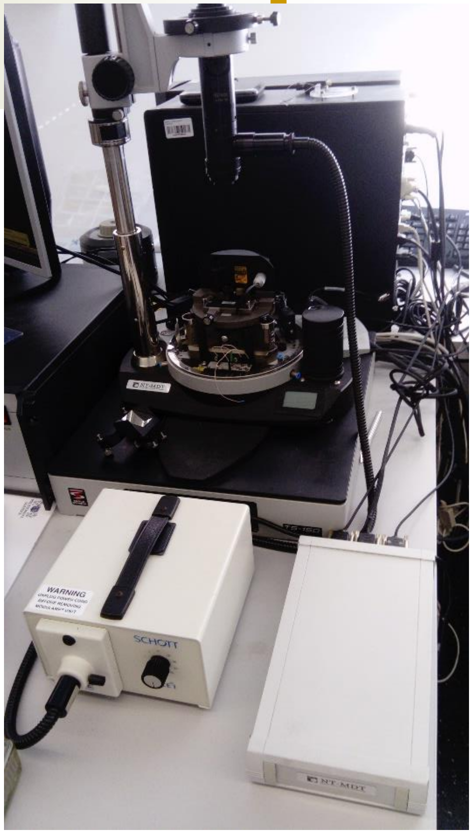
AFM beyond topography

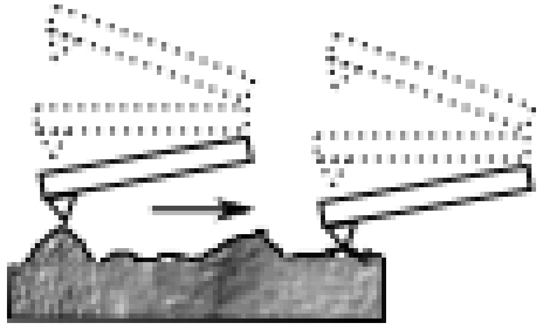


Introduction

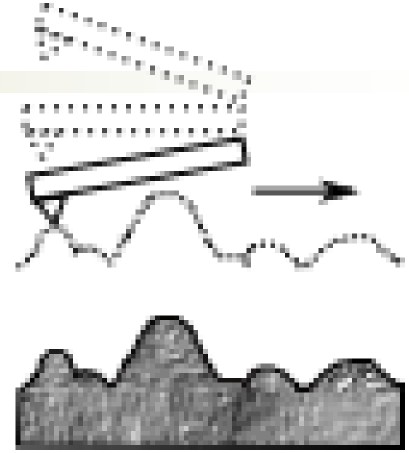
The interaction between the AFM probe tip and the surface may include additional electric, magnetic, indentation, adhesive, and capillary forces. Some of them are the basis for measuring modes that extend the applicability of atomic force microscopy. This presentation presents selected methods of AFM work divided by the way the measurement is performed.

Measurement modes

Contact



Vibrating mode



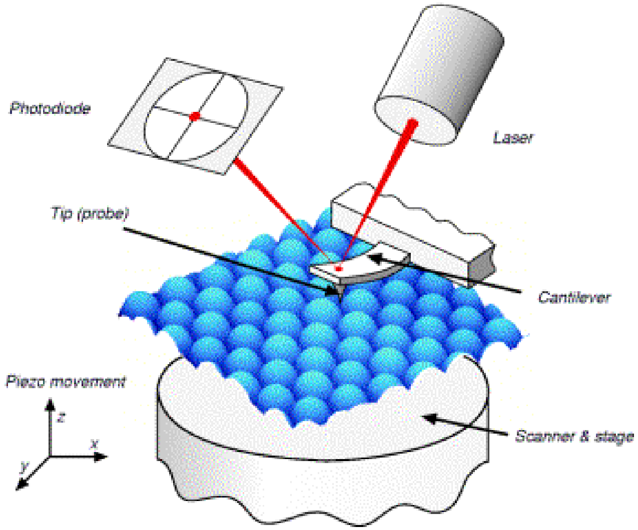
Many pass

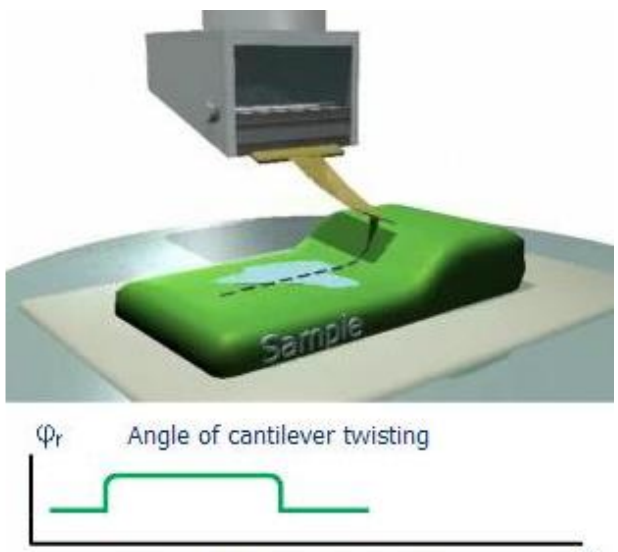
- **LFM**: lateral forces microscopy
- **SSRM**: scanning spreading resistance microscopy
- **SThM**: scanning thermal microscopy

- **FMM**: force modulation microscopy
- **AFAM**: atomic force acoustic microscopy

- **MFM**: magnetic force microscopy
- **EFM**: electric force microscopy
- **SKM:** scanning Kelvin microscopy
- **SCM:** scanning capacitance microscopy

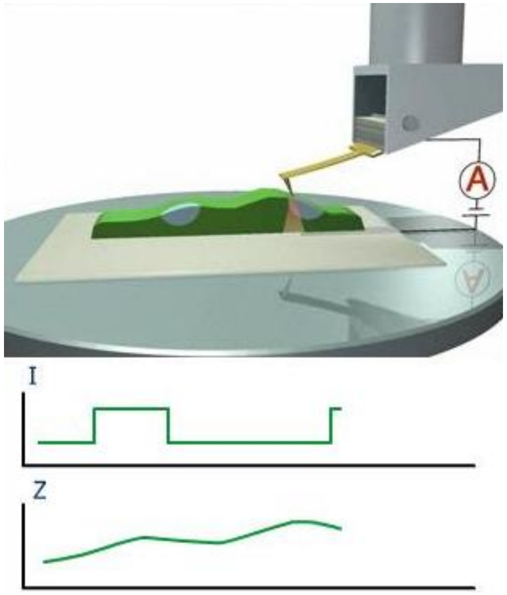
Lateral forces imaging

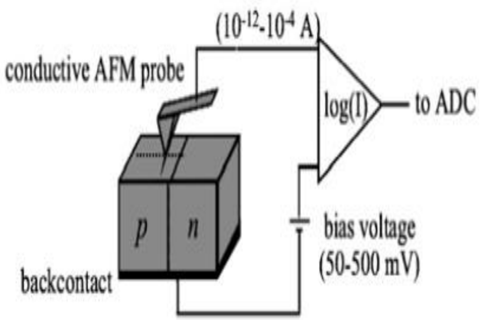


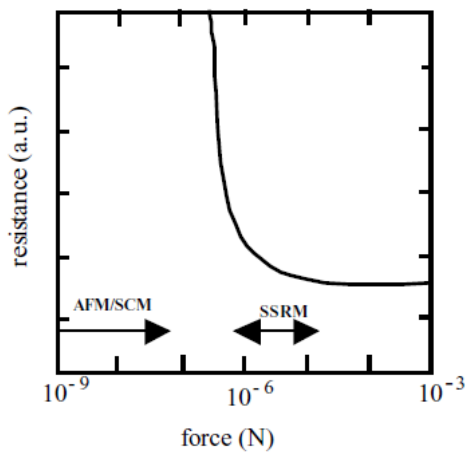


- The lateral force technique allows you to visualize the differences in friction force on the sample surface.
- During constant-force scanning, in addition to the bending force acting in the "z" direction, the friction forces in the "x" and "y" directions also affect the lever. The torsion angle of the lever is proportional to these forces. It is measured by the differential signal between the left and right quadrant photodiodes.

Spreading resistance imaging

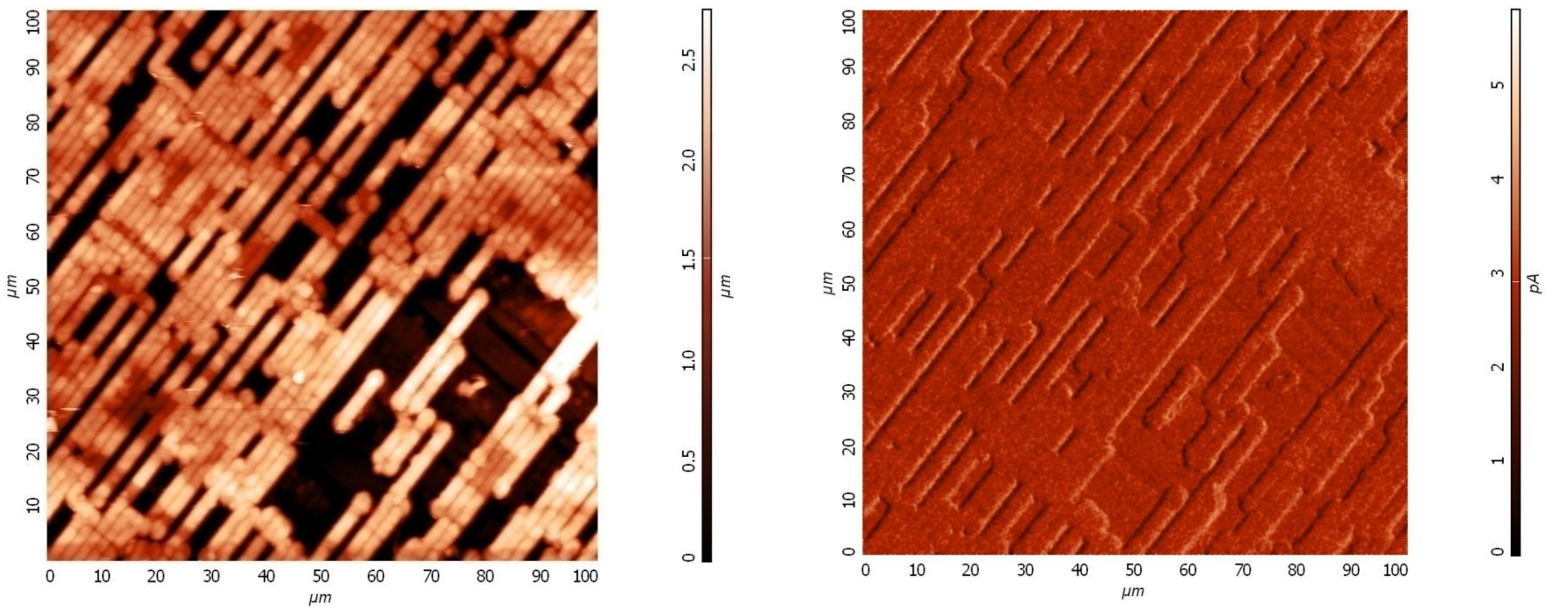






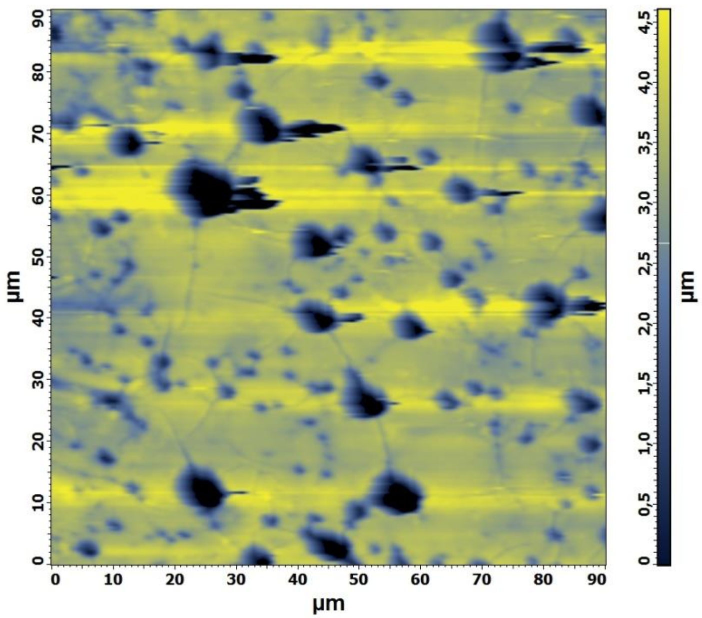
- Use of a conductive probe allows to measure the local electrical conductivity of a sample called "spreading resistance".
- When a constant voltage to the sample/tip junction is applied, assuming a constant contact force, the current flow determines local resistance of a small volume of material in the vicinity of the tip.

Spreading resistance imaging

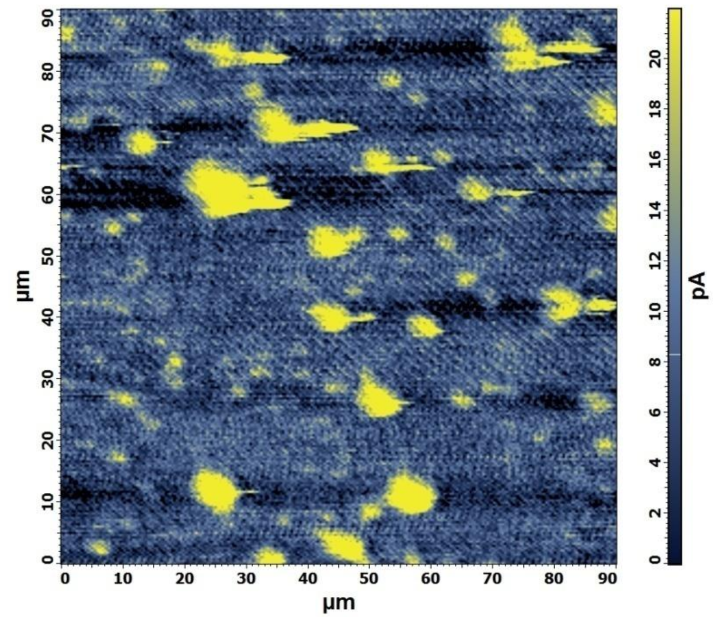


- Use of the spreading resistance measurement technique to study the conductivity distribution (right) on the surface of the integrated circuit (left).

Alternating current imaging

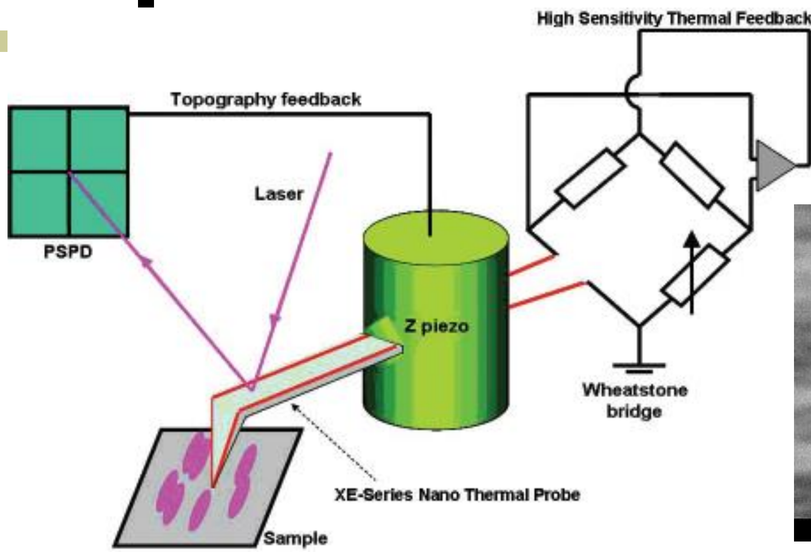


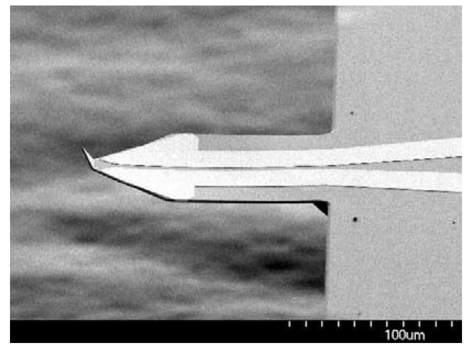
- Acrylic coating destroyed by exposure to 3% NaCl solution for 3 months.

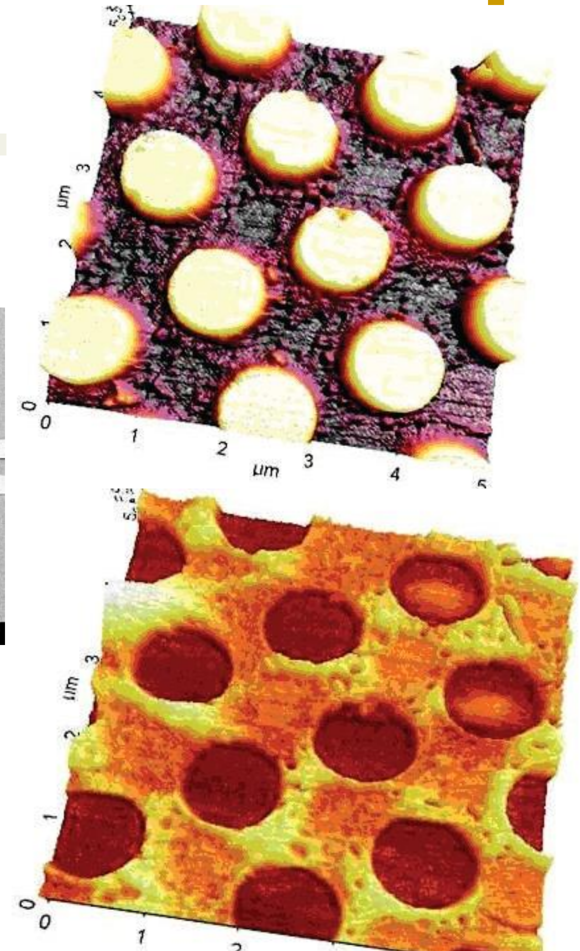


- Image of 3 kHz current magnitude for the same area.

Scanning thermal microscopy



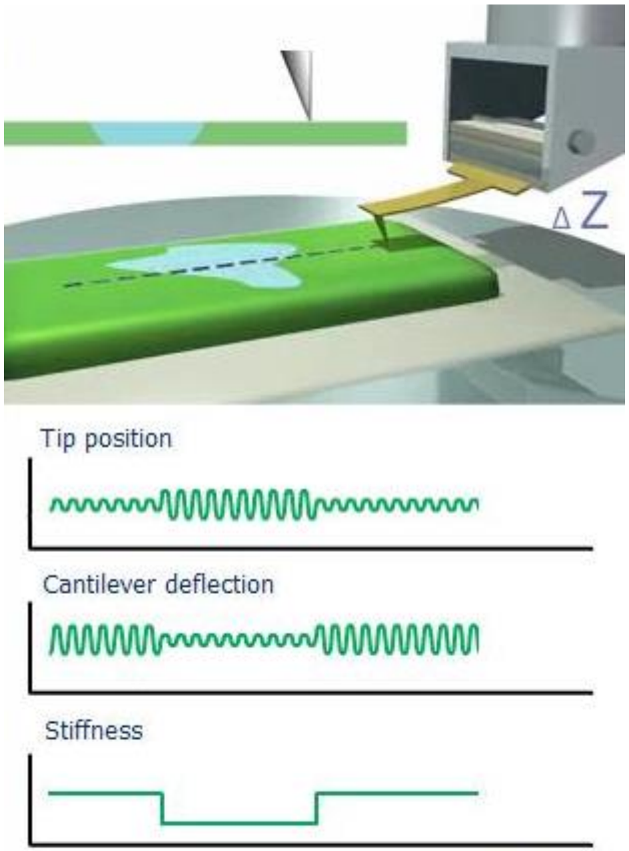




- Diagram of operation of the microscope in thermal measurement mode. The V-shaped probe contains a thermistor and is part of the Wheatstone bridge, allowing local measurement of the temperature.

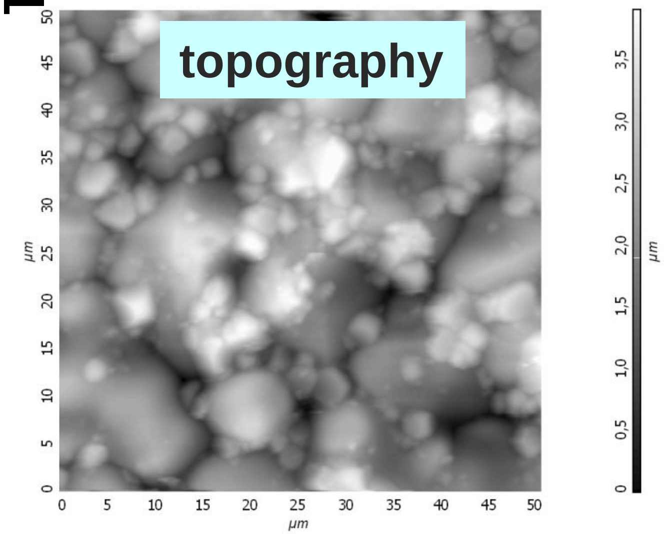
- Image topography (top) and thermal conductivity (bottom) of sample in the form of polymer inclusions in silicone substrate

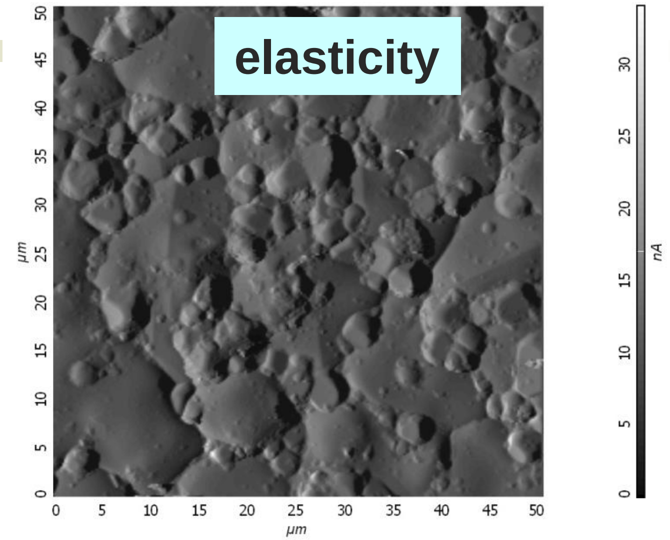
Force modulation

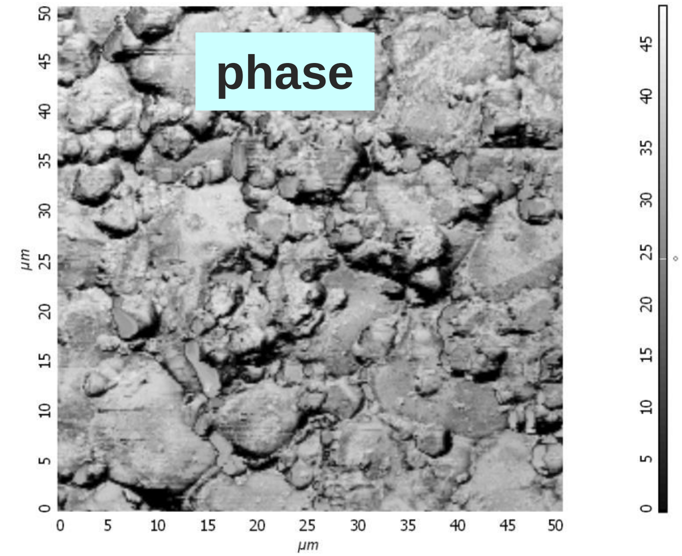


- In force modulation mode, the scanner performs periodic oscillations during constant-force scan. As a result, the free end of the lever makes an indentation of the surface of the sample. In areas with high hardness, the recess is negligible and the deflection of the levers is large. In regions with low hardness, the degree of indentation is higher.
- Modulation measurement allows to determine local changes in sample hardness.

Force modulation



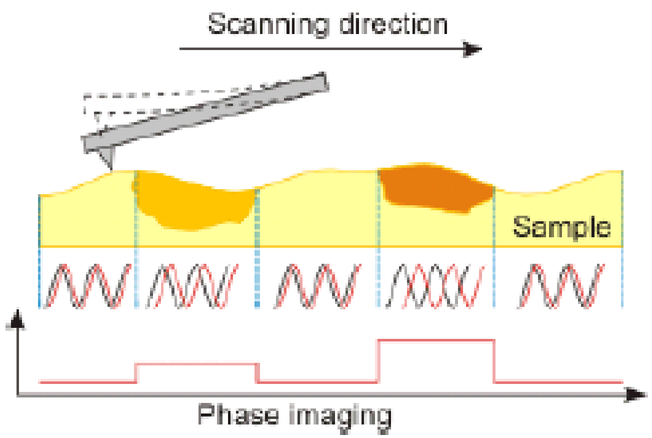




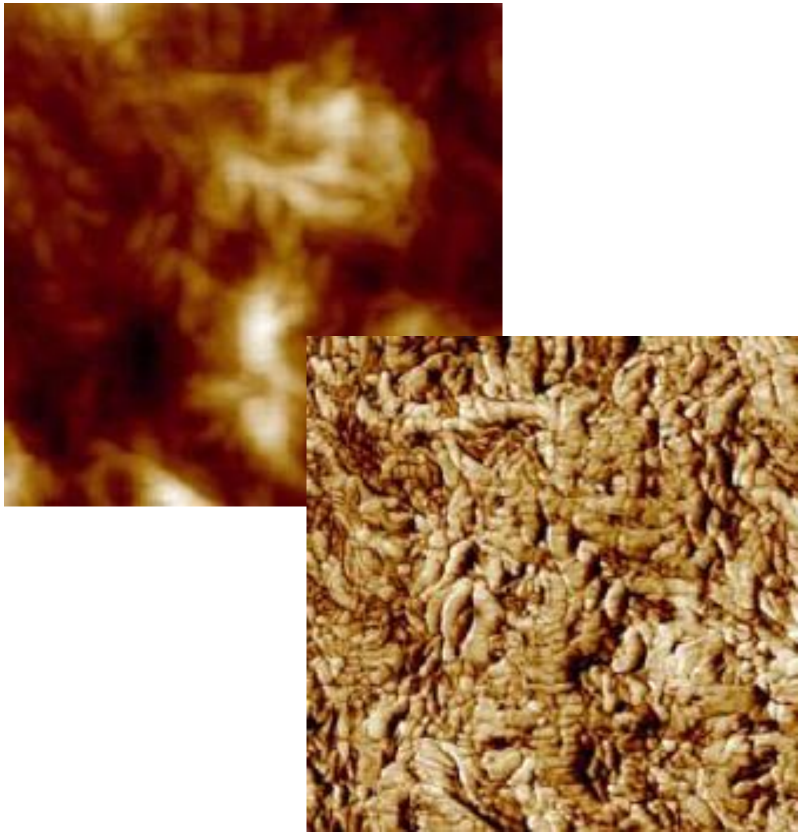
- Example of stiffness distribution of semiconductor material. The quality of the varistor produced from the presented plates is dependent on their granularity and hardness of the interstitial boundaries.

Phase imaging

- This mode is usually performed concurrently with topographic imaging. It allows you to map surface properties such as friction, elasticity or adhesion.

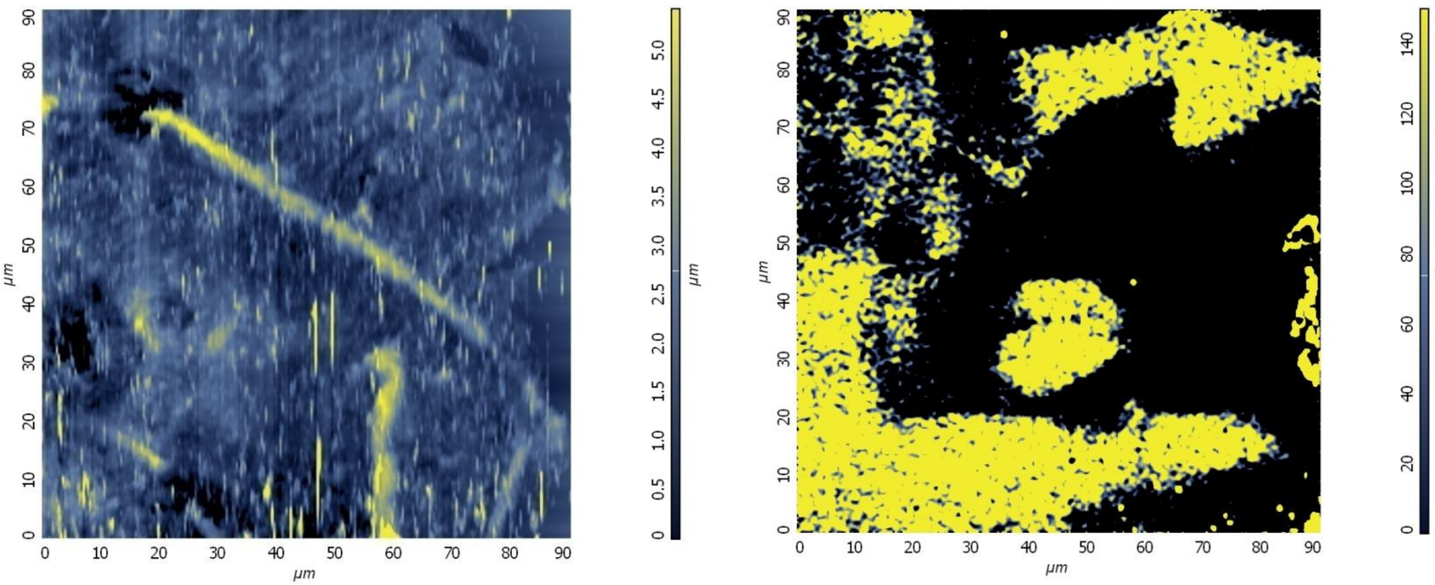


- Scheme of the measurement



- Topographic and phase image of polyethylene sample

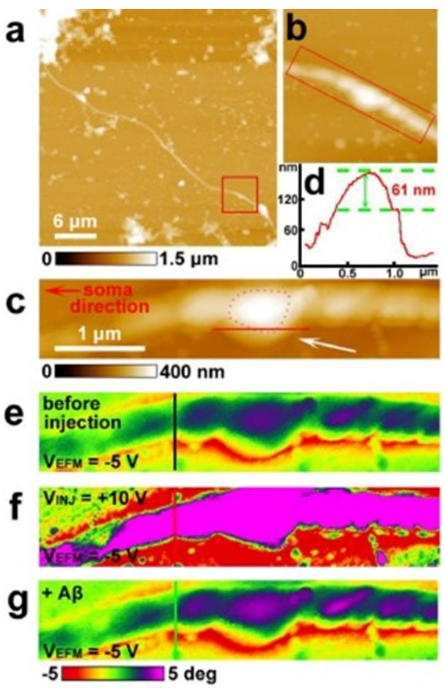
AFAM



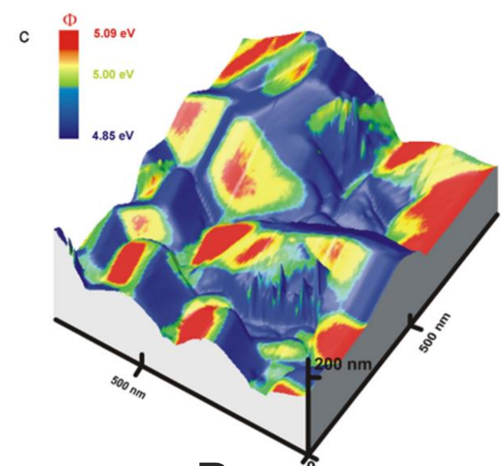
- The Atomic Force Acoustic Microscopy technique involves vibrating the sample under test. The vibrations are transferred to the tip and the cantilever in contact with the sample. Based on the vibration analysis, it is possible to differentiate areas with different mechanical properties as well as local hardness determination with submicron resolution.

Electrostatic force microscopy

- The EFM technique allows mapping of the spatial distribution of the electric field intensity vector. Between the conductive probe and the surface of the sample the voltage is applied producing the electric field.
- The measurement is performed in two passes. The topography is determined in the first one. The second scan is carried out along the route providing a constant distance between the sample and the probe. The distance in the second run must be sufficiently large to eliminate van der Waals short-range forces and leave only long distance electrical interference.



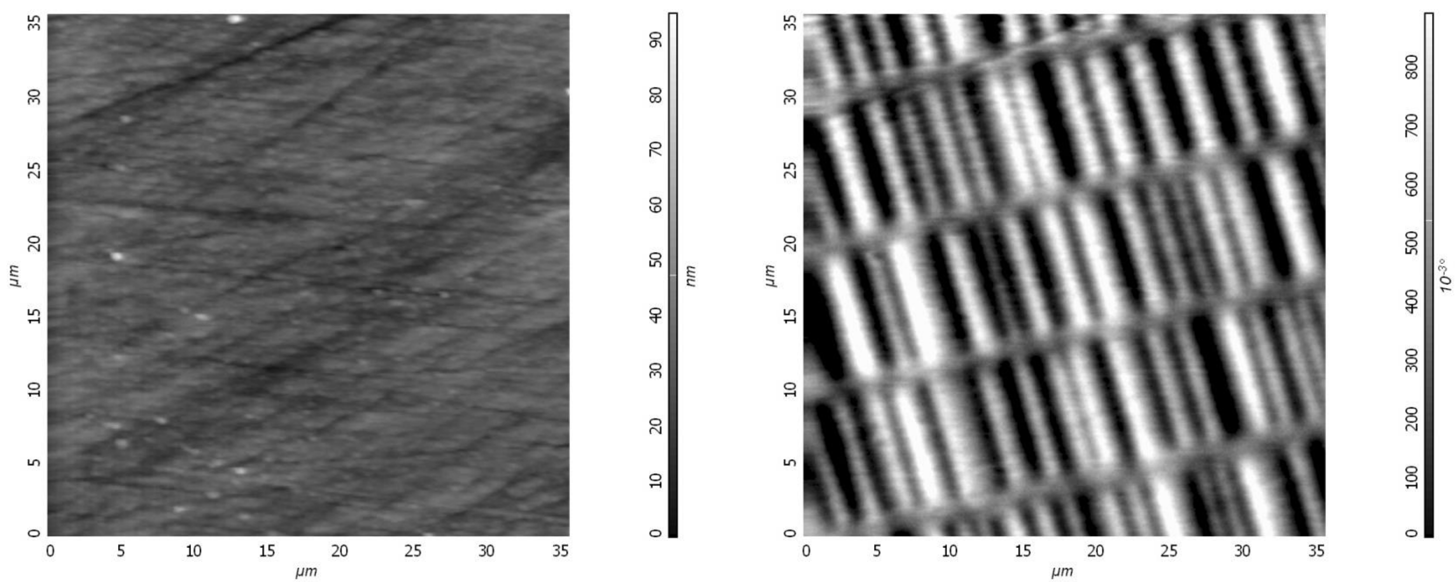
- W. Zhao, W. Cui, S. Xu, Y. Wang K. Zhang D. Wang, L-Z. Cheong F. Besenbacher, C. Shen, Ultramicroscopy, 196 (2019) 24.



- T. Glatzel, H. Steigert, S. Sadewasser, R. Klenk, M.C. Lux-Steiner, Thin Solid Films 480 (2005) 177.

Magnetic force microscopy

- The MFM technique allows mapping of the spatial distribution of the magnetic field strength vector. The probe tip is covered with a layer of ferromagnetic material. Magnetic force imaging can be performed in both vibration and non-contact mode.



- Topographical and magnetic scan of hard disk surface

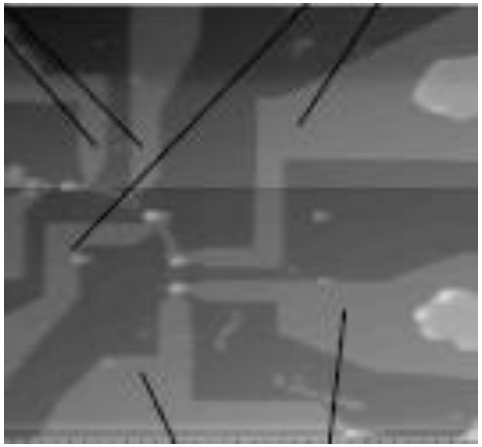
Scanning Kelvin probe microscopy

- SKM is used to map the surface potential of sample $\Phi(x)$. It is based on the use of two passes. The first is the topographic one. During the second scan the potential is applied to the tip:

$$V_{tip} = V_{dc} + V_{ac}\sin(\omega t)$$

- The resultant force is:

$$F_{cap} = \frac{1}{2}\left(V_{tip} - \Phi(x)\right)^2 \frac{dC}{dz}$$

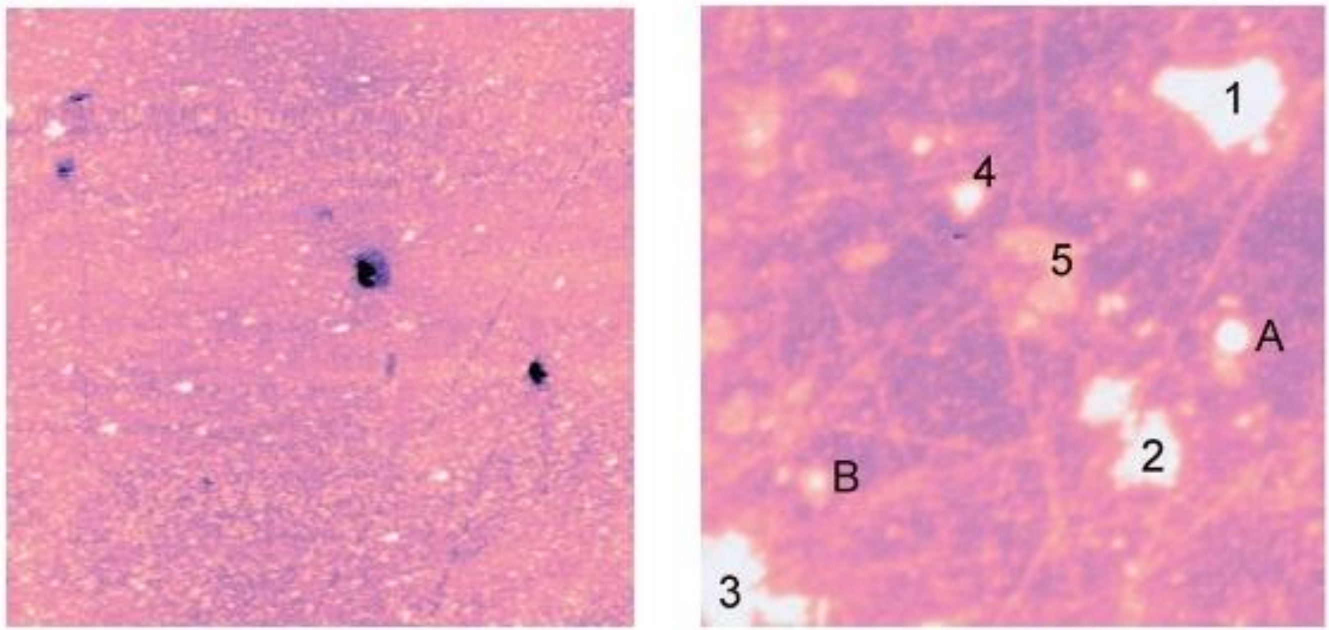


- The first harmonic force causes the lever oscillations:

$$F_{cap,1\omega} = \frac{dC}{dz}\left(V_{dc} - \Phi(x)\right)V_{ac}\sin(\omega t)$$

- Feedback feedback changes the V_{dc} value causing attenuation of oscillations. In such a situation $V_{dc} = \Phi(x)$ so that the constant potential map reflects the distribution of surface potential.

Metallographic investigations



- Image of the surface of the alloy sample AA2024-T3 (left) and distribution of surface potential (right image). The potential value of the Al-Cu-Mg intermetallic phase is unknown, although its presence is not detected in the topographic image.

Scanning capacitance microscopy

- The technique is based on the use of two passes the same as in SKPM. Polarization of the the tip with the potential in the form:

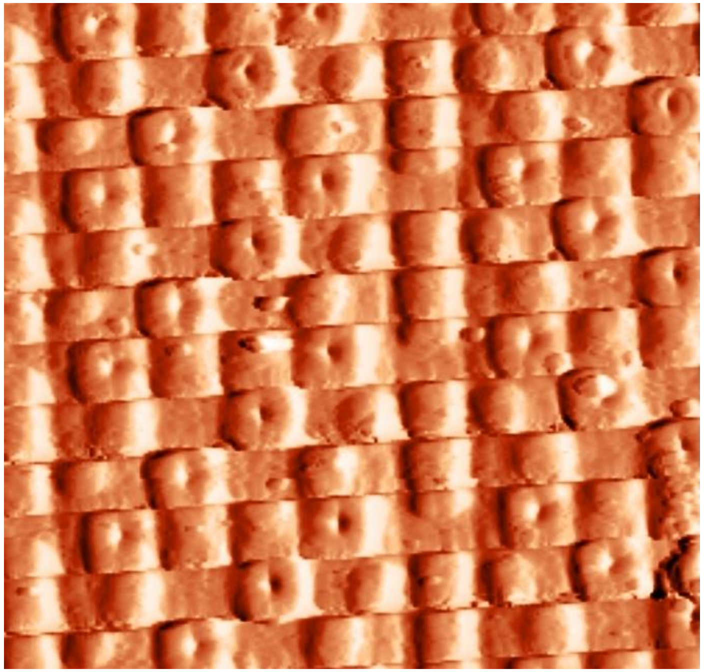
$$V_{tip} = V_{dc} + V_{ac}\sin(\omega t)$$

- Creates a capacitive force:

$$F_{cap} = \frac{1}{2}\left(V_{tip} - \Phi(x)\right)^2 \frac{dC}{dz}$$

- The second harmonic of the force can be used to determine the capacitive contrast *dC/dz*

$$F_{cap,2\omega} = \frac{1}{2}\frac{dC}{dz}V_{ac}^2\sin(2\omega t)$$



Further information

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