

Contents

1	Introduction	1
	Seizo Morita	
1.1	Rapidly Developing High Performance AFM	1
1.1.1	Tip Modification	2
1.1.2	Control of Atomic Force	3
1.1.3	Pauli Repulsive Force Imaging	5
1.1.4	Atomic/Submolecular Imaging in Liquids	6
1.2	Summary	7
	References	7
2	3D Force Field Spectroscopy	9
	Mehmet Z. Baykara and Udo D. Schwarz	
2.1	Introduction	9
2.2	Experimental Methodology	11
2.3	Sources of Artifacts in 3D Force Field Spectroscopy	14
2.3.1	Thermal Drift	14
2.3.2	Piezo Nonlinearities	15
2.3.3	Tip Asymmetry	16
2.3.4	Tip Elasticity	19
2.4	Comparison of Data Acquisition and Processing Strategies for 3D Force Field Spectroscopy	20
2.5	Combination of 3D Force Field Spectroscopy with Scanning Tunneling Microscopy: 3D-AFM/STM	22
2.6	Conclusions and Outlook	26
	References	27

3	Simultaneous nc-AFM/STM Measurements with Atomic Resolution.	29
	P. Hapala, M. Ondráček, O. Stetsovych, M. Švec and P. Jelínek	
3.1	Introduction	29
3.2	High-Resolution AFM/STM Images with Functionalized Tips . . .	32
3.3	Numerical Modeling of High-Resolution AFM/STM Images with Functionalized Tips.	35
3.4	Effect of Intra-molecular Charge on High-Resolution Images. . .	41
3.5	Conclusions and Outlook	45
	References.	46
4	Manipulation and Spectroscopy Using AFM/STM at Room Temperature	51
	Masayuki Abe, Yoshiaki Sugimoto and Seizo Morita	
4.1	Introduction	51
4.2	Relation Between Manipulation Probability and Tip Reactivity	53
4.2.1	AFM Setup	53
4.2.2	Vacancy Formation on the Si(111)-(7 × 7) Surface . . .	54
4.2.3	Confirmation of Tip Reactivity.	55
4.2.4	Atom Manipulation Procedures.	55
4.2.5	Relation Between Measured Force and Atom Manipulation Probability	56
4.2.6	Tip Reactivity and Manipulation Capability	58
4.2.7	Tip Reactivity and Spatial Resolution	59
4.3	Inter-nanospace Atom Manipulation for Structuring Nanoclusters.	59
4.3.1	Method for Inter-nanospace Atom Manipulation	60
4.3.2	AFM/STM Setup for the INSAM Operation.	61
4.3.3	Inter-nanospace Atom Manipulation of Various Elements	62
4.3.4	Fabrication of Nanocluster Using Inter-nanospace Atom Manipulation	63
4.3.5	Distance Spectroscopic Measurement During INSAM Operation.	65
	References.	68
5	The Phantom Force	71
	Alfred John Weymouth and Franz J. Giessibl	
5.1	Introduction and Background	71
5.1.1	Frequency-Modulation Atomic Force Microscopy	72
5.1.2	The Forces at Play at the Atomic Scale	74
5.1.3	Electrostatic Attraction Between Metal Surfaces	75
5.1.4	Conductance in an Atomic-Scale Junction	76

5.1.5	Including Resistance in Our Overall Picture of Tunneling	77
5.1.6	Summary	78
5.2	Observations	80
5.2.1	Characterizing the Phantom Force	83
5.2.2	Kelvin Probe Force Microscopy	86
5.2.3	Observations on H-Terminated Si(100)	88
5.2.4	Molecular Adsorbate on Graphene	89
5.3	Concluding Remarks and Outlook	90
	References.	91
6	Non-contact Friction	93
	Marcin Kisiel, Markus Samadashvili, Urs Gysin and Ernst Meyer	
6.1	Introduction: Dissipation at Large Separation	93
6.2	The Pendulum AFM System	95
6.2.1	The Microscope	95
6.2.2	Internal Friction of the Cantilever	96
6.3	Non-contact Friction Due to Tip-Sample Interaction	98
6.4	Origins of Non-contact Friction	99
6.4.1	Phononic Friction	99
6.4.2	Joule Dissipation	100
6.4.3	van der Waals Friction	101
6.5	Dissipation at Large Separation.	101
6.6	Suppression of Electronic Friction in the Superconducting State	103
6.7	The Non-contact Friction Due to Phase Slips of the Charge Density Wave (CDW) in NbSe ₂ Sample	105
6.8	Conclusion.	109
	References.	110
7	Magnetic Exchange Force Spectroscopy	111
	Alexander Schwarz and Stefan Heinze	
7.1	Introduction	111
7.2	The Tip-Sample System.	112
7.2.1	Sample Preparation	112
7.2.2	Tip Preparation.	113
7.3	Determining the Magnetic Exchange Interaction	114
7.3.1	Data Acquisition Procedure	114
7.3.2	First-Principles Calculations	116
7.3.3	Comparison Between Theory and Experiment	119
7.4	Magnetic Exchange Induced Switching	120
7.4.1	Experimental Observation	120
7.4.2	Modified Néel-Brown Model	122

7.4.3	Magnetic Stability of Tips	122
7.5	Conclusion.	123
	References.	124
8	Revealing Subsurface Vibrational Modes by Atomic-Resolution Damping Force Spectroscopy	127
	Makoto Ashino and Roland Wiesendanger	
8.1	Introduction	127
8.2	Damping Force Spectroscopy	128
	8.2.1 Dynamic AFM Operation	128
	8.2.2 The Damping Signals ΔE	128
8.3	DFS on Complex Molecular Systems	131
	8.3.1 Supramolecular Assembly	131
	8.3.2 Dynamic AFM Instrumentation.	133
	8.3.3 Topography and Damping on Peapods.	134
	8.3.4 Packing and Optimum Geometry of Peapods	137
	8.3.5 Molecular Dynamics Simulations	140
	8.3.6 Summary	143
	References.	144
9	Self-assembly of Organic Molecules on Insulating Surfaces.	147
	Felix Kling, Ralf Bechstein, Philipp Rahe and Angelika Kühnle	
9.1	Introduction	148
9.2	Self-assembly Principles	149
	9.2.1 General Considerations	149
	9.2.2 Special Situation on Insulator Surfaces	157
9.3	Studied Systems—State of the Art	159
	9.3.1 Strategies for Anchoring	159
	9.3.2 Decoupling Molecule-Surface and Intermolecular Interactions	164
9.4	Outlook	165
	References.	166
10	Atomic-Scale Contrast Formation in AFM Images on Molecular Systems	173
	Fabian Schulz, Sampsa Hämäläinen and Peter Liljeroth	
10.1	Introduction	173
10.2	Tip Reactivity and Atomic Contrast	174
	10.2.1 Well-Defined Tips and a Model Surface	174
	10.2.2 Force Spectroscopy with Reactive and Non-Reactive Tips on Epitaxial Graphene	176
	10.2.3 (Non-)Reactivity Determines the Imaging Contrast	178

10.3	Relating Electronic Properties with Atomic Structure.	179
10.3.1	AFM Versus STM and Finite-Size Effects in Graphene.	180
10.3.2	Imaging Defects in Graphene Nanoribbons	182
10.4	Understanding Measurements with a Flexible Tip Apex.	183
10.4.1	Measuring Interaction Energies with a Molecule-Terminated Tip.	183
10.4.2	Can Atomic Positions Be Measured Quantitatively by AFM with Molecule-Terminated Tips?	184
10.4.3	Can AFM Images Be Background Corrected on the Atomic Scale?	186
10.4.4	AFM Contrast on Intra- and Intermolecular Bonds	188
10.5	Conclusions	192
	References.	193
11	Single Molecule Force Spectroscopy.	195
	Rémy Pawlak, Shigeki Kawai, Thilo Glatzel and Ernst Meyer	
11.1	Introduction: Towards Single Molecule Investigations with nc-AFM.	196
11.2	Experimental Requirements	197
11.2.1	Single Molecules at Surfaces	197
11.2.2	Three-Dimensional Spectroscopic Measurements.	198
11.3	Probing Mechanical Properties at the Sub-molecular Level.	203
11.3.1	3D-Force Field of Fullerene C ₆₀	203
11.3.2	Directed Rotation of Porphyrins	206
11.3.3	Vertical Manipulation of Long Molecular Chains	210
11.3.4	Lateral Manipulation of Single Porphyrin: Atomic-Scale Friction Pattern.	212
11.4	Prospects in Probing the Electronic Properties of Single Molecules	213
11.4.1	LCPD Mapping of a Donor-Acceptor Molecule	214
11.4.2	LCPD Mapping of Metal-Phtalocyanin on Thin Insulating Films	215
11.4.3	Towards Probing Optical Properties of Single Molecules	216
11.5	Conclusion and Perspectives.	219
	References.	220
12	Atomic Resolution on Molecules with Functionalized Tips	223
	Leo Gross, Bruno Schuler, Fabian Mohn, Nikolaj Moll, Jascha Repp and Gerhard Meyer	
12.1	Experimental Set-up and Tip Functionalization.	223
12.2	The Origin of Atomic Contrast	227
12.3	Bond-Order Discrimination and CO-Tip Relaxation.	232

12.4	Adsorption Geometry Determination	237
12.5	Molecular Structure Identification	239
12.6	Kelvin Probe Force Microscopy with Sub-molecular Resolution	241
12.7	Summary	243
	References.	244
13	Mechanochemistry at Silicon Surfaces	247
	Adam Sweetman, Samuel Paul Jarvis and Philip Moriarty	
13.1	Introduction	247
13.2	Experimental Methods	249
	13.2.1 Force Extraction	250
13.3	Computational Methods	251
13.4	Si(100) Results	252
	13.4.1 The Si(100) Surface Structure Viewed by NC-AFM.	252
	13.4.2 Dimer Manipulation by Mechanical Force	254
	13.4.3 Energetic Pathway to Manipulation	260
	13.4.4 Visualising the Effect of Surface Strain on Dimer Stability	263
13.5	Imaging and Manipulation with Reactive and Passivated Tip Structures	264
13.6	The Hydrogen Passivated Silicon Surface: H:Si(100).	268
	13.6.1 Feasibility of Mechanical Extraction of Hydrogen.	270
13.7	Summary	271
	References.	272
14	Scanning Tunnelling Microscopy with Single Molecule Force Sensors.	275
	R. Temirov and F.S. Tautz	
14.1	Introduction	275
14.2	A Survey of Experimental Results	279
	14.2.1 Geometric Contrast in STM	279
	14.2.2 Tip Functionalization.	280
	14.2.3 Image Distortions	283
	14.2.4 Structural Sensitivity	285
	14.2.5 Mixed Contrasts	285
	14.2.6 Further Image Features	287
14.3	The Sensor-Transducer Model of Geometric STM Contrast	288
14.4	A Unified Model of STM and AFM with Nanoscale Force Sensors	291
14.5	Conclusion and Outlook	298
	References.	300

15 Nanostructured Surfaces of Doped Alkali Halides	303
Clemens Barth	
15.1 Introduction	303
15.2 Low Defect Concentration—the Debye-Frenkel Layer	304
15.3 High Defect Concentration—The Suzuki Phase	307
15.3.1 Structure and Surface of the Suzuki Phase	308
15.3.2 Surface Morphology	309
15.3.3 Atomic Resolution and Identification	313
15.4 Supported Nano-objects on the Suzuki Surface	317
15.4.1 Metal Nanoparticles	317
15.4.2 Functionalized Molecules	320
References.	323
16 The Atomic Structure of Two-Dimensional Silica	327
Christin Büchner, Leonid Lichtenstein, Markus Heyde and Hans-Joachim Freund	
16.1 Introduction	327
16.2 The 2D Glass Model	329
16.3 The Realization of an Amorphous Model System	330
16.4 The Limits of Scanning Probe Methods	331
16.5 Assignment of Atomic Positions	333
16.6 Atomic Force Microscopy Challenges X-Ray Diffraction	336
16.6.1 Structural Unit—Range I	337
16.6.2 Interconnection of Silica Units—Range II	339
16.6.3 Network Topology—Range III	341
16.6.4 Density Fluctuations—Range IV	345
16.7 Crystalline-Vitreous Interface in 2D Silica	346
16.8 Topological Analyses of Two-Dimensional Network Structures	348
16.9 Summary	350
References.	351
17 Imaging Molecules on Bulk Insulators Using Metallic Tips	355
David Z. Gao, Alexander Schwarz and Alexander L. Shluger	
17.1 Introduction	355
17.2 Experimental Set-Up and Procedures	357
17.2.1 Tip Preparation and Control	357
17.3 Theoretical Methodology	359
17.4 Chemical Resolution on NaCl(001) and NiO(001).	360
17.5 Metallic Tip Characterization and Imaging Mechanisms	362
17.5.1 Characterizing Metallic AFM Tips	363
17.5.2 Explicit Determination of Tip Dipoles	366
17.5.3 Imaging the CO Molecule	370

17.5.4	Imaging Larger Polar Molecules	374
17.6	Discussion and Conclusions	375
	References.	377
18	Simulating Solid-Liquid Interfaces in Atomic Force Microscopy	379
	Bernhard Reischl, Filippo Federici Canova, Peter Spijker, Matt Watkins and Adam Foster	
18.1	Introduction	379
18.2	Methodology	381
18.2.1	Simulation Level	382
18.2.2	Free Energy Calculations	383
18.2.3	Simulation Setup	385
18.2.4	Interactions	387
18.2.5	Tips and Tricks	389
18.3	Case Studies	392
18.3.1	Simple Ionic Surfaces	392
18.3.2	Calcite.	395
18.3.3	Molecular Crystal <i>p</i> -Nitroaniline.	398
18.3.4	Ionic Liquids	400
18.4	Discussion	402
	References.	403
19	Recent Progress in Frequency Modulation Atomic Force Microscopy in Liquids	411
	Kei Kobayashi and Hirofumi Yamada	
19.1	Brief Overview.	411
19.1.1	Introduction	411
19.1.2	Characteristic Features in FM-AFM Solid-Liquid Interface Measurements.	412
19.2	Quantitative Force/Dissipation Measurement Using FM-AFM in Liquids	415
19.2.1	Effect of Phase Shifting Elements in FM-AFM.	415
19.2.2	Photothermal Excitation of Cantilevers in Liquids.	418
19.2.3	Optimum Oscillation Amplitude for FM-AFM in Liquids	419
19.2.4	2D and 3D Force Mapping Techniques	420
19.3	Application of FM-AFM 1: 2D/3D Force Mapping.	421
19.3.1	3D Hydration Force Mapping on Muscovite Mica.	421
19.3.2	3D Electrostatic Force Mapping on Surfactant Aggregates	425

19.4	Application of FM-AFM 2: High-Resolution Imaging of Biomolecules	427
19.4.1	DNA	427
19.4.2	Self-assembled Monoclonal Antibodies	429
19.5	Summary and Outlook	432
	References	432
20	Advanced Instrumentation of Frequency Modulation AFM for Subnanometer-Scale 2D/3D Measurements at Solid-Liquid Interfaces	435
	Takeshi Fukuma	
20.1	Introduction	435
20.2	Advanced Instrumentation	437
20.2.1	3D Scanning Force Microscopy	438
20.2.2	Improvements of Fundamental Performance	439
20.3	Applications of Liquid-Environment FM-AFM	445
20.3.1	2D Imaging	445
20.3.2	3D Imaging	451
20.4	Summary	456
	References	457
21	Electrochemical Applications of Frequency Modulation Atomic Force Microscopy	461
	Yasuyuki Yokota and Ken-ichi Fukui	
21.1	Surface Electrochemistry	461
21.1.1	Electrochemical Interfaces	461
21.1.2	Surface Analysis	463
21.1.3	Electrochemical Scanning Probe Microscopy	464
21.2	EC-FM-AFM	468
21.2.1	Instruments of EC-FM-AFM	468
21.2.2	Soft Imaging of Adsorbates	469
21.2.3	Solvation Structures by Force Curves	471
21.3	Outlook	474
	References	477
22	High-Speed Atomic Force Microscopy	481
	Takayuki Uchihashi, Noriyuki Kodera and Toshio Ando	
22.1	Introduction	481
22.2	Theoretical Considerations	483
22.3	Cantilever and Tip	485
22.4	OB System for Small Cantilevers	488
22.5	Fast Amplitude Detector	491

- 22.6 Scanner 494
 - 22.6.1 Piezoelectric Actuator 494
 - 22.6.2 Scanner Design 495
- 22.7 Control Techniques 497
 - 22.7.1 Active Damping of Z-scanner Vibrations 498
 - 22.7.2 Control Techniques to Damp XY-scanner
Vibrations 500
 - 22.7.3 Compensation for Nonlinearity and Crosstalk 502
 - 22.7.4 Dynamic PID Controller 504
 - 22.7.5 Drift Compensator 506
- 22.8 HS-AFM Imaging of Protein Molecules in Action. 507
 - 22.8.1 Myosin V 507
 - 22.8.2 Intrinsically Disordered Proteins 510
- 22.9 Future Prospects 513
- References. 514

- Index 519**



<http://www.springer.com/978-3-319-15587-6>

Noncontact Atomic Force Microscopy

Volume 3

Morita, S.; Gießibl, F.; Meyer, E.; Wiesendanger, R.

(Eds.)

2015, XXII, 527 p. 256 illus., 159 illus. in color.,

Hardcover

ISBN: 978-3-319-15587-6