

R. Wiesendanger H.-J. Güntherodt (Eds.)

Scanning Tunneling Microscopy II

Further Applications
and Related Scanning Techniques

With Contributions by

W. Baumeister P. Grütter R. Guckenberger
H.-J. Güntherodt T. Hartmann H. Heinzelmann
H. J. Mamin E. Meyer D. W. Pohl D. Rugar
H. Siegenthaler U. Staufer H. K. Wickramasinghe
W. Wiegräbe R. Wiesendanger

With 159 Figures

Springer-Verlag

Berlin Heidelberg New York

London Paris Tokyo

Hong Kong Barcelona

Budapest

Contents

1. Introduction

By <i>R. Wiesendanger</i> and <i>H.-J. Güntherodt</i>	1
1.1 STM in Electrochemistry and Biology	1
1.2 Probing Small Forces on a Small Scale	2
1.3 Related Scanning Probe Microscopies	3
1.4 Nanotechnology	4
References	5

2. STM in Electrochemistry

By <i>H. Siegenthaler</i> (With 13 Figures)	7
2.1 Principal Aspects	9
2.2 Experimental Concepts for Electrolytic STM at Potential-Controlled Electrodes	12
2.2.1 Potential Control Circuitry, STM Cell Design, Counter and Reference Electrodes	12
2.2.2 Tunneling Tips	19
2.2.3 Sample Preparation and Transfer Procedures	26
2.3 Electrochemical Applications of In Situ STM at Potential-Controlled Electrodes	31
2.3.1 STM Studies at Metal Electrodes	31
2.3.2 STM Studies at Carbon and Semiconductor Electrodes	42
2.3.3 Miscellaneous Investigations	45
2.4 Outlook	45
References	45

3. The Scanning Tunneling Microscope in Biology

By <i>R. Guckenberger</i> , <i>T. Hartmann</i> , <i>W. Wiegräbe</i> , and <i>W. Baumeister</i> (With 23 Figures)	51
3.1 Instrumentation	53
3.1.1 The STM Head	53
3.1.2 Auxiliary Microscopes	54
3.1.3 Electronics	55
3.1.4 Controlling the Environment of the STM Head	58
3.1.5 Tunneling Tips	58
3.2 Processing of STM Images	61
3.2.1 Correction of Imaging Faults	61

3.2.2 Evaluation of STM Images	61
3.2.3 Representation of the Images	63
3.3 Preparation	63
3.3.1 Substrates	63
3.3.2 Specimen Deposition	67
3.3.3 Specimen Dehydration	68
3.3.4 Coating with Conductive Films	69
3.3.5 Examining the Quality of Preparations	70
3.4 Applications.	70
3.4.1 Nucleic Acids	70
3.4.2 Proteins	74
3.4.3 Biological Membranes	79
3.5 Imaging and Conduction Mechanisms	84
3.5.1 Practical Observations in STM Imaging of Uncoated Biological Material	84
3.5.2 Measurements of Conductivity and Related Parameters	85
3.5.3 Basic Electron Transfer Mechanisms	88
3.5.4 Intrinsic Conduction in Organic and Biological Material: Theoretical Considerations	89
3.5.5 External Conduction Mechanisms	90
3.5.6 Image Formation	91
3.6 Conclusions	92
References	93
4. Scanning Force Microscopy (SFM)	
By <i>E. Meyer</i> and <i>H. Heinzelmann</i> (With 31 Figures)	99
4.1 Experimental Aspects of Force Microscopy	101
4.1.1 Preparations of Cantilevers	101
4.1.2 Techniques to Measure Small Cantilever Deflections	103
4.1.3 Modes of Operation	107
4.2 Forces and Their Relevance to Force Microscopy	111
4.2.1 Forces Between Atoms and Molecules	111
4.2.2 Forces in Relation to Scanning Force Microscopy.	112
4.3 Microscopic Description of the Tip-Sample Contact	117
4.3.1 Empirical Potentials	117
4.3.2 Molecular Dynamics	119
4.3.3 Continuum Elasticity Theory	123
4.3.4 Ab Initio Calculations	123
4.4 Imaging with the Force Microscope	127
4.4.1 SFM on Layered Materials	127
4.4.2 Ionic Crystals	133
4.4.3 Organic Molecules	139
4.4.4 Applications of SFM on a Nanometer Scale	141
4.5 Conclusions and Outlook.	145
References	146

5. Magnetic Force Microscopy (MFM)

By <i>P. Grütter, H.J. Mamin and D. Rugar</i> (With 38 Figures)	151
5.1 Basic Principles of MFM	152
5.2 Measurement Techniques	154
5.2.1 Force Detection	154
5.2.2 Force Gradient Detection	154
5.2.3 Deflection Sensors	158
5.2.4 Servo Considerations	159
5.3 Force Sensors	160
5.3.1 Basic Properties	160
5.3.2 Electrochemically Etched Tips	161
5.3.3 Tips Coated with Magnetic Thin Films	163
5.4 Theory of MFM Response	165
5.4.1 Magnetic Interaction	165
5.4.2 Image Simulation	168
5.4.3 Mutual Disturbance of Tip and Sample	170
5.5 Imaging Data Storage Media	171
5.5.1 Longitudinal Magnetic Recording Media	171
5.5.2 Modeling Longitudinal Media	174
5.5.3 Magnetic Recording Studies	175
5.5.4 Magneto-Optic Recording Media	178
5.6 Imaging Soft Magnetic Materials	181
5.6.1 Iron Whiskers	183
5.6.2 NiFe (Permalloy).	185
5.6.3 Tip-Sample Interactions	187
5.7 Resolution	190
5.7.1 Experimental Results	191
5.7.2 Theoretical Considerations	192
5.8 Separation of Magnetic and Topographic Signals	198
5.9 Comparison with Other Magnetic Imaging Techniques	200
5.10 Conclusions and Outlook	202
References	205

6. Related Scanning Techniques

By <i>H.K. Wickramasinghe</i> (With 18 Figures)	209
6.1 Historical Background	209
6.2 STM and Electrical Measurements	210
6.2.1 Basic Principle of STM	210
6.2.2 Scanning Noise Microscopy and Scanning Tunneling Potentiometry	211
6.3 STM and Optical Effects	212
6.3.1 Optical Rectification and Scanning Photon Microscope	212
6.3.2 STM and Inverse Photoemission Microscopy	213
6.4 Near-Field Thermal Microscopy	214
6.5 Scanning Force Microscopy and Extensions	219

6.6 Conclusion	229
References	230
 7. Nano-optics and Scanning Near-Field Optical Microscopy	
By <i>D.W. Pohl</i> (With 23 Figures)	233
7.1 Nano-optics: Optics of Nanometer-Size Structures	234
7.1.1 General Considerations	234
7.1.2 Theoretical Approach	235
7.1.3 Gap Fields and Tip Plasmons	235
7.1.4 Pointed Tips as Near-Field Optical Probes	236
7.1.5 Spherical Particle Above Substrate	238
7.1.6 Nano-Apertures	242
7.1.7 Dipole Above Ground	245
7.2 Experimental Work	247
7.2.1 SNOM Designs	247
7.2.2 Aperture/Transmission	247
7.2.3 Aperture/Reflection	250
7.2.4 Protrusion/Reflection	250
7.2.5 Pointed Transparent Fiber/Transmission	250
7.2.6 The Photon-Emitting STM	252
7.2.7 Basic NFO Experiments	252
7.2.8 Aperture/Transmission	253
7.2.9 Aperture/Reflection	254
7.2.10 Protrusion/Reflection	254
7.2.11 Pointed Optical Fiber (PSTM, STOM)	254
7.2.12 Pointed Metal Tip	256
7.3 Plasmons and Spectroscopic Effects	256
7.3.1 Protrusions: Influence of Particle Size	256
7.3.2 Apertures: Enhanced Spectroscopy	258
7.4 Imaging by SNOM	258
7.4.1 Transmission	258
7.4.2 Reflection/Aperture	262
7.4.3 Reflection/Protrusion	263
7.4.4 Optical Fiber (PSTM, STOM)	265
7.4.5 SNOM-Type Imaging with the STM	266
7.5 Discussion, Outlook, Conclusions	267
7.5.1 Problems Solved	267
7.5.2 Open Questions, Comparison of Different Methods	268
7.5.3 Outlook	269
References	270
 8. Surface Modification with a Scanning Proximity Probe Microscope	
By <i>U. Staufer</i> (With 13 Figures)	273
8.1 Overview	273

8.2	Microfabrication with a Scanning Probe Microscope.	276
8.2.1	A Universal Approach	276
8.2.2	Discussion of the Basic Parameters	277
8.3	Investigation of the Fabrication Process	285
8.3.1	Indirect Investigations.	285
8.3.2	Direct Investigations	286
8.3.3	Response of Different Samples and Environments	289
8.4	Review of SXM Lithography	290
8.4.1	Exposure of an Electron or Photo-Resist	290
8.4.2	Mechanical Machining	291
8.4.3	Deposition	292
8.4.4	Thermal Treatment	294
8.4.5	Decomposition of Organometallic Gases	295
8.4.6	Manipulation of Molecules and Atoms	296
8.4.7	Electrochemical and Photoelectrochemical Processes	297
8.4.8	Ion and Electron Etching.	298
8.4.9	Modifications of Indeterminate Origin	299
	References	300
	Subject Index	303