EPFL

MICRO-331
Microfabrication technologies

J. Brugger
M. Gijs
& teams

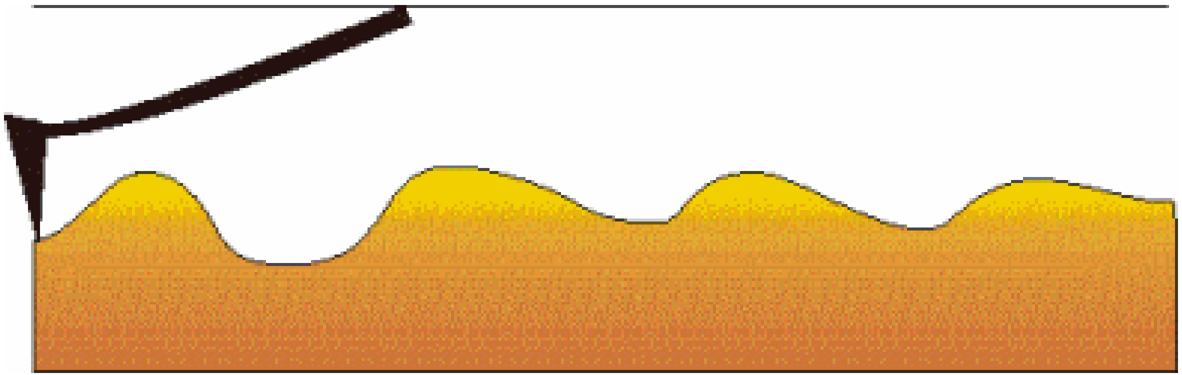
Micro for nano Part II

Nanoscale MEMS or NEMS

- What is different when going from micro to nanoscale?
- Nanoparticles (0D), nanowires (1D), nanoflakes (2D)
- New functionality of devices that are unique to the nanoscale size
- Nanoscale imaging by scanning probe microscopy (=nano-MEMS)
- Microfabrication of nanotips
- Nanoscale fabrication (top down)
- Nanoscale fabrication (bottom up)

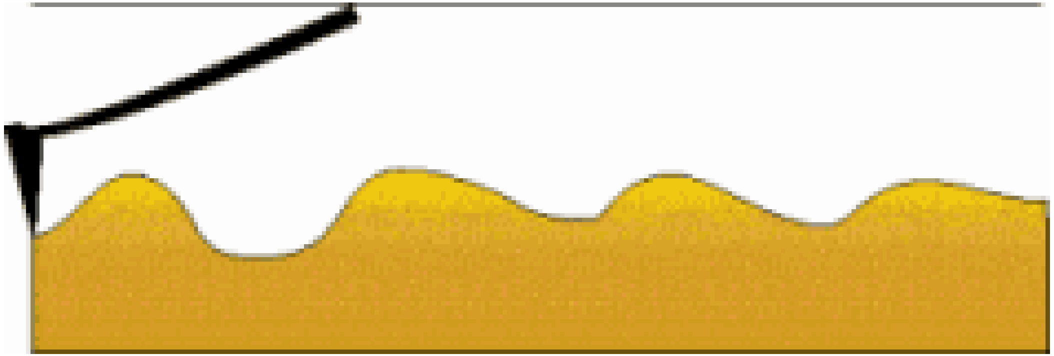
Contact mode SFM/AFM (constant height)

- Constant height (no z-axis actuation)
- Cantilever is bending
- Contact force is modulated
- Risk of tip and/or sample damage



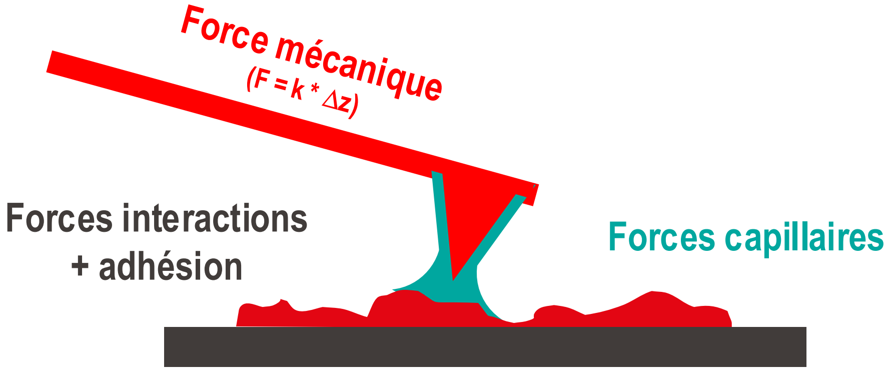
Contact mode SFM/AFM (constant force)

- Constant force during scanning (z-axes actuation)
- Cantilever bending is constant
- Z-feedback moves sample vs. probe
- Avoid tip damage
- Avoid sample damage
- Important for friction force measurements

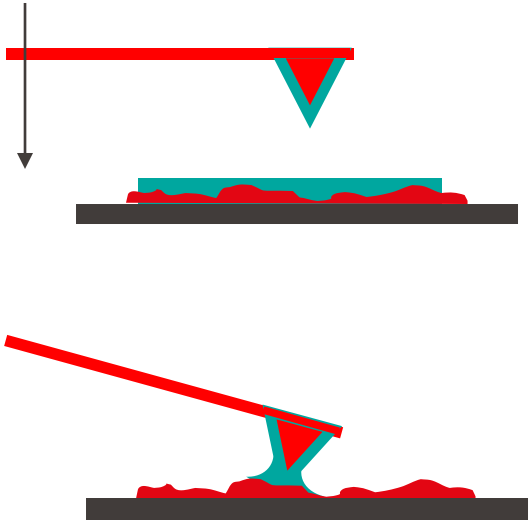


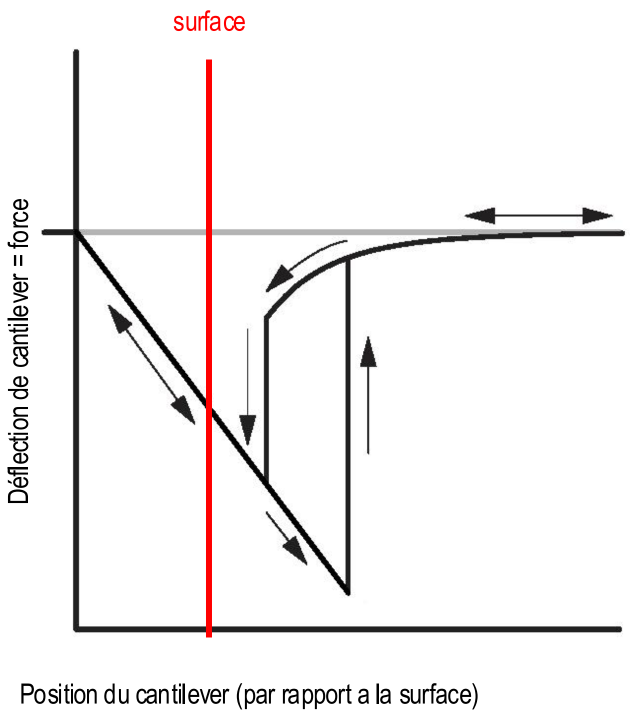
Forces in AFM

Because the AFM relies on the forces between the tip and sample, knowing these forces is important for proper imaging. **The force is not measured directly, but calculated by measuring the deflection of the lever, and knowing the stiffness of the cantilever. Hook's law gives F = -kz,** where F is the force, k is the stiffness of the lever, and z is the distance the lever is bent.



Force distance curves



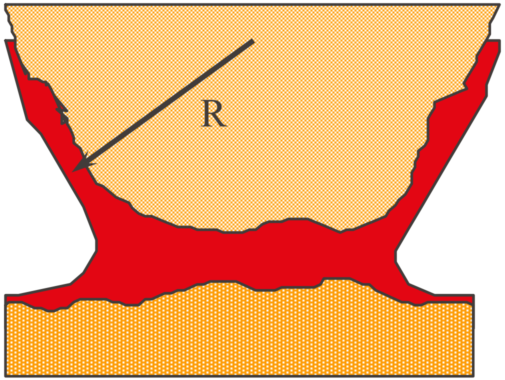


Capillary Forces

General expression:

$F_{max} = 4 \pi R \gamma \cos(\Theta)$

$\gamma(H_2O) = 0.074$ N/m tip radius: R=100nm
contact angle for hydrophilic surfaces $\Theta \sim 0°$

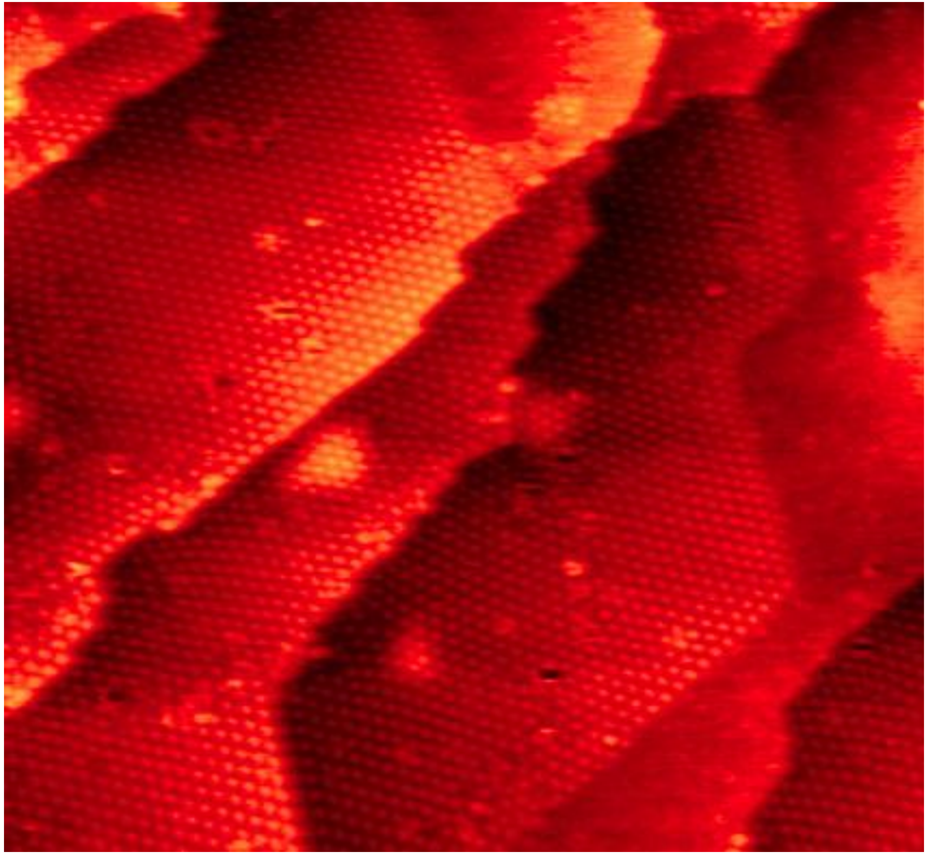


$F_{max} = 90$ nN

Numerical example:
Cantilever spring constant k=1N/m
Q: How much is the cantilever deflecting?

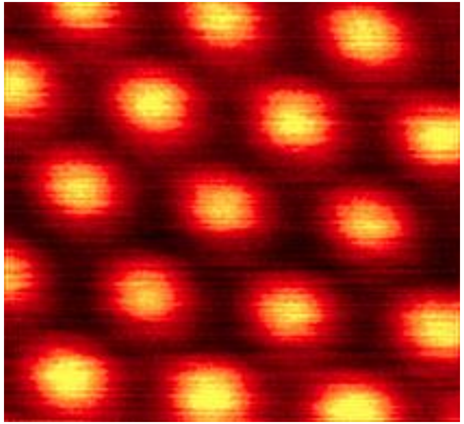
To avoid capillary forces:
Operate in vacuum
Immerse fully in liquid

AFM of graphene

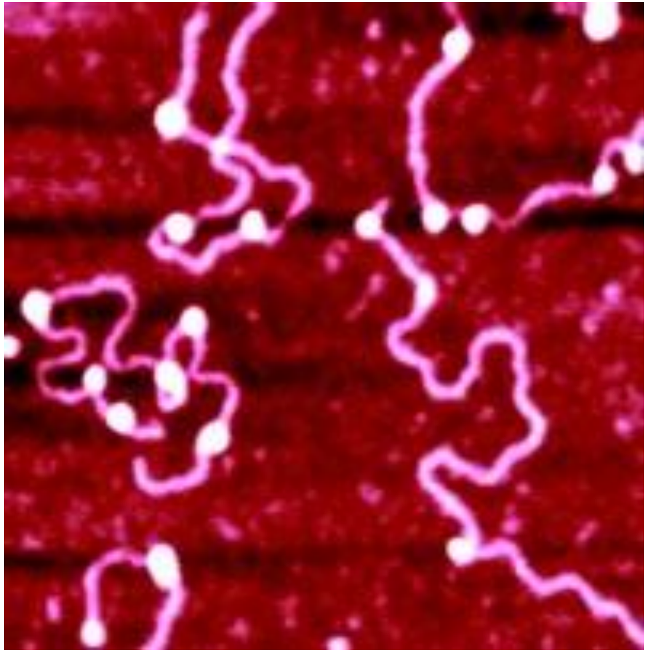


150 nm x 150 nm

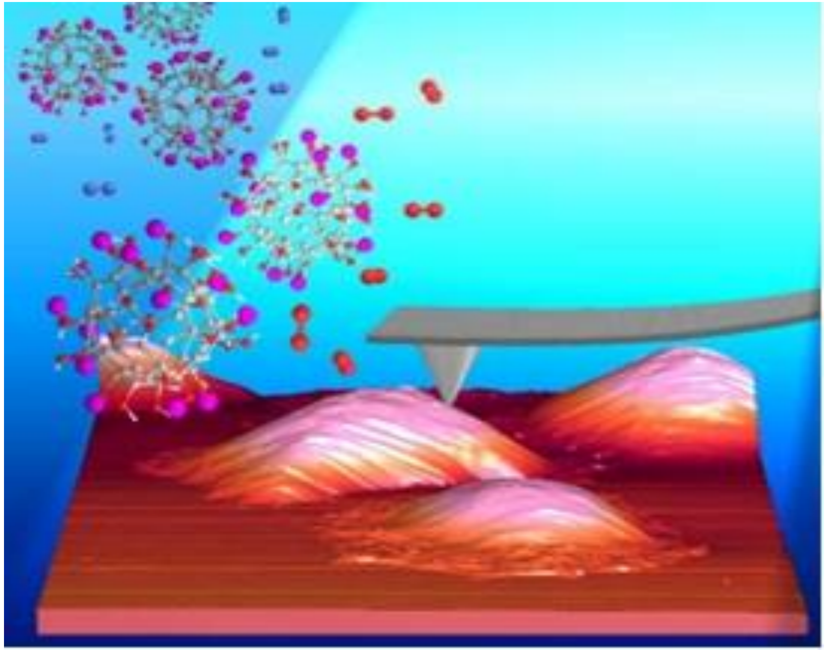
9nm x 9 nm



Microscopy in biology

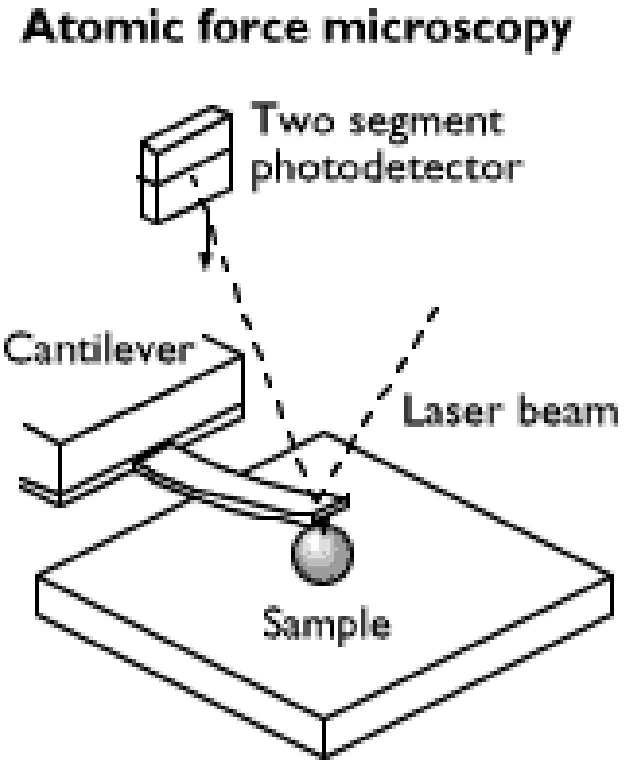


DNA molecules



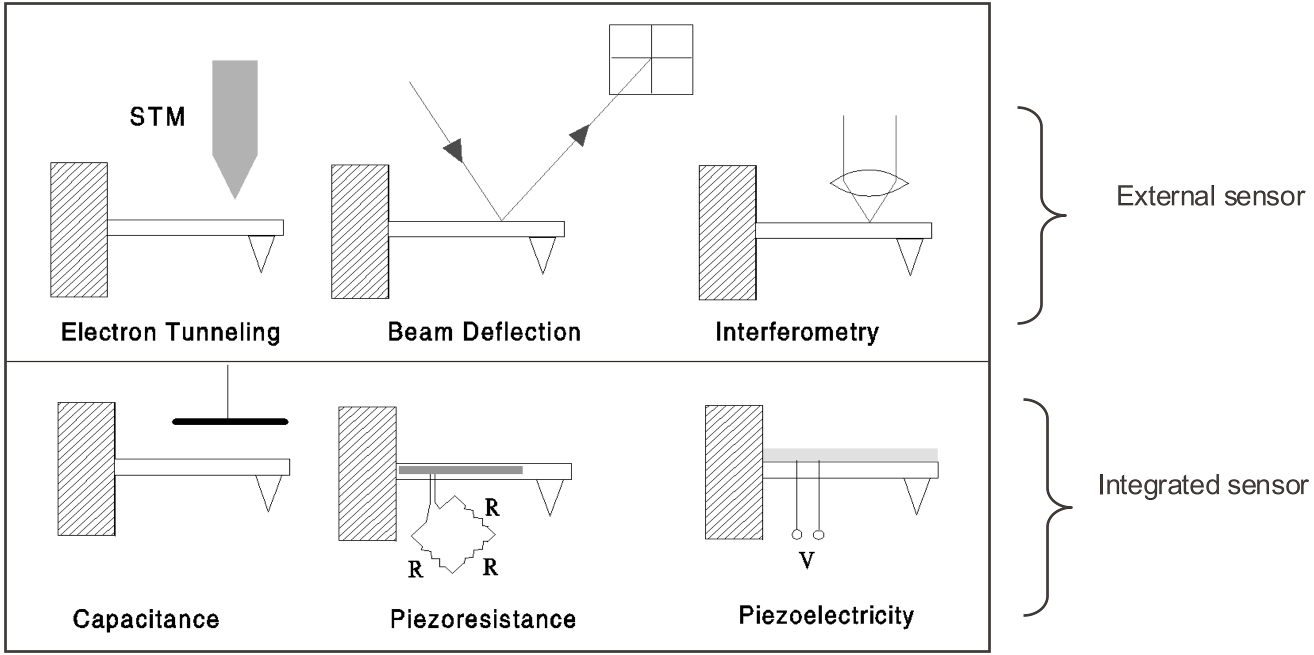
AFM on living cells

How to sense the cantilever deflection



Integrated sensors & actuators

Deflection Sensing in the Å Range

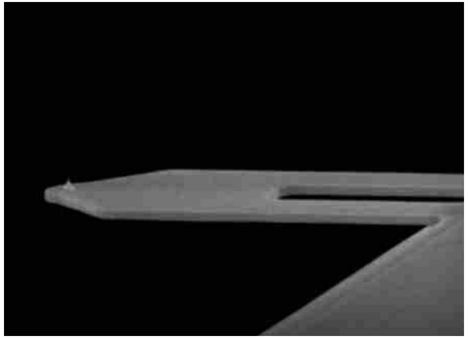


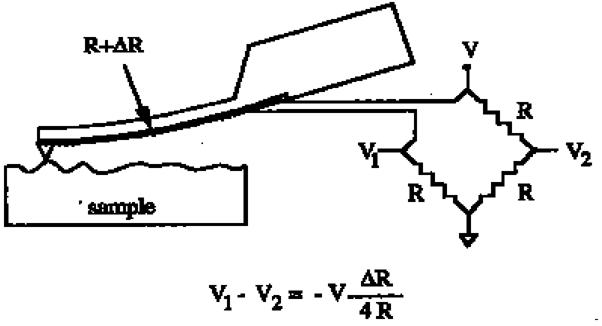
Integrated sensors & actuators

- What advantages are with integrated transducers?
- Compact = less disturbance by vibration and temperature changes.
- No detector adjustment.
- Special environment
  - vacuum chambers
  - low T
  - liquid cells
- Enabling parallel operation.

Piezoresistive cantilever

- Piezo = Strain
- Based on the piezoresistive effect, where the resistance of a material changes when the beam is deflected.
- Easy to fabricate using a small piece of either p-type or n-type silicon as the conductor.
- The disadvantage of piezoresistors is that the changes in resistance are very small and that they have a temperature dependency.

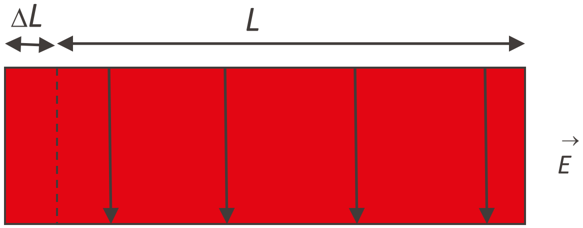




Piezoelectric cantilever

Piezoelectric actuators rely on the transversal piezoelectric effect. The crystal expands orthogonal to the applied electric field.

$$\Delta L = d_{31} \cdot L \cdot \vec{E}$$



E: electric field

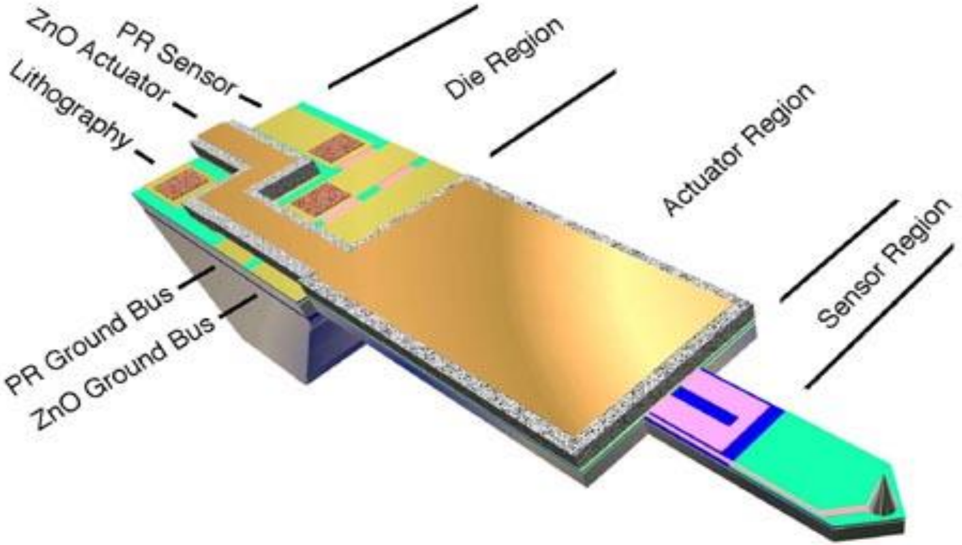
L: length

ΔL: length change

D_{31}: transversal piezoelectric coefficient

Piezo-electrical cantilever

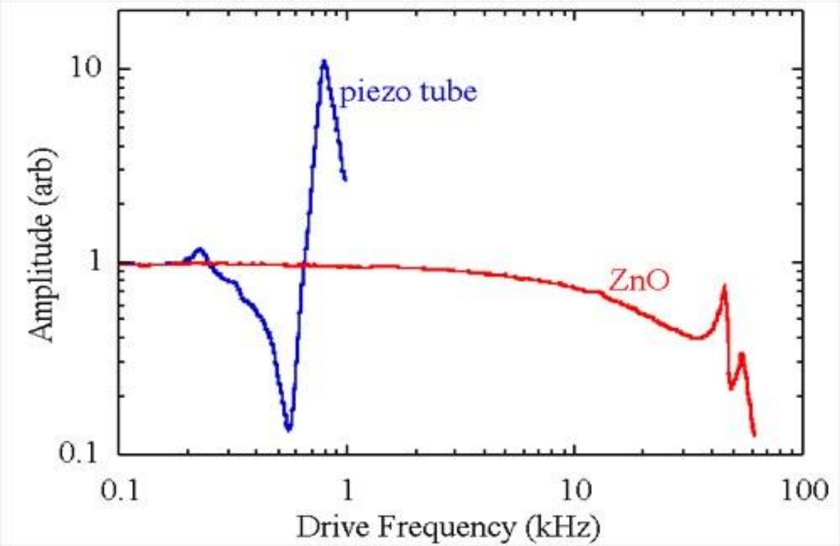
The cantilever includes an integrated piezoelectric actuator and a piezoresisitve sensor



Quate Group, Stanford

Piezoelectrical actuation

Bringing SPM up to high speed!



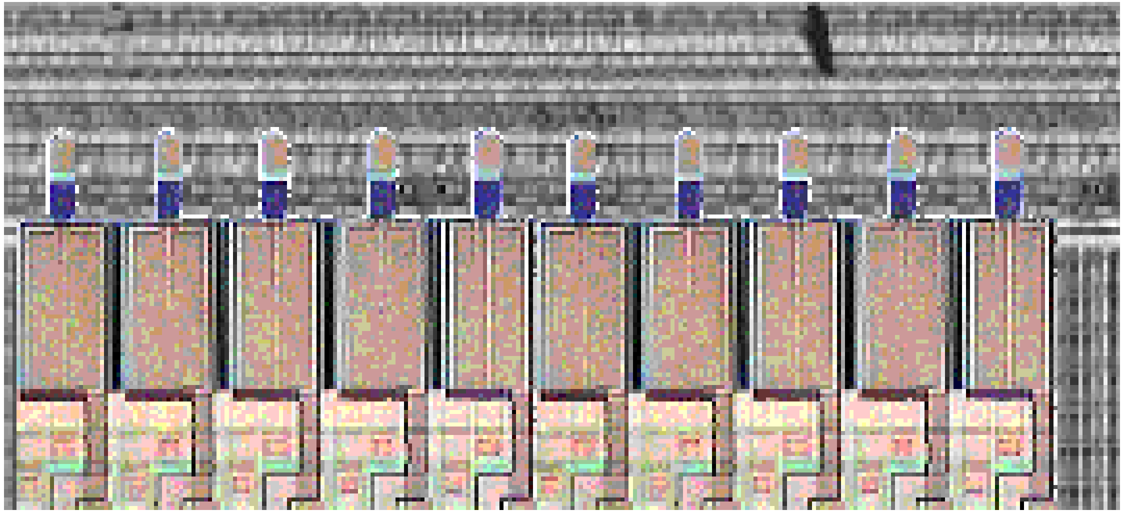
The plot compares the frequency responses of the piezotube actuator and the integrated Zinc Oxide actuator. The piezotube actuator has its first resonance around 1 kHz while the ZnO actuator doesn't see its first resonance until about 60kHz. This corresponds to constant force mode tip speeds of about 100 µm/s for the piezo tube and 1cm/s for the ZnO actuator.

Small is faster!

Parallel SPM systems

Probe array

- These 10 ZnO probes are part of an array of 50 probes. They each have their own integrated actuator and sensor and are able to collect information at tip speeds that are measured in mm/s instead of um/



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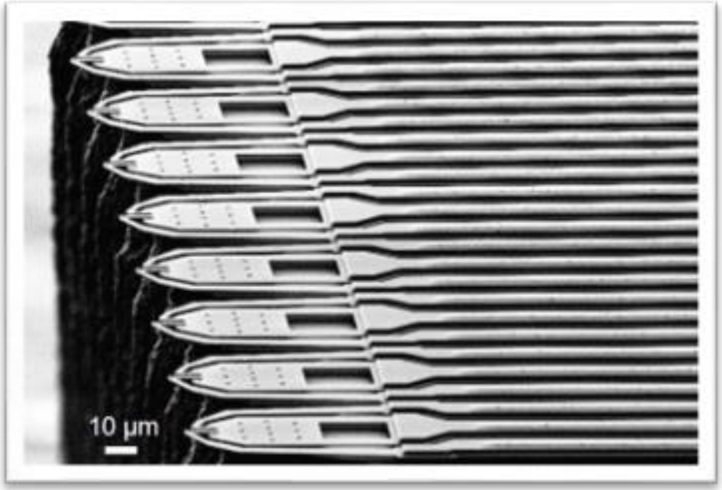
Parallel AFM image

Image of an IC memory cell that spans 2mm X 2mm taken with 10 ZnO scanning probes. This image is made up of 25 million pixels, taken at a tip speed of 1mm/s, over a total acquisition time of 30 minutes. It is 400 times larger than a conventional AFM image. Each of the 10 probes was responsible for a 2mm X 200um section of the overall image.

Quate Group, Stanford University

New generation of multi-tip systems (2025)

Heidelberg Instruments
Nanofrazor (ex. Swisslitho)



https://nanofrazor.com/

https://www.youtube.com/watch?v=NqcVfw2Fv70