NanoScience and Technology

B. Bhushan
H. Fuchs (Eds.)

Applied Scanning Probe Methods II

Scanning Probe Microscopy Techniques

Springer

NanoScience and Technology

NanoScience and Technology

Series Editors:
P. Avouris B. Bhushan 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.

Semiconductor Spintronics and Quantum Computation
Editors: D.D. Awschalom, N. Samarth, D. Loss

Nano-Optoelectonics
Concepts, Physics and Devices
Editor: M. Grundmann

Noncontact Atomic Force Microscopy
Editors: S. Morita, R. Wiesendanger, E. Meyer

Nanoelectrodynamics
Electrons and Electromagnetic Fields in Nanometer-Scale Structures
Editor: H. Nejo

Single Organic Nanoparticles
Editors: H. Masuhara, H. Nakanishi, K. Sasaki

Epitaxy of Nanostructures
By V.A. Shchukin, N.N. Ledentsov and D. Bimberg

Applied Scanning Probe Methods I
Editors: B. Bhushan, H. Fuchs, S. Hosaka

Nanostructures
Theory and Modeling
By C. Delerue and M. Lannoo

Nanoscale Characterisation of Ferroelectric Materials
Scanning Probe Microscopy Approach
Editors: M. Alexe and A. Gruverman

Magnetic Microscopy of Nanostructures
Editors: H. Hopster and H.P. Oepen

Silicon Quantum Integrated Circuits
Silicon-Germanium Heterostructure Devices: Basics and Realisations
By E. Kasper, D.J. Paul

The Physics of Nanotubes
Fundamentals of Theory, Optics and Transport Devices
Editors: S.V. Rotkin and S. Subramoney

Single Molecule Chemistry and Physics
An Introduction
By C. Wang, C. Bai

Atomic Force Microscopy, Scanning Nearfield Optical Microscopy and Nanoscratching
Application to Rough and Natural Surfaces
By G. Kaupp

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 Applications
Editors: B. Bhushan, H. Fuchs

Bharat Bhushan
Harald Fuchs (Eds.)

Applied Scanning Probe Methods II

Scanning Probe Microscopy Techniques

With 263 Figures
Including 7 Color Figures

Springer

Editors:
Professor Bharat Bhushan
Nanotribology Laboratory for Information Storage and MEMS/NEMS (NLIM)
650 Ackerman Road, Suite 255, The Ohio State University
Columbus, OH 43202-1107, USA
e-mail: Bhushan.2@osu.edu

Professor Dr. Harald Fuchs
Center for Nanotechnology (CeNTech) and Institute of Physics
University of Münster, Gievenbecker Weg 11, 48149 Münster, Germany
e-mail: fuchsh@uni-muenster.de

DOI 10.1007/b98404
ISSN 1434-4904
ISBN-10 3-540-26242-3 Springer Berlin Heidelberg New York
ISBN-13 978-3-540-26242-8 Springer Berlin Heidelberg New York

Library of Congress Control Number: 2003059049

Springer is a part of Springer Science+Business Media.

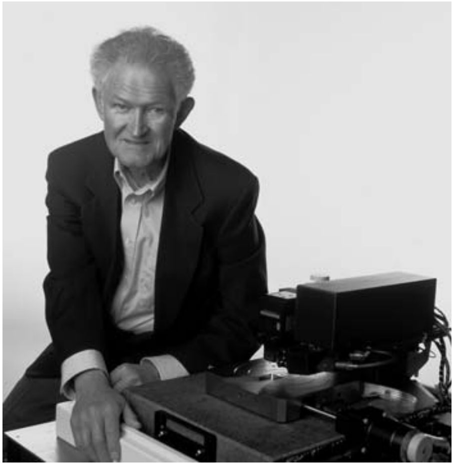
springer.com

Printed in Germany

Typesetting and production: LE-TEX Jelonek, Schmidt & Vöckler GbR, Leipzig
Cover design : *design & production*, Heidelberg

Printed on acid-free paper 2/3100/YL - 5 4 3 2 1 0

Foreword



The Nobel Prize of 1986 on Scanning Tunneling Microscopy signaled a new era in imaging. The scanning probes emerged as a new instrument for imaging with a precision sufficient to delineate single atoms. At first there were two – the Scanning Tunneling Microscope, or STM, and the Atomic Force Microscope, or AFM. The STM relies on electrons tunneling between tip and sample whereas the AFM depends on the force acting on the tip when it was placed near the sample. These were quickly followed by the Magnetic Force Microscope, MFM, and the Electrostatic Force Microscope, EFM. The MFM will image a single magnetic bit with features as small as 10 nm. With the EFM one can monitor the charge of a single electron. Prof. Paul Hansma at Santa Barbara opened the door even wider when he was able to image biological objects in aqueous environments. At this point the sluice gates were opened and a multitude of different instruments appeared.

There are significant differences between the Scanning Probe Microscopes or SPM, and others such as the Scanning Electron Microscope or SEM. The probe microscopes do not require preparation of the sample and they operate in ambient atmosphere, whereas, the SEM must operate in a vacuum environment and the sample must be cross-sectioned to expose the proper surface. However, the SEM can record 3D image and movies, features that are not available with the scanning probes.

The Near Field Optical Microscope or NSOM is also member of this family. At this time the instrument suffers from two limitations; 1) most of the optical energy is lost as it traverses the cut-off region of the tapered fiber and 2) the resolution is insufficient for many purposes. We are confident that NSOM's with a reasonable optical throughput and a resolution of 10 nm will soon appear. The SNOM will then enter the mainstream of scanning probes.

In the Harmonic Force Microscope or HFM, the cantilever is driven at the resonant frequency with the amplitude adjusted so that the tip impacts the sample on each cycle. The forces between tip and sample generate multiple harmonics in the motion of the cantilever. The strength of these harmonics can be used to characterize the physical properties of the surface.

It is interesting to note that this technology has spawned devices of a different kind. In one instance, the tip is functionalized in a way that allows the attachment of a single protein. Withdrawing the tip from a surface stretches the attached molecule and measures the elastic properties of single protein molecules. In another the surface tension on the surface of the cantilever is modified with a self-assembled monolayer of molecules such as thiols. The slight bending of the beam is easily detected with the components developed for use in the scanning probes. This system is used to detect the presence not only of the monomolecular layers but also of single molecules attached to the initial self-assembled monolayer.

The extensive material in this field means that the variety of topics is larger than can be accommodated in four volumes. The Editors, Profs. Bhushan and Fuchs, must have great powers of persuasion for they have done a remarkable job in collecting this set of paper in a relatively short period of time. The collection will become a milestone in the field of scanning probes.

c. f. quate
Leland T. Edwards Professor (Research) of Engineering
Stanford University
Stanford, California
Co-inventer of AFM in 1985

Preface

The rapidly increasing activities in nanoscience and nanotechnology supported by sizable national programs has led to a variety of efforts in the development and understanding of scanning probe techniques as well as their applications to industrial and medical environments. Beyond imaging, scanning probe techniques representing the eyes of nanotechnology allows us to investigate surfaces and interfaces close to surfaces at the nanometer scale and below, thus providing information about structure, mechanical, electronic, and magnetic properties. It became apparent during the collection phase of Vol. I in 2003 that many more activities exist which deserve presentation. Therefore, this three volume set was prepared in order to display the wide breadth of this field and also to provide an excellent compendium for recent developments in this area. The response of colleagues and research groups being asked to contribute has been very positive, such that we decided, together with the publisher, to rapidly move on in these areas. It became possible to collect excellent contributions displaying first hand information from leading laboratories worldwide.

The present volumes II–IV cover three main areas: scanning probe microscopy (SPM) techniques (Vol. II); characterization (basic aspects, research, Vol. III); and industrial applications (Vol. IV).

Volume II includes overviews on sensor technology based on SPM probes, high harmonic dynamic force microscopy, scanning ion conduction microscopy, spin polarized STM, dynamic force microscopy and spectroscopy, quantitative nanomechanical measurements in biology, scanning micro deformation microscopy, electrostatic force and force gradient microscopy and nearfield optical microscopy. This volume also includes a contribution on nearfield probe methods such as the scanning focus ion beam technique which is an extremely valuable tool for nanofabrication including scanning probes.

Volume III includes the application of scanning probe methods for the characterization of different materials, mainly in the research stage, such as applications of SPM on living cells at high resolution, macromolecular dynamics, organic supramolecular structures under UHV conditions, STS on organic and inorganic low dimensional systems, and ferroelectric materials, morphological and tribological characterization of rough surfaces, AFM for contact and wear simulation, analysis of fullerene like nanoparticles and applications in the magnetic tape industry.

The more relevant industrial applications are described in Vol. IV, which deals with scanning probe lithography for chemical, biological and engineering applications, nanofabrication with self-assembled monolayers by scanned probe lithography, fabrication of nanometer scale structures by local oxidation, template effects of molecular assemblies, microfabricated cantilever arrays, nanothermomechanics and applications of heated atomic force microscope cantilevers.

Certainly, the distinction between basic research fields of scanning probe techniques and the applications in industry are not sharp, as becomes apparent in the distribution of the individual articles in the different parts of these volumes. On the other hand, this clearly reflects an extremely active research field which strengthens the cooperation between nanotechnology and nanoscience.

The success of the series is solely based on the efforts and the huge amount of work done by the authors. We gratefully acknowledge their excellent contributions in a timely manner which helps to inform scientists in research and industry about latest achievements in scanning probe methods. We also would like to thank Dr. Marion Hertel, Senior Editor Chemistry, and Mrs. Beate Siek of Springer Verlag for their continuous support, without which this volume could never make it efficiently to market.

January, 2006

Prof. Bharat Bhushan, USA
Prof. Harald Fuchs, Germany

Contents – Volume II