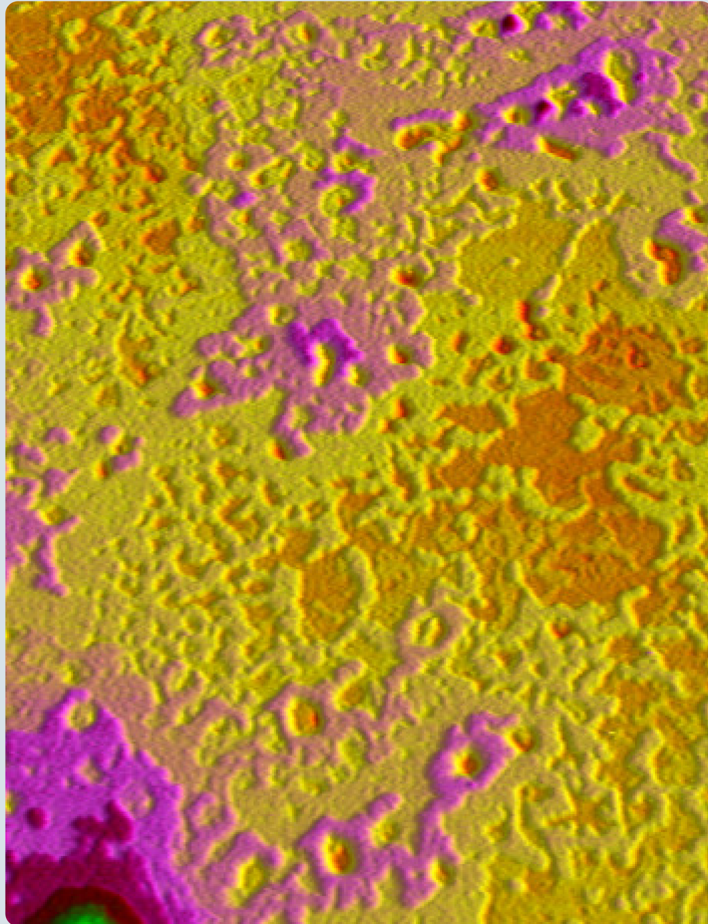
BRUKER



Scanning Probe Microscopy for NanoElectronics

May 25, 2011

P. De Wolf, T. Mueller, C. Li, C. Su
Bruker Nano, Santa Barbara
peter.dewolf@bruker-nano.com

Outline

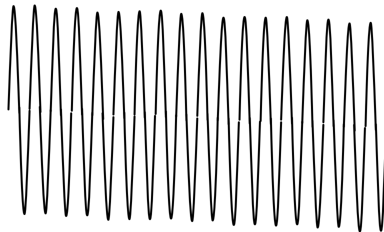
1. High resolution structural imaging
   - At lower forces
   - At higher throughput

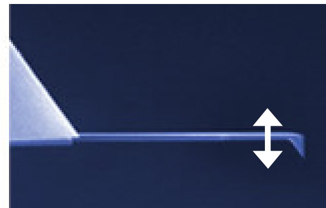
2. Property imaging:
   - Mechanical characterization
   - Electrical characterization
   - Chemical characterization

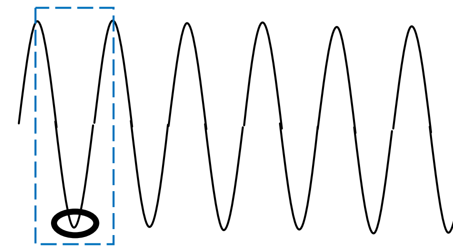
Lower Force Imaging using Peak Force Tapping

- Tapping:
  - Resonance (typ. 300kHz)
  - Measure & control Amplitude

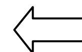
- Peak Force Tapping:
  - Sub-resonance (e.g. 2kHz)
  - Continuously measure the forces
  - Control the 'Peak Force'

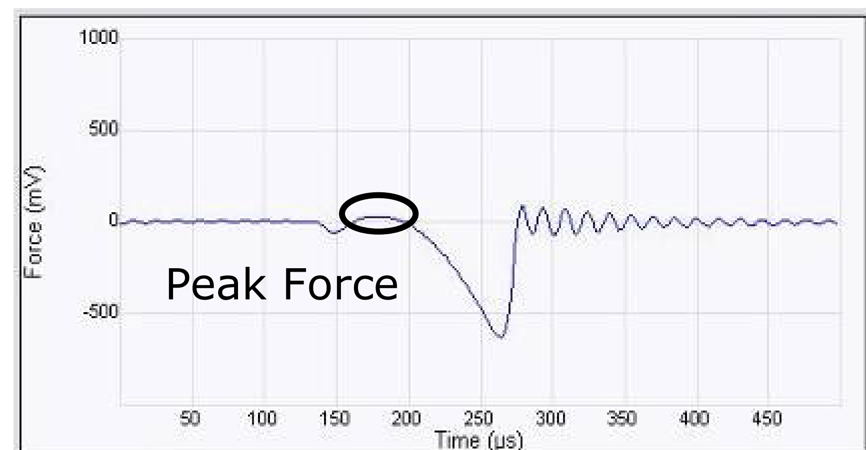




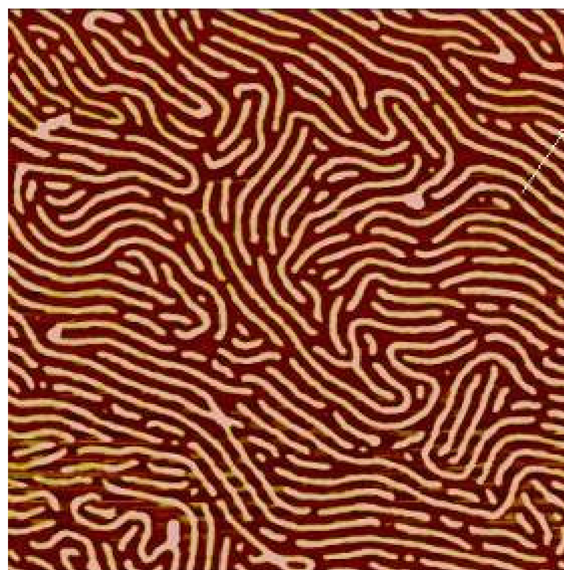


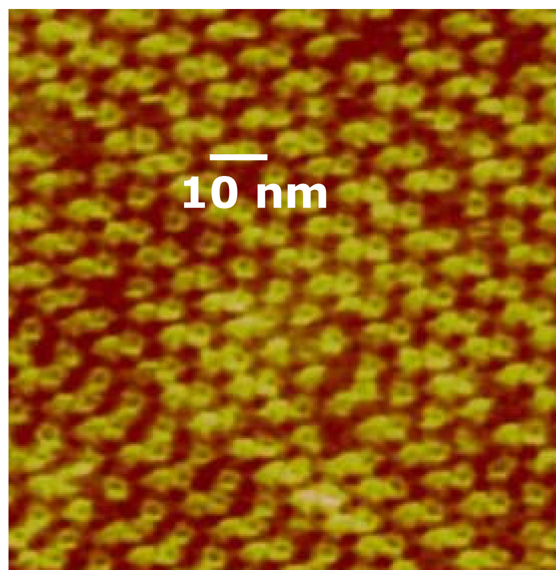
- Result:
  - Lower force imaging (< 50pN)
  - Longer tip lifetime
  - Higher resolution

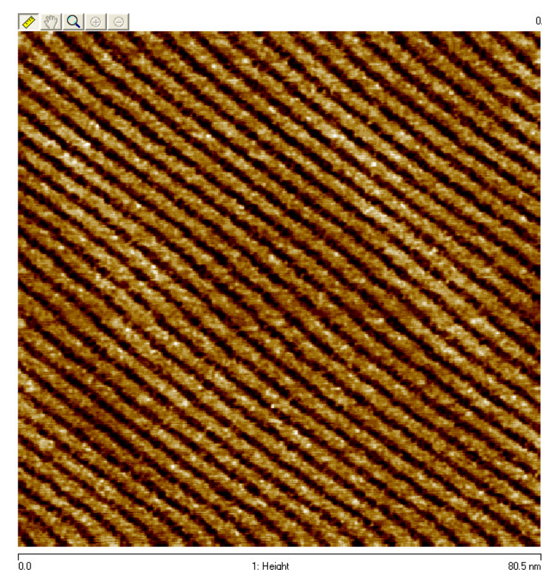




High Resolution
Peak Force Tapping Examples







Self-Assembled Molecular Brushes

1500x1500 nm scan

(OmpG Dimer) Protein Membrane Pores

100x100 nm scan

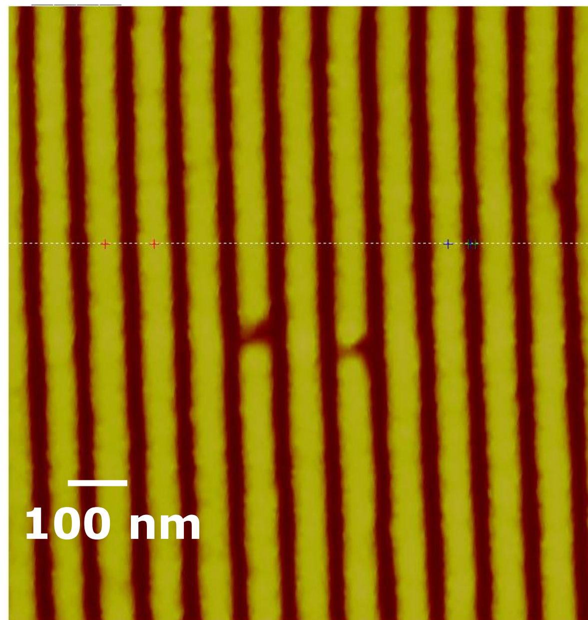
$C_{18}H_{38}$ Alkane Molecules

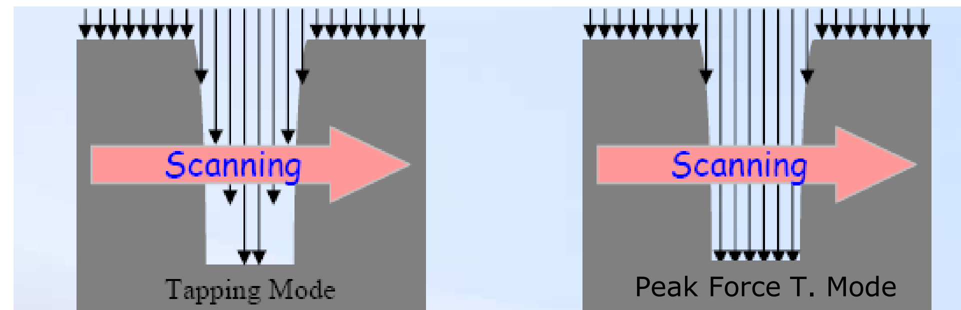
80x80 nm scan

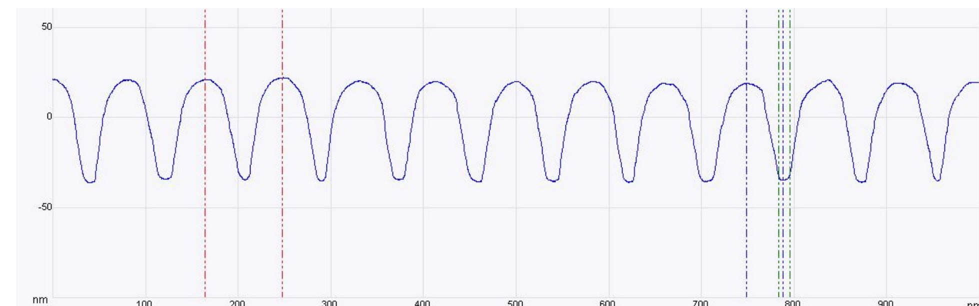
Sample courtesy:
Ch. Bippes, MPI Dresden

Nanotrench Metrology using Peak Force Tapping

- Challenging in Tappingmode due to excessive damping of the probe oscillation, preventing the tip from reaching the bottom.
- Peak Force Tapping can more easily reach the bottom, while maximum force is tightly controlled to low values.



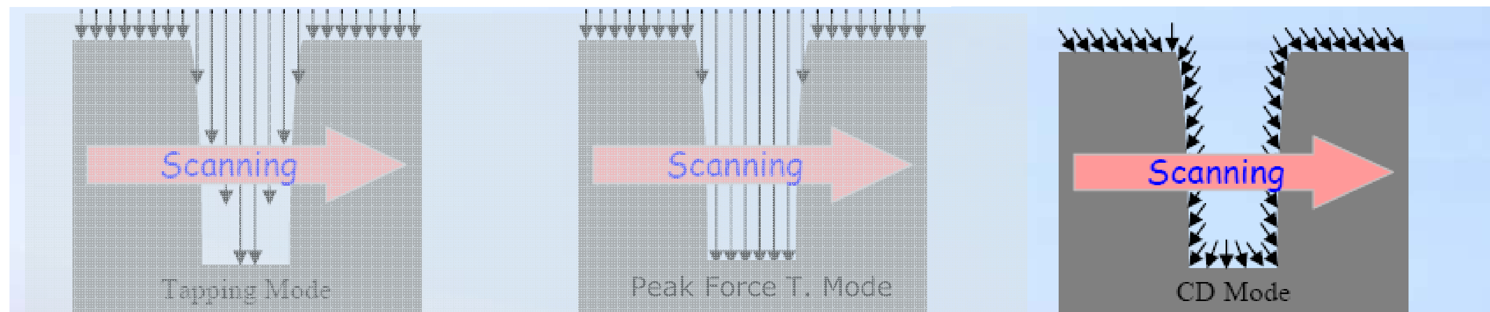


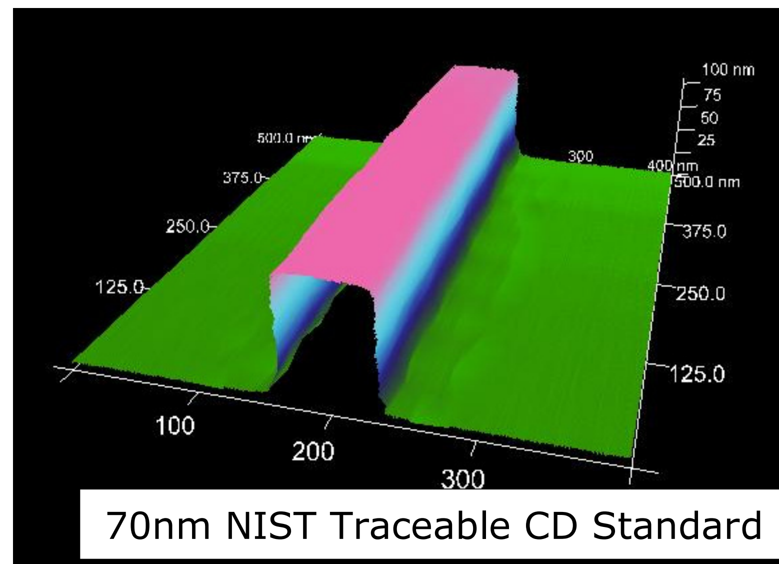


1000x1000 nm scan
Pitch = 80 nm, Depth =55 nm, Bottom travel = 13 nm

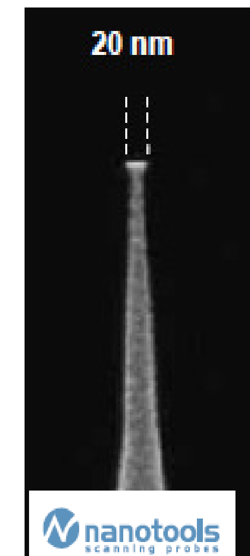
Critical Dimension (CD) Mode

- Scanner servos in X-Z or Y-Z direction
- Data is taken on sidewall as well as flat surface





70nm NIST Traceable CD Standard



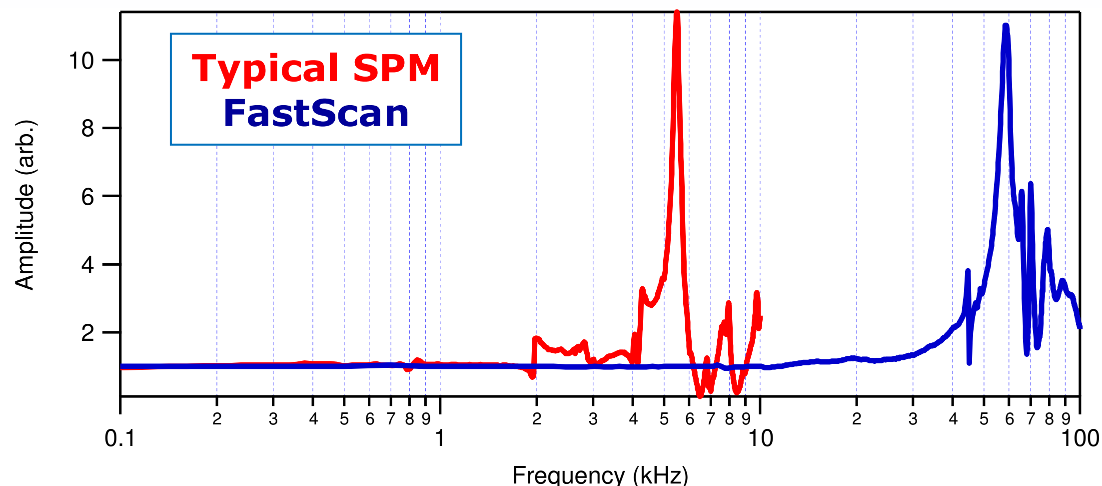
Outline

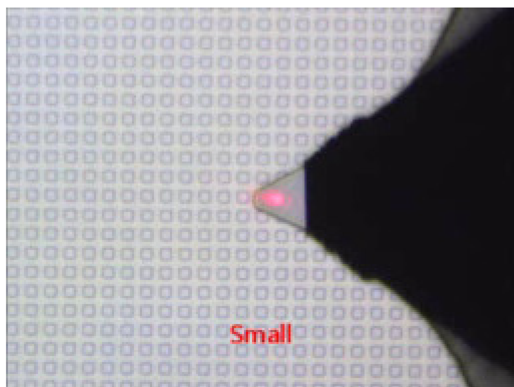
1. High resolution structural imaging
    - At lower forces
    - At higher throughput

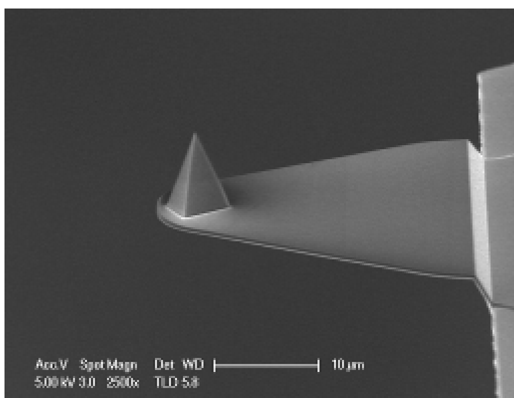
2. Property imaging:
    - Mechanical characterization
    - Electrical characterization
    - Chemical characterization

2 Elements limiting SPM speed: ‘Z’-scanner & Tips

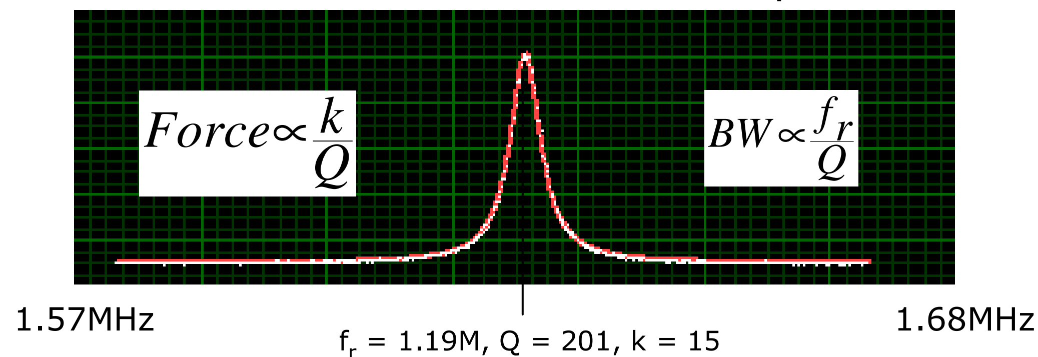
Z-Scanner Resonance > 55kHz







Small Cantilevers & Laser Spot

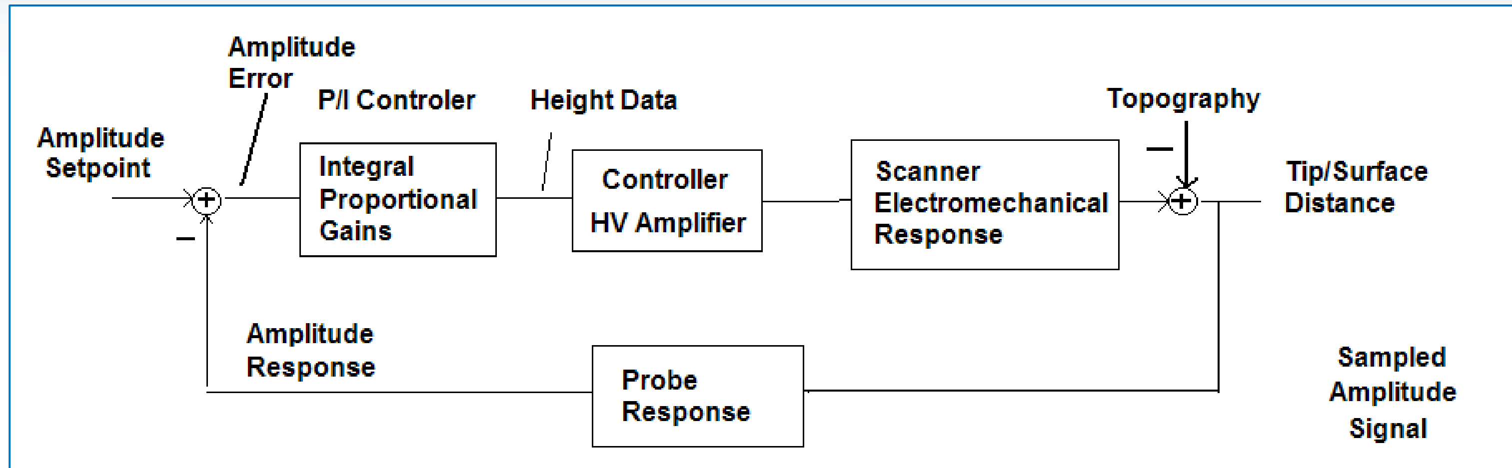


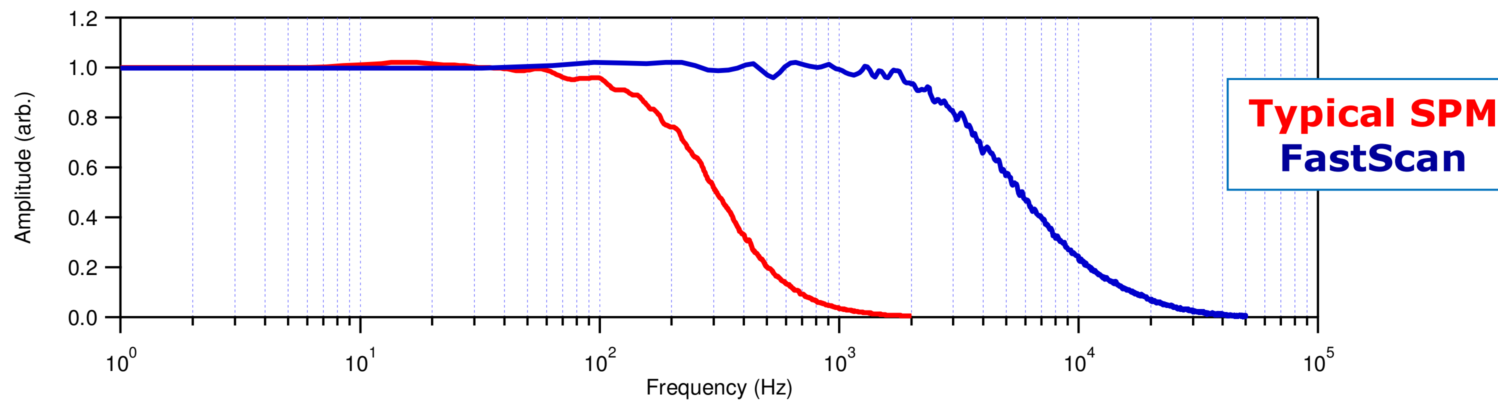
1.57MHz

1.68MHz

f_r = 1.19M, Q = 201, k = 15

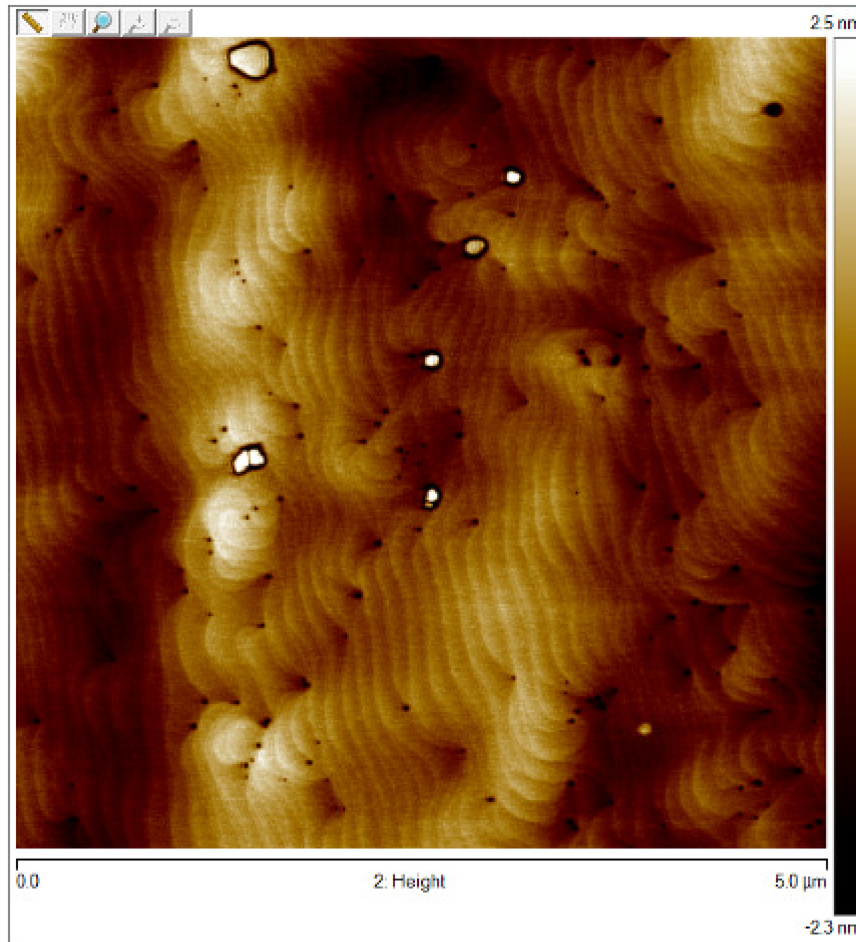
SPM System Transfer Function





- 20x increased bandwidth
- Same image quality, same force control

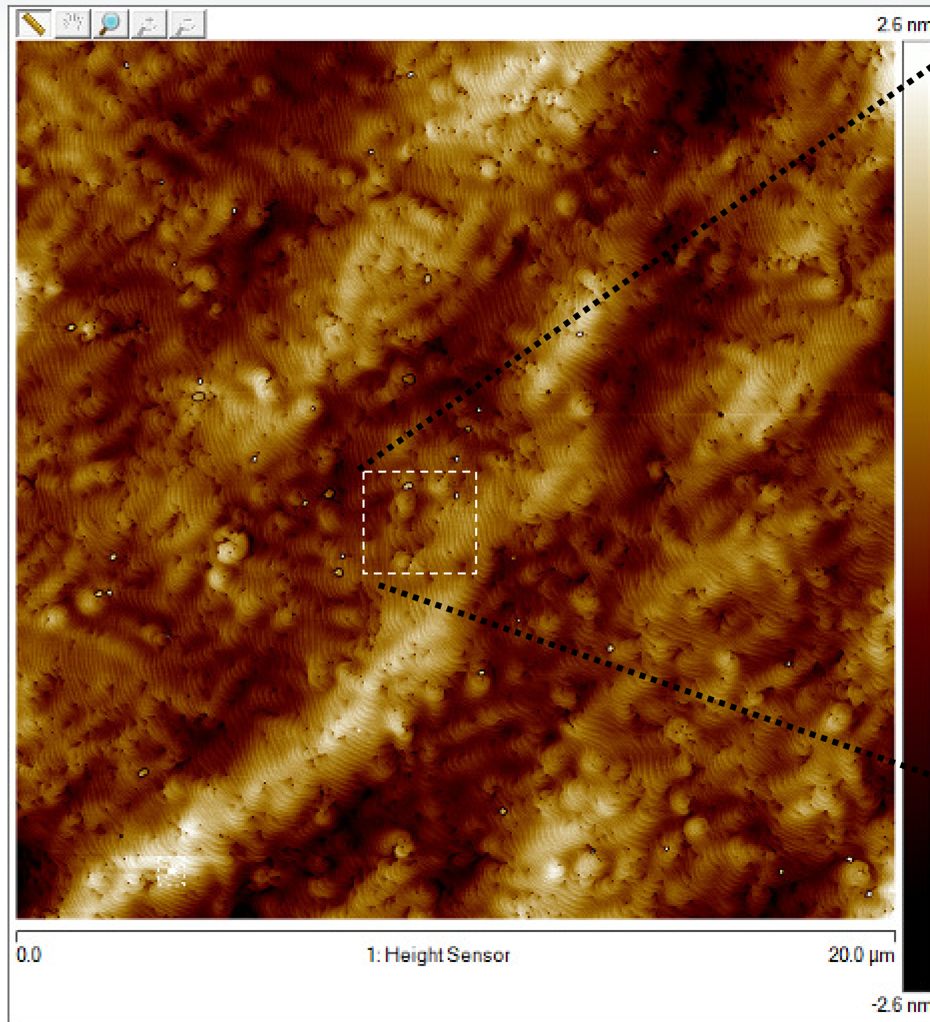
GaN on SiC
512x512 pixels, 38Hz Line Rate

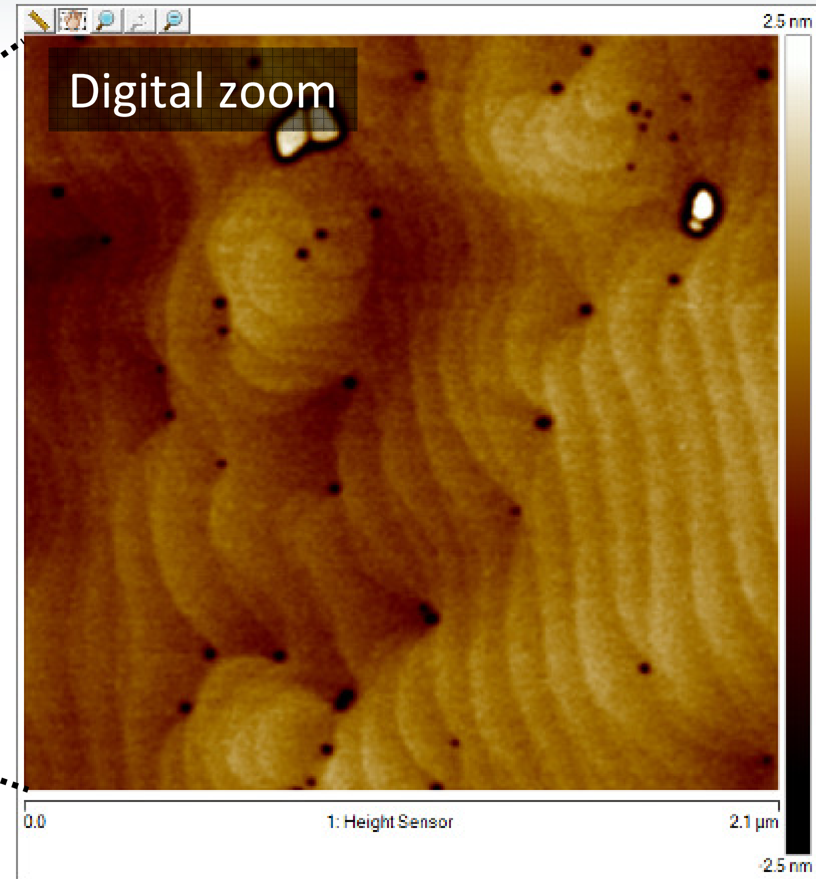


High-resolution image of:
- Edge & Screw dislocations
- Atomic steps

13.5 seconds/image

GaN on SiC
4kx4k pixels, 10Hz Line Rate





6 min/image = typical image rate for traditional SPM, but now we have an image with 64x more pixels.

22Hz Line Rate on Poly-Si (512x512 pixels)

http://www.youtube.com/watch?v=I25zRZ2ng_E

2x2 µm scan, 25 Seconds per image

Dynamics: Molecular Studies (DNA in Fluid)

http://www.youtube.com/watch?v=5cylVbEioIE

Sample courtesy of Y. Lyubchenko, Univ. of Nebraska Med. Ctr.

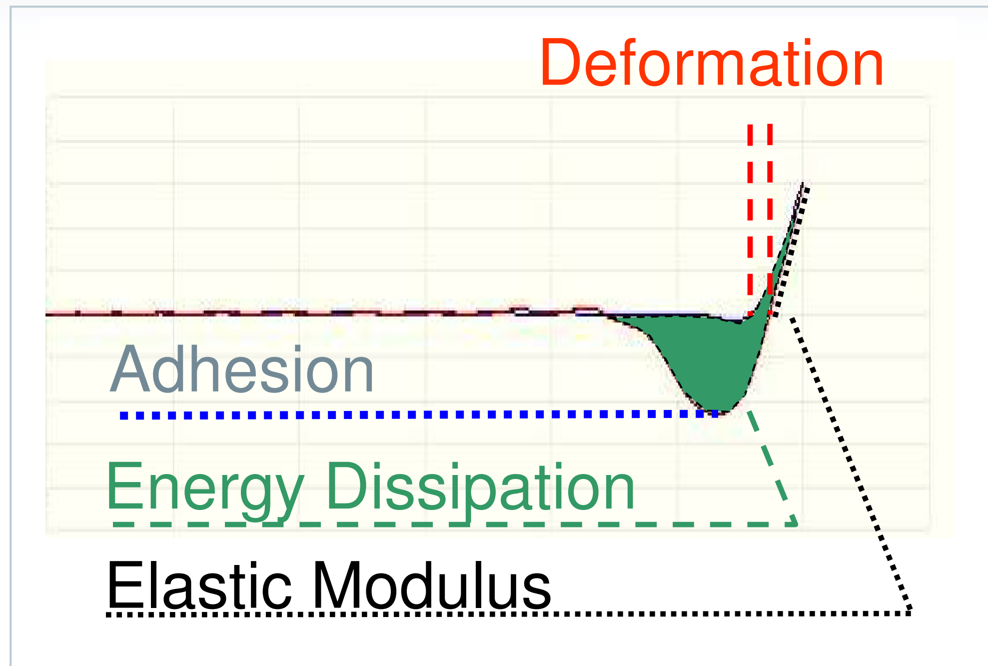
1 second per image (2100 images)

Outline

1. High resolution structural imaging
   - At lower forces
   - At higher throughput

2. Property imaging:
   - Mechanical characterization
   - Electrical characterization
   - Chemical characterization

Quantitative Nanomechanical Mapping (QNM)



Modulus:	0.6 MPa-60 GPa
Energy dissipation:	1eV-tens keV
Adhesion:	10 pN ~ μN
Deformation:	10 pm ~ 100 nm

QNM on Siloxane Liquid Crystal

Height

Modulus

Adhesion

1.64 MPa

7.52 MPa

13.7 MPa

0.748 nN

4.83 nN

crystals

amorphous (liquid) phase

substrate

Acquisition time, spatial resolution similar as standard imaging.

QNM on Benchmark Samples

Samples	Expec.	Meas.
DP150	0.63	0.76
DP130	0.73	0.87
DP110	0.86	1.2
DP60	1.58	2.2
DP25	3.78	4.1
DP8	11.8	14.5
LDPE90	60	58
LDPE93	400	370
SiLK	2400	2200
PS Film	2700	2500
HOPG	10500	12800
Au Foil	77200	50200
SiO2	71700	59400

Measured (MPa)

100000
10000
1000
100
10
1
0.1

QNM Data

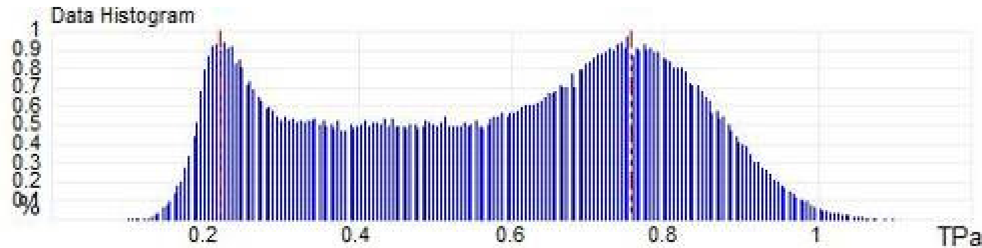
0.1 1 10 100 1000 10000 100000

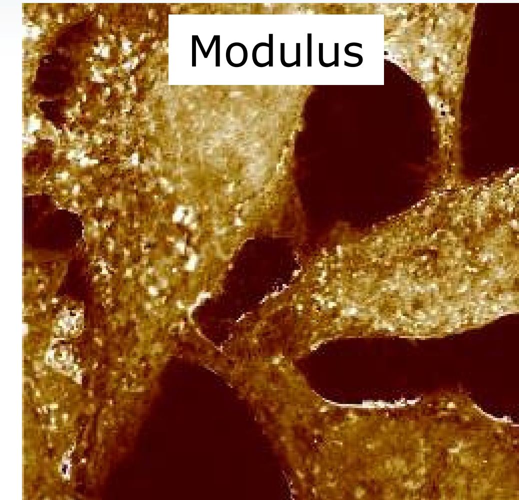
Expected (MPa)

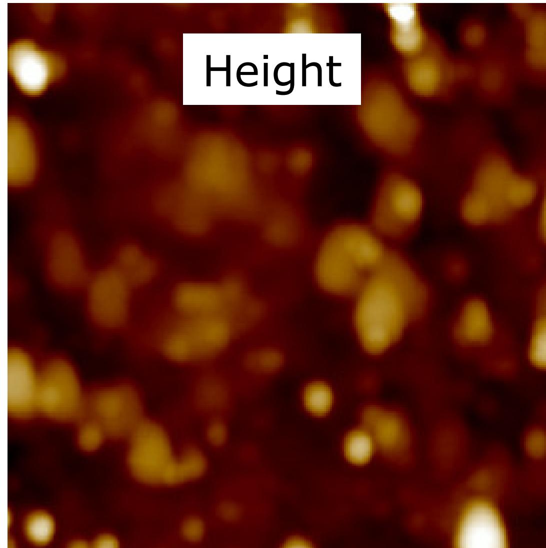
QNM
on Very Hard & Very Soft Samples

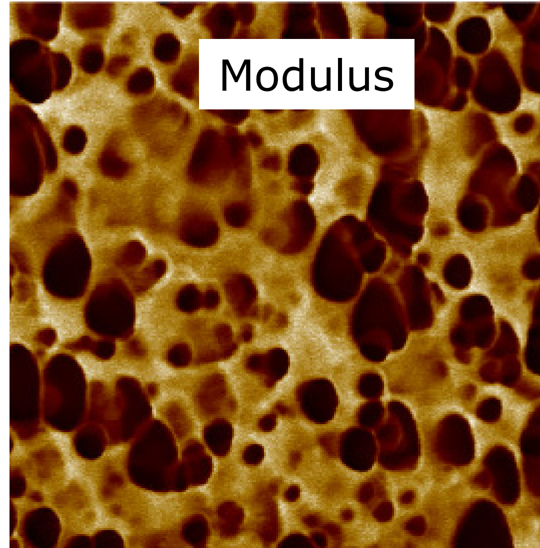
10x10 µm scan size
WC / C sample
E ~ 650 / 50 GPa

80x80 µm scan size
HELA cells
E ~ 10-100kPa









Electrical Characterization

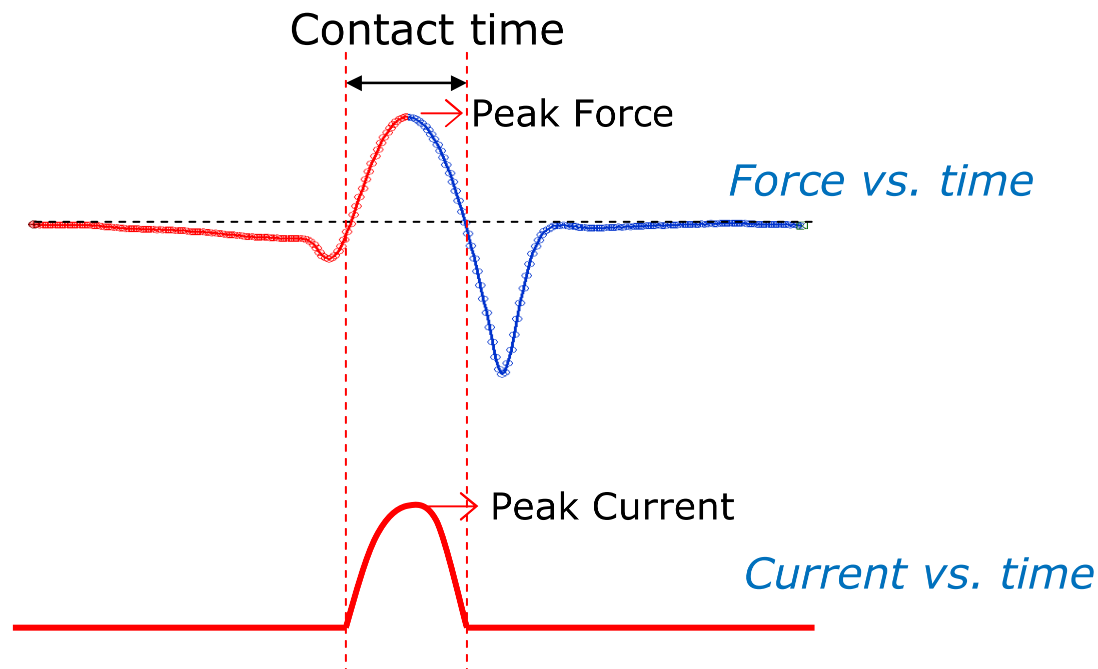
- SPM-based electrical modes are often based on 'Contact mode' operation. The high vertical and lateral forces can cause:
  - Tip & sample damage
  - Limited reproducibility
  - Reduced resolution
  - Artifacts

- Solution?

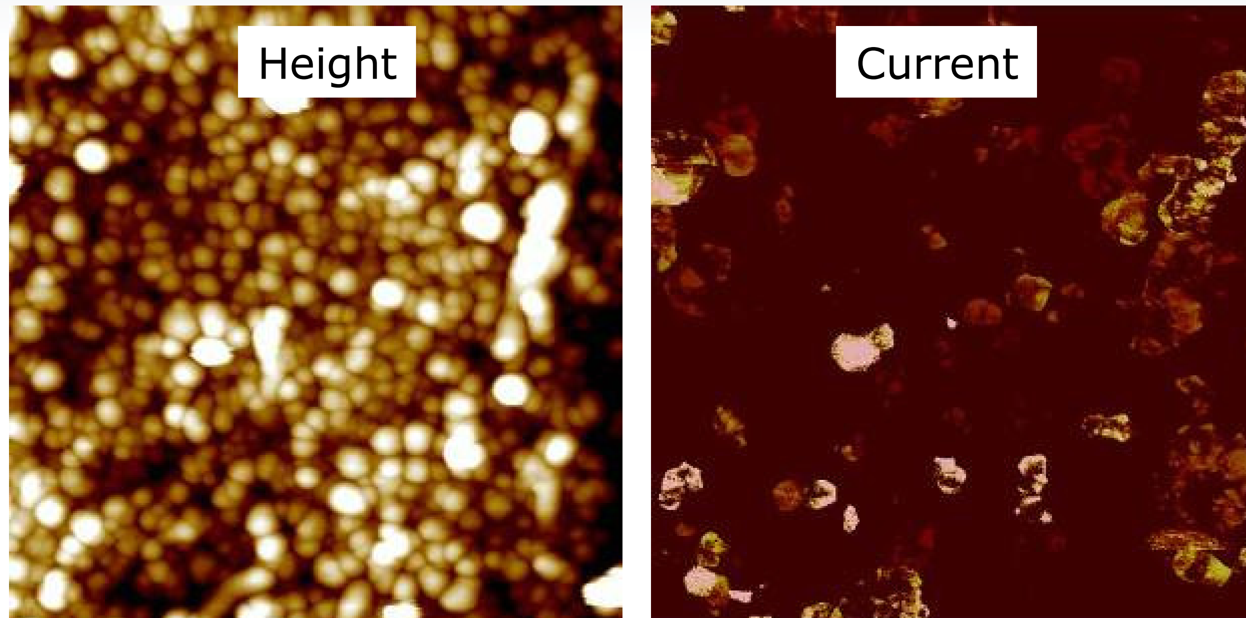
	Force Levels	Contact Time
Tapping	✓	✗
Peak Force Tapping	✓	✓

Combination of Peak Force Tapping / Conductive-AFM (or Tunneling-AFM)

- Tip oscillates at 1kHz. Contact time is typically 20 – 200 µs.
- The average current during contact time & the peak current are measured.
- Requires fast C-AFM electronics: 20kHz bandwidth, <100fA noise



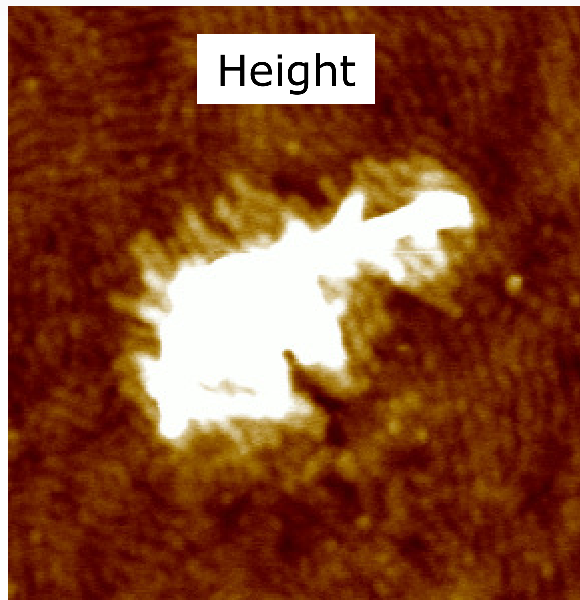
PF-TUNA Example:
Carpet of standing Carbon Nanotubes

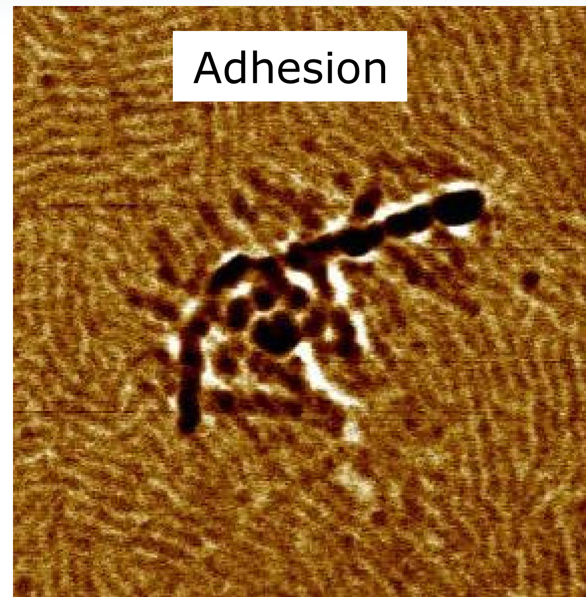


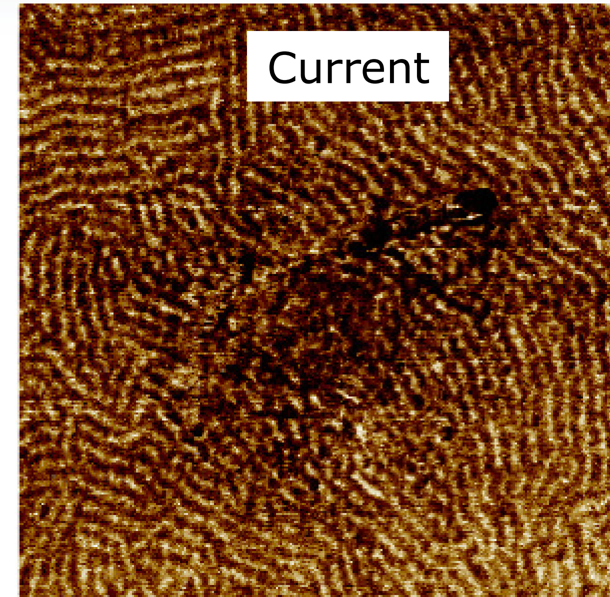
1000x1000 nm scan size

- Impossible in contact mode, as forces are too high.
- Reveals strong conductivity variations

PF-TUNA Example: Network of Conductive Polymer Macromolecules, around CNT







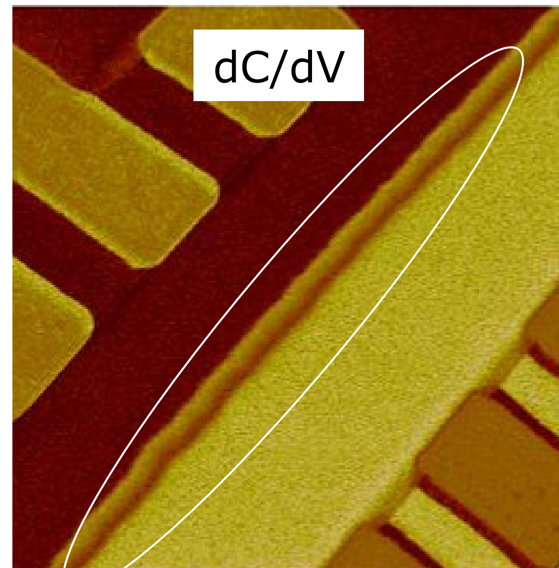
700x700 nm scan size

- Impossible in contact mode, as forces are too high.
- Higher resolution vs. contact mode.

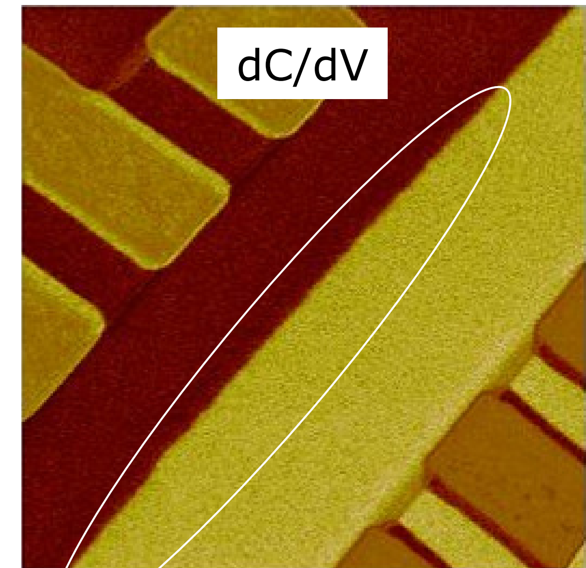
Sample courtesy:
Ph. Leclere, Uni Mons (B)

Eliminating the Effect of the AFM laser light

8x8 µm scan size



Laser on



Laser off

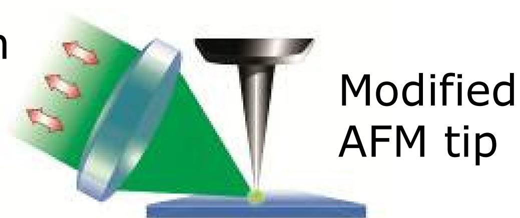
The surface is scanned twice:

1) With laser light (measure topography)
2) Without laser light (measure artifact-free electrical info)

Chemical Characterization: TERS

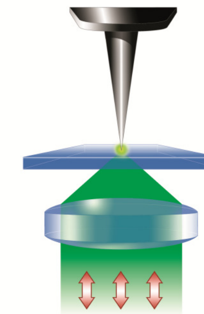
- Principle: Local field enhancement is achieved with a sharp metal structure that exhibits a surface plasmon resonance at the appropriate optical frequency, providing enhanced spatial resolution (Tip Enhanced Raman Spectroscopy)

Raman optical path



Modified AFM tip

Opaque samples: tilted optical access



Transparent samples: inverted optical access

Key Elements of the AFM-Raman

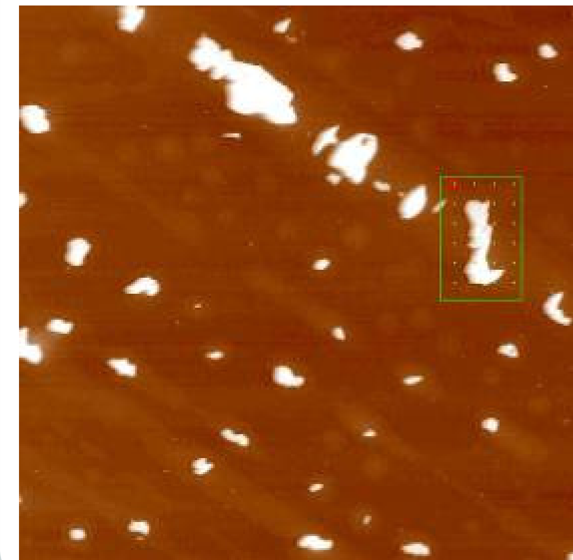
- Probes:
  - Forward pointing geometry
  - Silicon Nitride base (avoids Raman background from Silicon)
  - Coating of Ag (for excitation in blue or green), or Au (for excitation in red or NIR)

- Optimized optical access:
  - high numerical aperture (0.42 NA, 50x)
  - off-axis optical access to the tip (30 degree tilt)

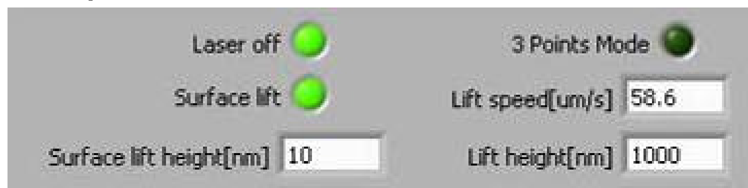
Key Elements of the AFM-Raman

1. AFM & Raman control from central software:

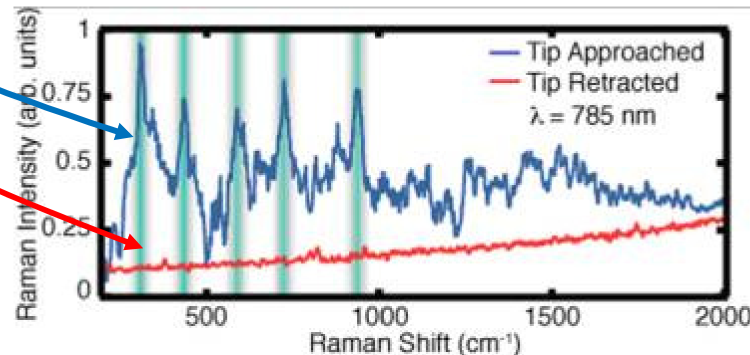
2. The AFM image is used to position the tip for Raman and/or TERS analysis.



3. "3 points mode" to test field enhancement:

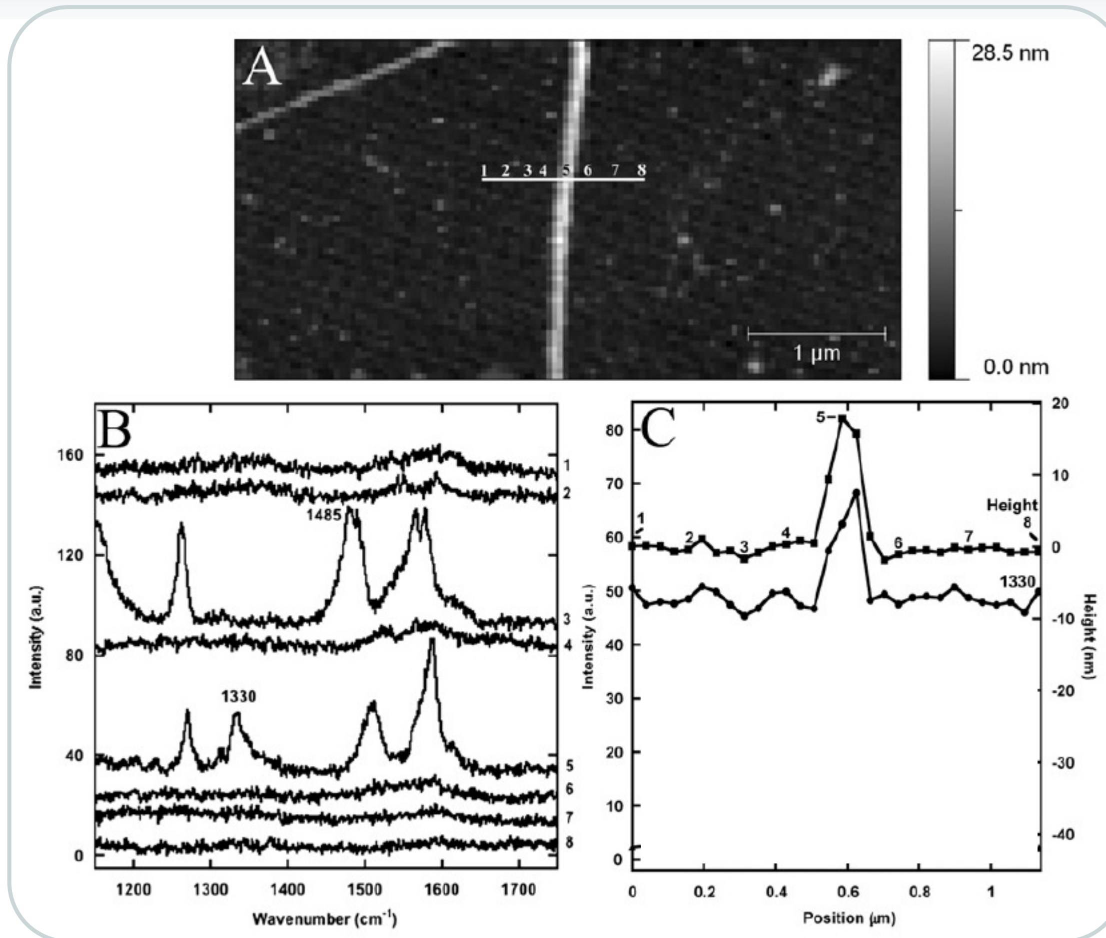


- Spectrum with tip on surface (i.e. near-field)
- Spectrum with tip off-surface (i.e. far-field or background)



Courtesy:
M. Raschke,
U. Colorado

TERS Example: Collagen I Fibrils



(A) AFM image with 1.1 µm path for TERS analysis.

(B) TERS spectra at different points along the path

(C) Height profile (squares) and the intensity of the 1330 peak (circles). FWHM = 100 nm.

Biophysical Journal Vol. 100, p 1837 (2011)

Acknowledgements

- Bruker Nano – Probes Division

- Sample & data courtesy:
  - L. Kreplak, Uni Dalhousie, Canada
  - M. Raschke, Uni Boulder, Colorado
  - Y. Lyubchenko, Uni Nebraska Med. Ctr.
  - Ch. Bippes, MPI Dresden
  - Ph. Leclère, Uni Mons, Belgium

- Bruker Nano - Apps Team