DEGGENDORF INSTITUTE of TECHNOLOGY, GERMANY

Micro- and Nano-Analytics Research Team

Prof. Dr. Werner Frammelsberger –
Mechanical Engineering & Mechantronics

Micro- and Nano-Analytics
Research Team

Atomic Force Microscopy –

Characteristics and Advanced Applications

Prof. Dr. Werner Frammelsberger
Mechanical Engineering & Mechatronics

Agenda

- Micro- and Nano-Analytics Research Team
- Introduction
- Atomic Force Microscope (AFM) – Principles and Fundamental Applications
- Conductive AFM (C-AFM), Tunnelling AFM (Tuna)
- Scanning Capacitance Microscopy (SCM) Techniques
- Kelvin Probe Force Microscopy (KPFM) Techniques
- Summary
- What's next?

Micro and Nano-Analytics – Basics

- Founded in 2000 by **Prof Dr. Günther Benstetter**
- Hosted at **Faculty of Electrical Engineering & Media Technology**
  http://www.hdu-deggendorf.de/de/fakultaeten/et-mt/forschungsteams/1300-mikro-und-nanoanalytik

Intention

- Concentration on complex and innovative analysis methods that require high-level expertise
- Competent service and development partner for regional and superregional economy and industry, predominantly SEMs
- Basis for various academic activities at Bachelor, Master and PhD level

Concept – three main steps

- Development of basic analysis principles and analysis methods with international universities and research institutions and in with participation of industrial partners from SMEs..
- Application centred optimisation of methods and techniques – accompanied with associated numerical simulations
- Customised analysis and measurement services

SME: Small and Medium-Sized Enterprises

Micro and Nano-Analytics – Organisation

Electrical Engineering & Media Technology

Natural Sciences & Industrial Engineering

Micro & Nano Analytics

Mechanical Engineering & Mechatronics

Prof. Raimund Förg

Projects
Funding
Cooperation

Prof. Dr. Günther Benstetter

Heading
Management
Projects
Funding
Laboratories
Staff

Prof. Dr. Werner Frammelsberger

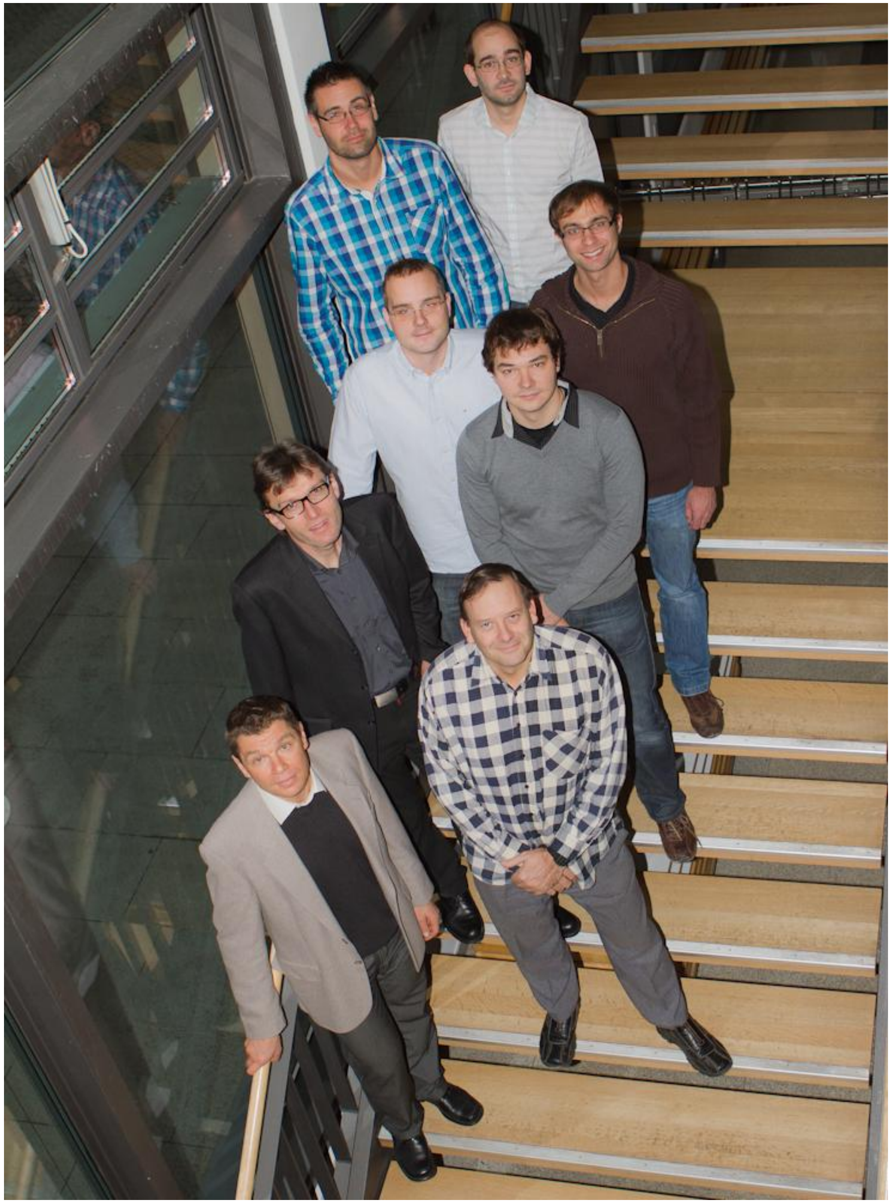
Projects
Funding
Cooperation

Civil & Construction Engineering

Business Administration & Business Informatics

Currently at DIT: 15 Bachelor and 7 Master degree programs

Micro and Nano-Analytics – Research Team



Founder and head:
Prof. Dr. Günther Benstetter
Electrical Engineering and Media Technology

Team-Members:
Prof. Raimund Förg (staff)
Prof. Dr. Werner Frammelsberger (staff)
Dipl. Phys. Edgar Lodermaier (staff)
MEng Heiko Ranzinger (staff)
MEng Tobias Berthold (PhD candidate)
MEng Alexander Hofer (PhD candidate)
MEng Albin Bayerl (PhD candidate)
BEng Manuel Bogner (MEng candidate)

MEng Andreas Stadler (MEng finished)
Dr. Roland Biberger (PhD, finished)
MEng Werner Bergbauer (Master, finished)
Prof. Dr. Dongping Liu (former staff, Dalian Nationalities University, China)

Micro and Nano-Analytics – Activities, Services

Application and services include:

- Manufacturing associated quality assurance, reliability and failure analysis
- System characterizations: Failure, construction and reliability analysis in electronic and optoelectronic devices and systems
- Basic material characterization (defects, contamination, physical properties, organic and inorganic materials)
- Surface and thin film characterization (roughness analysis, investigations of surface properties including abrasion and scratch resistance)
- …

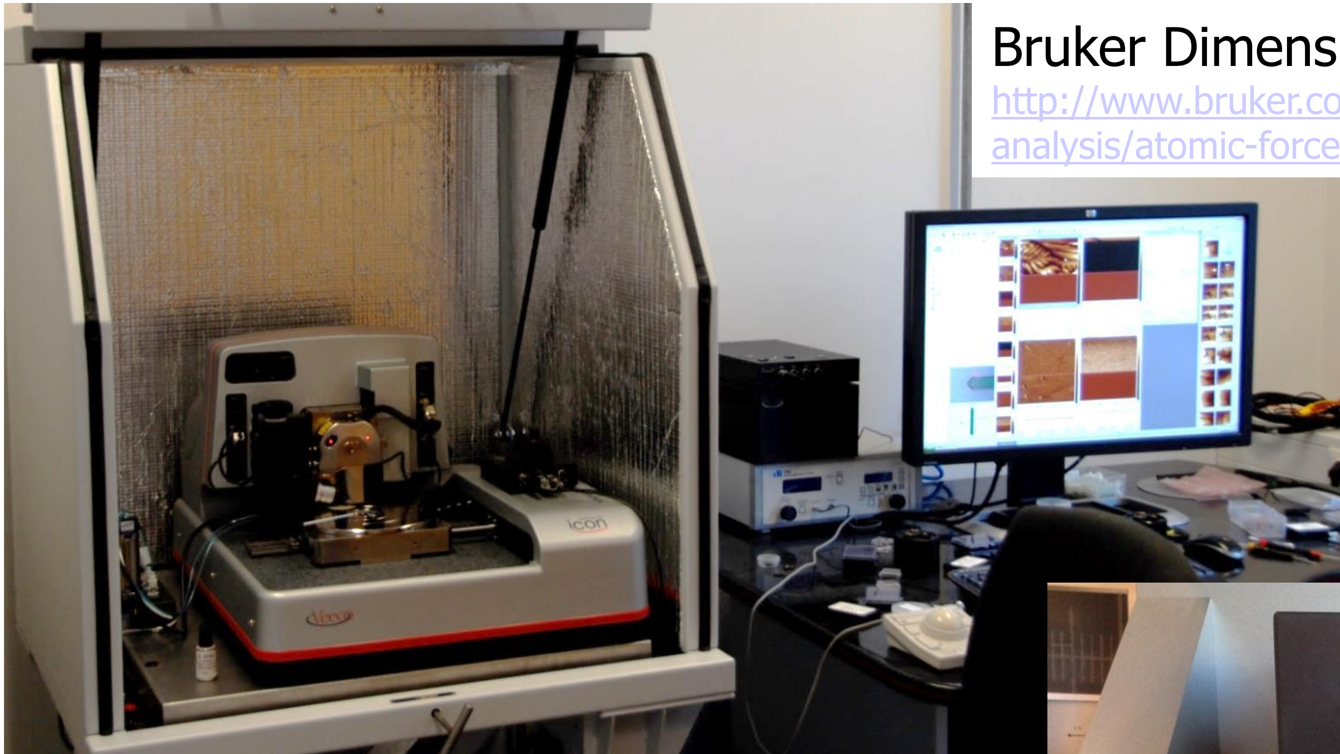
Academic Activities:

- **Bachelor and Master**
  Lectures, student projects, hands on training, internships, theses, academic supervision
- **Master Applied Research** (joint project) http://www.forschungsmaster.de/
  Projects, lectures, administration, management, academic supervision
- **PhD studies** and research projects
  Funding, management, administration, academic supervision
- Applied research
  - in cooperation with German and international Universities and Universities of Applied Sciences and
  - Numerous German and international corporate partners

Micro and Nano-Analytics – Key Equipment and Methods

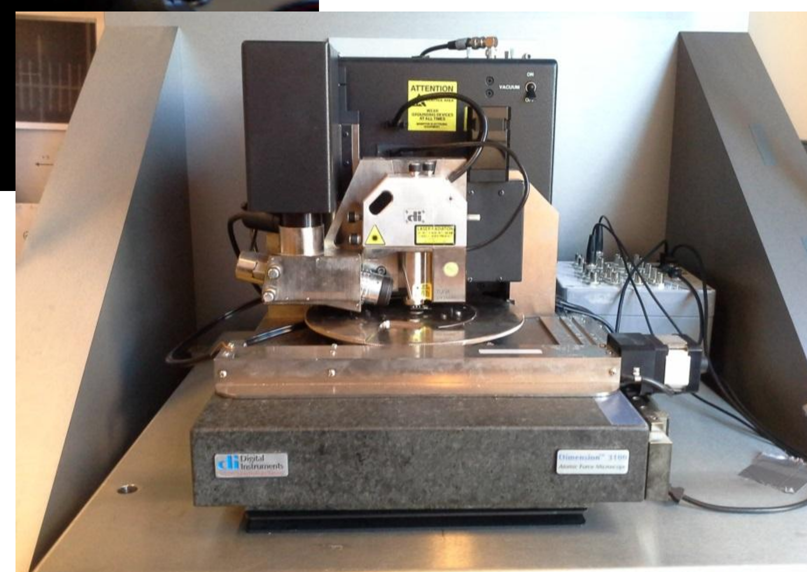
- **Scanning electron microscopy** (SEM) based methods including: Energy dispersive X-ray spectroscopy (EDX), Wavelength-dispersive X-ray spectroscopy (WDX), Electron backscatter diffraction (EBSD), Micro X-ray fluorescence spectroscopy (µXRF), Scanning Transmission Electron Microscopy (STEM)
- **Scanning probe microscopy** (SPM) based methods including: Scanning capacitance microscopy (SCM) and spectroscopy (SCS), Tunnelling current microscopy (C-AFM, TUNA), Scanning Spreading Resistance Microscopy (SSRM), Kelvin Probe Force Microscopy (KPFM), Electric Force Microscopy (EFM), Magnetic Force Microscopy (MFM), Nano-scratch and wear tests, Thermal scanning probe microscopy (ThSPM)
- Additional and supporting equipment and units: Fourier Transformation Spectroscope (FT-IR), plasma cleaner/coater, wafer prober, sample preparation lab and optical microscopy…

Micro and Nano-Analytics –AFM

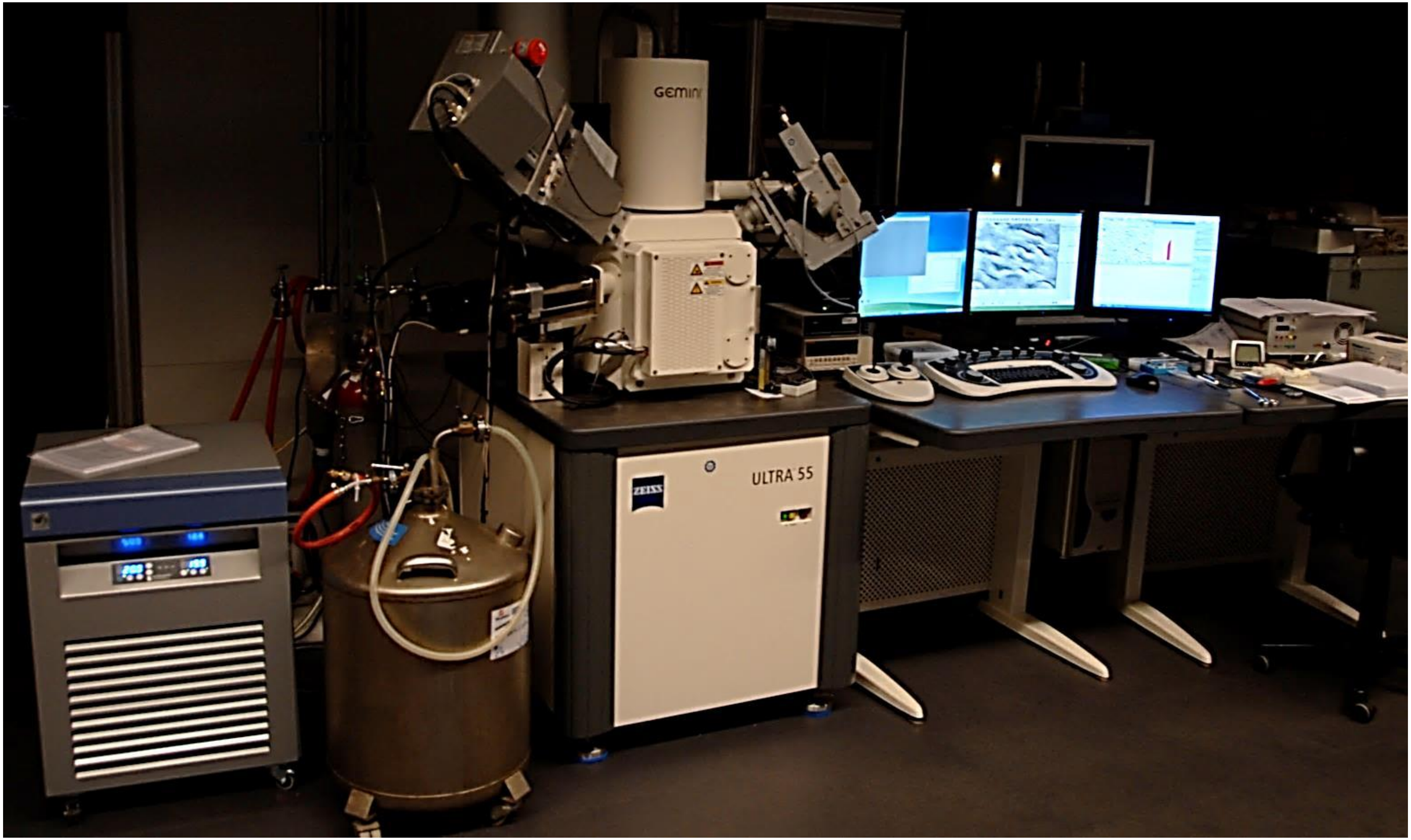


Bruker Dimension Icon
http://www.bruker.com/products/surface-analysis/atomic-force-microscopy.html

Bruker (Veeco) Dimension 3100
http://www.bruker.com/products/surface-analysis/atomic-force-microscopy.html



Micro and Nano-Analytics – Zeiss Ultra 55



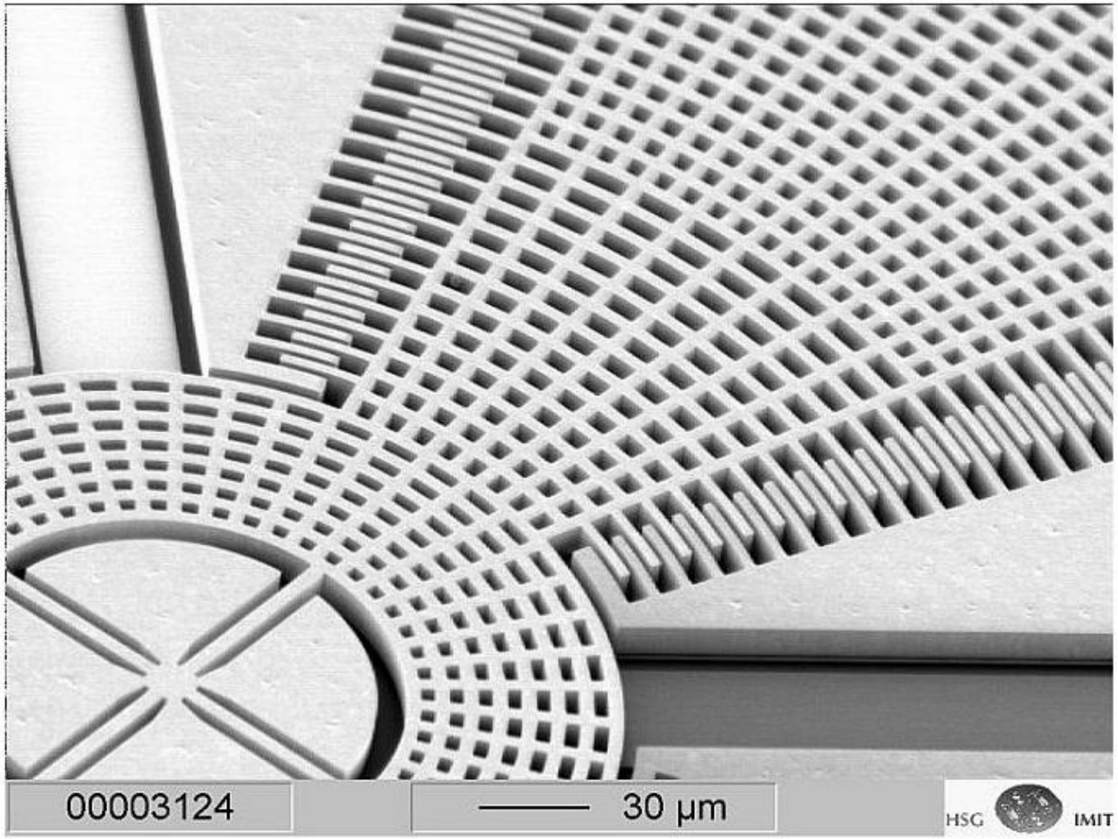
Micro and Nano-Analytics –Preparation

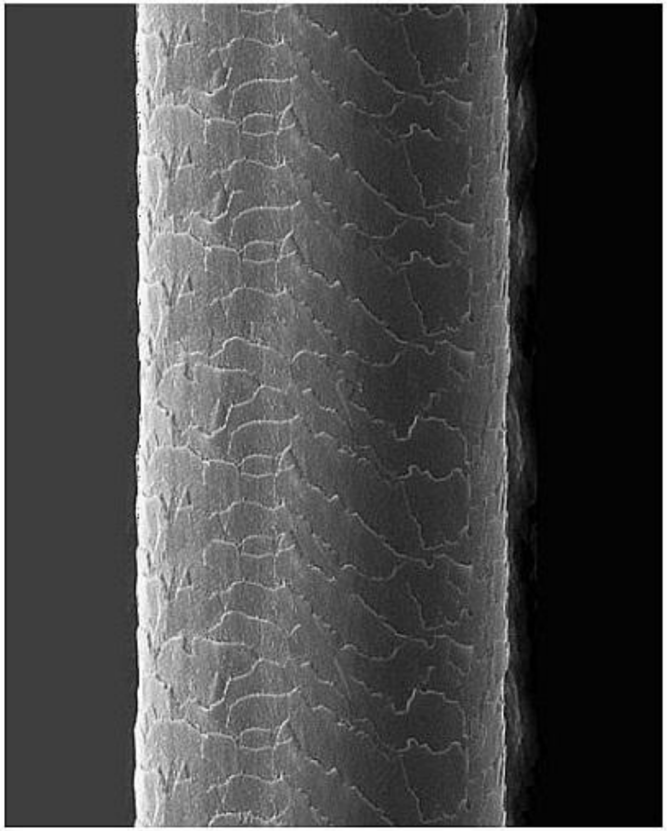
Preparation lab

Plasma cleaner/coater, GATAN 652

Introduction

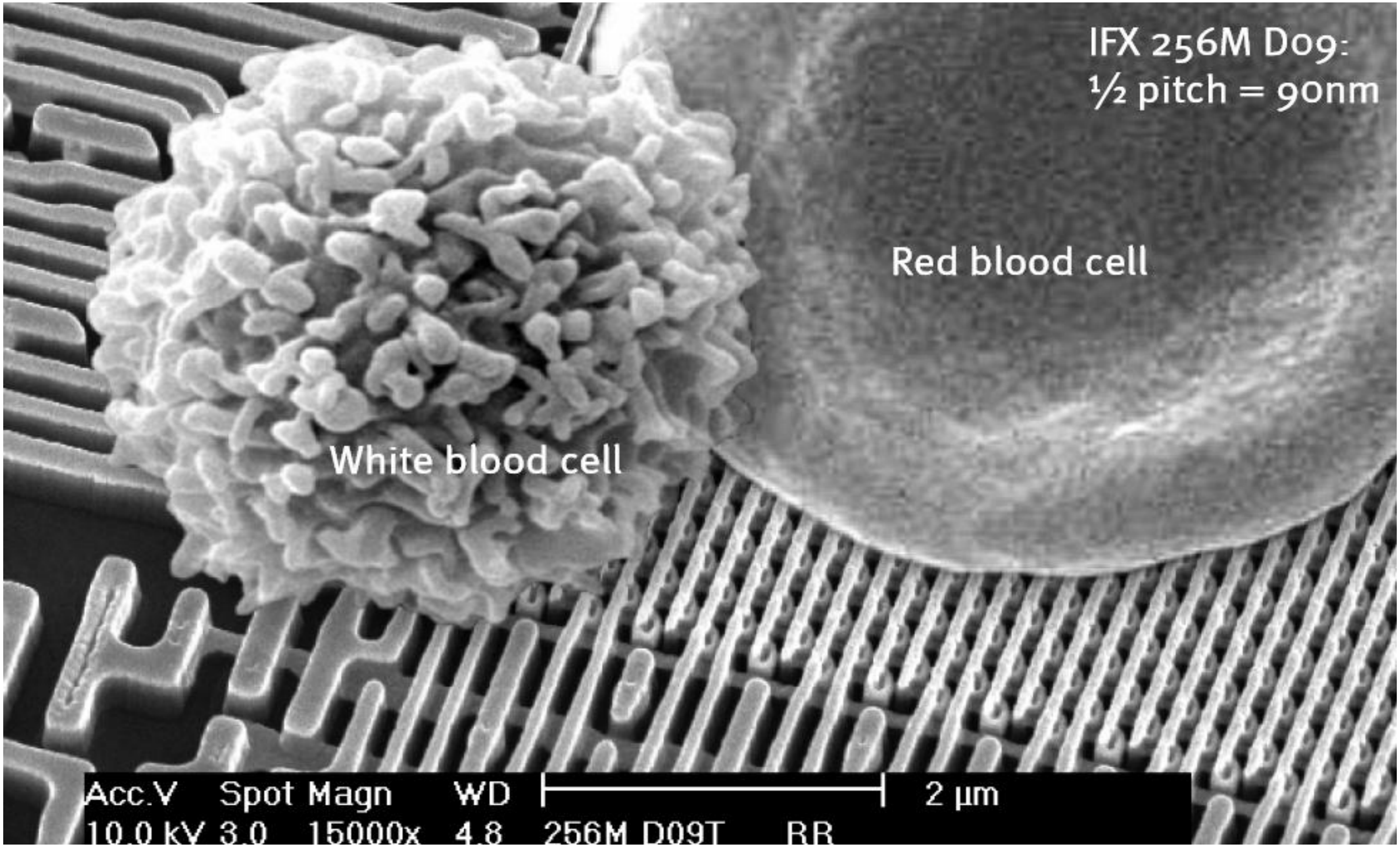
Gyro-meter compared to a human hair





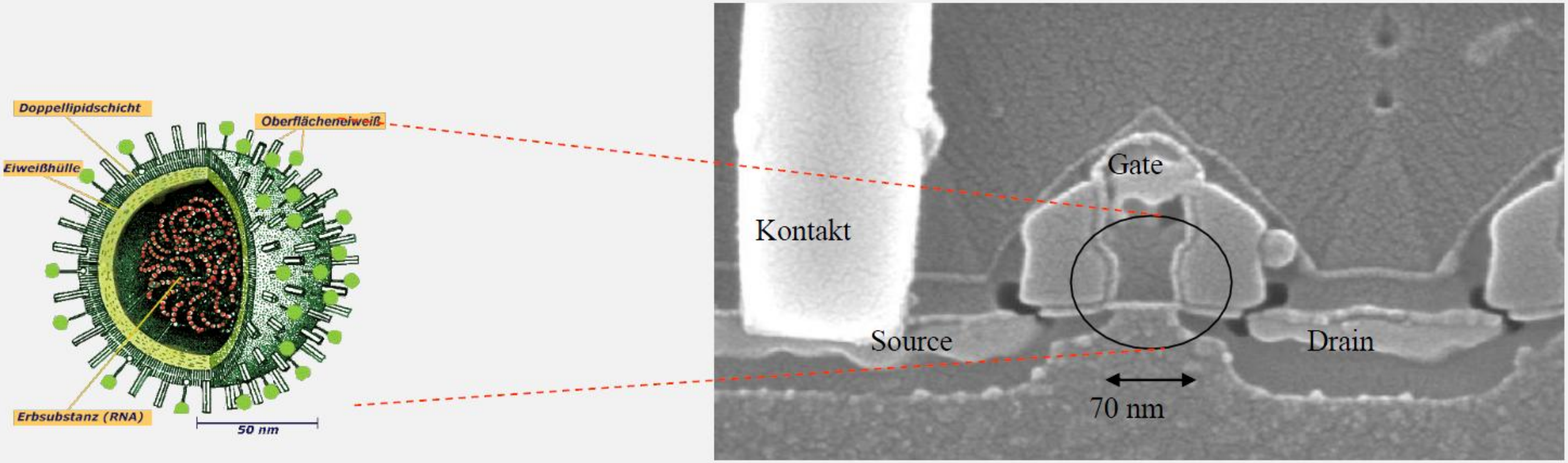
Zengerle 2008, IMTEK, lecture

Introduction



Chr. Esser Infineon Technologies

Introduction



Influenza virus
100 nm diameter
400 atoms

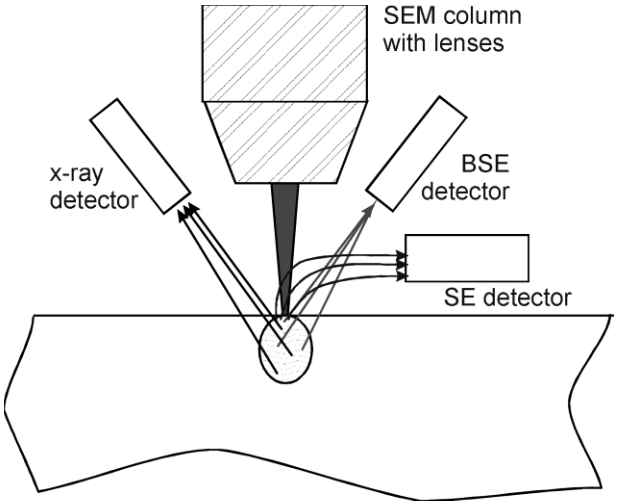
MOS-Transistor
70 nm gate length
300 atoms

Hansch, UniBW München

From diameter point of view, a virus may host approximately three transistors, currently.

Introduction

Scanning-Electron-Microscope(REM)
Ernst Ruska 1931! Nobel price 1986



Elektronen +
Magnetfelder +
Elektronik

Transmissions-
Electron-Microscope
(TEM)

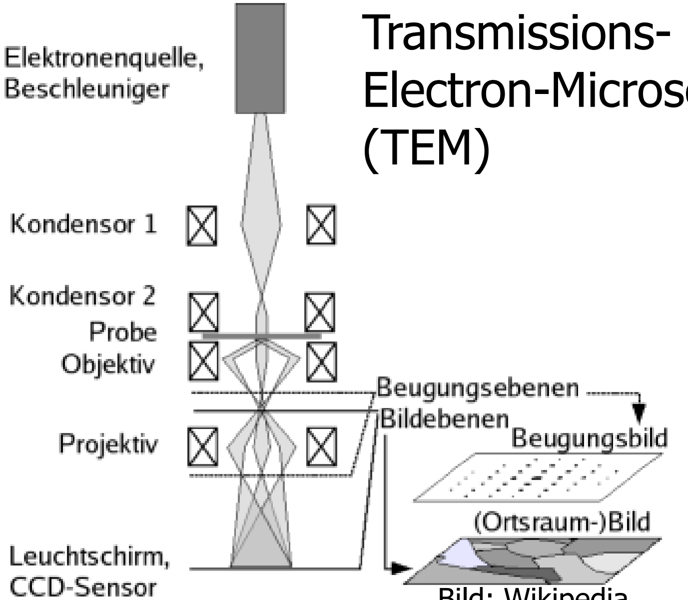
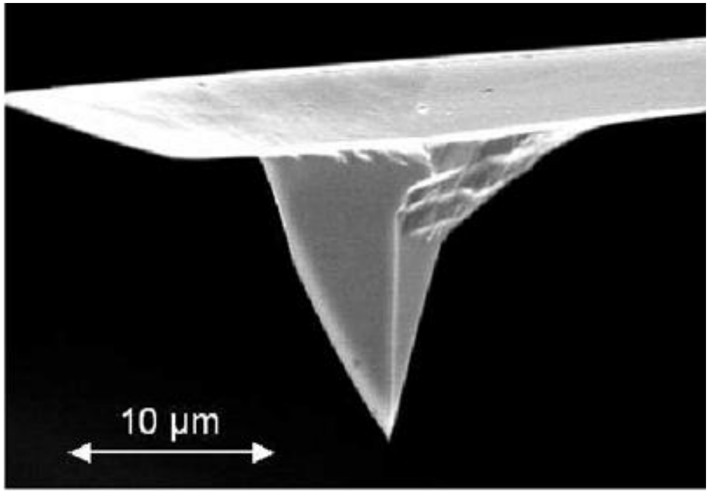
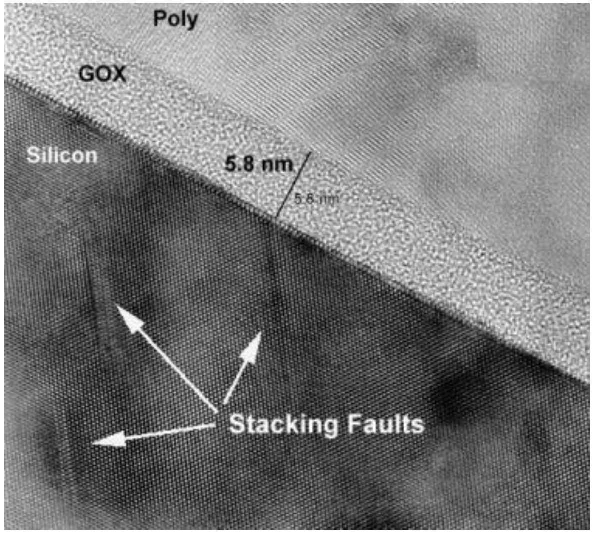


Bild: Wikipedia





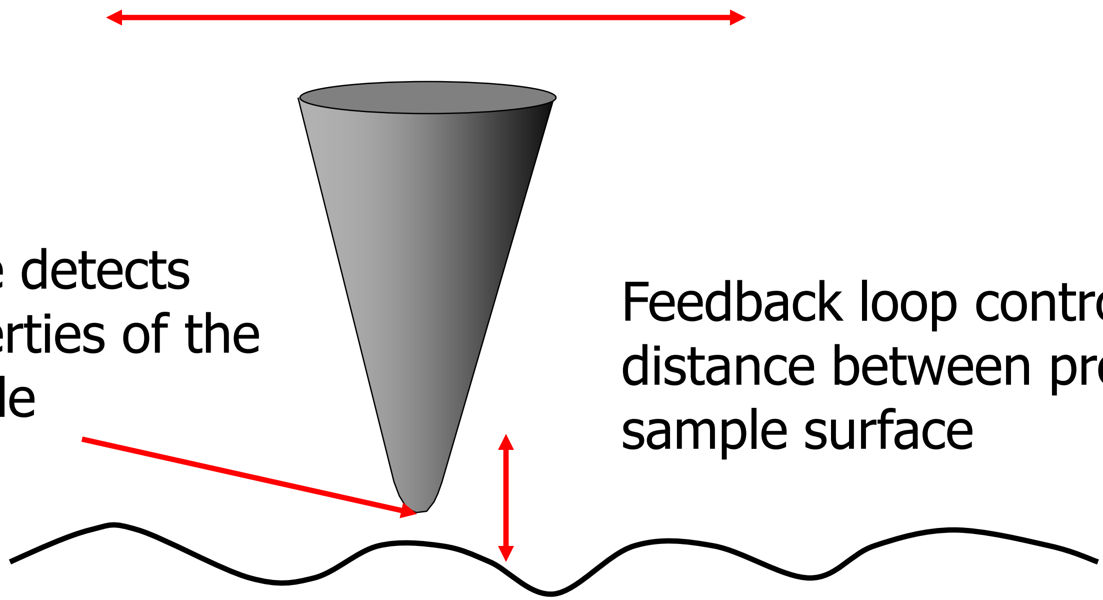
Introduction

- High resolution imaging of micro and nanostructures with SEM possible
- Content analysis with SEM based techniques (EDX, WDX…) possible, however:
  - Conductive specimen necessary
  - Limited 3D-imaging
  - No liquid specimen possible
  - Limited information from thin films
  - No information about mechanical properties
  - No information about electrical properties
  - No high resolution chemical/physical analysis
- Alternative analysis techniques necessary

Atomic Force Microscope – Principles

Probe moves relativeley to the sample surface

Probe detects properties of the sample



Feedback loop controlles distance between probe an sample surface

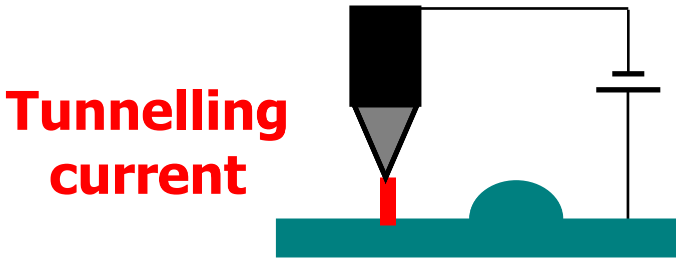
Atomic Force Microscope – Principles

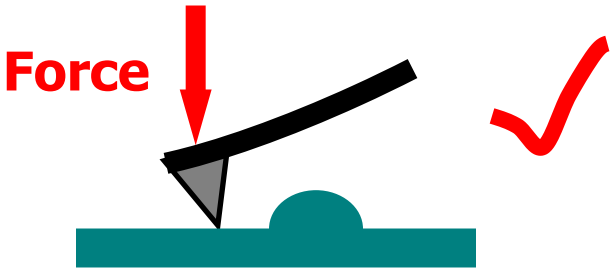
- Scanning probe microscopes are a family of instruments used for **studying surface properties** from the micron to atomic level
- The components that make scanning probe microscopy possible are the **probe** and the **scanner**.
- The **probe** is the point of interface between the SPM and the sample and intimately interrogates various qualities of the surface.
- The **scanner** controls the precise position of the probe in relation to the surface, both vertically and laterally.

Atomic Force Microscope – Principles

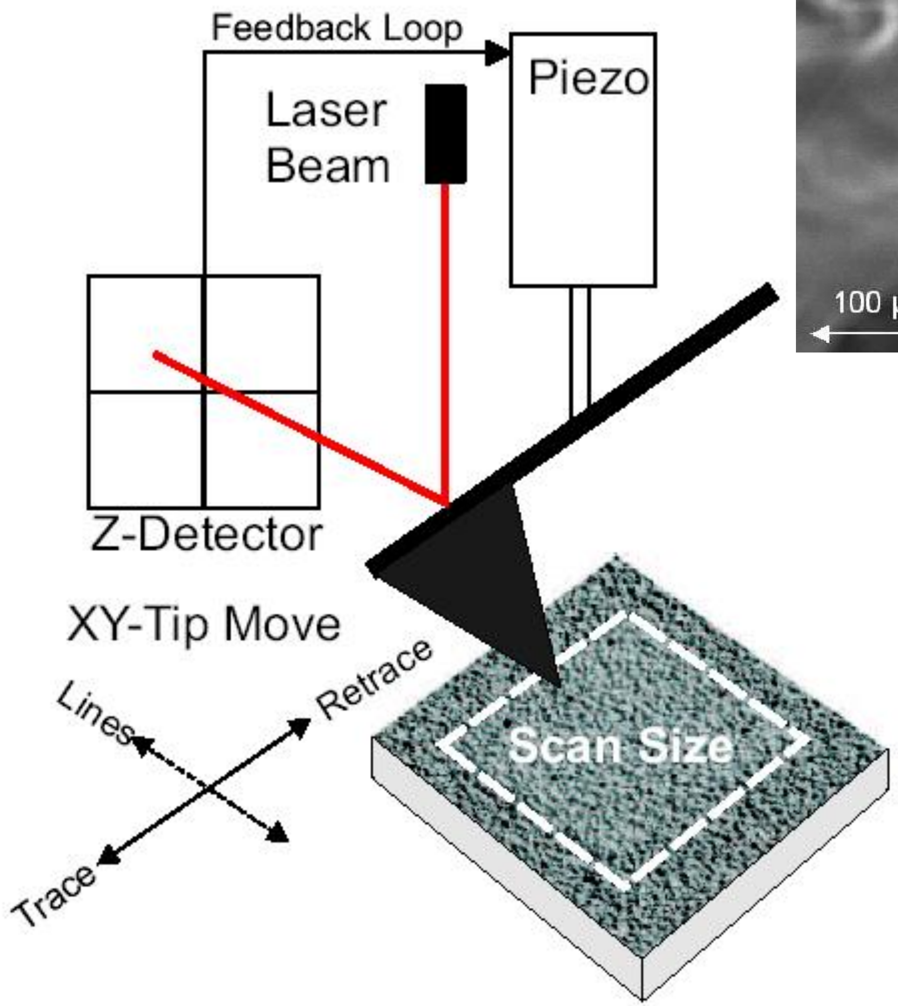
Discrimination: distance controll system

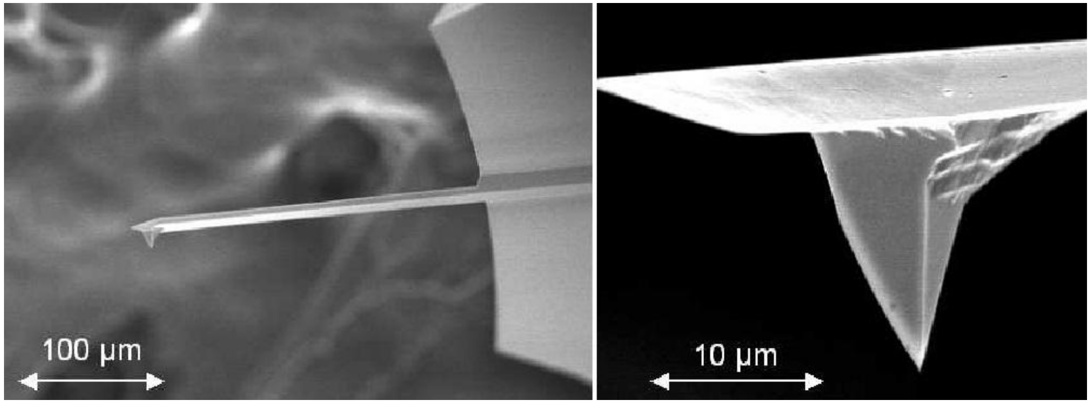
Scanning probe microscopy (SPM)	
Scanning tunnelling microscopy (STM)	Atomic force microscopy (AFM)
1981 Binnig, Rohrer Nobel price 1986	1985 Binnig, Quate, Gerber



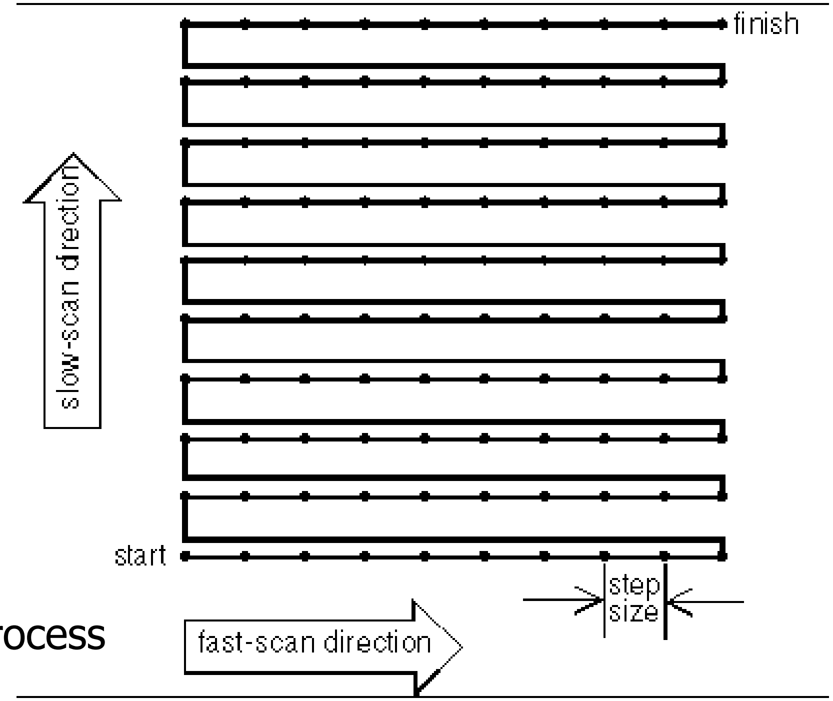


Atomic Force Microscope – Principles





SEM image, typical probe tip



Scan process

Atomic Force Microscope – Principles

Bruker (Veeco), Dimension 3100

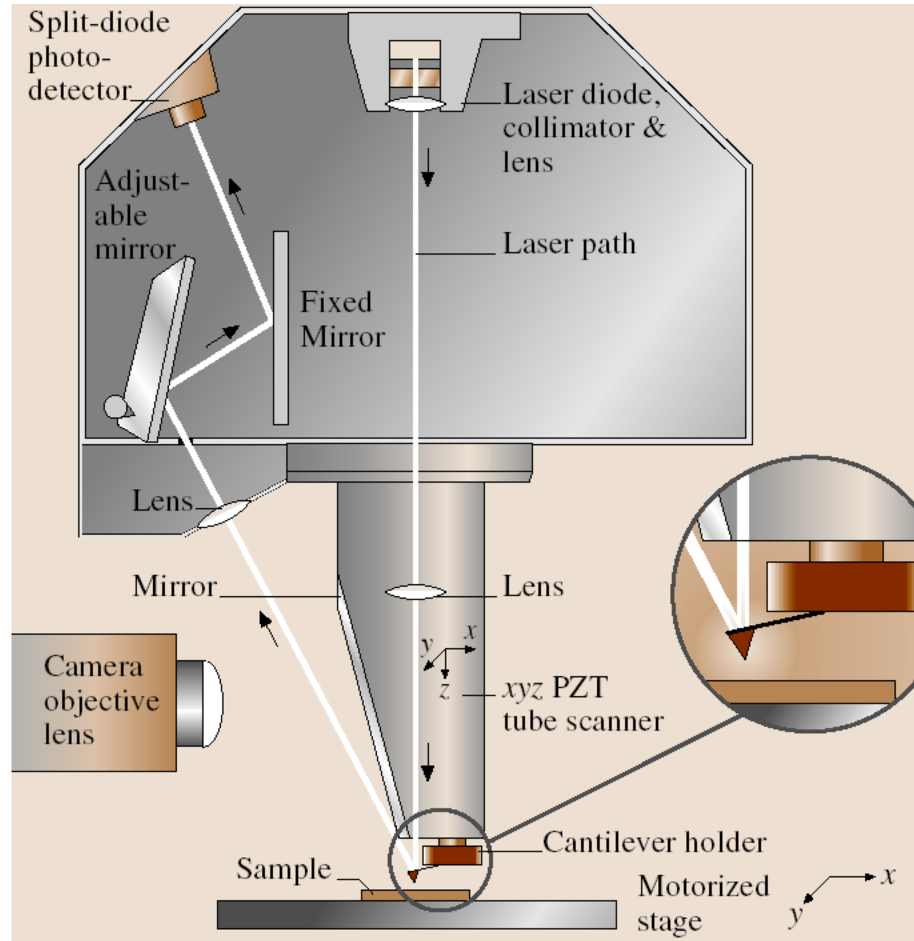
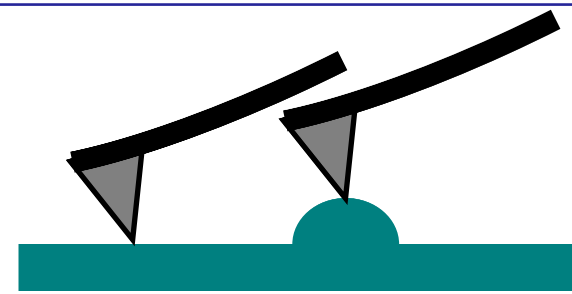


Image Bushan (2004)

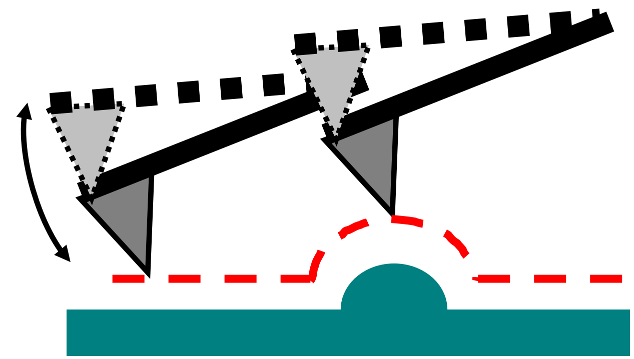
Atomic Force Microscope – Principles

- Contact AFM (Cont-AFM)
  - High resulution
  - Low distortion
  - High lateral forces→high wear



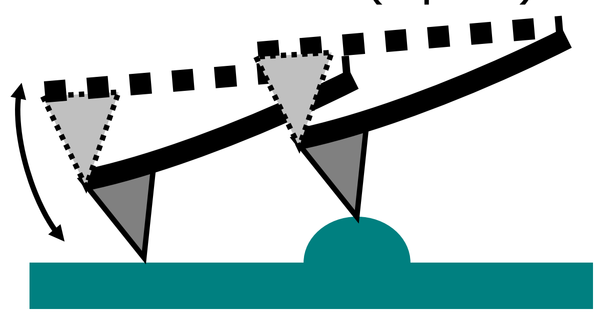
Hard surfaces

- Non Contact AFM (NC-AFM)
  - Low resolution
  - High distortion
  - No lateral forces→no wear



Soft surfaces (liquids)

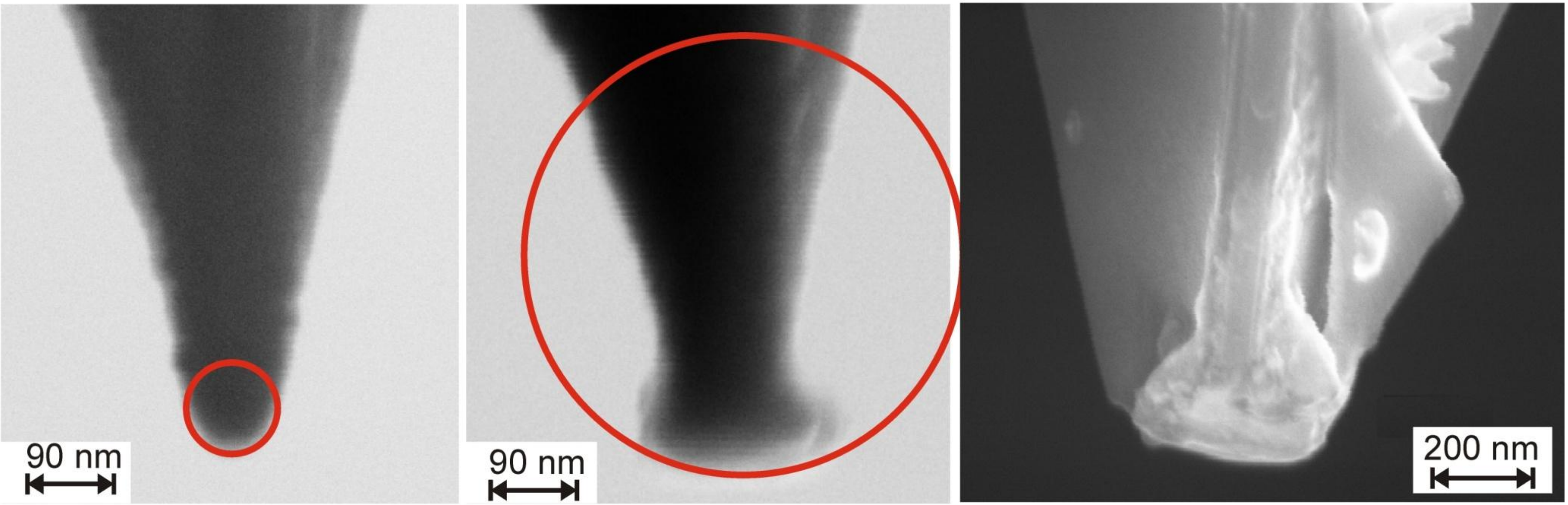
- Intermittent Contact AFM (IC-AFM, Tapping Mode)
  - High resolution
  - Low distortion
  - Low (no) lateral forces→low wear



Hard surfaces, Soft surfaces

AFM – Tip wear

Conductive metal-coated probe tips



Increase of tip radius from ~50 nm to ~300nm due to tip wear

Severe damage:

metal coating completely worn off

Tip wear is most critical in contact mode

AFM – Peak-Force Tapping (PF-xxx)

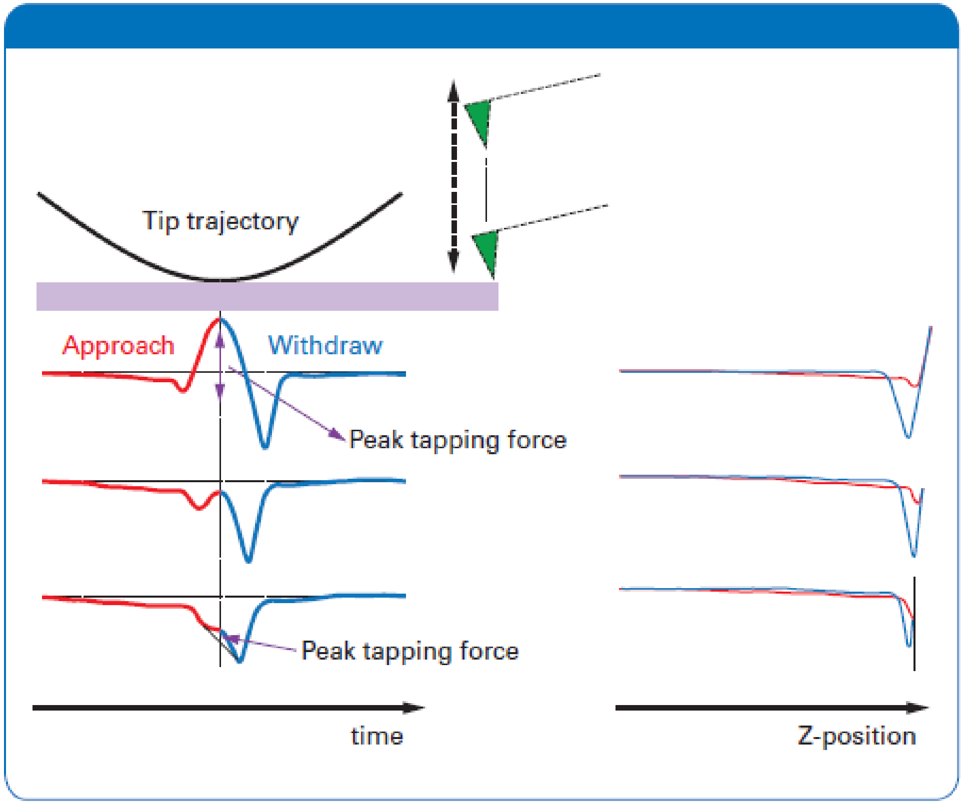
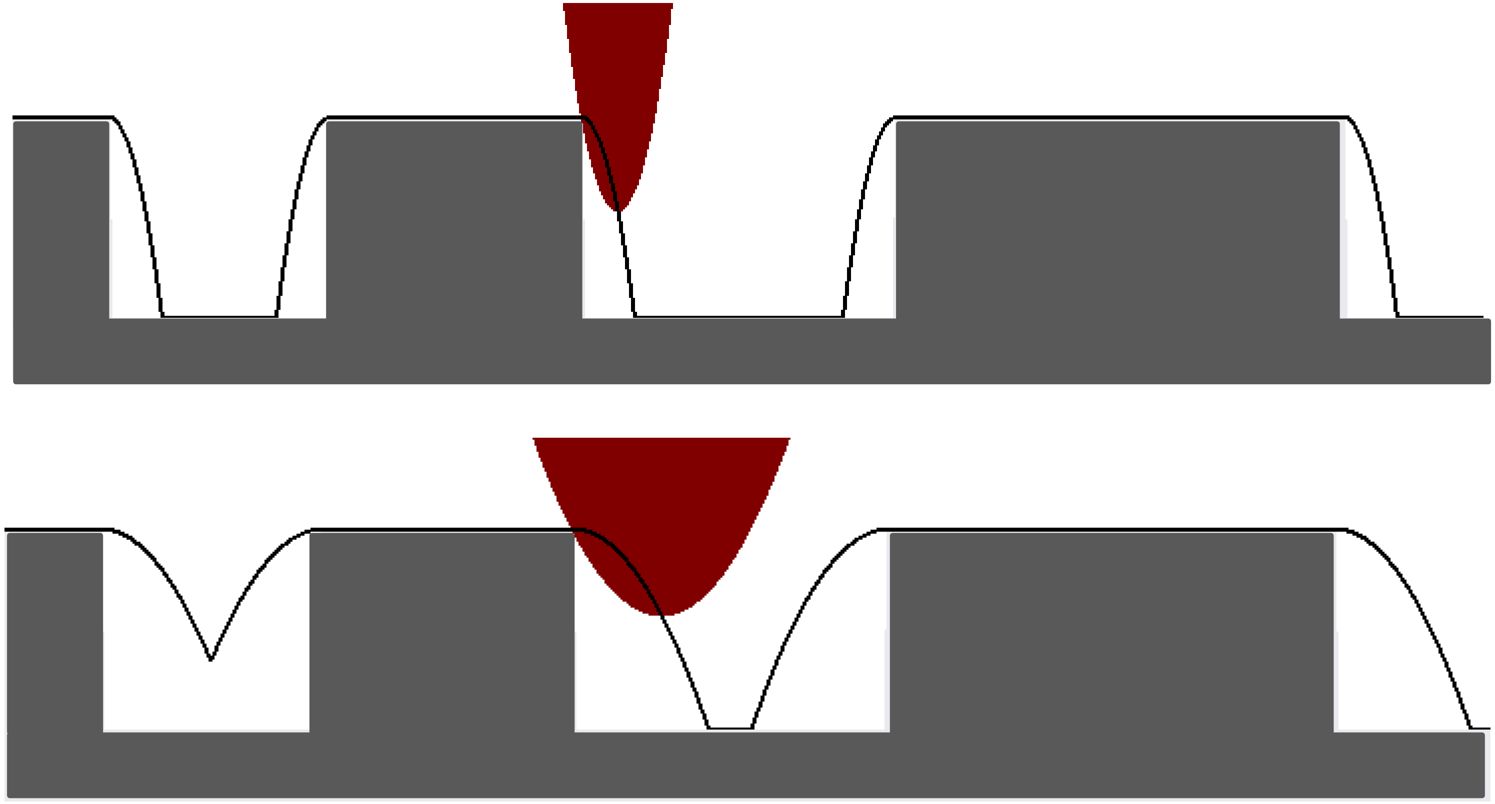


Figure 9. Experimental data of force curves for a cantilever operated in PeakForce Tapping. The lever is driven by a sinusoidal wave and the curves are displayed as force versus time and force versus distance.

- Avoids lateral forces
- Continuous force curves at frequencies between 1kHz and 10kHz
- Imaging speeds comparable to TappingMode
- Non-resonant mode, f below cantilever resonance (50 kHz-450 kHz)
- Avoiding the filtering effect and dynamics of a resonating system and unwanted resonance on turnaround point (sine z-positioning)
- Combines the benefits of contact and TappingMode imaging: Direct force control and avoidance of lateral forces.
- Hard and soft surfaces
- Combination with C-AFM, SCM, KPFM
- Quantitative Nanomechanical Property Mapping possible (PF-QNM)

http://www.bruker.com/fileadmin/user_upload/8-PDF-Docs/SurfaceAnalysis/AFM/ApplicationNotes/Introduction_to_Brukers_ScanAsyst_and_PeakForce_Tapping_Atomic_Force_Microscopy_Technology_AFM_AN133.pdf

AFM – Tip sample convolution



- Geometric convolution of tip and surface shape
- Aspect ratio of tip and sample determines the result
- Surface structures may influence results of advanced methods

Simulation: Joseph Griffith, NC State University

AFM – Environment and Resolution

Environment

- Ultra-high vaccuum (UHV)
- Gas (Nitrogen, inert gas)
- Liquids (Alcohol, oil…)
- Air

Resolution

- Lateral resolution depends on environment and probe tip
  - **UHV (<10K):** atomic resolution possible (topography mapping)
  - **Air:** typically 10 nm (topography mapping)
- Height resolution typically < 0,1 nm
- Lateral resolution of advanced methods depend highly on the method employed and the probe tip type used.
  For Electrical methods typically some ten nanometres.

AFM – Overview techniques

Mechanical properties	Electric and magnetic properties…

Mechanical properties

- Topography
- Nano hardness
- Nano wear
- Friction
- Adhesion (CFM, QNM)
- …

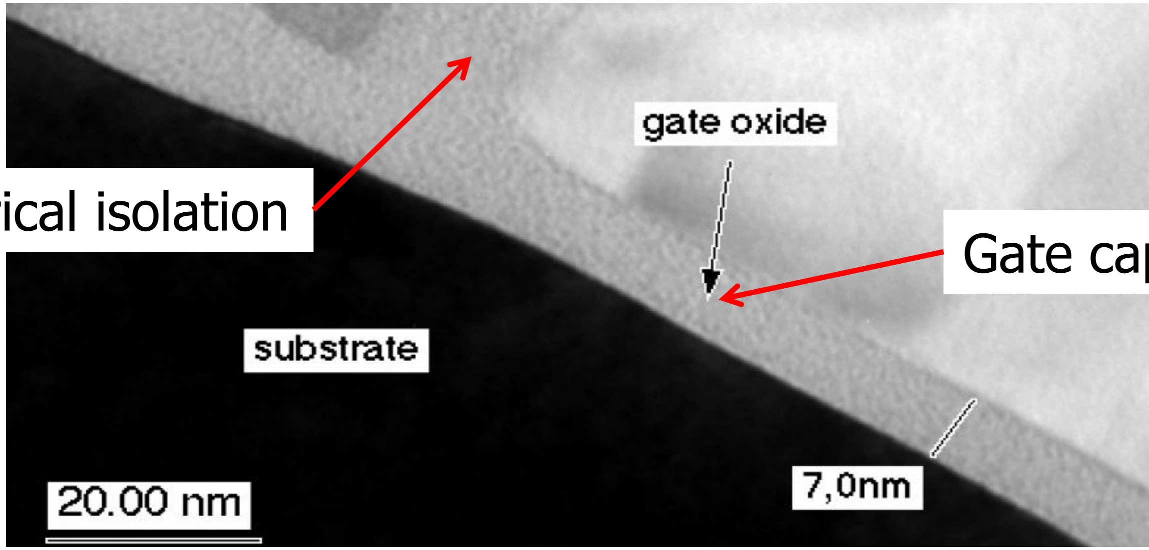
Electric and magnetic properties…

- Current (C-AFM)
- Capacitance (SCM and related techniques)
- Resistivity (SSRM)
- Magnetism (MFM)
- Surface potential (KPFM)
- …

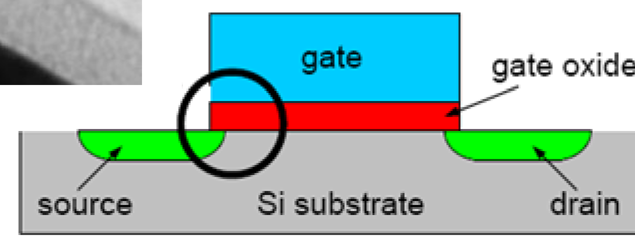
CFM: Chemical Force Microscopy
QNM: Quantitative Nanomechanical Mapping

SSRM: Scanning Spreading Resistance Microscopy
MFM: Magnetic Force Microscopy

C-AFM – Semiconductor application

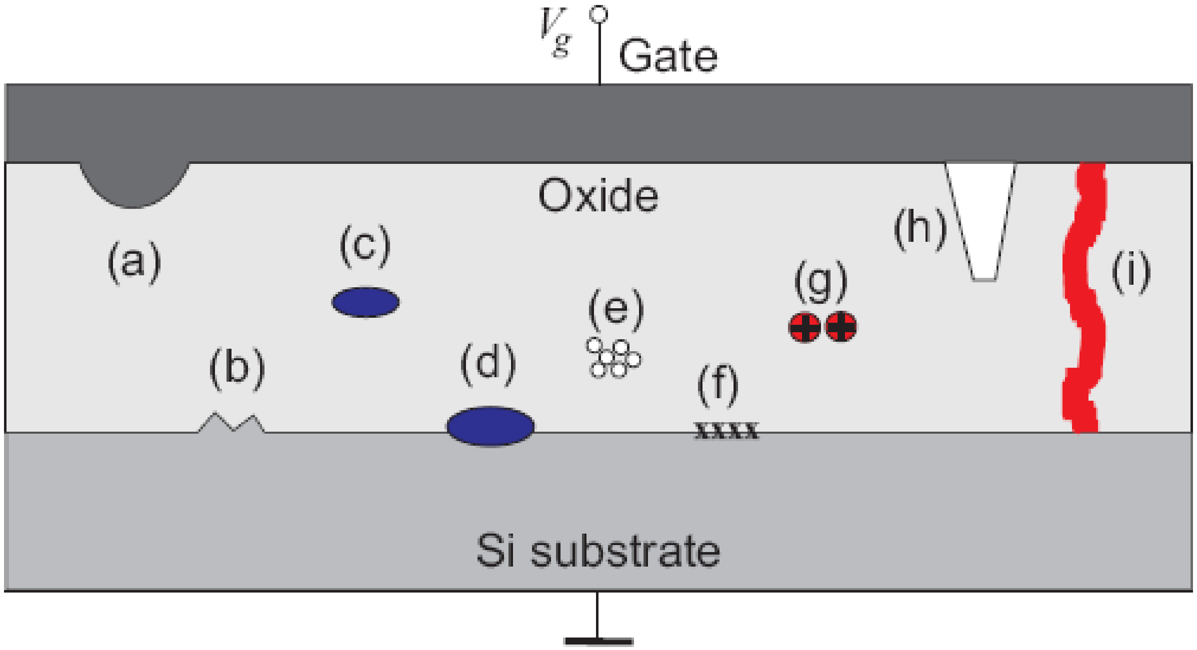


O. Storbeck, 6. Dresdner Sommerschule 2005



- Thin dielectric films in semiconductor applications
- Gate dielectric in MOS devices
- The integrity and reliability of dielectric films is of utmost importance

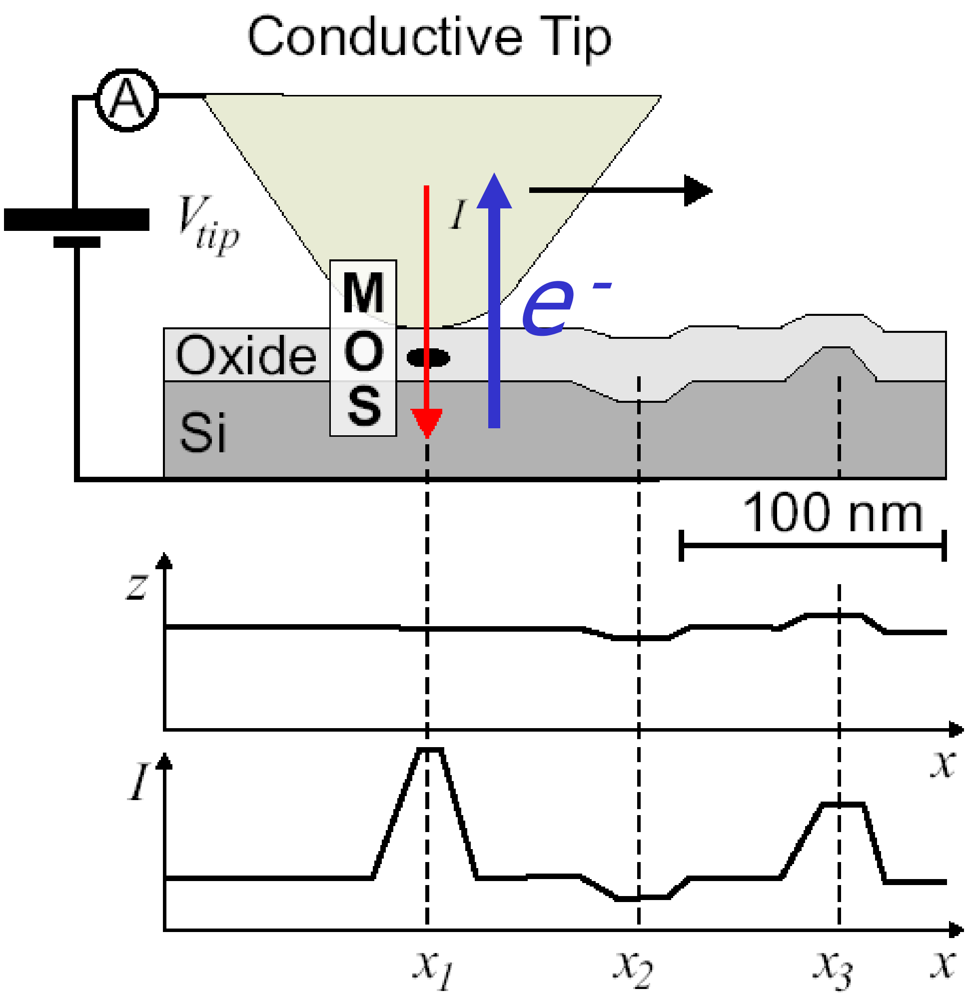
C-AFM – Microscopic defects



(a) thinned oxide, (b) asperities (c) impurities, (d) particles, (e) regions with increased trap generation rate, (f) regions with reduced barrier height, (g) mobile ions, (h) voids, (i) interconnections

Microscopic defects are a serious problem for oxide integrity and device reliability

C-AFM – Principle



- Microscopic MOS-Structure
- Emission area (20-200 nm^2) << macroscopic MOS-structure
- Current and topography measurement simultanously and independently
- High current at electrically weak sites and vice versa
- C-AFM enable the detection of single microscopic weak sites

Important: Substrate injection of the electrons due to anodic oxidation effects

C-AFM – Microscopic vs. macroscopic

Macroscopic methods

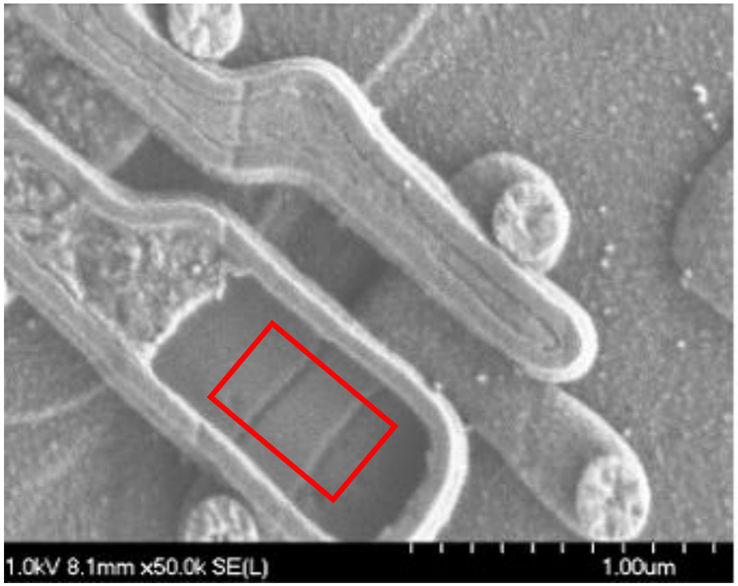
- Conventional methods
- Devices or capacitors
- General information over the test structures
- Time to breakdown, charge to breakdown, reliability tests
- Single weak sites or defects may not be ascertained
- 10^{-8}…10^{-4} cm^2 small area capacitors
- 10^{-2}…1 cm^2 large area capacitors

Microscopic methods

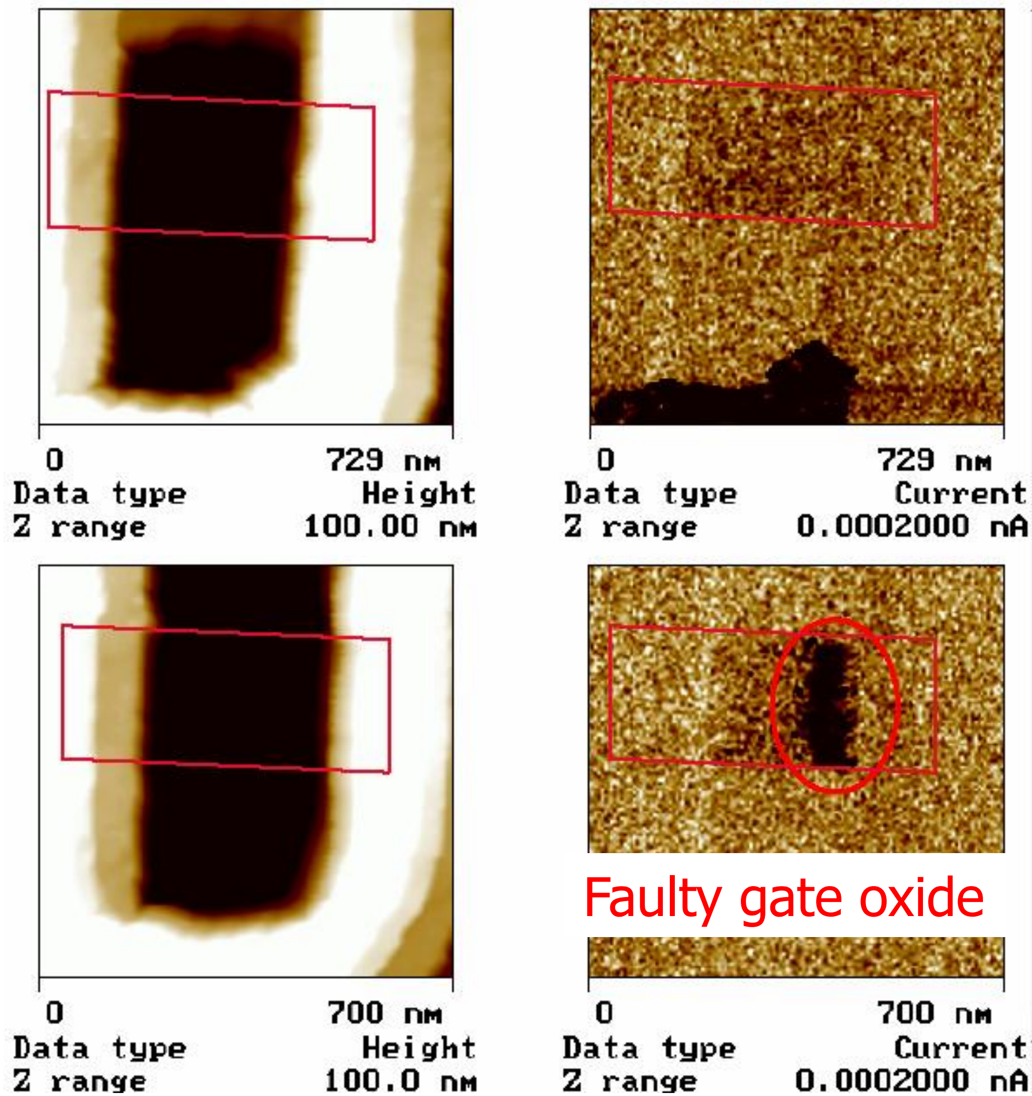
- Advanced methods
- Area to be investigated depends on the method
- Very local information (20-200 nm^2)
- Limited information about device performance
- Single weak sites or defects are detectable
- Physical root cause analysis is possible

Atomic force microscopy (AFM) based techniques

C-AFM – Case study gate oxide



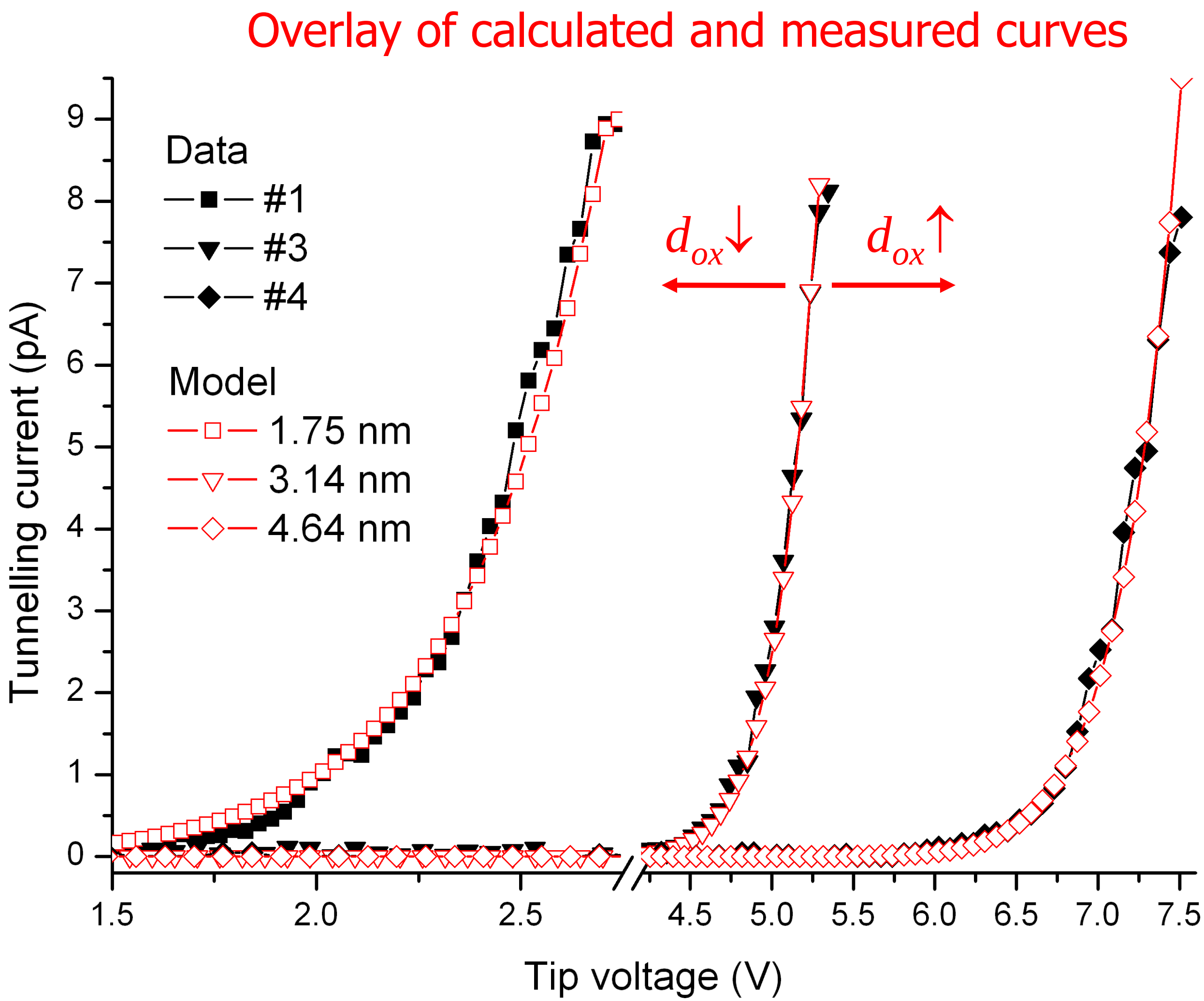
SEM after preparation of a 130 nm generation gate



C-AFM images
Topographie (l), current (r)

Frammelsberger et. al, ISTFA 2003
Schweinböck oral presentation

C-AFM – Thickness determination



C-AFM – Tunnelling model

Combined DT-FNT-model

Tunnelling equation

$$^{*}J = \frac{q^3}{16\pi^2\hbar} \cdot \frac{m_e}{m_{ox}} \cdot \frac{1}{\phi_B} \cdot F_{ox}^2 \qquad V_{ox} > \phi_B / q \Rightarrow 1$$

$$\exp\left(-\frac{4}{3} \cdot \frac{\sqrt{2m_{ox}}}{q\hbar} \cdot \frac{\phi_B^{3/2}}{F_{ox}} \cdot \left(1 - \left(1 - \overbrace{\frac{qV_{ox}}{\phi_B}}^{1} \right)^{3/2} \right) \right)$$

$$I = J \cdot A_{eff} \qquad F_{ox} = V_{ox} / d_{ox} \qquad V_{ox} = V_{tip} - V_{off}$$

Parameters

Tunnel parameters**

$$\phi_B = 3.25\,\text{eV}$$

$$m_{ox} = 0.37 m_e$$

Tip parameters**

$$V_{off} = 0 \ldots 1.6\,\text{V}$$

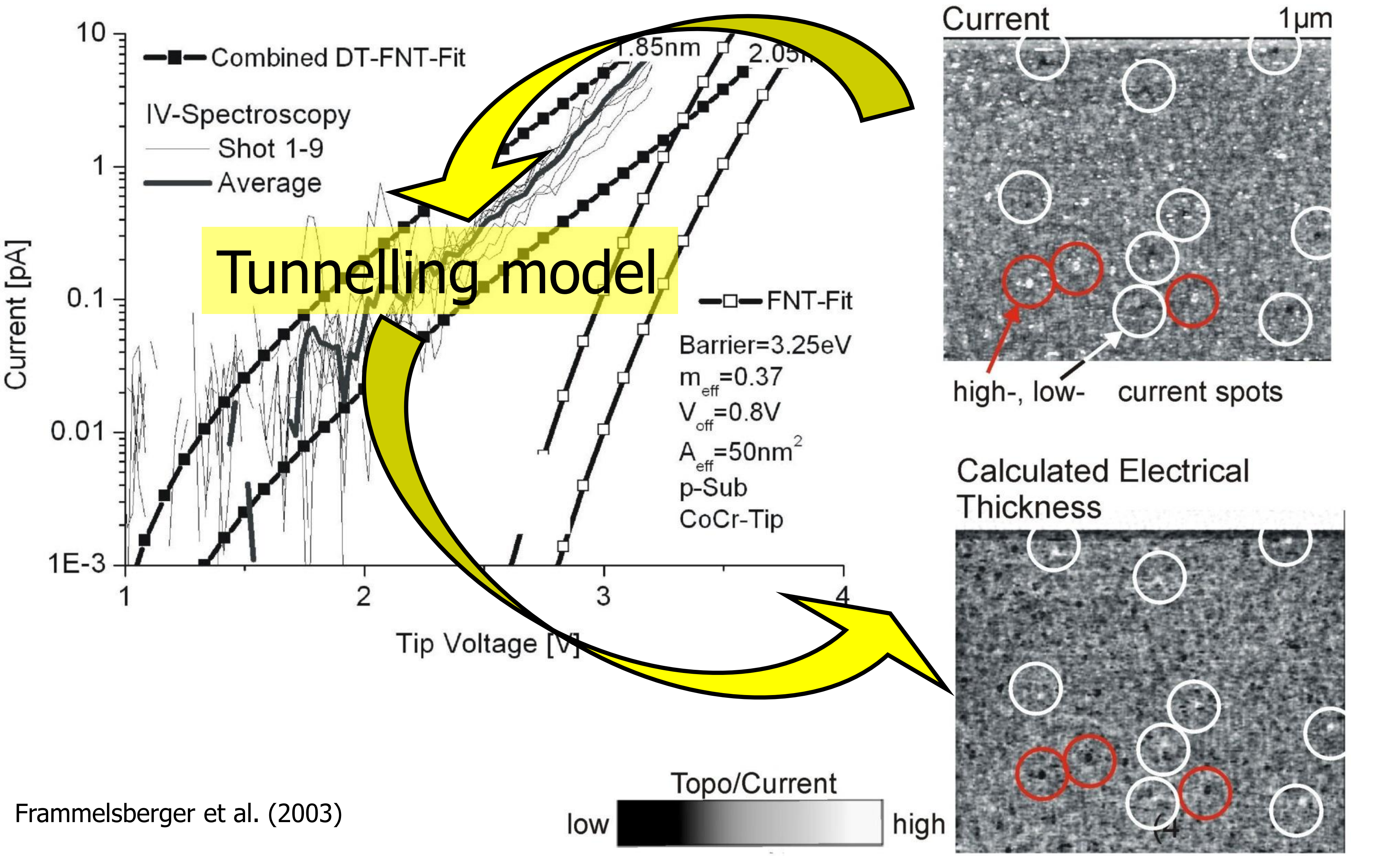
$$A_{eff} = 20 \ldots 200\ \text{nm}^2$$

Independent of oxide thickness and tunnelling regime

*Schuegraf and Hu (1994)
** Frammelsberger et al. (2005-2007)

Values for SiO_2 on Si substrate

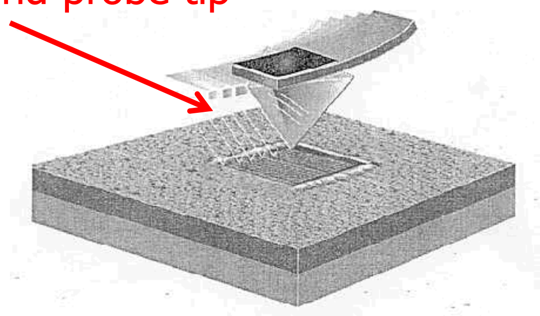
C-AFM – "Electrical" thickness mapping

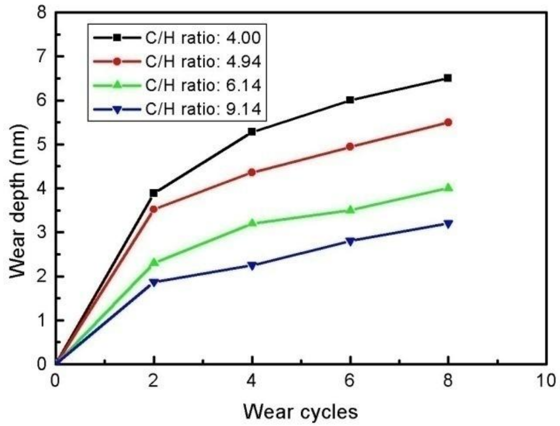


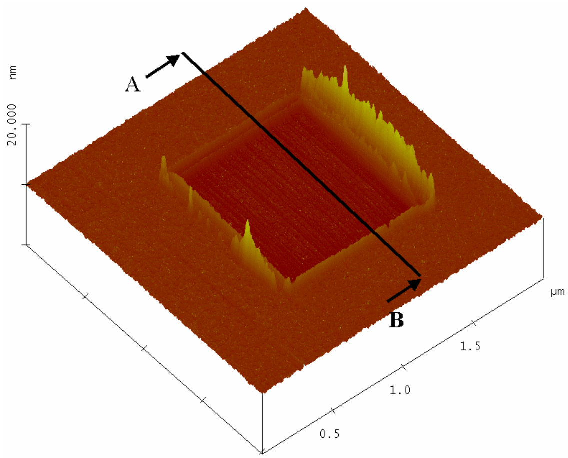
Frammelsberger et al. (2003)

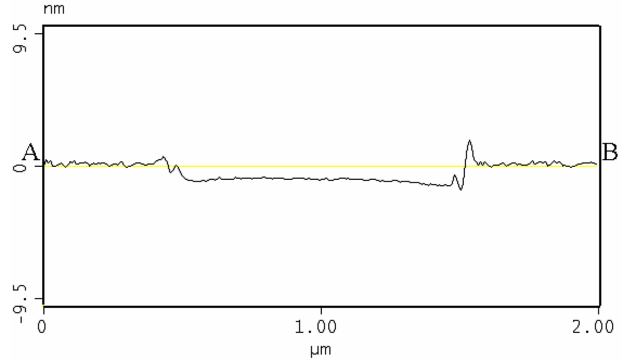
C-AFM – Combined methods

Bulk diamond probe tip







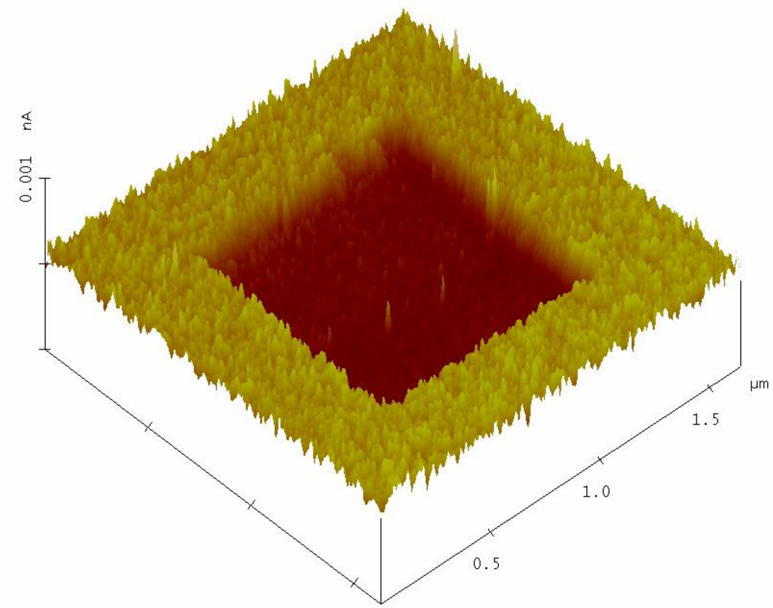


AFM wear tests with diamond tipped cantilever. DLC films deposited on p-type 100 silicon substrate exhibit a low density layer at the surface.

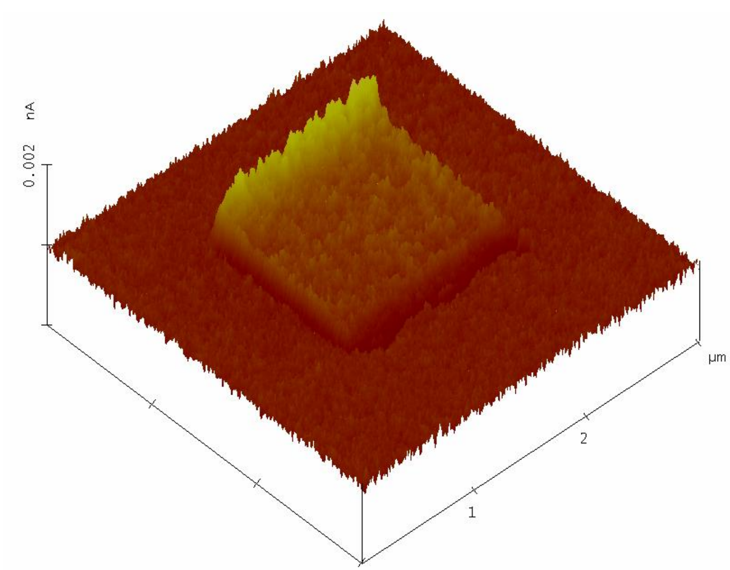
D. Liu et al. (2006)

C-AFM – Combined methods

100 nm a-C film
wear depth 1.7nm



100 nm a-C:H film
wear depth 1.1nm



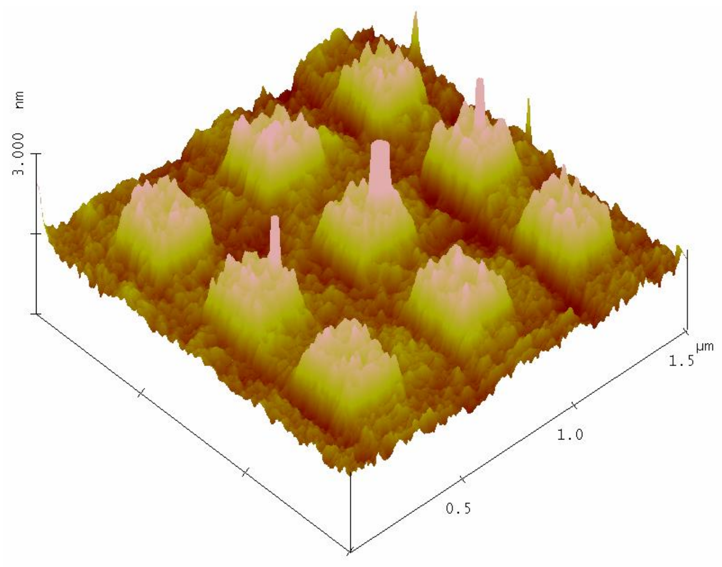
Improved low-field electron emission properties because of graphite like surface layer

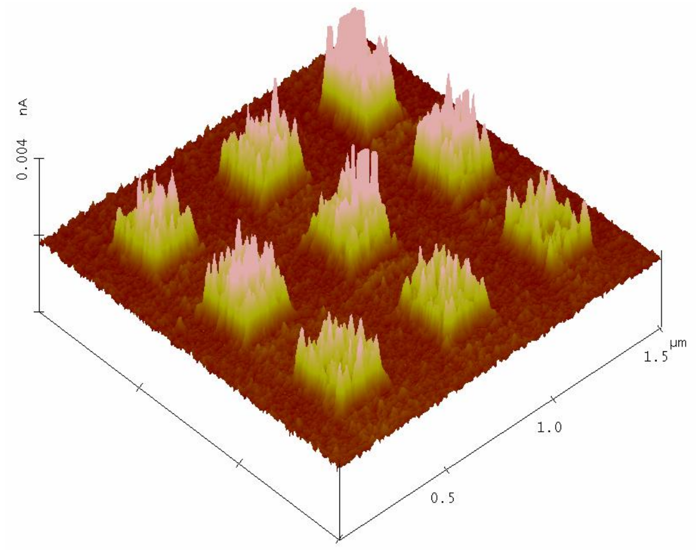
Reduced low-field electron emission properties because of H and sp^3 C enriched surface layer

D. Liu et al. (2006)

C-AFM – Combined methods

3x3 emitter array by structuring of graphite-like surface layer





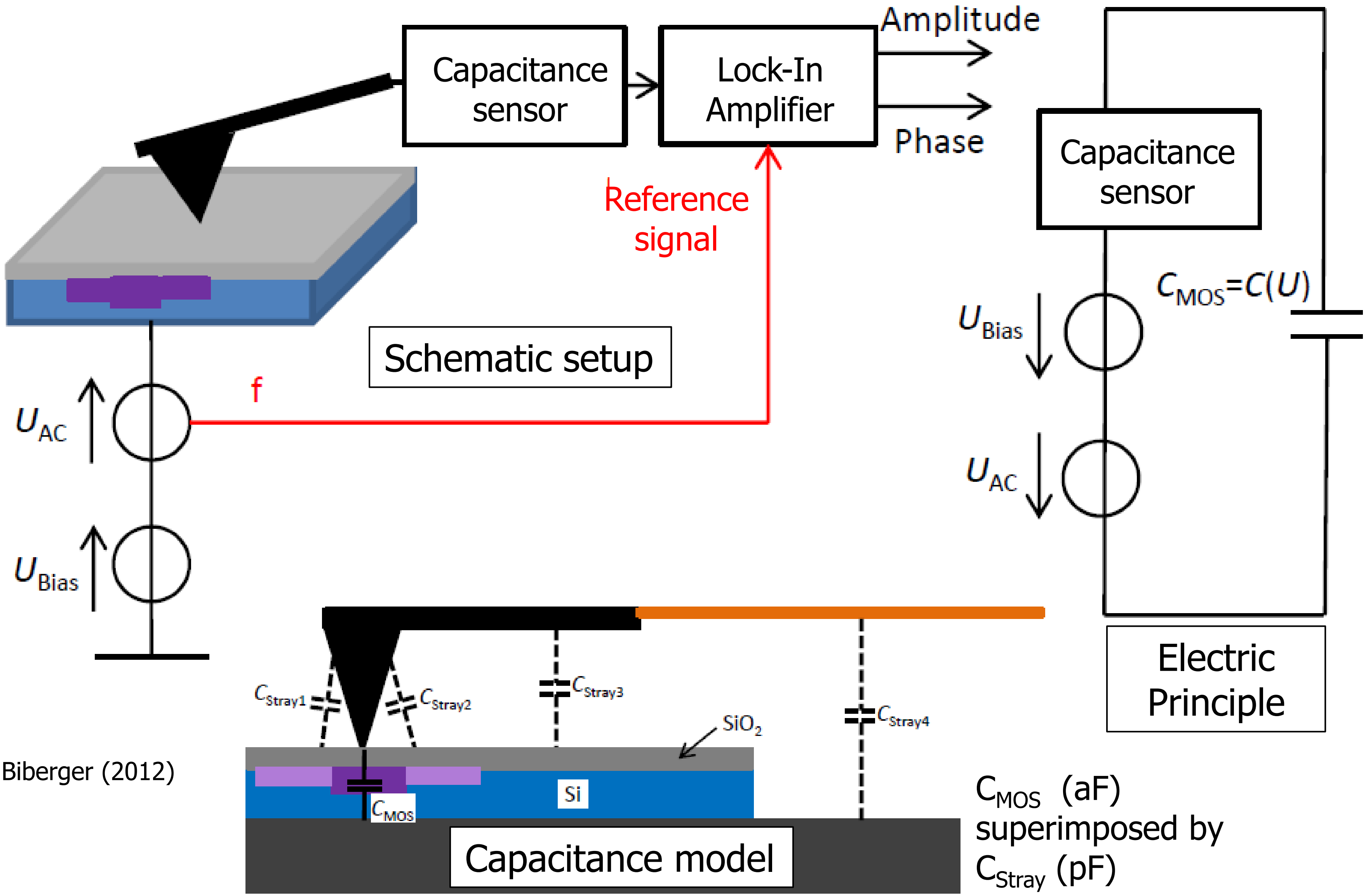
Surface topography of AFM-structured ta-C film
Wear depth: 1nm

Simultaneously recorded current image of structured ta-C film

Topography an current image may be used to discriminate physical and chemical properties of surface layers at marked areas

D.Liu et al.(2005)

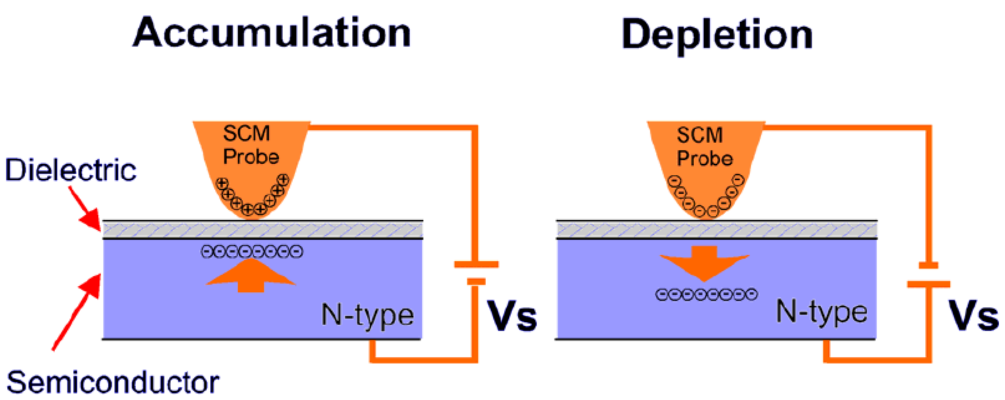
SCM – Principle



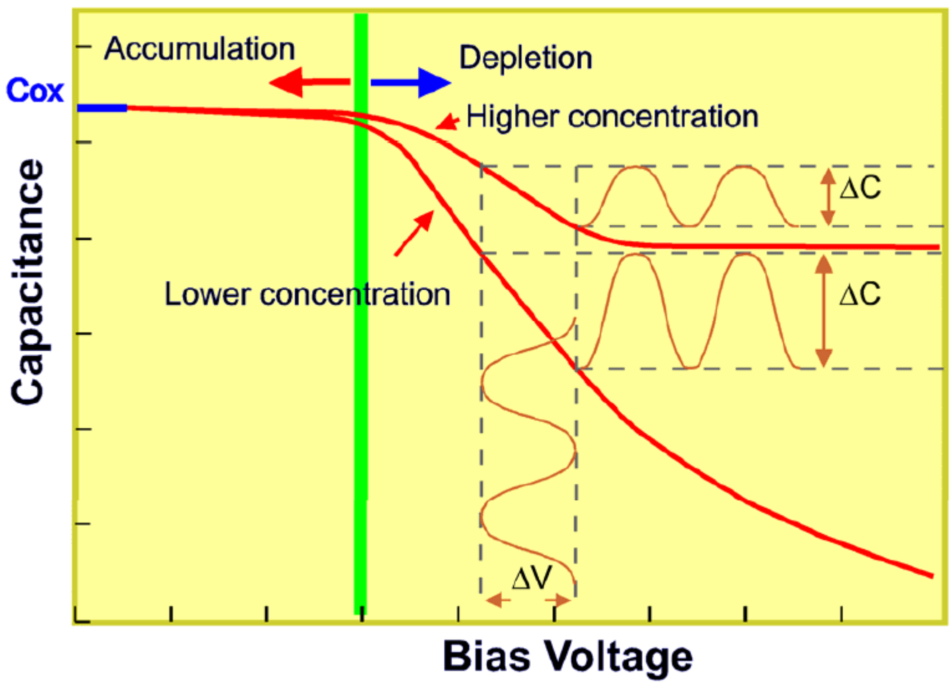
Biberger (2012)

C_{MOS} (aF) superimposed by C_{Stray} (pF)

SCM – C(V) Characteristic



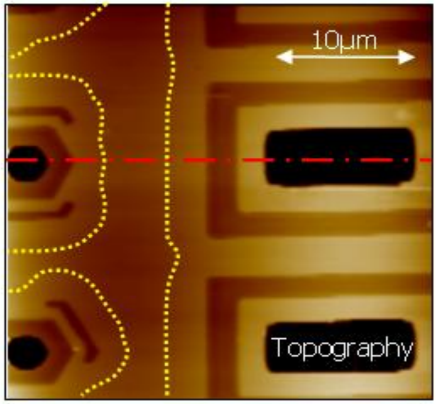
http://www.ph.utexas.edu/~shih/SCM-1.pdf

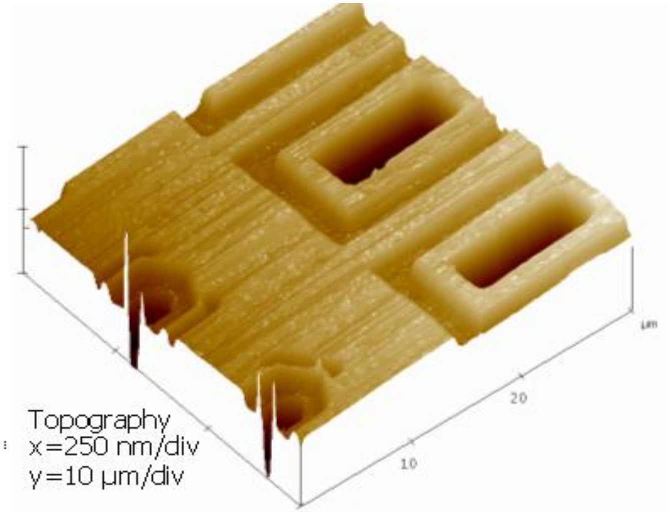


- SCM-Signal output: dC/dV (x,y)
- High Doping has low slope
- Low doping has high slope in C(V) Curve
- Determination of dopant type and absolute concentration value only with significant additional effort

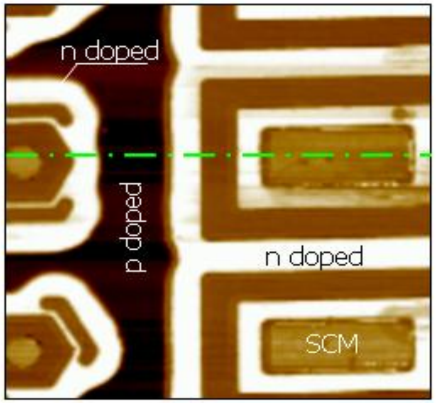
SCM – Case study

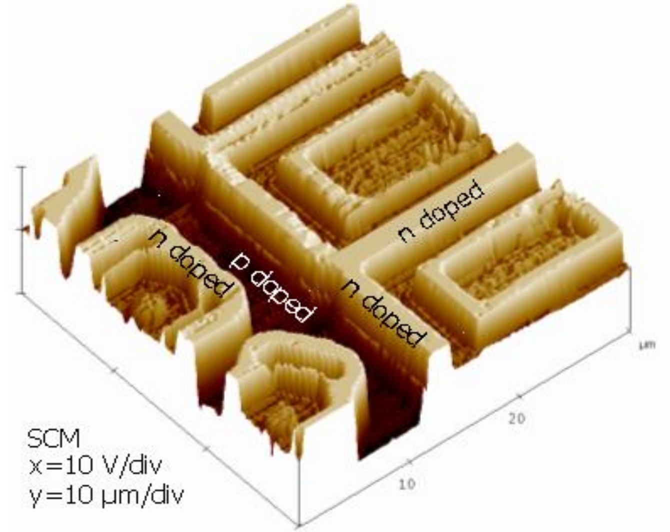
Topographie





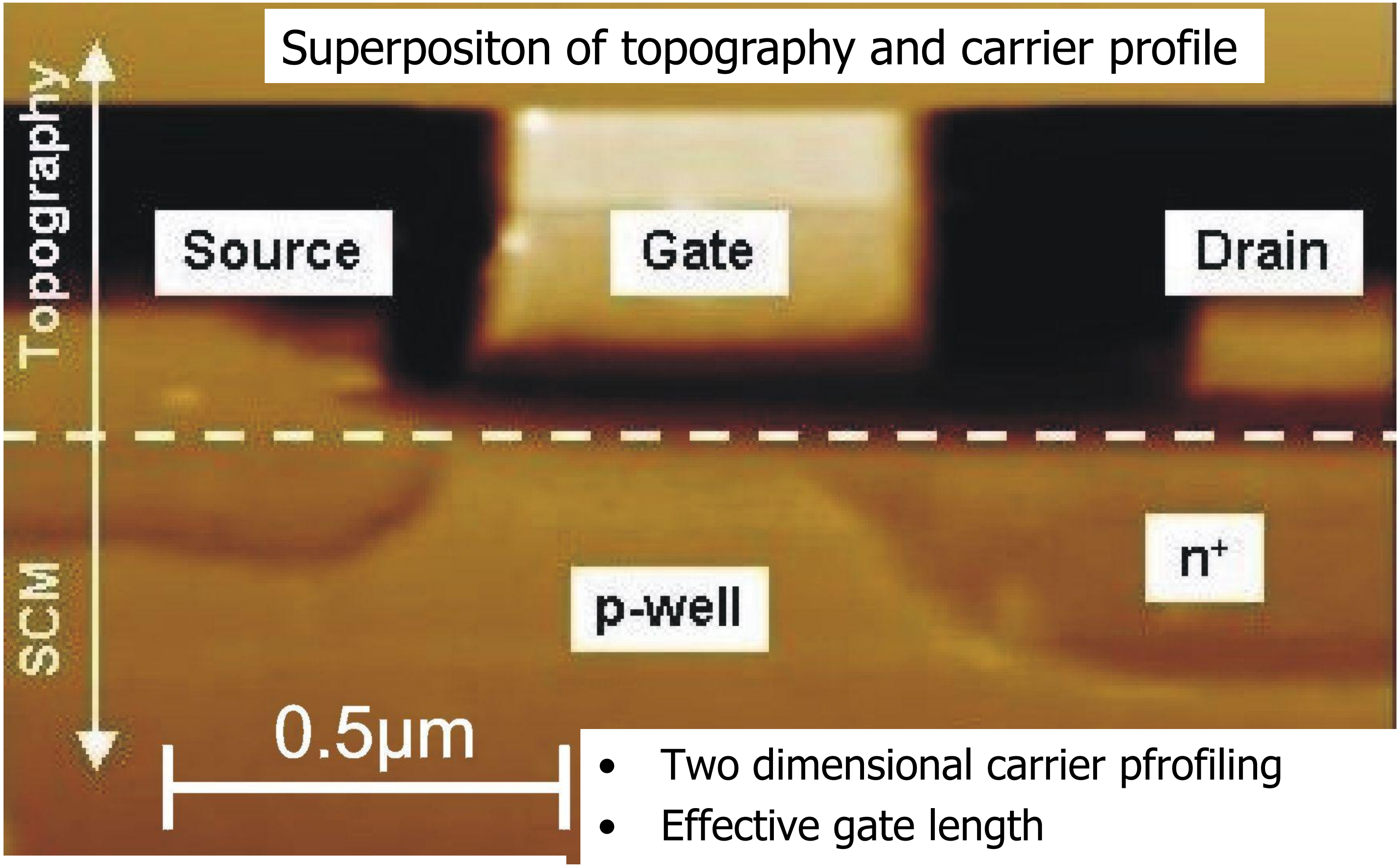
Doping





Resolution solely possible by AFM!

SCM – Case study



- Two dimensional carrier pfrofiling
- Effective gate length
- p-n-junction

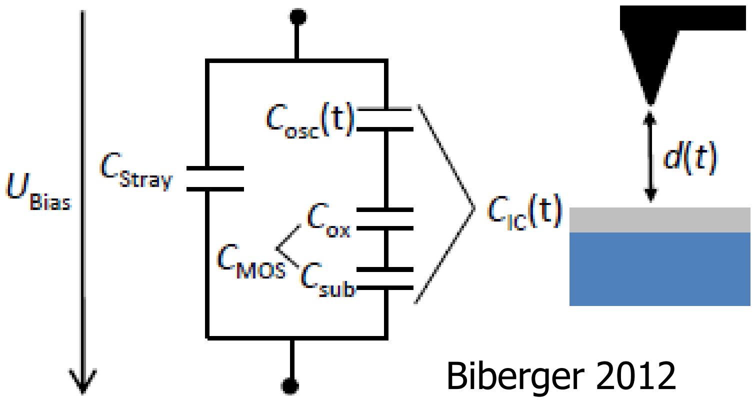
Flasch memory cell

Schweinböck et al. (2003)

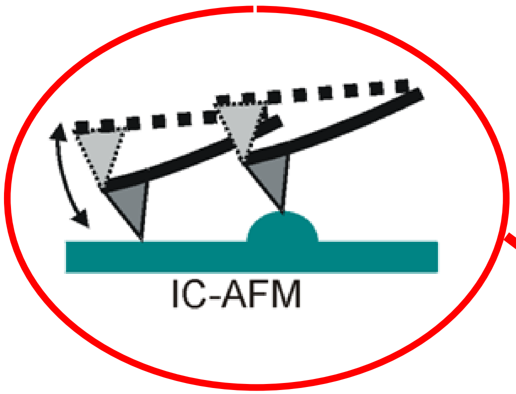
SCM – IC-SCM

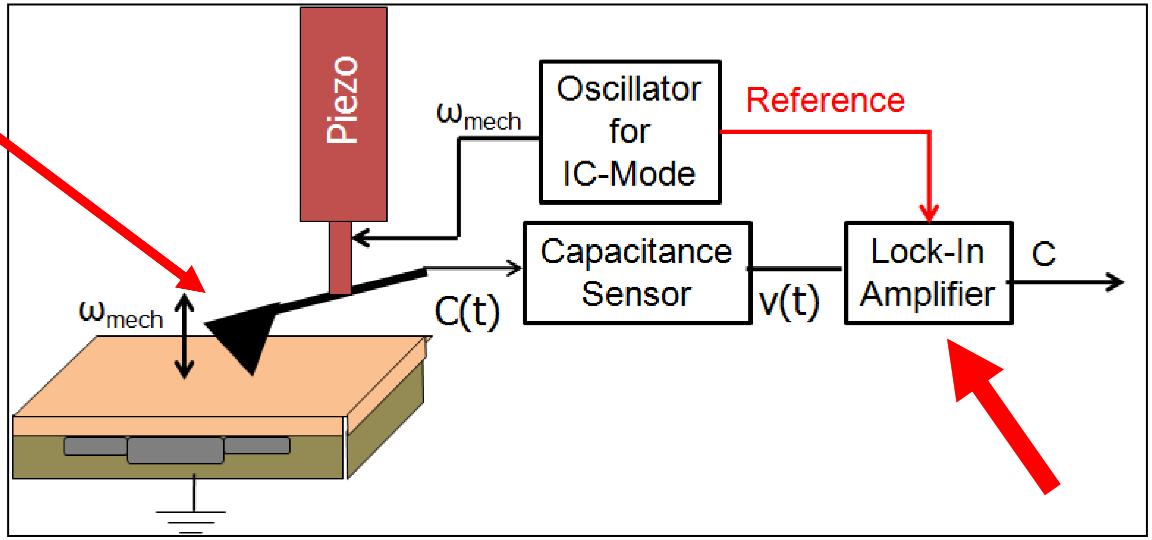
Detection system of IC-SCM

- Based on lock in amplifier with
- "Tapping" frequency as reference signal



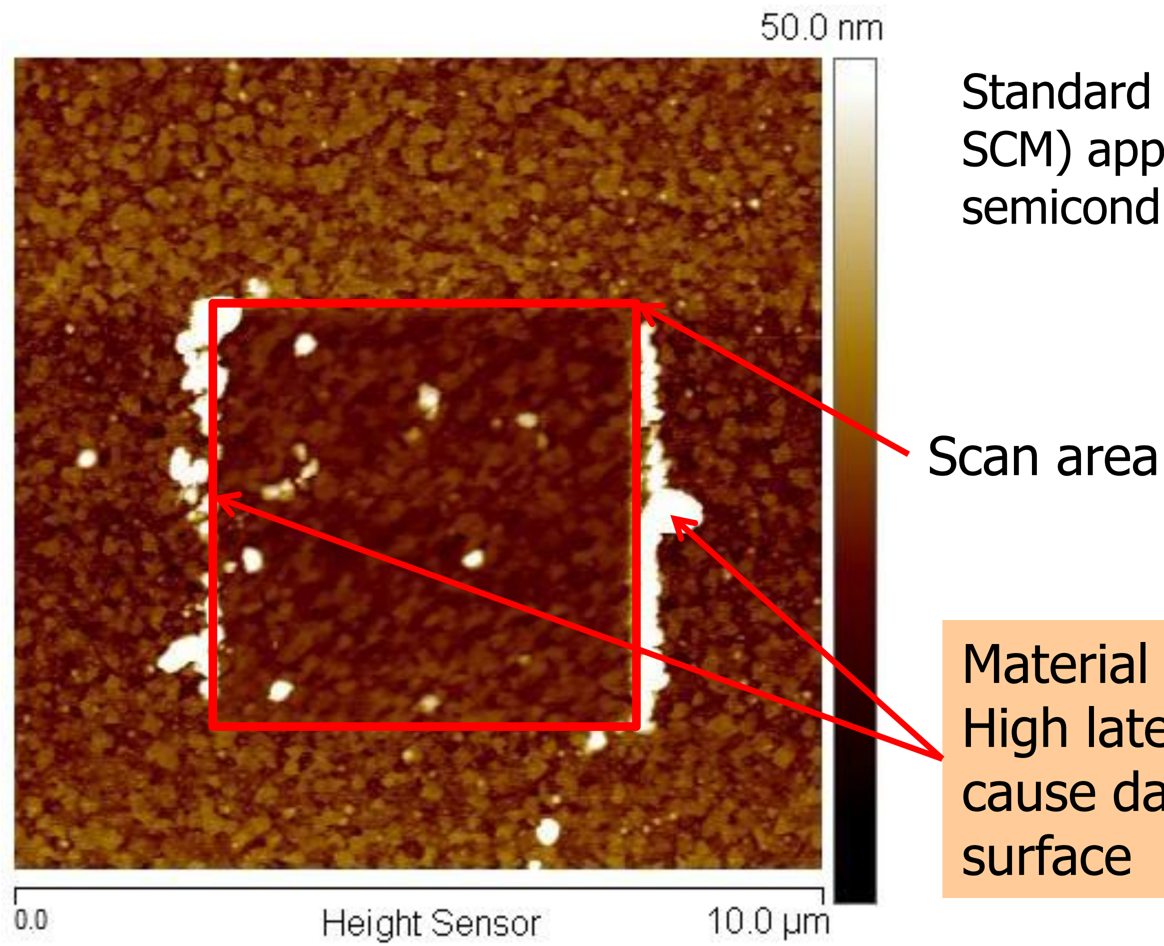
Biberger 2012





Benstetter, et al. (2010): US Patent 7788732

SCM – Organic semiconductor

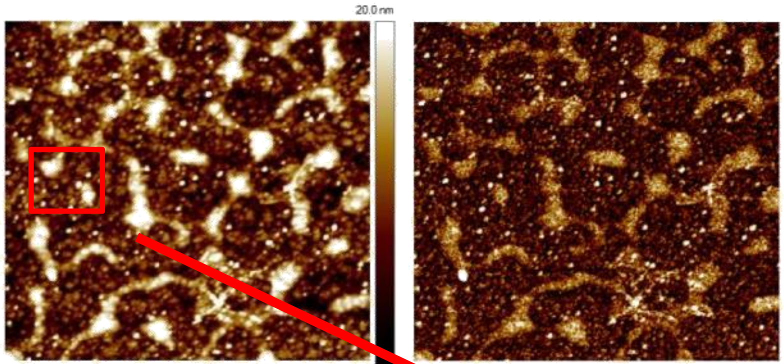


Standard SCM (contact mode, C-SCM) application on organic semiconductors (P3HT)

Material pile up!
High lateral forces of C-SCM cause damage to the sample surface

Hofer et al. (2011)

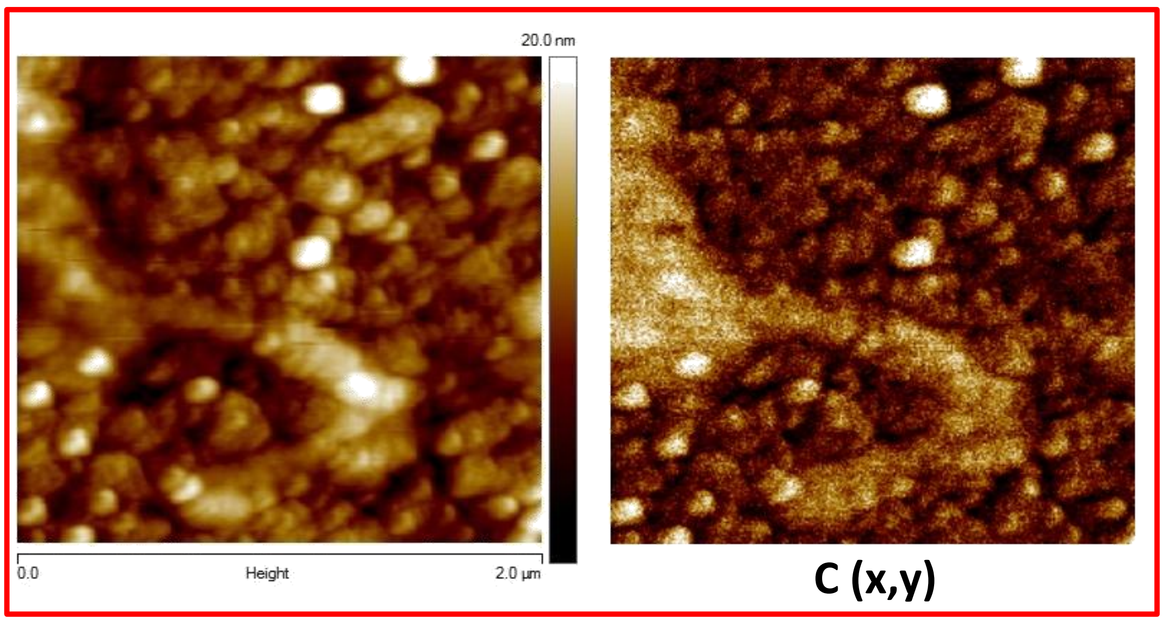
IC-SCM – Organic Semiconductor



C (x,y)

Capacitance imaging possible by IC-SCM
30 nm thick P3HT film
➔No surface damage
➔Capacitance detection
➔ 20 nm lateral resolution
➔ 1 aF (10^{-18} F) precision

Hofer et al. (2011)



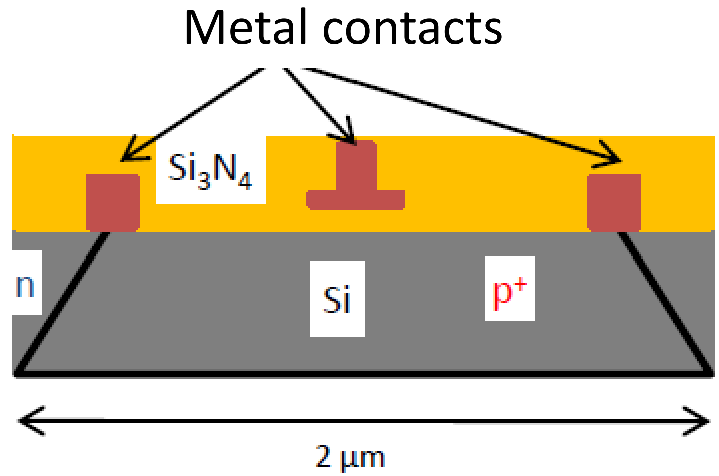
C (x,y)

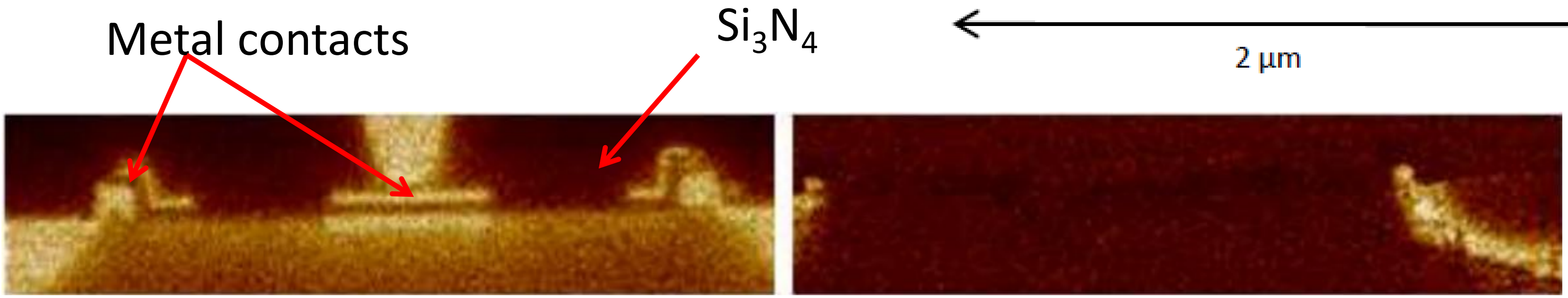
P3HT organic p-semiconductor, Polythiophene group

IC-SCM – Semiconductor structures

- High material contrast imaging
- Metallisation and contamination are clearly visible

Example: MOS-transistor cross-section





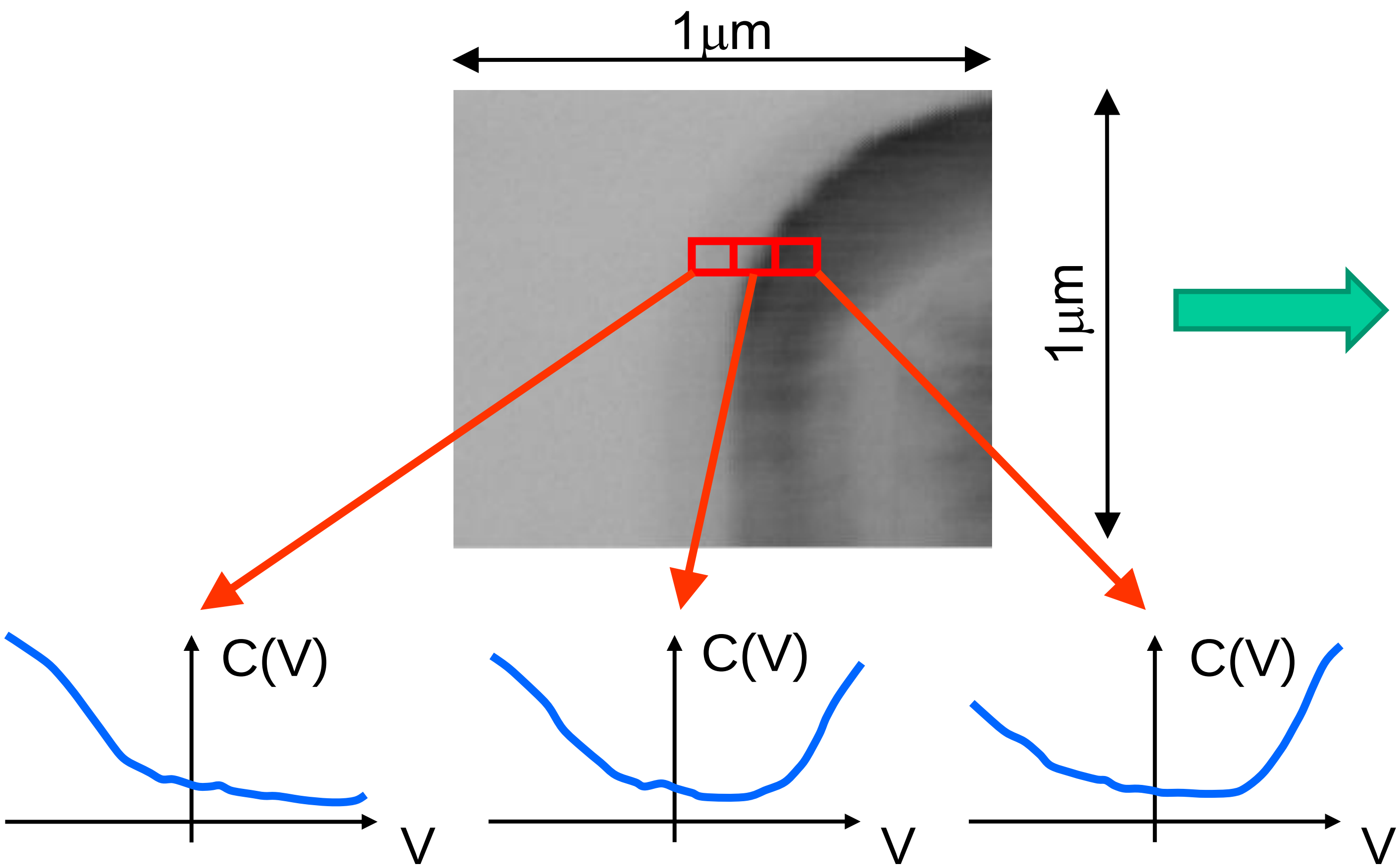
IC-SCM
Intermittent contact mode SCM

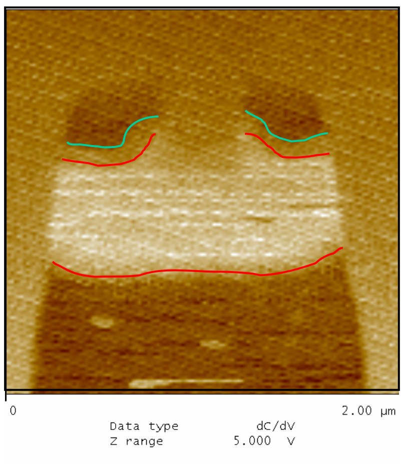
C-SCM
Contact mode SCM (standard)

Biberger et al. (2008), Biberger (2012)

SCM – Scanning capacitance spectroscopy (SCS)

- Spectroscopy by use of complete bias ramp (-V → +V)
- In C-SCM and IC-SCM possible

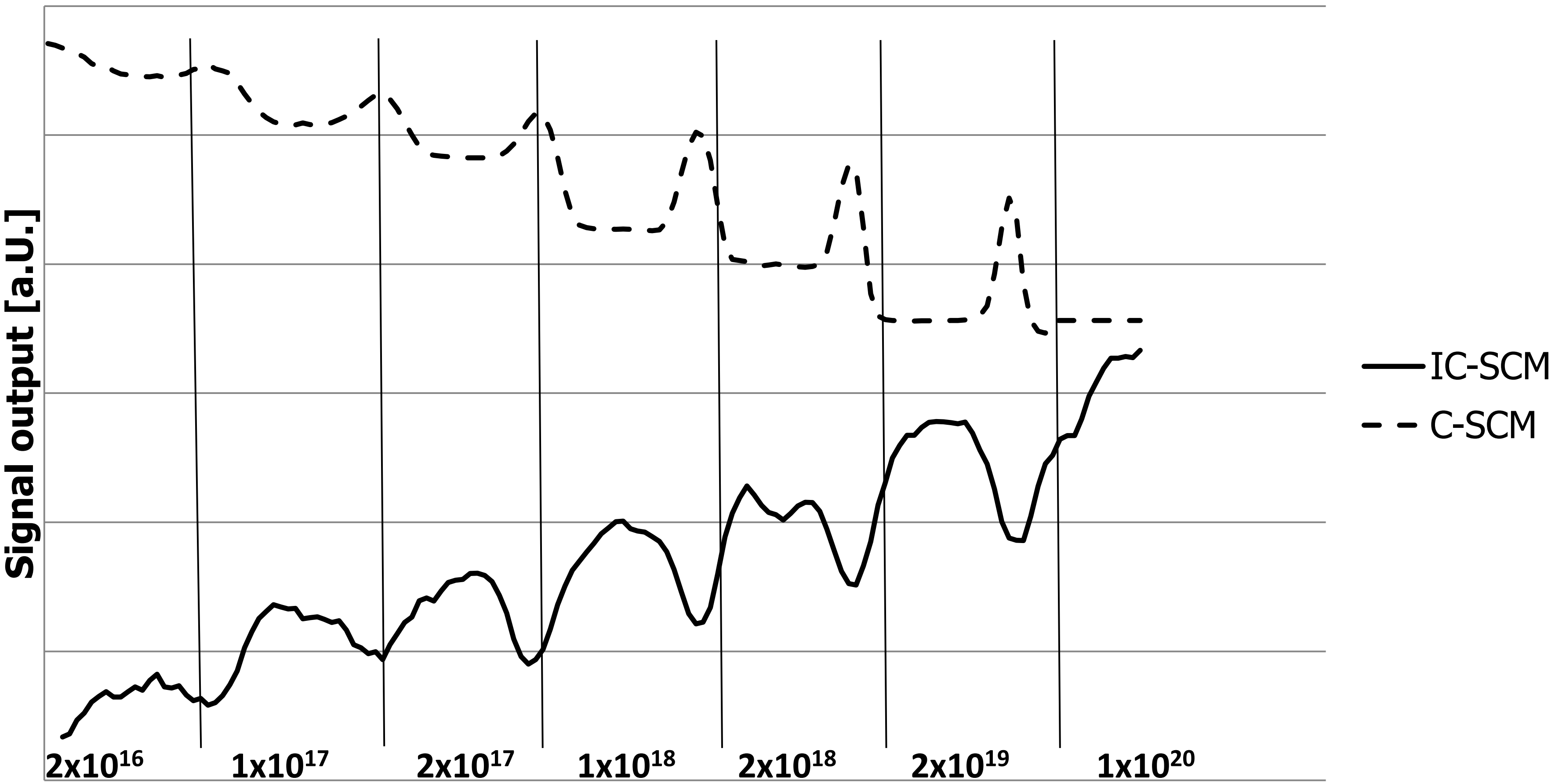




Biberger et al. (2010)

Precise localisation of pn-junction possible

SCM – Dopant concentration



- Comparison of IC-SCM and C-SCM line scans using a sample with increasing dopant concentrations.
- IC-SCM with improved dopant resolution

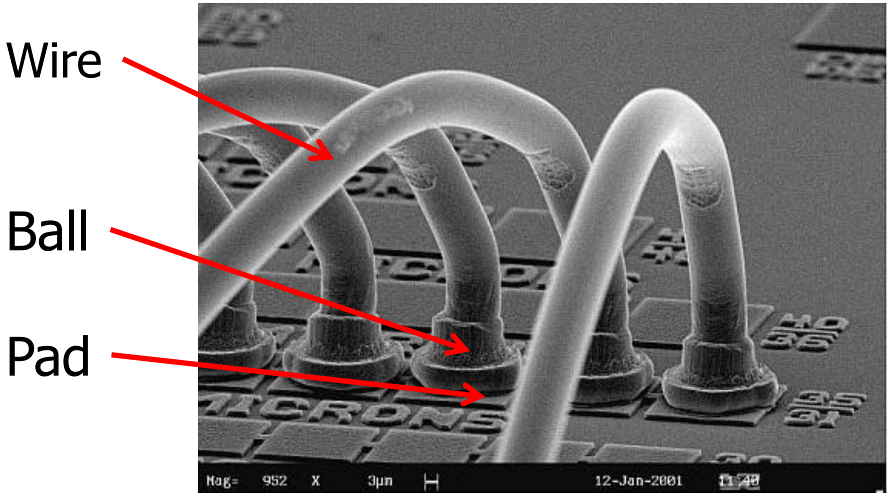
Biberger (2012)

SCM – Overview

	Contact-SCM	Intermittent-Contact -SCM	SCS (HSSCS)
Application	2D dopant profiling	- 2D dopant profiling - material mapping	- precise localization of p/n junctions
Scan-Speed	moderate	moderate-high	low
Signal output	dC/dV (x,y)	C (x,y)	complete C(V) (x,y)
Possible dopant resolution	10^{15} - 10^{19}	10^{15} - 10^{20}	

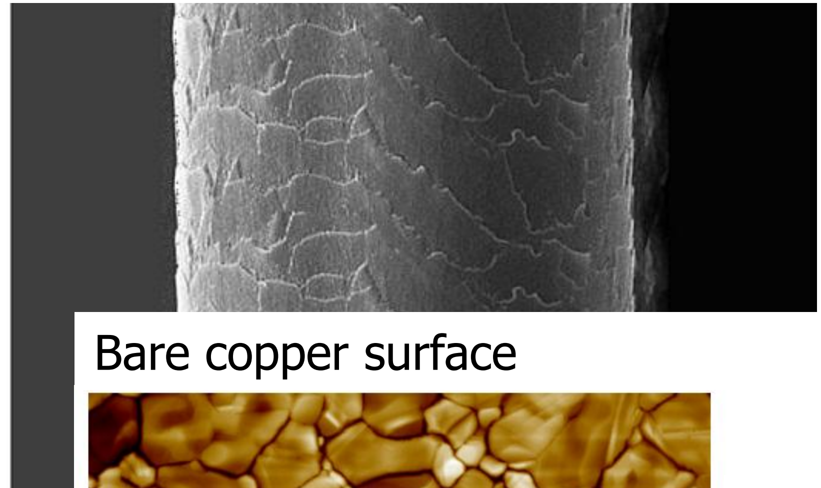
KPFM – Copper wire bonding

Wire chip bonding (here gold)

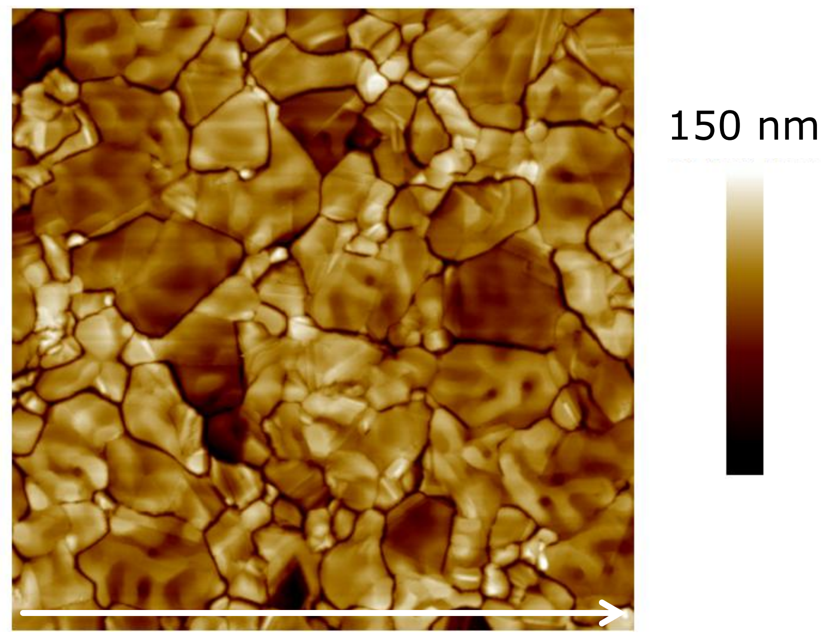


http://it-material.de/category/wirtschaft/computerindustrie/wire-bonding/#X_10662

Hair



Bare copper surface



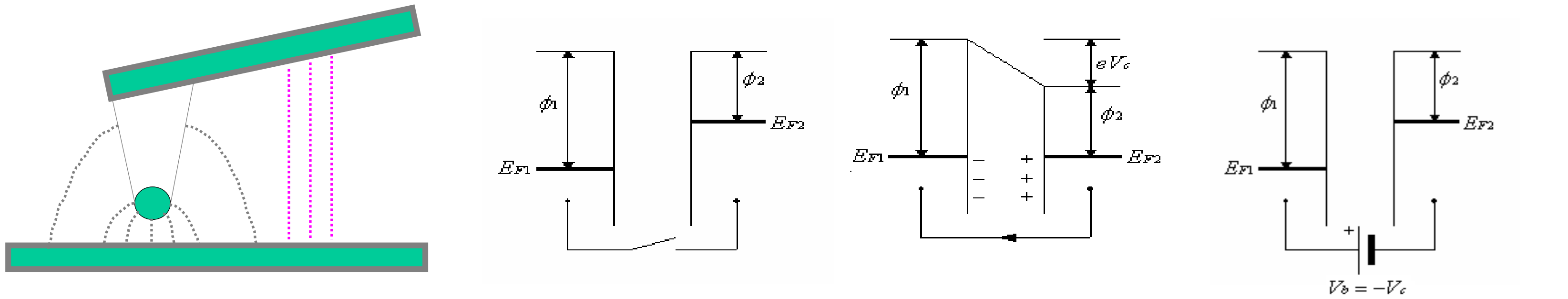
Topography

Image Rq: 20.1 nm

- Copper wire bonding is important for further device scaling
- Copper oxidation is a serious problem for copper wire chip bonding
- Copper oxidation behaviour and dynamics is not yet fully understood

Berthold et al. (2013)

KPFM – Principle



KPFM measures the work function difference of tip/sample.

AM	Amplitude-Modulation
FM	Frequency-Modulation ✓ Better spatial resolution ✓ Better accuracy

- **PF-KPFM** is a modification of the frequency modulated (FM)-KPFM mode.
- PF-KPFM enables contact potential difference (CPD) with improved sensitivity and repeatability.

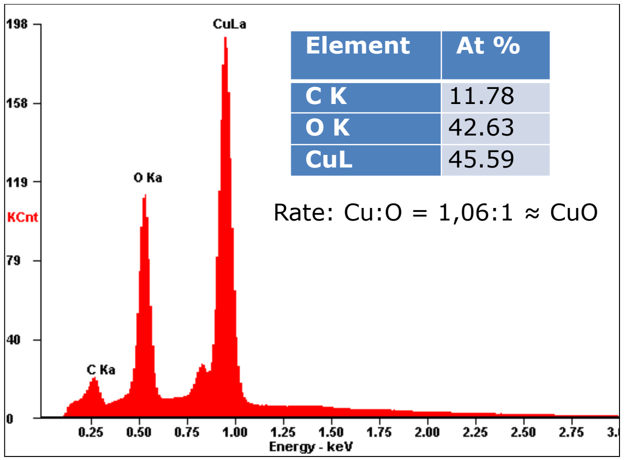
May be employed for material discrimination
→ Copper oxidation characteristics
→ Parameter and capabilities unknown

Physical Review B 2005, 71(12) 125424

T. Mueller, Bruker, PeakForce KPFM, 06.08.2012, Sales presentation (partly)

KPFM – CuO parameter

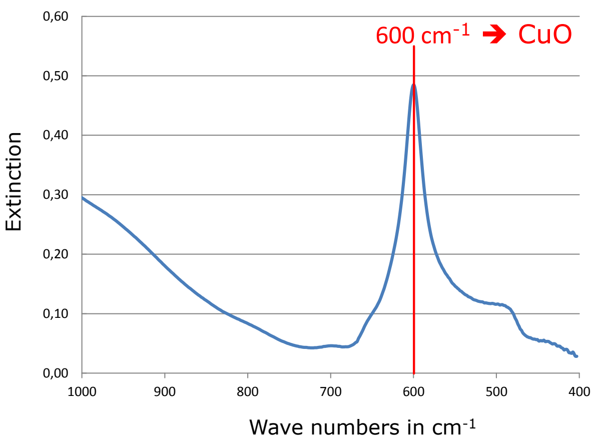
EDX



Element	At %
C K	11.78
O K	42.63
CuL	45.59

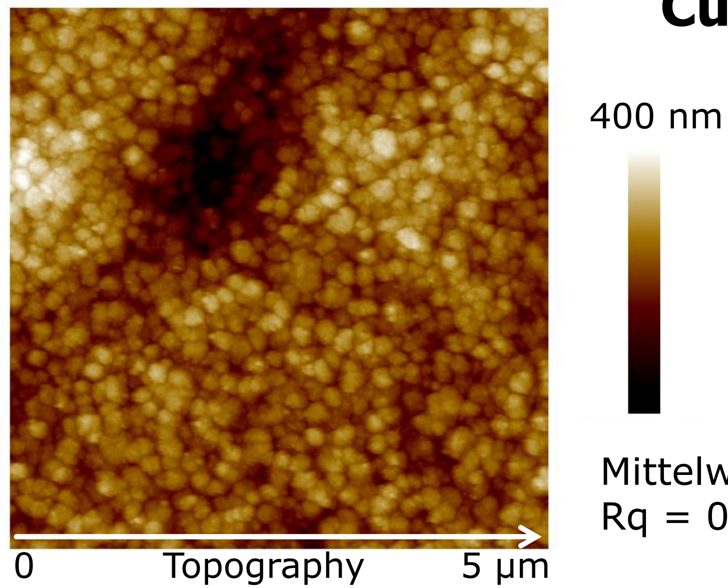
Rate: Cu:O = 1,06:1 ≈ CuO

FTIR



PF-KPFM

CuO



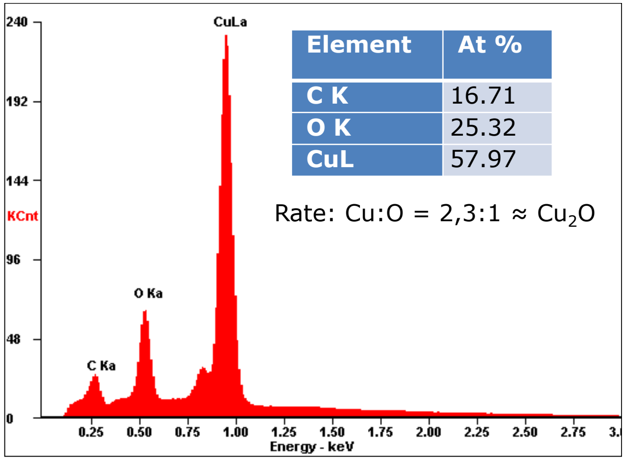
Mittelwert V_{CPD}: -1,07 V
Rq = 0,0386V

- EDX shows a copper to oxygen ratio of 1,06:1 → CuO
- FTIR shows an absorption at 600cm^{-1} → CuO
- KPFM shows a potential difference value of -1,07V

Berthold et al. (2013)

KPFM – Cu_2O parameter

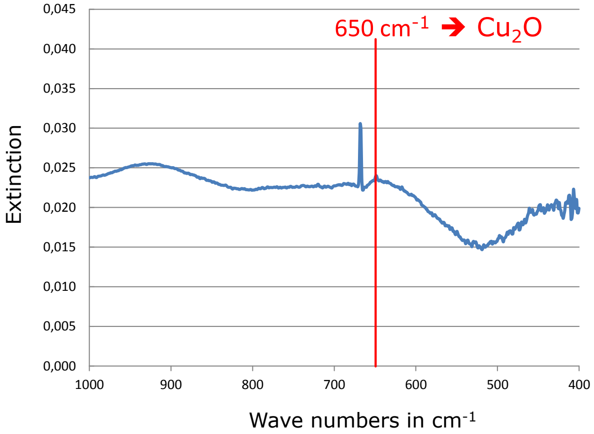
EDX



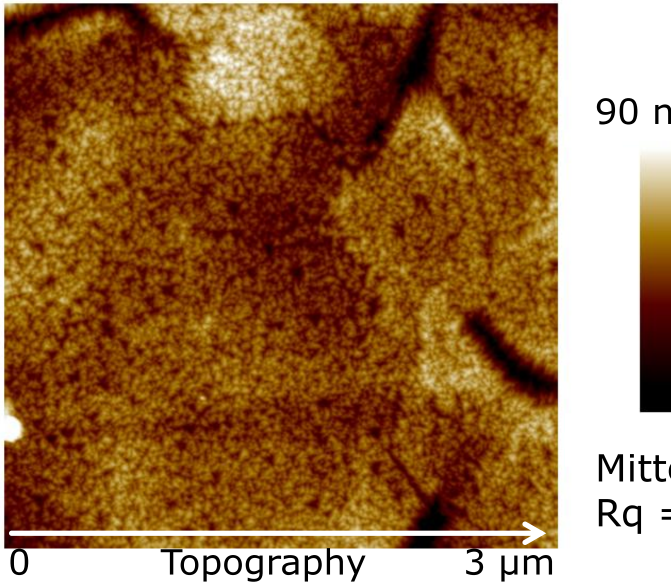
Element	At %
C K	16.71
O K	25.32
CuL	57.97

Rate: Cu:O = 2,3:1 ≈ Cu_2O

FTIR



PF-KPFM



Cu_2O

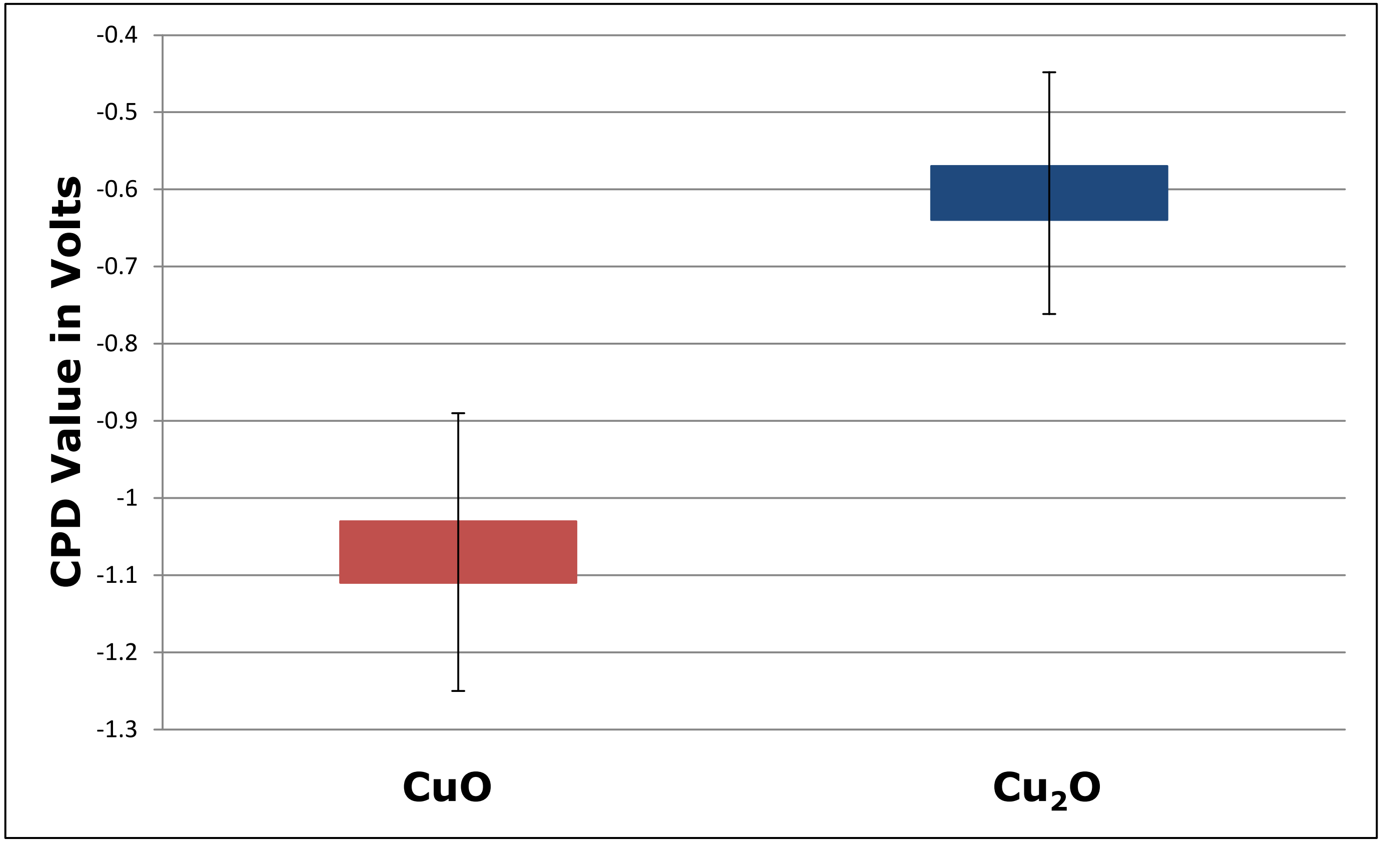
90 nm

Mittelwert V_{CPD}: -0,535 V
Rq = 0,0372V

- EDX shows a copper to oxygen ratio of 2,3:1 → Cu_2O
- FTIR shows an absorption at 600cm^{-1} → Cu_2O
- KPFM shows a potential difference value of -0,535V

Berthold et al. (2013)

KPFM – Cu_xO parameter



- CPD values of the CuO and Cu_2O measurements with standard deviation from the mean value, minimum and maximum values.
- CPD value may be used to distinguish between CuO (-1,07 V) and Cu_2O (-0,56 V)

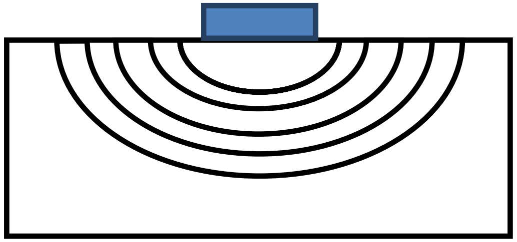
Berthold et al. (2013)

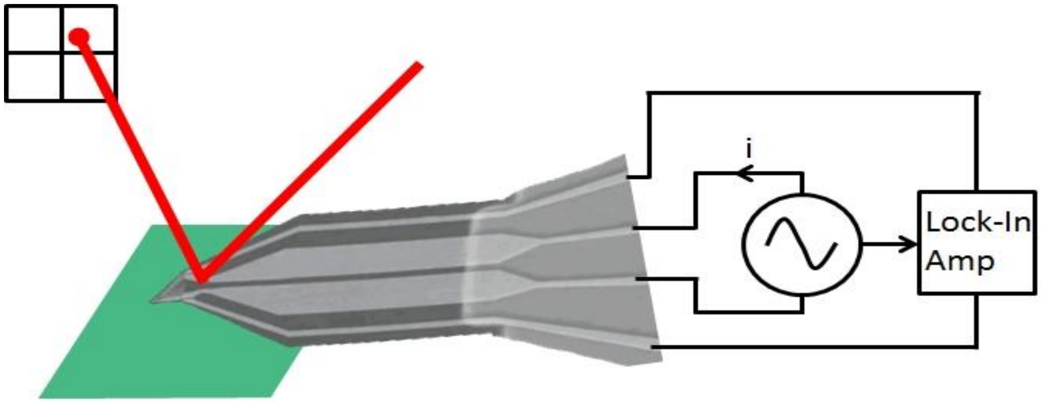
Summary

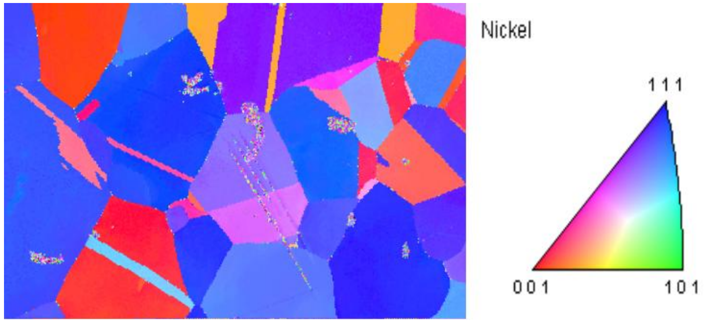
- AFM based techniques enable high resolution structural and physical characterisation of materials and thin films
- Probe tip and AFM operation mode is critical to quality and reliability of results
- AFM-techniques operating in contact mode are critical with respect to sample interference and tip wear
- It is possible to transfer originally contact mode applications to intermittent contact mode applications and
  - to extend the measurement capabilities
  - to increase quality and reliability of the results
- Combination of different AFM methods as well as combination of AFM methods and SEM based techniques may further extent analysis capabilities
- As martial properties in the nanometre scale become increasingly important, research is necessary to keep pace with applicable and reliable analysis methods

What’s next?

Nanostructured films for thermal generators:





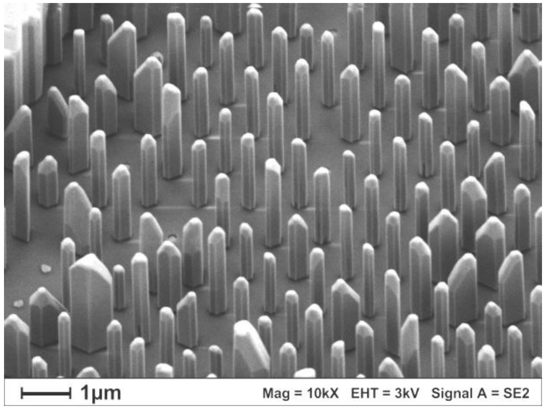


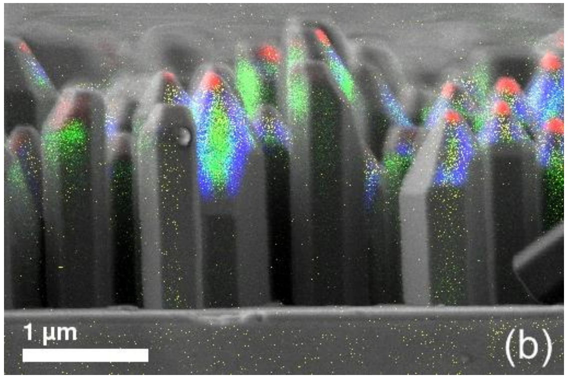
High resolution characterisation of thermal conductivity of ultra-thin films

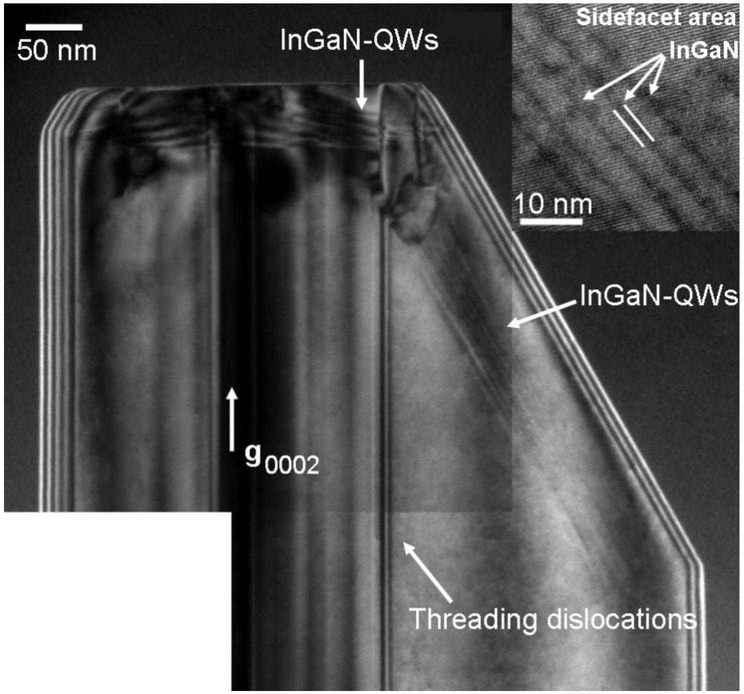
➔Texture-analysis?

Wie geht's weiter?

Neue Lichtquellen: GaN Nanorods:







Quelle: W. Bergbauer et. al., Nanotechnology 21 (2010) 305201

Exakte Bestimmung von Dotierungen / Profilen

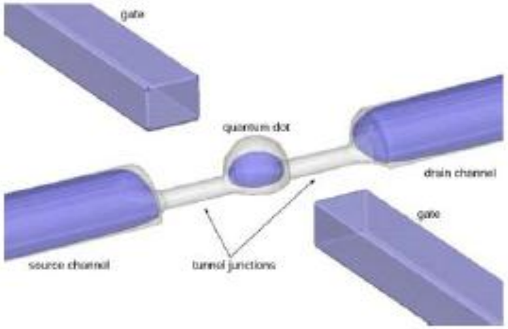
What‘s next?

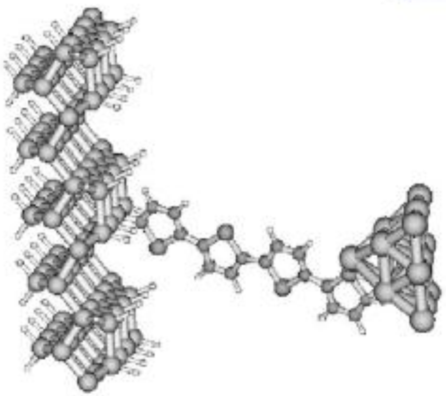
Nanostructured carbon:

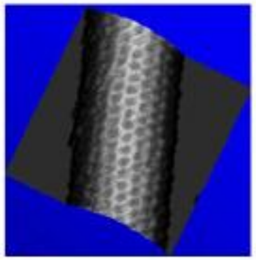
- Graphene
- Carbon-nanotubes CNT
- C60 Fullerene

Further concepts:

- One electron transistors
- One electron memories
- Organic microelectronics
- Molecular nano-electronics
- Wide-Bangap-Semiconductor (SiC, GaN),
- Application on biological systems and cells







Quelle: A. Schenk, ETH Zürich

Further reading

- Benstetter, G.; Breitschopf, P.; Frammelsberger, W.; Ranzinger, H.; Reislhuber, P.; Schweinboeck, T. (2004): AFM-based scanning capacitance techniques for deep sub-micron semiconductor failure analysis. ESREF, European Symposium on the Reliability of Electron Devices, Failure Physics and Analysis, 15. In: *Microelectronics Reliability* 44 (9-11), S. 1615–1619.
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- Benstetter, Günther; Biberger, Roland; Liu, Dongping (2009): A review of advanced scanning probe microscope analysis of functional films and semiconductor devices. 4th International Conference on Technological Advances of Thin Films and Surface Coatings. In: *Thin Solid Films* 517 (17), S. 5100–5105.
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Further reading

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- Frammelsberger, Werner; Benstetter, Guenther; Kiely, Janice; Stamp, Richard (2006): Thickness determination of thin and ultra-thin SiO2 films by C-AFM IV-spectroscopy. In: *Applied Surface Science* 252 (6), S. 2375–2388.
- Frammelsberger, Werner; Benstetter, Guenther; Kiely, Janice; Stamp, Richard (2007): C-AFM-based thickness determination of thin and ultra-thin SiO2 films by use of different conductive-coated probe tips. In: *Applied Surface Science* 253 (7), S. 3615–3626.
- Frammelsberger, Werner; Benstetter, Guenther; Schweinboeck, Thomas; Stamp, Richard J.; Kiely, Janice (2003): Characterization of thin and ultra-thin SiO2 films and SiO2/Si interfaces with combined conducting and topographic atomic force microscopy. 14th European Symposium on Reliability of Electron Devices, Failure Physics and Analysis. In: *Microelectronics Reliability* 43 (9–11), S. 1465–1470.

Further reading

- Frammelsberger, Werner; Benstetter, Guenther; Stamp, Richard; Kiely, Janice; Schweinboeck, Thomas (2005): Simplified tunnelling current calculation for MOS structures with ultra-thin oxides for conductive atomic force microscopy investigations. In: *Materials Science and Engineering: B* 116 (2), S. 168–174.
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- Schweinbock, T.; Schomann, S.; Alvarez, D.; Buzzo, M.; Frammelsberger, W.; Breitschopf, P.; Benstetter, G. (2004): New trends in the application of scanning probe techniques in failure analysis. ESREF, European Symposium on the Reliability of Electron Devices, Failure Physics and Analysis, 15. In: *Microelectronics Reliability* 44 (9-11), S. 1541–1546.

Partner

HELMUT SCHMIDT UNIVERSITÄT
Universität der Bundeswehr Hamburg

- Kooperative Promotionen
- Verbesserung von organischen Halbleiter-Strukturen

UAB
Universitat Autònoma de Barcelona

- Kooperative Promotionen
- Untersuchung von Silizium Halbleiter Ausfallmechanismen

Technische Universität Braunschweig

- Untersuchung von nanorod LED-Strukturen

NANYANG TECHNOLOGICAL UNIVERSITY

- Org. „Thin –Films“-Konferenz
- Dünnschicht-Charakterisierung

UR
Universität Regensburg

- Gem. Forschungskolleg beantragt
- Kooperation RSM

大连理工大学
Dalian University of Technology

- Charakterisierung von DLC Schichten
- Opt. von Plasmaprozessen

大連民族學院
Dalian Nationalities University

- Dünnschicht-Charakterisierung
- Opt. von Plasmaprozessen

Partner

- Untersuchung der Ausfallmechanismen von LED/Laser Strukturen

- Oberflächen-Charakterisierung
- Opt. von Plasmaprozessen

- Kooperative Promotionen
- Biologische AFM-Anwendung

Die Projekte werden ganz oder Teilweise gefördert durch verschiedene Förderprojekte des

- Freistaates Bayern
- Bundesministeriums für Bildung und Forschung

Partner

- AFM-Analytik
- Prozesskontrolle

- Silizium-Wafertests

- Untersuchung von nanorod LED-Strukturen

Never stop thinking

- Untersuchung von Kupferbonds
- Vergleichsmessungen

- Verbesserung der LockIn-Verstärkertechnik
- Vergleichsmessungen

- Umsetzung eines Messplatzes für chemical RSM

- Untersuchung der Ausfallmechanismen von LED/Laser Strukturen

- Verwertung der Ergebnisse
- Vermarktung

Thank you