industrial applications in Vol. XIII. The three volumes will complement the previous volumes I–X, and this demonstrates the rapid development of the field since Vol. I was published in 2004. The purpose of the series is to provide scientific background to newcomers in the field as well as provide the expert in the field sound information about recent development on a worldwide basis.

Vol. XI contains contributions about recent developments in scanning probe microscopy techniques. The topics contain new concepts of high frequency dynamic SPM technique, the use of force microscope cantilever systems as sensors, ultrasonic force microscopy, nanomechanical and nanoindentation methods as well as dissipation effects in dynamic AFM, and mechanisms of atomic friction.

Vol. XII contains contributions of SPM applications on a variety of systems including biological systems for the measurement of receptor–ligand interaction, the imaging of chemical groups on living cells, and the imaging of chemical groups on live cells. These biological applications are complemented by nearfield optical microscopy in life science and adhesional friction measurements of polymers at the nanoscale using AFM. The probing of mechanical properties by indentation using AFM, as well as investigating the mechanical properties of nanocontacts, the measurement of viscous damping in confined liquids, and microtension tests using in situ AFM represent important contributions to the probing of mechanical properties of surfaces and materials. The atomic scale STM can be applied on heterogeneous semiconductor surfaces.

Vol. XIII, dealing with biomimetics and industrial applications, deals with a variety of unconventional applications such as the investigations of the epicuticular grease in potato beetle wings, mechanical properties of mollusc shells, electro-oxidative lithography for bottom-up nanofabrication, and the characterization of mechanical properties of biotool materials. The application of nanomechanics as tools for the investigation of blood clotting disease, the study of piezo-electric polymers, quantitative surface characterization, nanotribological characterization of

carbonaceous materials, and aging studies of lithium ion batteries are also presented in this volume.

We gratefully acknowledge the support of all authors representing leading scientists in academia and industry for the highly valuable contribution to Vols. XI–XIII. We also cordially thank the series editor Marion Hertel and her staff members Beate Siek and Joern Mohr from Springer for their continued support and the organizational work allowing us to get the contributions published in due time.

We sincerely hope that readers find these volumes to be scientifically stimulating and rewarding.

August 2008

Bharat Bhushan
Harald Fuchs

Contents – Volume XII

9	Direct Force Measurements of Receptor–Ligand Interactions on Living Cells	
	<i>Robert H. Eibl</i>	1
9.1	Introduction	2
9.2	Procedure	8
9.2.1	Principle of AFM Force Spectroscopy	9
9.2.2	Cell–Cell Interactions	9
9.2.3	Cell–Substrate Measurements	12
9.2.4	Specificity and Blocking Antibodies	14
9.2.5	Activation by SDF-1	17
9.3	Protocols	20
9.3.1	Cantilever Functionalization	20
9.3.2	AFM Measurement on Living Cells	22
9.3.3	Inhibition with Blocking Antibodies, Peptidomimetic Inhibitors or EDTA	25
9.3.4	Activation with Mg^{2+} , Mn^{2+} Ions, Activating Antibodies, Phorbol ester or Chemokines	26
9.3.5	AFM Measurement—Cell Free	26
9.4	Conclusion and Future Developments	27
	References	29
10	Imaging Chemical Groups and Molecular Recognition Sites on Live Cells Using AFM	
	<i>David Alsteens, Vincent Dupres, Etienne Dague, Claire Verbelen, Guillaume André, Grégory Francius, Yves F. Dufrêne</i>	33
10.1	Introduction	33
10.2	Chemical Force Microscopy	34
10.2.1	Methods	34
10.2.2	Probing Hydrophobic Forces	35
10.2.3	Chemical Force Microscopy of Live Cells	38
10.3	Molecular Recognition Imaging	42
10.3.1	Spatially Resolved Force Spectroscopy	43

10.3.2	Immunogold Imaging	45
10.4	Conclusions	47
	References	47
11	Applications of Scanning Near-Field Optical Microscopy in Life Science <i>Pietro Giuseppe Gucciardi</i>	49
11.1	Introduction	50
11.2	Experimental Techniques in Near-Field Optical Microscopy	51
11.2.1	Principles of Near-Field Optical Microscopy	51
11.2.2	Fluorescence Near-Field Optical Microscopy	53
11.2.3	Near-Field Optical Microscopy in Liquid	55
11.2.4	Tip-Enhanced Near-Field Optical Microscopy	57
11.3	Applications of Near-Field Optical Microscopy in Life Science	58
11.3.1	Infrared Imaging of Tobacco Mosaic Virus with Nanoscale Resolution	58
11.3.2	Co-Localization of Malarial and Host Skeletal Proteins in Infected Erythrocytes by Dual-Color Near-Field Fluorescence Microscopy	59
11.3.3	Co-Localization of α -Sarcoglycan and β 1D-Integrin in Human Muscle Cells by Near-Field Fluorescence Microscopy	61
11.3.4	Single Molecule Near-Field Fluorescence Microscopy of Dendritic Cells	62
11.3.5	Chemical Information of Bacterial Surfaces and Detection of DNA Nucleobases by Tip-Enhanced Raman Spectroscopy	64
11.4	Conclusions	65
	References	66
12	Adhesion and Friction Properties of Polymers at Nanoscale: Investigation by AFM <i>Sophie Bistac, Marjorie Schmitt</i>	69
12.1	Introduction	69
12.2	Experimental Part	72
12.3	Nano-Adhesion Investigation	73
12.4	Nano-Friction Investigation	75
12.5	Relation Between Adhesion and Friction at Nanoscale	78
12.6	Comparison with Macroscale Results	79
	References	83
13	Mechanical Characterization of Materials by Micro-Indentation and AFM Scanning <i>Gabriella Bolzon, Massimiliano Bocciarelli, Enzo J. Chiarullo</i>	85
13.1	Introduction	85

13.2	Experimental Techniques	89
13.2.1	Micro-Indentation	89
13.2.2	AFM Scanning	90
13.3	Inverse Analysis for Materials Characterization	94
13.3.1	Simulation of the Test	94
13.3.2	Optimization Procedures	100
13.4	Applications	102
13.4.1	On the Role of Friction	103
13.4.2	Tests Concerning HHM and DP Models	104
13.4.3	Anisotropic Materials	105
13.4.4	Self Stresses	109
13.4.5	Coatings and Layered Systems	110
	References	116

14 Mechanical Properties of Metallic Nanocontacts

	<i>G. Rubio-Bollinger, J.J. Riquelme, S.Vieira, N. Agrait</i>	121
14.1	Introduction	122
14.2	Experimental Tools	123
14.2.1	The Scanning Tunneling Microscope Supplemented with a Force Sensor	125
14.2.2	The Mechanically Controllable Break-Junction Technique	126
14.3	Electron Transport Through Metallic Nanocontacts	128
14.4	Mechanical Properties of Metallic Nanocontacts	129
14.4.1	Fabrication of Metallic Nanocontacts	129
14.4.2	Elasticity and Fracture of Metallic Nanocontacts	131
14.4.3	The Shape of Metallic Nanocontacts	132
14.4.4	Inelastic Scattering by Phonons in Nanocontacts	134
14.5	Suspended Chains of Single Gold Atoms	135
14.5.1	Fabrication of Chains of Atoms Using Local Probes	136
14.5.2	Mechanical Processes During Formation of Atomic Chains	137
14.5.3	Phonons in Atomic Chains	140
14.6	Metallic Adhesion in Atomic-Sized Tunneling Junctions	144
	References	146

15 Dynamic AFM in Liquids: Viscous Damping and Applications to the Study of Confined Liquids

	<i>Abdelhamid Maali, Touria Cohen-Bouhacina, Cedric Hurth, Cédric Jai, R. Boisgard, Jean-Pierre Aimé</i>	149
15.1	Introduction	149

15.2	Viscous Hydrodynamic Damping of the Cantilever in a Water Medium	150
15.3	Improving the Acoustic Excitation of the Cantilever-Tip	153
15.4	Theoretical Description of the Motion of an Acoustically Driven Cantilever in Liquid	155
15.5	Atomic Force Microscopy Study of the Molecular Ordering of a Confined Liquid	160
15.6	Conclusion	163
	References	163
16	Microtensile Tests Using In Situ Atomic Force Microscopy <i>Udo Lang, Jurg Dual</i>	165
16.1	Introduction	166
16.2	Literature Review	166
16.2.1	Organic Samples	166
16.2.2	Anorganic Samples	170
16.2.3	Summary	172
16.3	Recent Developments at the Center of Mechanics of ETH Zurich ...	172
16.3.1	Setup	172
16.3.2	Results	176
16.3.3	Outlook	179
16.4	Conclusions	180
	References	180
17	Scanning Tunneling Microscopy of the Si(111)-7×7 Surface and Adsorbed Ge Nanostructures <i>Haiming Guo, Yeliang Wang, Hongjun Gao</i>	183
17.1	Introduction	184
17.2	STM Imaging on Si(111)-7×7: Resolving the Rest Atoms	185
17.2.1	The Familiarity: Si(111)-7×7 Structure and STM	185
17.2.2	The Simultaneous Imaging of the Rest Atoms and Adatoms	187
17.2.3	Voltage-Dependent Imaging of Rest Atoms	188
17.2.4	First-Principles Calculations	191
17.3	Atomic Manipulation on Si(111)-7×7 Surfaces with STM	193
17.3.1	Introduction	193
17.3.2	Fabricating Groove Nanostructures on Si(111)-7×7 Surfaces	193
17.3.3	The Modification Mechanism	195
17.4	Ge Nanostructure Growth on Si(111)-7×7 Surfaces	197
17.4.1	Introduction	197

17.4.2	Experimental Aspects	198
17.4.3	Initial Adsorption of Ge Atoms on the Si(111)- 7×7 Surface	198
17.4.4	Temperature Dependence of Formation and Arrangement of Ge Clusters	205
17.4.5	Electronic Structures of Ge Clusters and Evolution of the Hexagonal Superlattice	208
17.4.6	Formation of Ge Islands and Ge–Si Intermixing at High Temperature	212
17.5	Conclusions	216
	References	217
	Subject Index	221

Contents – Volume XI

1	Oscillation Control in Dynamic SPM with Quartz Sensors	
	<i>Johann Jersch, Harald Fuchs</i>	1
1.1	Introduction	1
1.2	Definition and Measurement of Signal Parameters	3
1.3	Connection Between Oscillation Parameters and Tip–Sample Interactions	7
1.4	Oscillation Control for QCR, Technical Realization	8
1.5	Applications of the Oscillation Controllers	12
1.6	Summary	13
	References	14
2	Atomic Force Microscope Cantilevers Used as Sensors for Monitoring Microdrop Evaporation	
	<i>Elmar Bonaccorso, Dmytro S. Golovko, Paolo Bonanno, Roberto Raiteri, Thomas Haschke, Wolfgang Wiechert, Hans-Jürgen Butt</i>	17
2.1	Introduction	18
2.2	Background, Materials and Methods	19
2.2.1	Drop in Equilibrium	19
2.2.2	Evaporating Drop	21
2.2.3	Experimental Setup	22
2.3	Evaporation Results on Microdrops	24
2.3.1	Evaporation Curve	24
2.3.2	Force Model	24
2.3.3	Negative Inclination	26
2.3.4	Mass and Inclination	28
2.3.5	Vaporization Heat	30
2.4	Further Applications of Drops on Cantilevers	31
2.4.1	Spring Constant Calibration	31
2.4.2	Contamination Control of Cantilevers	33

2.5	Conclusions	36
	References	36
3	Mechanical Diode-Based Ultrasonic Atomic Force Microscopies	
	<i>M. Teresa Cuberes</i>	39
3.1	Introduction: Acoustic Microscopy in the Near Field	39
3.1.1	Acoustic Microscopy: Possibilities and Limitations	39
3.1.2	Ultrasonic Atomic Force Microscopies	41
3.2	Ultrasonic Force Microscopy: The Mechanical Diode Effect	44
3.2.1	The Mechanical Diode Effect	44
3.2.2	Experimental Implementation of UFM	46
3.2.3	Information from UFM Data	47
3.2.4	Applications of UFM in Nanofabrication	52
3.3	Mechanical Diode Ultrasonic Friction Force Microscopy	54
3.3.1	The Lateral Mechanical Diode Effect	54
3.3.2	Experimental Implementation of MD-UFFM	56
3.3.3	Comparison of MD-UFFM with UFFM and TRmode AFM	56
3.3.4	Information from MD-UFFM Data	58
3.4	Heterodyne Force Microscopy: Beats at Nanocontacts	62
3.4.1	Beats at Nanocontacts	62
3.4.2	Experimental Implementation of HFM	64
3.4.3	Comparison of HFM with UFM	65
3.4.4	Information from HFM: Time Resolution	66
	References	68
4	Contact Atomic Force Microscopy: A Powerful Tool in Adhesion Science	
	<i>Maurice Brogly, Houssein Awada, Olivier Noel</i>	73
4.1	Introduction	73
4.2	Adhesion Science	74
4.2.1	Adhesion and Adhesive Strength	74
4.2.2	Adhesion at a Local Scale	75
4.3	Force vs. Distance Measurements with an AFM	76
4.4	AFM Calibration	77
4.4.1	Selection of Tips	77
4.4.2	Determination of the Spring Constant of the Cantilever	78
4.4.3	Determination of the Tip Radius	78
4.4.4	Nonlinearity of the Quadrant of Photodiodes	79
4.4.5	Scan Rate of the Cantilever	79
4.4.6	Systematic Check	79
4.4.7	Estimation of the Uncertainties Related to the Experimental Pull-Off Force Measurements	79

4.5	Adhesion Forces and Surface Energies	80
4.5.1	Materials	80
4.5.2	Preparation of Oxidized Silica Surface	80
4.5.3	Grafting of Functionalized SAMs on Silicon Wafer	81
4.5.4	Characterization of the SAMs	81
4.5.5	Force-Distance Curves on Rigid Systems Having Controlled Surface Chemistry	82
4.5.6	Influence of Capillary Forces on Adhesion Forces	84
4.6	Adhesion Forces Measurements on Polymers	85
4.6.1	Cross-Linking and Functionalization of PDMS Networks	85
4.6.2	Force-Distance Curves on Soft Polymer Surfaces	86
4.6.3	Real Indentation of the AFM Tip Inside a Soft Polymer	88
4.7	AFM Nano-Indentation Experiments on Polymer Networks	89
4.7.1	Force-Indentation Curves	89
4.7.2	Nano-Indentation and Nano-Adhesion on Soft Polymers Having Controlled Surface Chemistry and Mechanical Properties	91
4.8	Conclusion	94
	References	94

5	Contact Resonance Force Microscopy Techniques for Nanomechanical Measurements <i>Donna C. Hurley</i>	97
5.1	Introduction	99
5.2	Cantilevers for Contact Resonance Force Microscopy	101
5.3	Data Acquisition Techniques	103
5.4	Data Analysis Methods	107
5.4.1	Model for Cantilever Dynamics	107
5.4.2	Model for Contact Mechanics	111
5.5	Survey of Contact Resonance Force Microscopy Measurements . . .	113
5.6	Theoretical Principles for Optimizing Experiments	116
5.6.1	Cantilever Dynamics: Which Modes?	116
5.6.2	Contact Mechanics: What Forces?	119
5.6.3	An Example	121
5.7	Practical Issues for Optimizing Experiments	122
5.7.1	Exciting and Detecting the Cantilever's Resonant Modes	122
5.7.2	Tip Shape and Tip Wear	124
5.8	Imaging with Contact Resonance Force Microscopy	127
5.9	The Road Ahead	132
	References	135

6	AFM Nanoindentation Method: Geometrical Effects of the Indenter Tip	
	<i>Lorenzo Calabri, Nicola Pugno, Sergio Valeri</i>	139
6.1	Introduction	139
6.2	Experimental Configuration	144
6.2.1	FIB Nanofabrication	145
6.2.2	Tip Radius of Curvature Characterization	148
6.2.3	Nanoindentation Experimental Setup	149
6.3	Numerical Model	150
6.4	Theoretical Model: A Shape/Size-Effect Law for Nanoindentation	151
6.5	Deconvolution of the Indentation Impressions	157
6.6	Results	157
6.7	Conclusion	162
	References	163
7	Local Mechanical Properties by Atomic Force Microscopy Nanoindentations	
	<i>Davide Tranchida, Stefano Piccarolo</i>	165
7.1	Introduction	166
7.2	The Scale of AFM Nanoindentations	169
7.3	The Relationship with Microhardness and Analysis of the Unloading Curve	173
7.4	Models to Describe the Force Curves	178
7.5	Final Remarks on Loading History, Adhesion, Roughness Effects	187
7.6	Selected Applications	190
	References	195
8	Thermal Activation Effects in Dynamic Force Spectroscopy and Atomic Friction	
	<i>Mykhaylo Evstigneev</i>	199
8.1	Introduction	200
8.1.1	Determination of Bond Strength of Biological Complexes	201
8.1.2	Atomic Friction	202
8.2	Standard Method of Data Analysis	204
8.2.1	Rate Equation Approach	204
8.2.2	Most Probable Rupture Force	206
8.2.3	DFS Pulling Experiments: Mean Rupture Force	209
8.2.4	Atomic Friction: Average Force in the Stick-Slip Regime	210
8.3	Alternative Method of Data Analysis	213

8.4	Application to DFS Pulling Experiments	216
8.5	Application to Atomic Friction	219
8.6	Conclusions	225
	References	226
	Subject Index	231

Contents – Volume XIII

18	Visualization of Epicuticular Grease on the Covering Wings in the Colorado Potato Beetle: A Scanning Probe Approach	
	<i>D. Voigt, H. Peisker, S. Gorb</i>	1
18.1	Introduction	2
18.1.1	Epicuticular Grease: Introductory Remarks	2
18.1.2	Covering Wings and Mating Behaviour	3
18.2	Methods	4
18.2.1	Insects and Sample Preparation	4
18.2.2	Scanning Probe Microscopy	5
18.2.3	Cryo-SEM	6
18.3	Results	7
18.3.1	Elytra Topography and Grease Visualization	7
18.3.2	Adhesive Properties of the Elytra Surface	9
18.4	Discussion	10
18.5	Conclusions	13
	References	13
19	A Review on the Structure and Mechanical Properties of Mollusk Shells – Perspectives on Synthetic Biomimetic Materials	
	<i>Francois Barthelat, Jee E. Rim, Horacio D. Espinosa*</i>	17
19.1	Introduction	17
19.1.1	Mollusk Shells: Overview	18
19.2	Cross-Laminar Shells: The Pink or Queen Conch (<i>Strombus gigas</i>) . .	19
19.2.1	Structure	19
19.2.2	Mechanisms of Toughening	21
19.3	Nacreous Shells	24
19.3.1	Overview of Nacre	26
19.3.2	Structure	26
19.3.3	The Deformation of Nacre	27

19.3.4	The Fracture of Nacre	32
19.4	Artificial Shell Materials	34
19.4.1	Large-Scale “Model Materials”	34
19.4.2	Ice Templatation	36
19.4.3	Layer-by-Layer Deposition	38
19.4.4	Thin Film Deposition: MEMS-Based Structure	39
19.5	Conclusions	41
	References	41
20	Electro-Oxidative Lithography and Self-Assembly Concepts for Bottom-Up Nanofabrication	
	<i>Stephanie Hoeppener, Ulrich S. Schubert</i>	45
20.1	Introduction	45
20.2	Chemically Active Surface Templates	46
20.2.1	Locally Confined Self-Assembled Monolayers	46
20.2.2	Electrical Structuring Techniques of SAMs	48
20.3	Conclusions	66
	References	67
21	Application of SPM and Related Techniques to the Mechanical Properties of Biotoool Materials	
	<i>Thomas Schöberl, Ingomar L. Jäger, Helga C. Lichtenegger</i>	71
21.1	Introduction	72
21.2	Typical Biotoool Materials	74
21.2.1	Chemistry	74
21.2.2	Structures	76
21.2.3	Mechanical Properties	78
21.3	Experimental Methods and Setups	79
21.3.1	SPM and Indentation	79
21.3.2	Scratch and Wear Tests	81
21.3.3	Dynamic Modes	82
21.3.4	Fracture Toughness Tests	83
21.4	Samples	84
21.4.1	Choice	84
21.4.2	Storage	85
21.4.3	Preparation	86
21.5	Experimental Conditions	87
21.5.1	Moisture	87
21.5.2	Temperature	88
21.5.3	Probe Tips	88

21.5.4	Test Velocity	89
21.6	Results	89
21.6.1	Sources of Error	89
21.6.2	Interpretation	94
21.7	Examples from the Literature	95
	References	98
22	Nanomechanics and Microfluidics as a Tool for Unraveling Blood Clotting Disease <i>D.M. Steppich, S. Thalhammer, A. Wixforth, M.F. Schneider</i>	105
22.1	Introduction	105
22.2	Topography	106
22.2.1	Little Story of Blood Clotting	107
22.2.2	High-Resolution Imaging	110
22.3	Lab-on-a-Chip	117
22.3.1	Nanomechanical Diagnostics	118
22.3.2	Mimicking Blood Flow Conditions on a Surface Acoustic Wave-Driven Biochip	120
22.4	The Lab on a Chip – AFM – Hybrid	122
22.4.1	Experimental Setup	122
22.4.2	Bundle Relaxation	124
22.4.3	Stream Line Manipulation and Flow Sensoring	128
22.5	Summary and Outlook	132
	References	133
23	Atomic Force Microscopic Study of Piezoelectric Polymers <i>Hyungoo Lee · Ke Wang · Taekwon Jee · Hong Liang</i>	137
23.1	Piezoelectric Materials	137
23.2	Atomic Force Microscopy	138
23.3	Atomic Force Microscope Measurement	139
23.3.1	Sample Materials	141
23.3.2	Surface Image Analysis	141
23.3.3	Surface Force Measurements	143
23.3.4	Nano-Piezoelectricity	146
23.3.5	Conductivity Measurement of PVDF Samples	149
23.3.6	Time-Dependent Study	149
	References	152

24	Quantitative Analysis of Surface Morphology and Applications	
	<i>Maria Cecília Salvadori</i>	153
24.1	Introduction	153
24.2	Quantifying Morphology	154
24.3	Applications of Quantitative Morphological Surface Analysis	157
24.3.1	Dynamic Growth of Thin Films	157
24.3.2	Periodicity Analysis of Lines Nanolithographed by AFM in PMMA	161
24.3.3	Electrical Resistivity of Nanostructured Thin Films	167
24.3.4	Morphological and Crystallographic Grain Sizes	173
24.4	Final Remarks	178
	References	178
25	Nanotribological Characterization of Carbonaceous Materials: Study of Diamond Coatings and Graphite	
	<i>Marjorie Schmitt, Sophie Bistac</i>	181
25.1	Introduction	182
25.2	Nanotribology of Carbonaceous Materials: State of the Art	182
25.2.1	Role of the Scanning Velocity	185
25.2.2	Role of the Environment	185
25.2.3	Role of the Contact Load	186
25.2.4	Role of the Chemistry	187
25.2.5	Role of the Chemistry – Bulk Chemistry	187
25.2.6	Role of the Chemistry—Superficial Chemistry	188
25.3	Experimental Details	188
25.3.1	Diamond Coatings: The Flame Process	188
25.3.2	Graphite Pins	189
25.3.3	Atomic Force Microscopy	189
25.3.4	Tribometer for Macroscopic Tests	190
25.3.5	Modification of the Superficial Energy of Silicon Wafers	190
25.4	Nanofriction Results	191
25.4.1	Diamond Coatings (Obtained by Flame Process)	191
25.4.2	Graphite	194
25.5	Conclusions	200
	References	201
26	Atomic Force Microscopy Studies of Aging Mechanisms in Lithium-Ion Batteries	
	<i>Shrikant C. Nagpure, Bharat Bhushan</i>	203
26.1	Introduction	203
26.1.1	Battery Types	206

26.2	Lithium-Ion Batteries	212
26.2.1	Electrochemistry of Lithium-Ion Batteries	212
26.2.2	Different Shapes of Lithium-Ion Batteries	213
26.2.3	Types of Lithium-Ion Batteries	214
26.2.4	Requirements in Modern Lithium-Ion Batteries	217
26.3	Aging of Lithium-Ion Batteries	217
26.3.1	Anode	218
26.3.2	Cathode	224
26.4	Closure	230
	References	231
	Subject Index	235

Contents – Volume I

Part I Scanning Probe Microscopy

1	Dynamic Force Microscopy <i>André Schirmeisen, Boris Anczykowski, Harald Fuchs</i>	3
2	Interfacial Force Microscopy: Selected Applications <i>Jack E. Houston</i>	41
3	Atomic Force Microscopy with Lateral Modulation <i>Volker Scherer, Michael Reinstädler, Walter Arnold</i>	75
4	Sensor Technology for Scanning Probe Microscopy <i>Egbert Oesterschulze, Rainer Kassing</i>	117
5	Tip Characterization for Dimensional Nanometrology <i>John S. Villarrubia</i>	147

Part II Characterization

6	Micro/Nanotribology Studies Using Scanning Probe Microscopy <i>Bharat Bhushan</i>	171
7	Visualization of Polymer Structures with Atomic Force Microscopy <i>Sergei Magonov</i>	207
8	Displacement and Strain Field Measurements from SPM Images <i>Jürgen Keller, Dietmar Vogel, Andreas Schubert, Bernd Michel</i>	253
9	AFM Characterization of Semiconductor Line Edge Roughness <i>Ndubuisi G. Orji, Martha I. Sanchez, Jay Raja, Theodore V. Vorburger</i>	277
10	Mechanical Properties of Self-Assembled Organic Monolayers: Experimental Techniques and Modeling Approaches <i>Redhouane Henda</i>	303

11	Micro-Nano Scale Thermal Imaging Using Scanning Probe Microscopy <i>Li Shi, Arun Majumdar</i>	327
12	The Science of Beauty on a Small Scale. Nanotechnologies Applied to Cosmetic Science <i>Gustavo Luengo, Frédéric Leroy</i>	363

Part III Industrial Applications

13	SPM Manipulation and Modifications and Their Storage Applications <i>Sumio Hosaka</i>	389
14	Super Density Optical Data Storage by Near-Field Optics <i>Jun Tominaga</i>	429
15	Capacitance Storage Using a Ferroelectric Medium and a Scanning Capacitance Microscope (SCM) <i>Ryoichi Yamamoto</i>	439
16	Room-Temperature Single-Electron Devices formed by AFM Nano-Oxidation Process <i>Kazuhiko Matsumoto</i>	459

Contents – Volume II

1	Higher Harmonics in Dynamic Atomic Force Microscopy <i>Robert W. Stark, Martin Stark</i>	1
2	Atomic Force Acoustic Microscopy <i>Ute Rabe</i>	37
3	Scanning Ion Conductance Microscopy <i>Tilman E. Schäffer, Boris Anczykowski, Harald Fuchs</i>	91
4	Spin-Polarized Scanning Tunneling Microscopy <i>Wulf Wulfhekel, Uta Schlickum, Jürgen Kirschner</i>	121
5	Dynamic Force Microscopy and Spectroscopy <i>Ferry Kienberger, Hermann Gruber, Peter Hinterdorfer</i>	143
6	Sensor Technology for Scanning Probe Microscopy and New Applications <i>Egbert Oesterschulze, Leon Abelmann, Arnout van den Bos, Rainer Kassing, Nicole Lawrence, Gunther Wittstock, Christiane Ziegler</i>	165
7	Quantitative Nanomechanical Measurements in Biology <i>Małgorzata Lekka, Andrzej J. Kulik</i>	205
8	Scanning Microdeformation Microscopy: Subsurface Imaging and Measurement of Elastic Constants at Mesoscopic Scale <i>Pascal Vairac, Bernard Cretin</i>	241
9	Electrostatic Force and Force Gradient Microscopy: Principles, Points of Interest and Application to Characterisation of Semiconductor Materials and Devices <i>Paul Girard, Alexander Nikolaevitch Titkov</i>	283
10	Polarization-Modulation Techniques in Near-Field Optical Microscopy for Imaging of Polarization Anisotropy in Photonic Nanostructures <i>Pietro Giuseppe Gucciardi, Ruggero Micheletto, Yoichi Kawakami, Maria Allegrini</i>	321

11	Focused Ion Beam as a Scanning Probe: Methods and Applications	
	<i>Vittoria Raffa, Piero Castrataro, Arianna Menciassi, Paolo Dario .</i>	361

Contents – Volume III

12	Atomic Force Microscopy in Nanomedicine <i>Dessy Nikova, Tobias Lange, Hans Oberleithner, Hermann Schillers, Andreas Ebner, Peter Hinterdorfer</i>	1
13	Scanning Probe Microscopy: From Living Cells to the Subatomic Range <i>Ille C. Gebeshuber, Manfred Drack, Friedrich Aumayr, Hannspeter Winter, Friedrich Franek</i>	27
14	Surface Characterization and Adhesion and Friction Properties of Hydrophobic Leaf Surfaces and Nanopatterned Polymers for Superhydrophobic Surfaces <i>Zachary Burton, Bharat Bhushan</i>	55
15	Probing Macromolecular Dynamics and the Influence of Finite Size Effects <i>Scott Sills, René M. Overney</i>	83
16	Investigation of Organic Supramolecules by Scanning Probe Microscopy in Ultra-High Vacuum <i>Laurent Nony, Enrico Gnecco, Ernst Meyer</i>	131
17	One- and Two-Dimensional Systems: Scanning Tunneling Microscopy and Spectroscopy of Organic and Inorganic Structures <i>Luca Gavioli, Massimo Sancrotti</i>	183
18	Scanning Probe Microscopy Applied to Ferroelectric Materials <i>Oleg Tikhomirov, Massimiliano Labardi, Maria Allegrini</i>	217
19	Morphological and Tribological Characterization of Rough Surfaces by Atomic Force Microscopy <i>Renato Buzio, Ugo Valbusa</i>	261
20	AFM Applications for Contact and Wear Simulation <i>Nikolai K. Myshkin, Mark I. Petrokovets, Alexander V. Kovalev</i>	299
21	AFM Applications for Analysis of Fullerene-Like Nanoparticles <i>Lev Rapoport, Armen Verdyan</i>	327