
Contents – Volume V

1	Integrated Cantilevers and Atomic Force Microscopes	
	<i>Sadik Hafizovic, Kay-Uwe Kirstein, Andreas Hierlemann</i>	1
1.1	Overview	1
1.2	Active Cantilevers	2
1.2.1	Integrated Force Sensor	4
1.2.2	Integrated Actuation	8
1.3	System Integration	10
1.3.1	Analog Signal Processing and Conditioning	10
1.3.2	Digital Signal Processing	13
1.4	Single-Chip CMOS AFM	16
1.4.1	Measurements	19
1.5	Parallel Scanning	19
1.6	Outlook	21
	References	21
2	Electrostatic Microscanner	
	<i>Yasuhiba Ando</i>	23
2.1	Introduction	23
2.2	Displacement Conversion Mechanism	24
2.2.1	Basic Conception	24
2.2.2	Combination with Comb Actuator	25
2.2.3	Various Types of Displacement Conversion Mechanism	27
2.3	Design, Fabrication Technique, and Performance	29
2.3.1	Main Structure of 3D Microstage	29
2.3.2	Amplification Mechanism of Scanning Area	31
2.3.3	Fabrication Using ICP-RIE	34
2.3.4	Evaluation of Motion of 3D Microstage	37
2.4	Applications to AFM	39
2.4.1	Operation by Using Commercial Controller	39

2.4.2	Evaluation of Microscanner Using Grating Image	41
2.4.3	SPM Operation Using Microscanner	45
References	49

3 Low-Noise Methods for Optical Measurements of Cantilever Deflections

Tilman E. Schäffer 51

3.1	Introduction	51
3.2	The Optical Beam Deflection Method	52
3.2.1	Gaussian Optics	52
3.2.2	Detection Sensitivity	54
3.3	Optical Detection Noise	55
3.3.1	Noise Sources	55
3.3.2	Shot Noise	55
3.4	The Array Detector	56
3.5	Dynamic Range and Linearity	59
3.5.1	The Two-Segment Detector	59
3.5.2	The Array Detector	61
3.6	Detection of Higher-Order Cantilever Vibration Modes	62
3.6.1	Normal Vibration Modes	63
3.6.2	Optimization of the Detection Sensitivity	64
3.7	Calculation of Thermal Vibration Noise	66
3.7.1	Focused Optical Spot of Infinitesimal Size	66
3.7.2	Focused Optical Spot of Finite Size	67
3.8	Thermal Spring Constant Calibration	69
References	70

4 Q-controlled Dynamic Force Microscopy in Air and Liquids

Hendrik Hölscher; Daniel Ebeling; Udo D. Schwarz 75

4.1	Introduction	75
4.2	Theory of <i>Q</i> -controlled Dynamic Force Microscopy	76
4.2.1	Equation of Motion of a Dynamic Force Microscope with <i>Q</i> -control	76
4.2.2	Active Modification of the <i>Q</i> -factor	78
4.2.3	Including Tip–Sample Interactions	80
4.2.4	Prevention of Instabilities by <i>Q</i> -control in Air	82
4.2.5	Reduction of Tip–Sample Indentation and Force by <i>Q</i> -control in Liquids	86
4.3	Experimental Applications of <i>Q</i> -control	89

4.3.1	Examples for Q -control Applications in Ambient Conditions	90
4.4	Summary	94
	References	95
5	High-Frequency Dynamic Force Microscopy	
	<i>Hideki Kawakatsu</i>	99
5.1	Introduction	99
5.2	Instrumental	99
5.2.1	Cantilever	99
5.2.2	Detection	102
5.2.3	Excitation	105
5.2.4	Circuitry	106
5.3	Experimental	107
5.3.1	Low-Amplitude Operation	107
5.3.2	Manipulation	108
5.3.3	Atomic-Resolution Lateral Force Microscopy	108
5.3.4	Other Techniques for High Frequency Motion Detection	108
5.4	Summary and Outlook	109
	References	110
6	Torsional Resonance Microscopy and Its Applications	
	<i>Chanmin Su, Lin Huang, Craig B. Prater, Bharat Bhushan</i>	113
6.1	Introduction to Torsional Resonance Microscopy	113
6.2	TRmode System Configuration	115
6.3	Torsional Modes of Oscillation	119
6.4	Imaging and Measurements with TRmode	123
6.4.1	TRmode in Weakly-Coupled Interaction Region	123
6.4.2	TRmode Imaging and Measurement in Contact Mode	127
6.5	Applications of TRmode Imaging	129
6.5.1	High-Resolution Imaging Application	129
6.5.2	Electric Measurements Under Controlled Proximity by TRmode .	132
6.5.3	In-Plane Anisotropy	138
6.6	Torsional Tapping Harmonics for Mechanical Property Characterization	140
6.6.1	Detecting Cantilever Harmonics Through Torsional Detection . .	142
6.6.2	Reconstruction of Time-Resolved Forces	142
6.6.3	Force-Versus-Distance Curves	143
6.6.4	Mechanical Property Measurements and Compositional Mapping .	144

6.7	Conclusion	145
References		146
7	Modeling of Tip-Cantilever Dynamics in Atomic Force Microscopy	
	<i>Yixin Song, Bharat Bhushan</i>	149
7.1	Introduction	155
7.1.1	Various AFM Modes and Measurement Techniques	155
7.1.2	Models for AFM Cantilevers	161
7.1.3	Outline	163
7.2	Modeling of AFM Tip-Cantilever Systems in AFM	163
7.2.1	Tip-Sample Interaction	164
7.2.2	Point-Mass Model	166
7.2.3	The 1D Beam Model	168
7.2.4	Pure Torsional Analysis of TRmode	171
7.2.5	Coupled Torsional-Bending Analysis	177
7.3	Finite Element Modeling of Tip-Cantilever Systems	187
7.3.1	Finite Element Beam Model of Tip-Cantilever Systems	188
7.3.2	Modeling of TappingMode	192
7.3.3	Modeling of Torsional Resonance Mode	196
7.3.4	Modeling of Lateral Excitation Mode	199
7.4	Atomic-Scale Topographic and Friction Force Imaging in FFM . .	200
7.4.1	FFM Images of Graphite Surface	202
7.4.2	Interatomic Forces Between Tip and Surface	204
7.4.3	Modeling of FFM Profiling Process	205
7.4.4	Simulations on Graphite Surface	208
7.5	Quantitative Evaluation of the Sample's Mechanical Properties .	213
7.6	Closure	216
A	Appendices	217
A.1	Stiffness and Mass Matrices of 3D Beam Element	217
A.2	Mass Matrix of the Tip	218
A.3	Additional Stiffness and Mass Matrices Under Linear Tip-Sample Interaction	219
References		220
8	Combined Scanning Probe Techniques for In-Situ Electrochemical Imaging at a Nanoscale	
	<i>Justyna Wiedemair, Boris Mizaikoff, Christine Kranz</i>	225
8.1	Overview	227
8.2	Combined Techniques	228

8.2.1	Integration of Electrochemical Functionality	230
8.2.2	Combined Techniques Based on Force Interaction	231
8.2.3	Combined Techniques Based on Tunneling Current	232
8.2.4	Combined Techniques Based on Optical Near-Field Interaction . .	233
8.2.5	Theory	234
8.2.6	Combined Probe Fabrication	234
8.3	Applications	243
8.3.1	Model Systems	244
8.3.2	Imaging Enzyme Activity	246
8.3.3	AFM Tip-Integrated Biosensors	249
8.3.4	Combined SPM for Imaging of Living Cells	253
8.3.5	Measurement of Local pH Changes	255
8.3.6	Corrosion Studies	257
8.4	Outlook: Further Aspects of Multifunctional Scanning Probes . .	259
	References	261

9 New AFM Developments to Study Elasticity and Adhesion at the Nanoscale

	<i>Robert Szoszkiewicz, Elisa Riedo</i>	269
9.1	Introduction	270
9.2	Contact Mechanics Theories and Their Limitations	271
9.3	Modulated Nanoindentation	273
9.3.1	Force-Indentation Curves	273
9.3.2	Elastic Moduli	276
9.4	Ultrasonic Methods at Local Scales	278
9.4.1	Brief Description of Ultrasonic Methods	278
9.4.2	Applications of Ultrasonic Techniques in Elasticity Mapping . .	281
9.4.3	UFM Measurements of Adhesion Hysteresis and Their Relations to Friction at the Tip-Sample Contact	282
	References	284

10 Near-Field Raman Spectroscopy and Imaging

	<i>Pietro Giuseppe Gucciardi, Sebastiano Trusso, Cirino Vasi, Salvatore Patanè, Maria Allegrini</i>	287
10.1	Introduction	287
10.2	Raman Spectroscopy	289
10.2.1	Classical Description of the Raman Effect	289
10.2.2	Quantum Description of the Raman Effect	291
10.2.3	Coherent Anti-Stokes Raman Scattering	295

10.2.4	Experimental Techniques in Raman Spectroscopy	296
10.3	Near-Field Raman Spectroscopy	299
10.3.1	Theoretical Principles of the Near-Field Optical Microscopy	300
10.3.2	Setups for Near-Field Raman Spectroscopy	302
10.4	Applications of Near-Field Raman Spectroscopy	306
10.4.1	Structural Mapping	307
10.4.2	Chemical Mapping	312
10.4.3	Probing Single Molecules by Surface-Enhanced and Tip-Enhanced Near-Field Raman Spectroscopy	314
10.4.4	Near-Field Raman Spectroscopy and Imaging of Carbon Nanotubes	321
10.4.5	Coherent Anti-Stokes Near-Field Raman Imaging	324
10.5	Conclusions	326
	References	326
	Subject Index	331