FURTHER ANALYTICAL METHODS

- **TOPOGRAPHY**
  - SPM
  - CLSM (confocal laser scanning microscope)
- **INTERNAL STRUCTURE**
  - X-ray microscope
  - scanning acoustic microscope

1

SPM – SCANNING PROBE MICROSCOPY

Advantages

- atomic resolution
- no difficult sample preparation

Disadvantages

- max. 10 um^2 area
- max. some um vertical resolution
- vibration sensitivity

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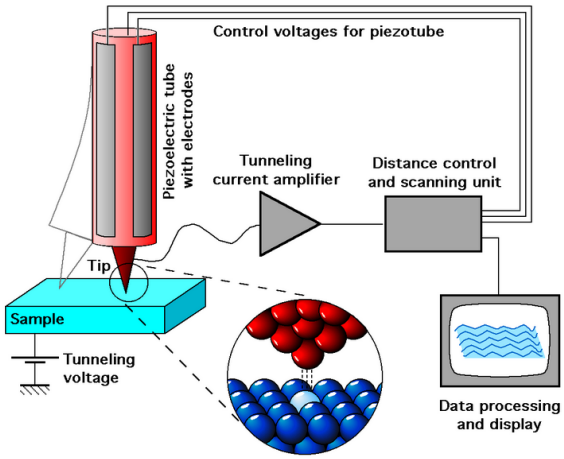
Scanning probe microscope



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HISTORY OF SPM METHODS NOBEL PRIZES

STM (Scanning Tuneling Microscope)

1981: Gerd Binnig, Heinrich Rohrer (IBM, Zürich);
Nobel: 1986
(shared with Ernst Ruska, inventor of TEM)

AFM (Atomic Force Microscope)

1986: Binnig, Rohrer, Quate (IBM, Zürich és Stanford University)

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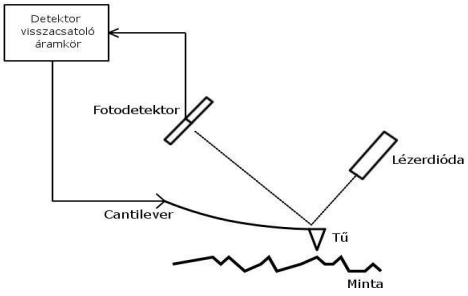
AFM – ATOMIC FORCE MICROSCOPE

A very sharp needle is moving over the sample surface. The vertical position of the needle is determined by the attractive and repulsive forces between the needle and the atoms of the surface. The needle is fixed on az elastic cantilever.



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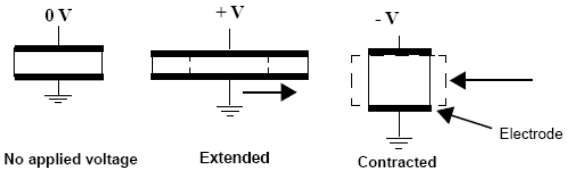
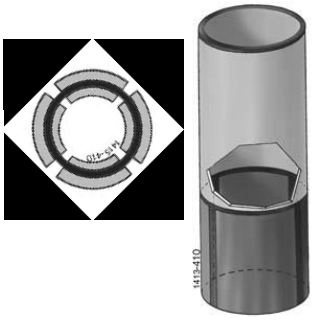
MOVEMENT OF AFM SAMPLE

- Inorganic crystal (e.g. litium-niobate - $LiNbO_3$, barium-titanate – $BaTiO_3$).
- The piezoelectric factor is typically $10^{-10}..10^{-11}$ m/V





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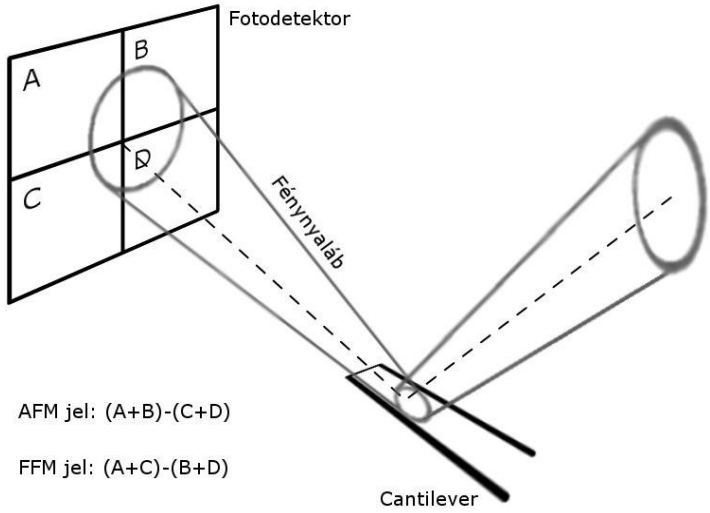
MEASUREMENT OF THE MOVEMENT OF THE CANTILEVER



2/10

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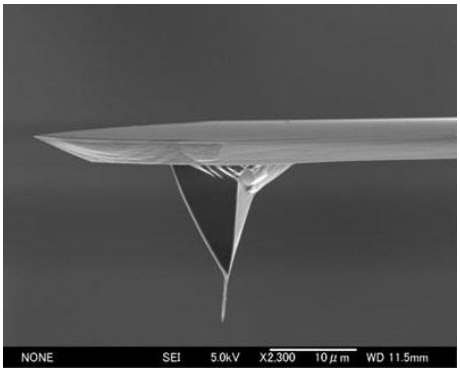
AFM NEEDLE



- Si mikromechanics
- Carbon nanotube
- SPM: ending in 1 atom
- AFM: 5-20 nm radius

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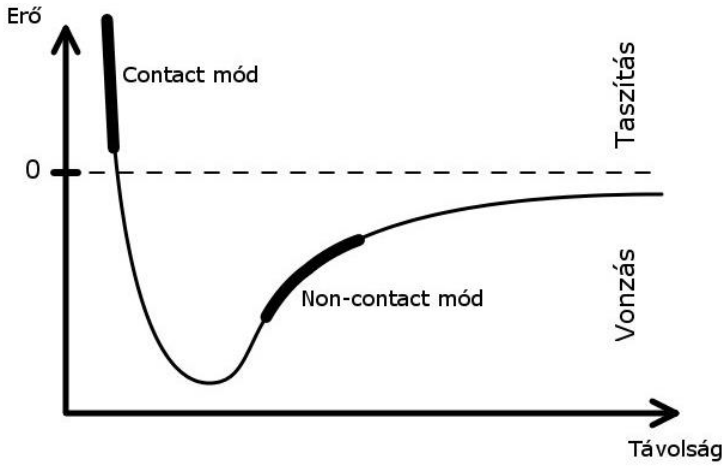
AFM MEASURING METHODS



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AFM methods

- 3 basic modes:
  - contact,
  - „tapping”,
  - Non-contact.
- Main properties of the cantilever:
  - rezonance-frequency,
  - elastic constant,
  - vibration amplitude.

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Contact mode

- Advantages:
  - quick,
  - atomic resolution,
  - measuring of non-uniform surfaces.
- Disadvantages:
  - effect of shear forces on the image,
  - sensitive samples can be hurt.

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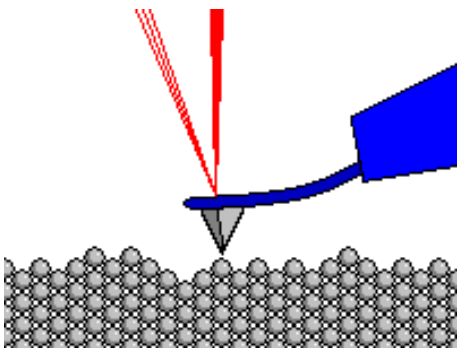
Contact mode



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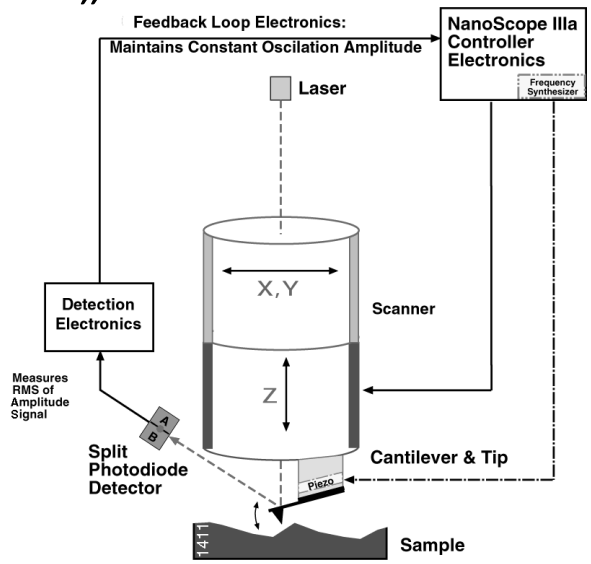
„TAPPING” mode



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„TAPPING” mode

- Rezonance-frequency ~300 kHz
- Feedback to the RMS of resonance-frequency.
- Amplitude: between 20nm and 100 nm
- Advantages:
  - resolution of 1 and 5 nm,
  - smaller forces on the sample,
  - no shear forces.
- Disadvantages:
  - lower scanning speed

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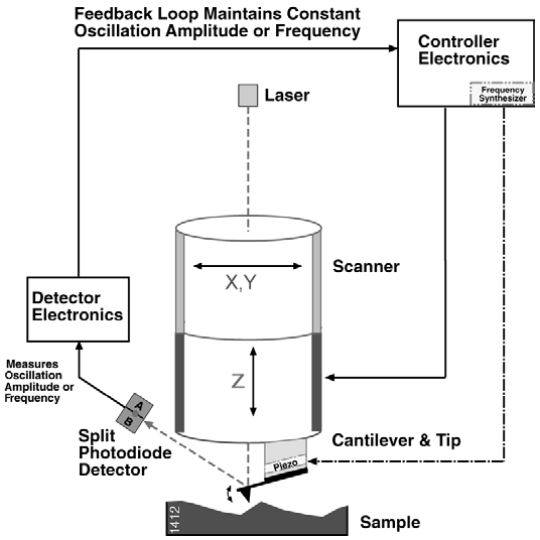
Non-contact mode



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NEM-KONTAKT MÓD

- Amplitude: <10 nm
- Resonance-frequency decreases as we go closer to the surface – this is dewtected
- Advantages:
  - resolution of 1 and 5 nm,
  - lower forces on the sample,
  - no shear forces.
- Disadvantages:
  - much lower scanning speed (to avoid the needle to be „sticked”)
  - lower resolution

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Image formation faults
Effect of the geometry of the needle

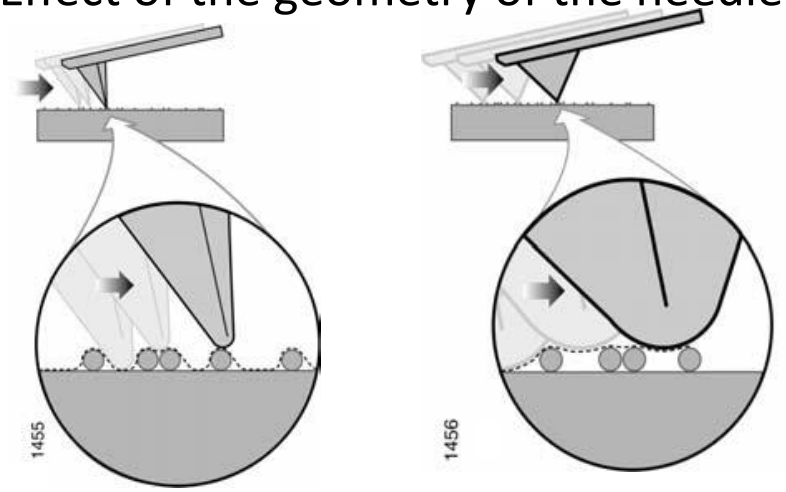

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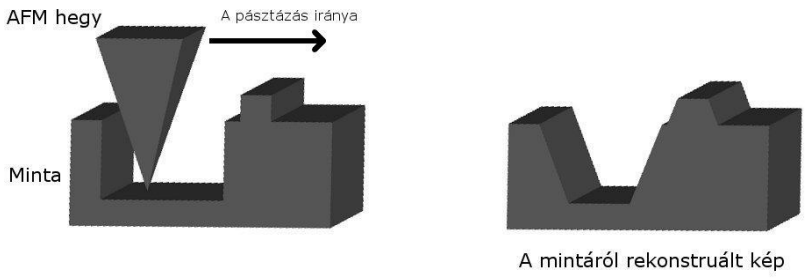
Image formation
Geometrical convolution



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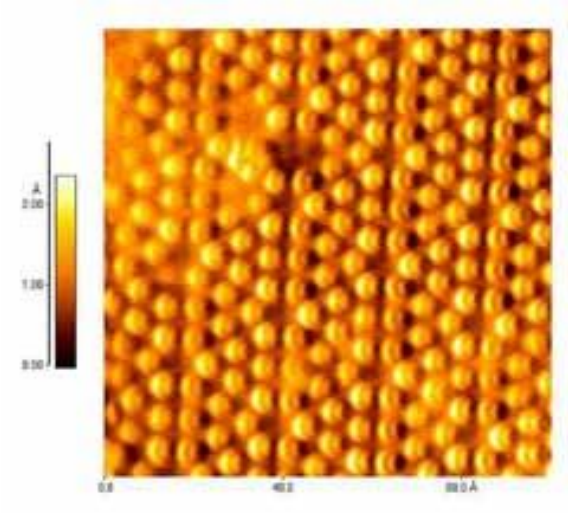
AFM



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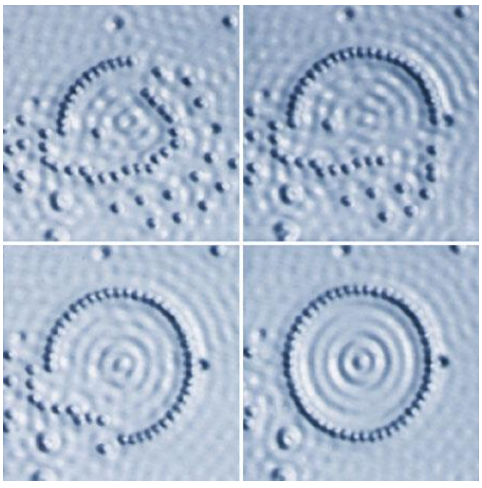
Moving atoms



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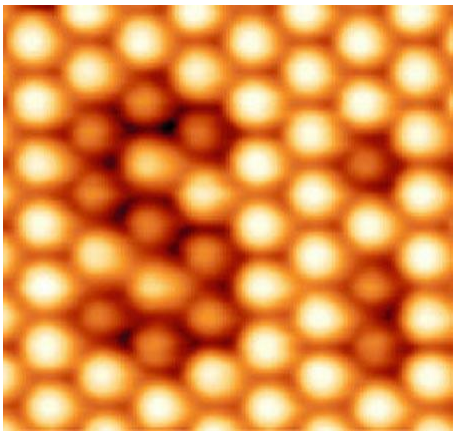
Smallest writing of the world



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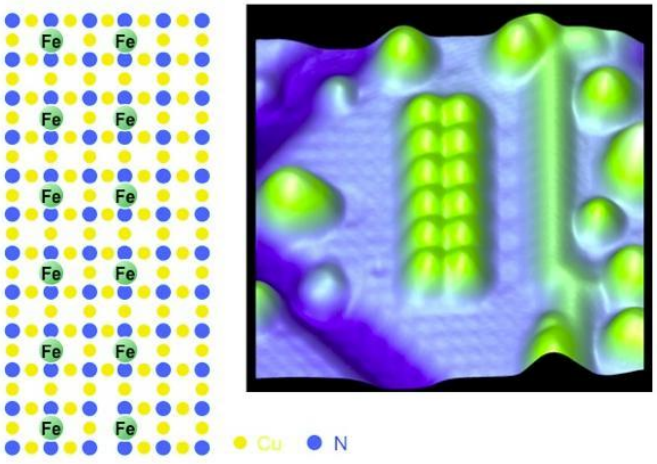
Data storage



Operates at~ 4 K... ☹

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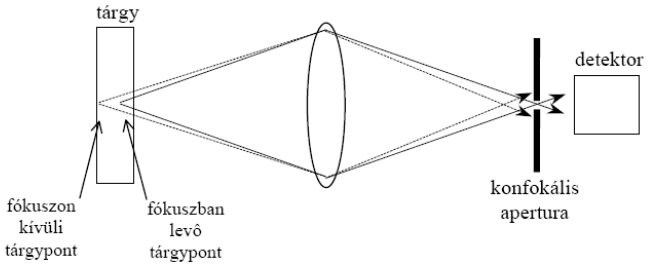
CLSM – CONFOCAL LASER SCANNING MICROSCOPE

Advantages

- high depth-of-field
- simple sample preparation
- quantitative results



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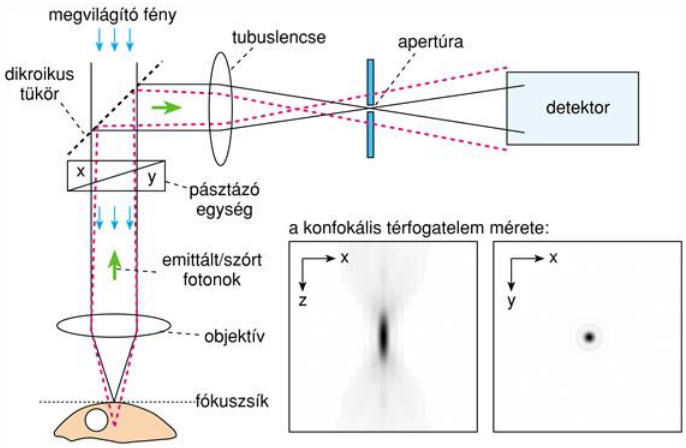
CLSM – CONFOCAL LASER SCANNING MICROSCOPE



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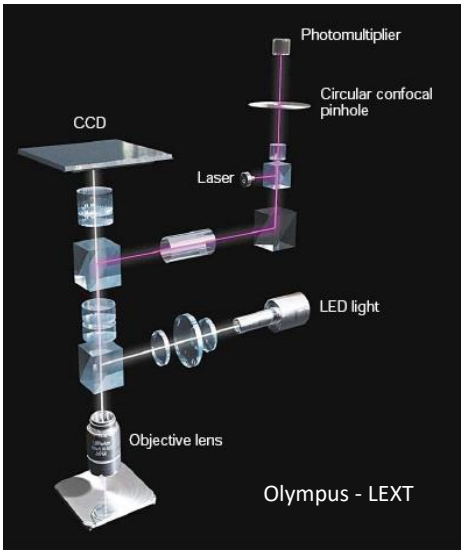
CLSM

- short wave (408 nm) laser illuminating– lateral resolution λ/2
- reflected light travels through an aperture – only one plane is sharp
- 3D image formation by moving the sample vertically



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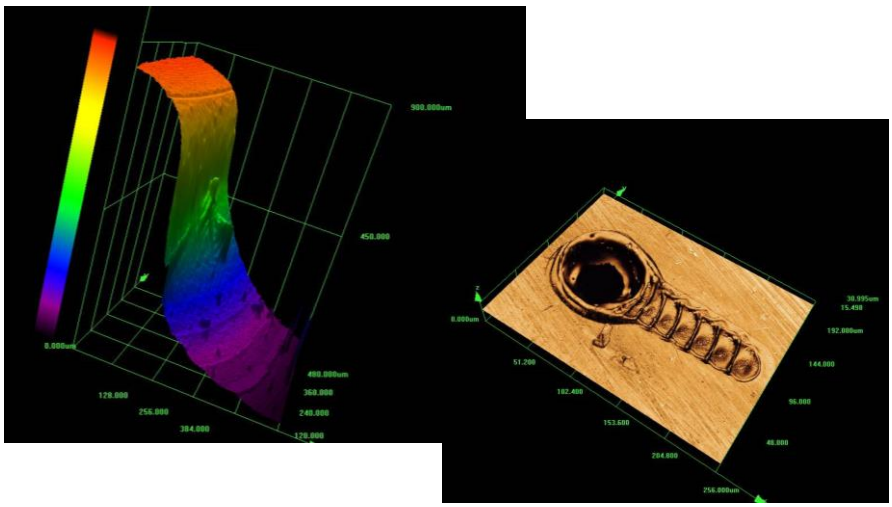
Solder meniscus – laser hole CLSM image



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CLSM – main parameters

- x-y (lateral) resolution:
  - wavelenght of light (~ λ/2) <- laser,
  - numeric aperture (~1/NA) <- objective lens
  - diameter of the confocal aperture
- z resolution:
  - cca. 0,5-1,5 µm „thick" optical sections
  - numeric aperture (~1/NA)
- speed
  - scanning speed vs. better signal/noise ratio

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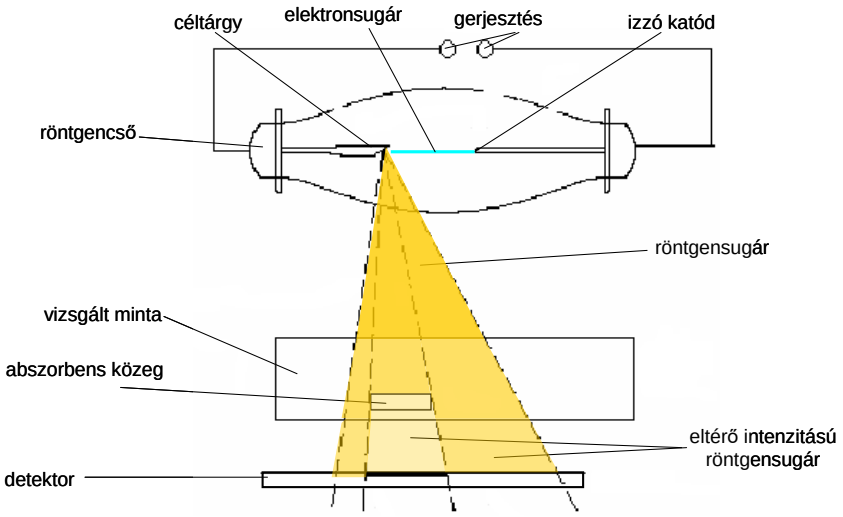
X-ray projection



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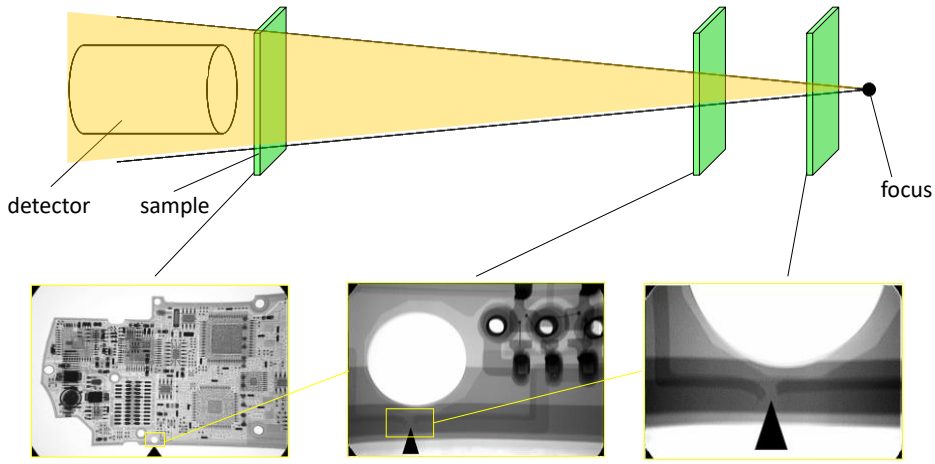
GEOMETRICAL MAGNIFICATION



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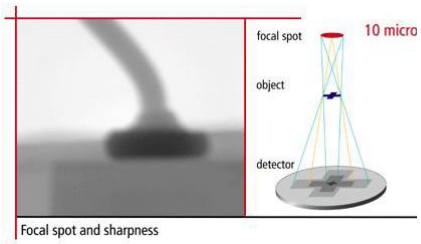
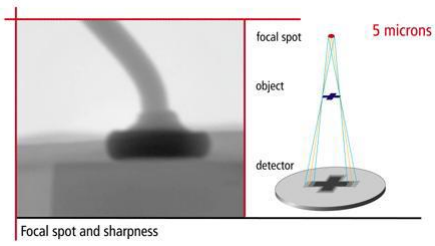
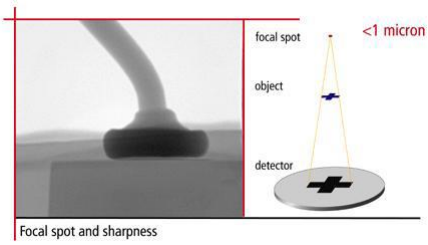
Resolution







Resolution vs. diameter of focal point.

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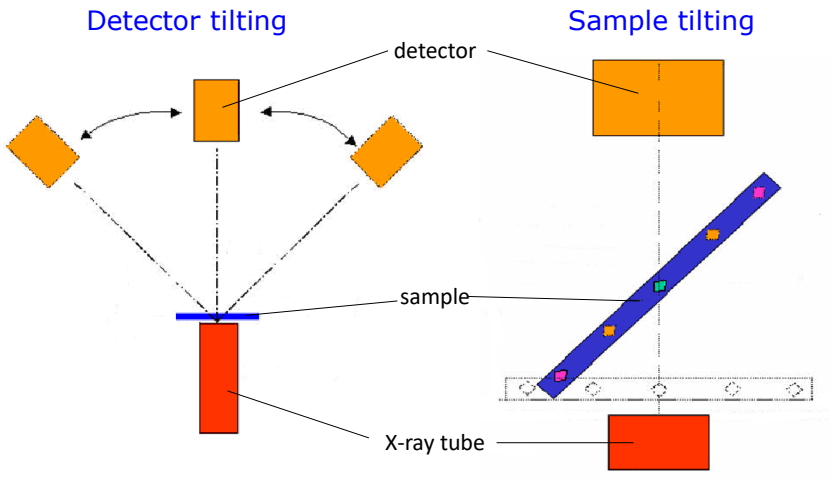
Image formation by tilted X-ray radiation



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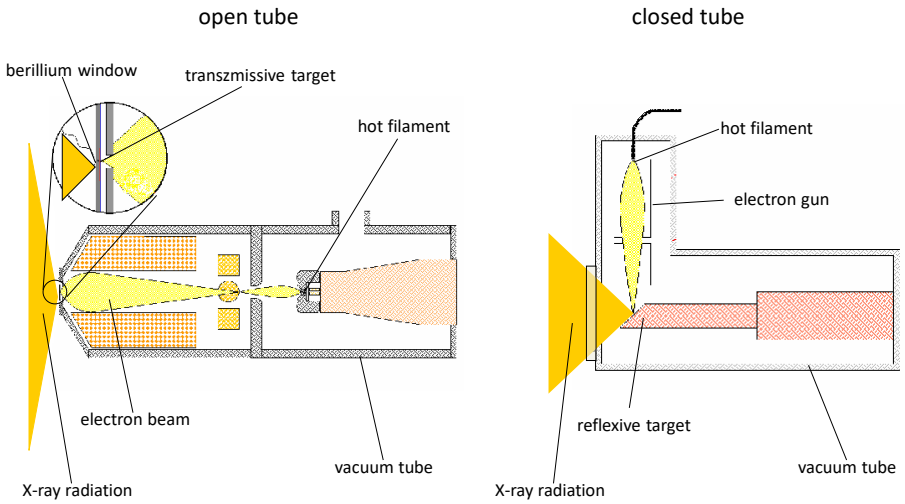
X-ray tubes



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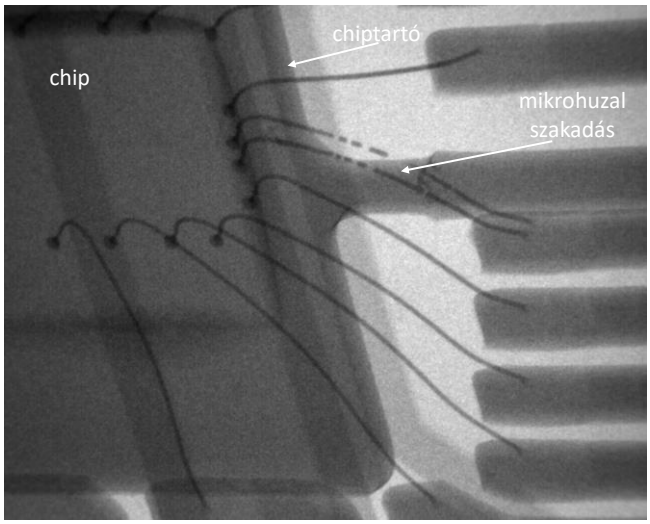
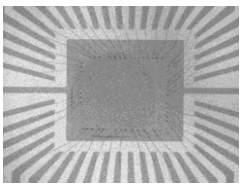
MIKROWIRES – FRACTURE



- too high current
- 2 mikrowires parallel, still molten
- tilted image shows the geometry of wires



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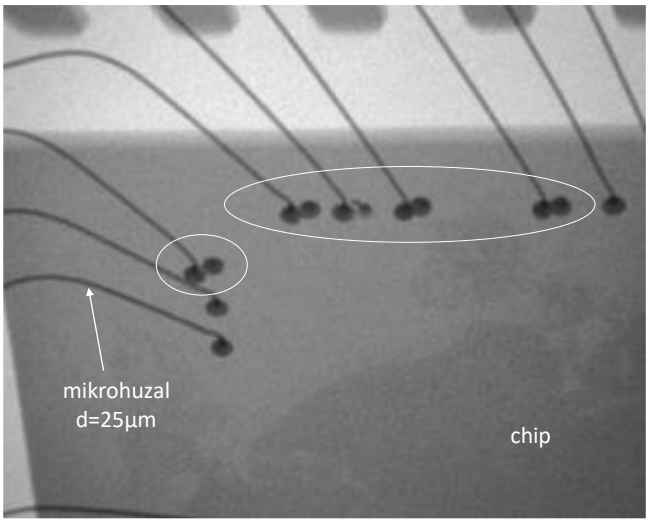
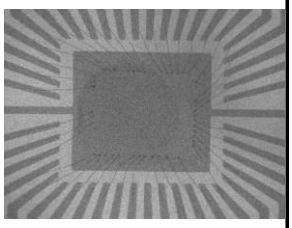
MIKROHWIRES - DELAMINATION



- tilted image shows delamination
- even chip glue is visible



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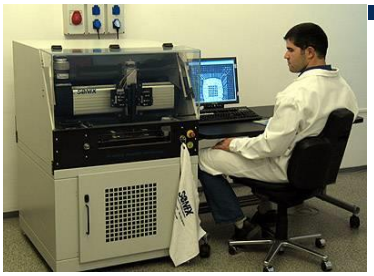
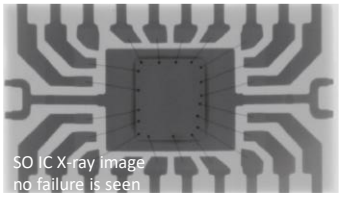
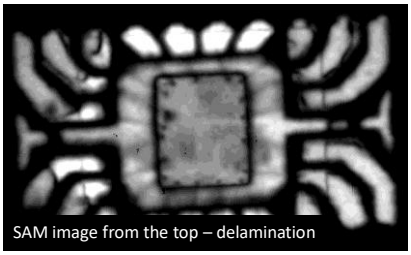
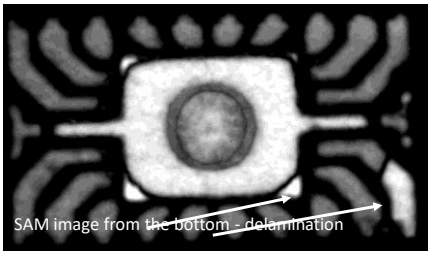
SAM - SCANNING ACOUSTIC MICROSCOPY

- Cracks, inclusions, delaminations, which are invisible for X-ray.
- 15, 50, 75 and 110MHz transducers









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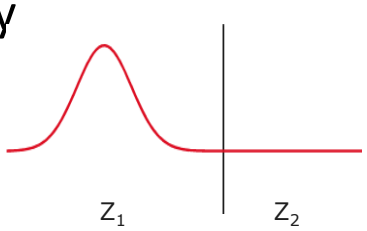
Principle of scanning acoustic microscopy

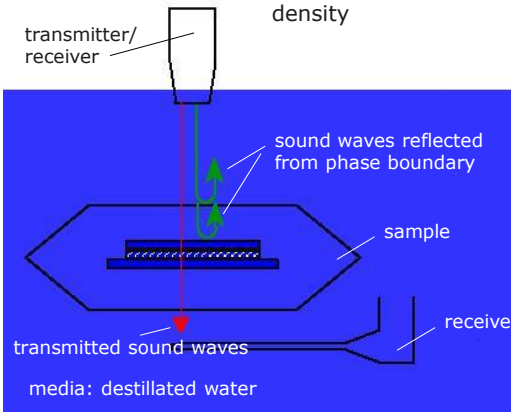
$$Z = \rho \cdot v$$

acoustic impedance

density

speed of the sound





Phase boundary reflection:
different acoustic impedances

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

reflecting factor

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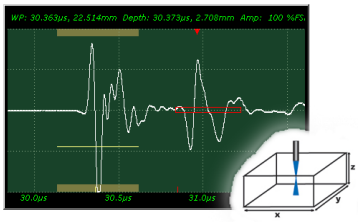
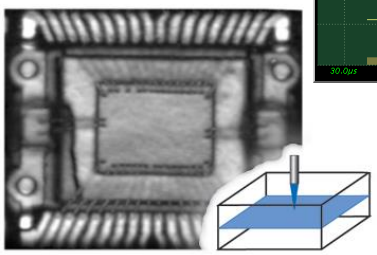
Image formation

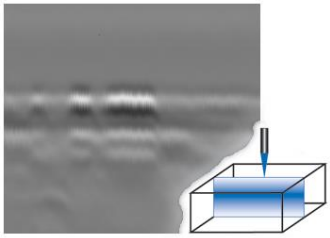
A-scan: point



B-scan: line scan



C-scan: plane sectioning



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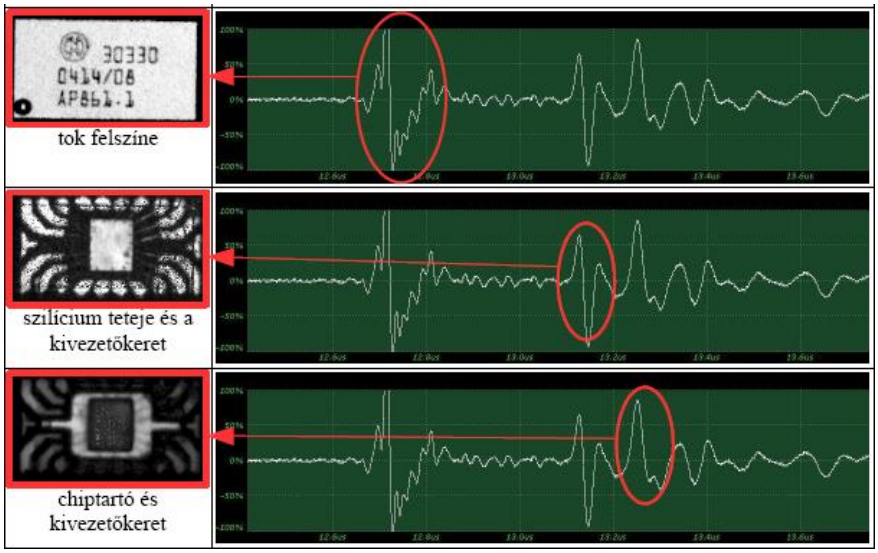
A-SCAN (WAVE) – C-SCAN (IMAGE)



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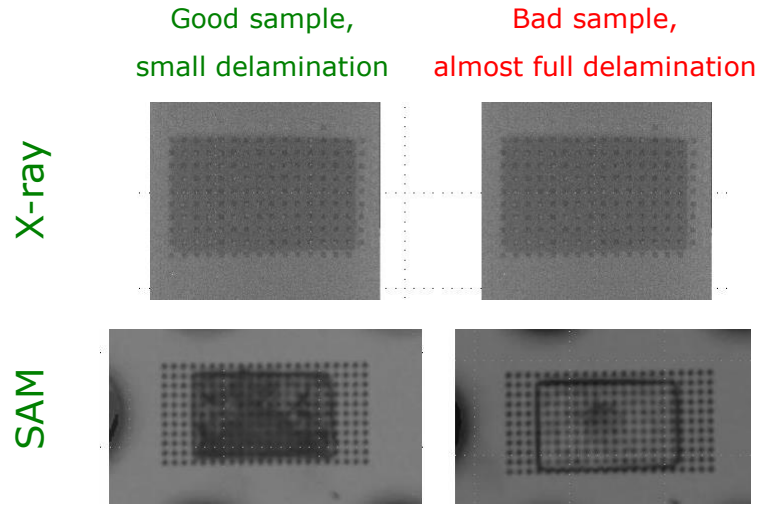
X-ray – acoustic imaging



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