

Mikroskopia sił atomowych

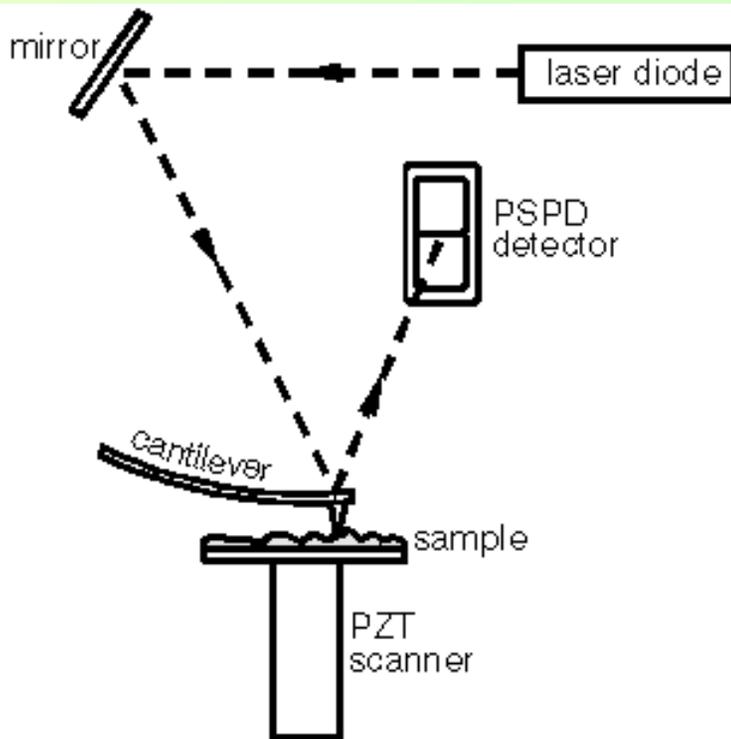
Atomic Force Microscope AFM

- Zasada działania
- Historia 'odkryć'
- Zastosowane rozwiązania
- Przykłady zastosowań

Bolesław AUGUSTYNIAK

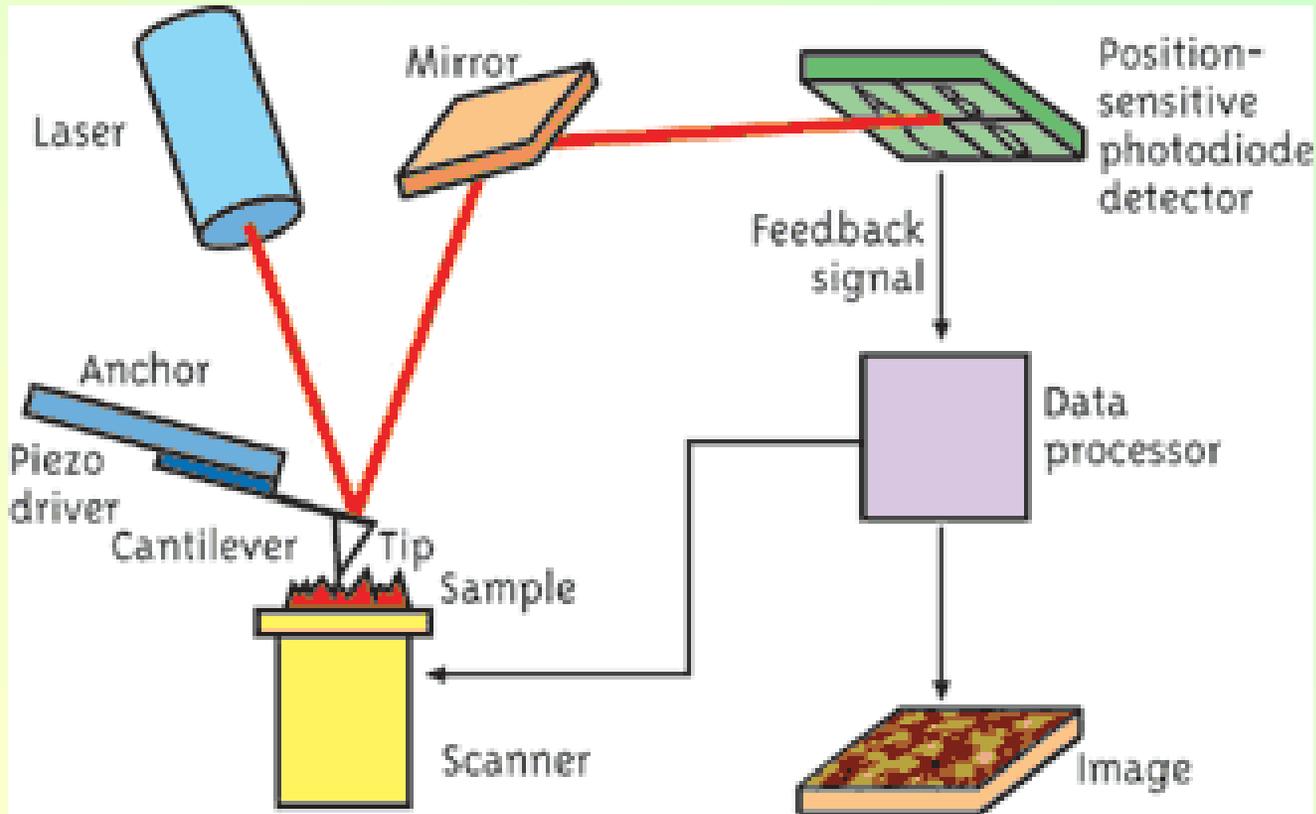
Zasada działania

http://www.inmat.pw.edu.pl/zaklady/zpim/Mikroskopy_STM_AFM.pdf



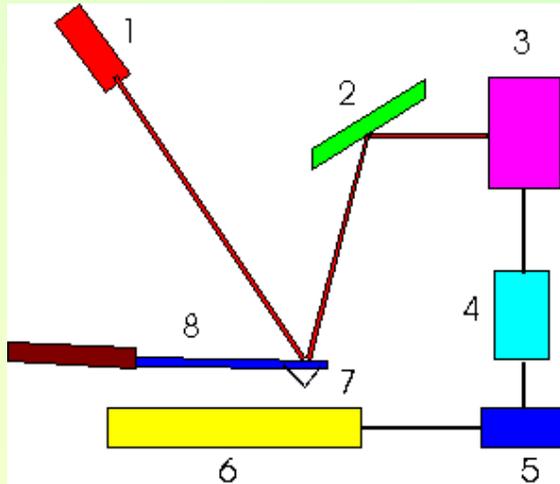
Mikroskop sił atomowych (AFM) bada powierzchnię próbki zaostrzoną sondą. Długość tej sondy jest rzędu kilku mikrometrów, zaś średnica końcówki mniejsza od 10 nm. Sonda umieszczona jest na swobodnym końcu dźwigienki. Długość dźwigienki waha się od 100 do 200 mikrometrów. Siła, jaka występuje pomiędzy igłą sondy a powierzchnią próbki, powoduje skrócenie lub ugięcie dźwigienki. Czuły detektor mierzy wychylenie dźwigienki, podczas gdy sonda przemieszcza się nad powierzchnią próbki, lub próbka przemieszcza się pod sondą ruchem skanującym. Pomiar wychylenia dźwigienki pozwala na utworzenie przez komputer topograficznej mapy powierzchni próbki. AFM może być stosowany do badania zarówno izolatorów jak półprzewodników, czy przewodników.

AFM – zasada działania 2



The basic AFM setup relies on a scanning tip and a detector. The tip, attached to the end of a cantilever, scans across the sample surface. A laser beam reflects from the top surface of the cantilever and is detected by a position-sensitive photodiode detector.

AFM - Zasada działania



1. Laser
2. Mirror
3. Photodetector
4. Amplifier
5. Register
6. Sample
7. Probe
8. Cantilever

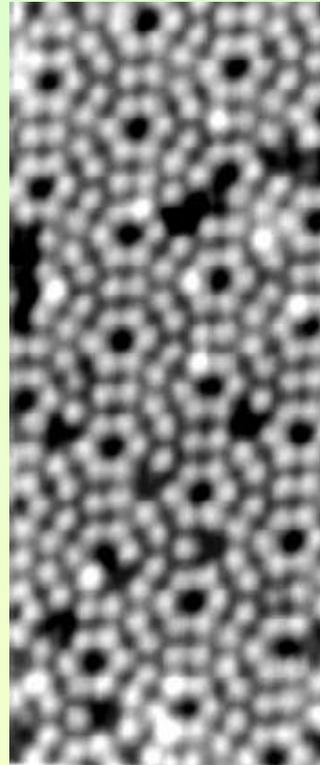
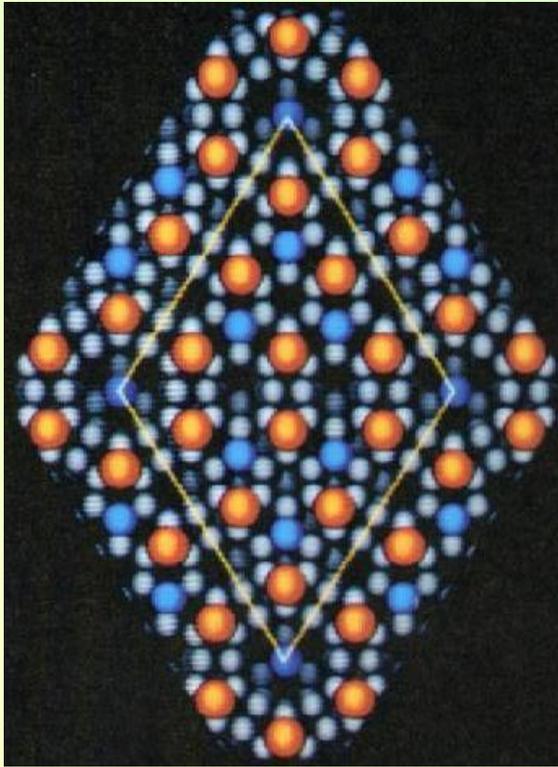
The force between the tip (7) and the sample surface is very small, usually less than 10^{-9} N. How to monitor such small forces is another story. The detection system does not measure force directly. It senses the deflection of the microcantilever (8). The detecting systems for monitoring the deflection fall into several categories. The interferometer is the most sensitive of the optical methods, but it is somewhat more complicated than the beam-bounce method which was introduced by Meyer and Amer. The beam-bounce method is now widely used as a result of the excellent work by Alexander and colleagues. In this system an optical beam is reflected from the mirrored surface on the back side of the cantilever onto a position-sensitive photodetector (3). In this arrangement a small deflection of the cantilever will tilt the reflected beam and change the position of beam on the photodetector. A third optical system introduced by Sarid uses the cantilever as one of the mirrors in the cavity of a diode laser. Motion of the cantilever has a strong effect on the laser output, and this is exploited as a motion detector

Historia odkrycia AFM

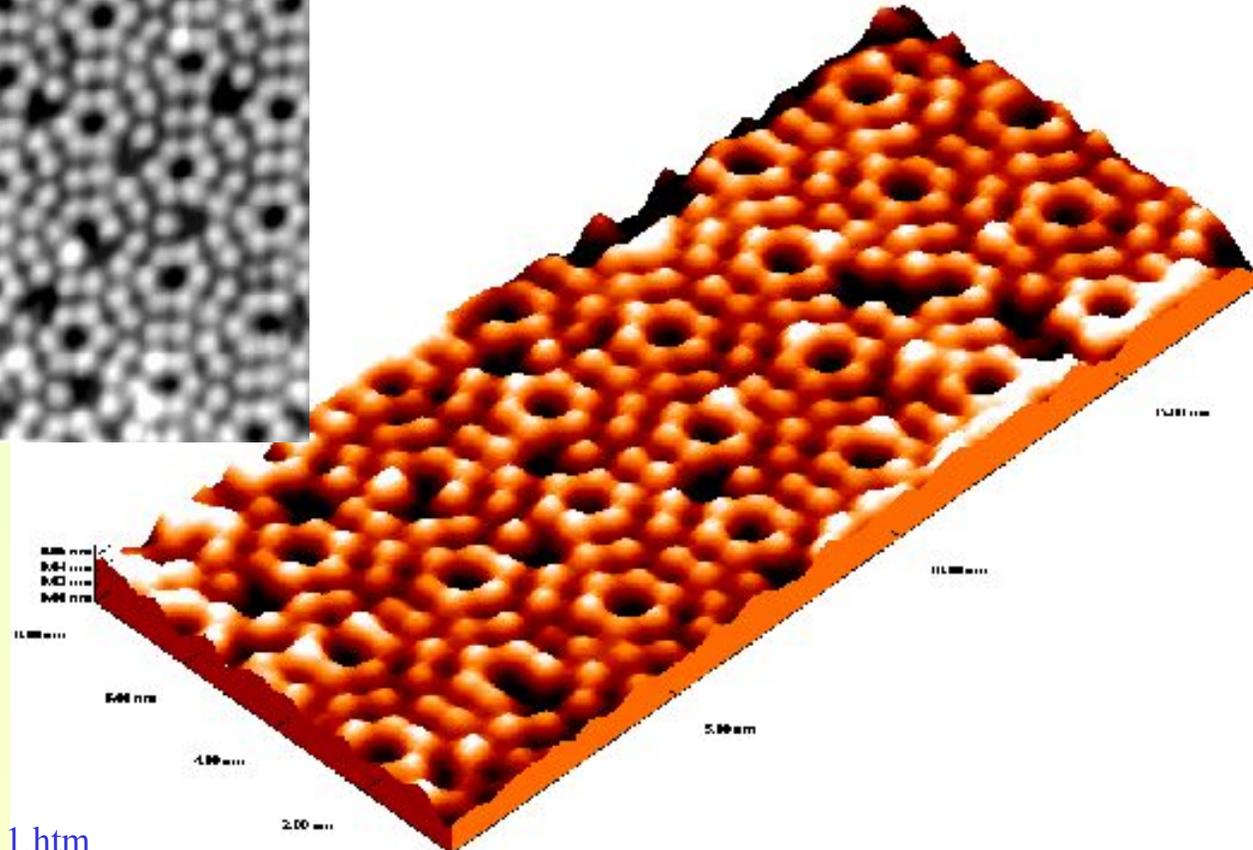
The first AFM was made by meticulously gluing a tiny shard of diamond onto one end of a tiny strip of gold foil. In the fall of 1985 Gerd Binnig and Christoph Gerber used the cantilever to examine insulating surfaces. A small hook at the end of the cantilever was pressed against the surface while the sample was scanned beneath the tip. The force between tip and sample was measured by tracking the deflection of the cantilever. This was done by monitoring the tunneling current to a second tip positioned above the cantilever. They could delineate lateral features as small as 300 Å. The force microscope emerged in this way. In fact, without the breakthrough in tip manufacture, the AFM probably would have remained a curiosity in many research groups. It was Albrecht, a fresh graduate student, who fabricated the first silicon microcantilever and measured the atomic structure of boron nitride. Today the tip-cantilever assembly typically is microfabricated from Si or Si₃N₄.

<http://www.chembio.uoguelph.ca/educmat/chm729/afm/introdn.htm>

Pierwszy obraz z AFM



The era of AFM came finally when the Zurich group released the image of a silicon (111) 7X7 pattern. When (111) surface of **Silicon** is heated to sufficiently high temperature under the Ultra-High Vacuum conditions the surface atoms rearrange for a more energetically stable configuration called **7x7 reconstruction**.



Nobel 1986

in Physics for work in scanning tunneling microscopy

G. Binnig was born in Frankfurt, Germany, on July 20, 1947, Dr. Binnig was educated at J.W. Goethe University in Frankfurt, where he received his bachelor's degree in 1973 and his doctorate degree in 1978. That year he joined a physics research group at IBM's Zurich Research Laboratory. Dr. Binnig was assigned to IBM's Almaden Research Center in San Jose, Calif., from 1985 to 1986, and was a visiting professor at nearby Stanford University from 1987 to 1988. Dr. Binnig was appointed an IBM Fellow in 1987 and remains a research staff member at IBM's Zurich Research Laboratory.

H. Rohrer was born in Buchs, Switzerland, on June 6, 1933, Dr. Rohrer was educated at the Swiss Federal Institute of Technology in Zurich, where he received his bachelor's degree in 1955 and his doctorate degree in 1960. After post-doctoral work at the Swiss Federal Institute and Rutgers University in the United States, Dr. Rohrer joined IBM's newly formed Zurich Research Laboratory, studying, among other things, Kondo materials and antiferromagnets before turning his attention to scanning tunneling microscopy. Dr. Rohrer was appointed an IBM Fellow in 1986, and was manager of the physical sciences department at the Zurich Research Laboratory from 1986 to 1988. He retired from IBM in July 1997

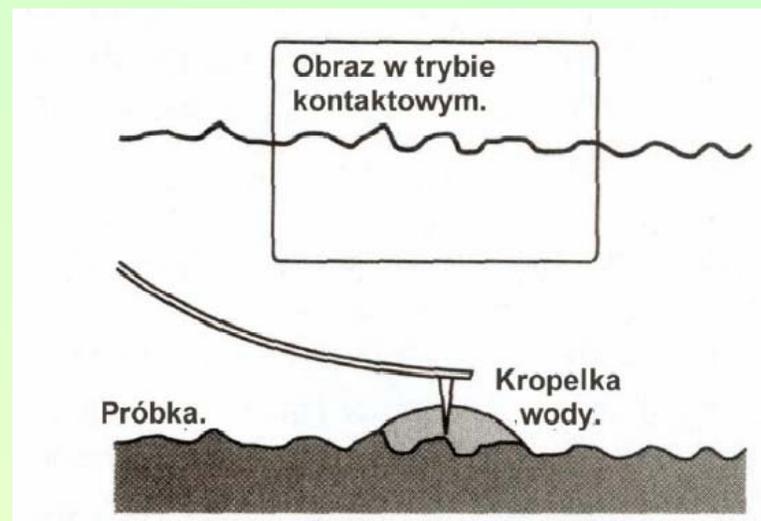
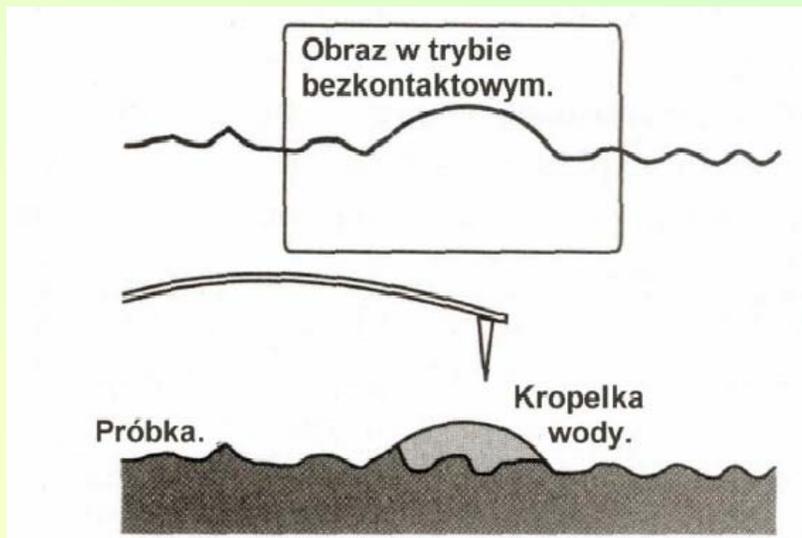


Gerd Binnig

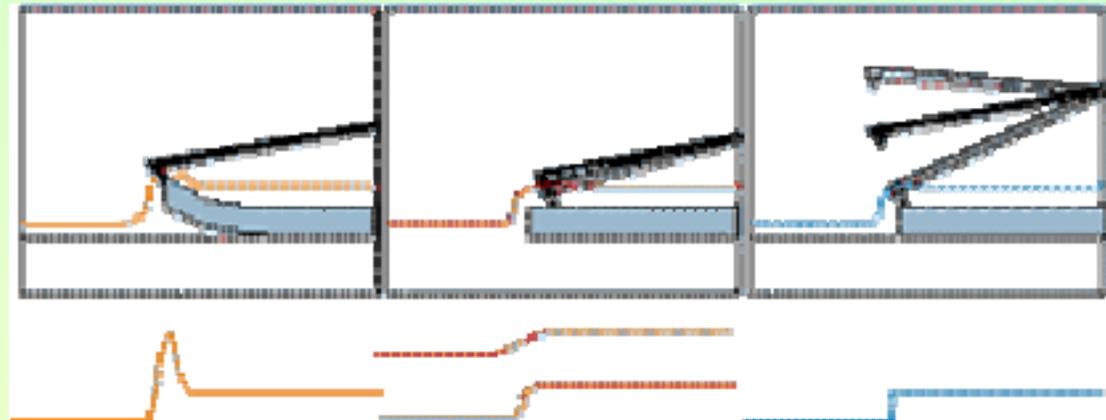


Heinrich Rohrer,

Zasadnicze mody pracy AFM



3 Modes Practical AFM



Contact

Non-contact

Tapping Mode

In contact AFM electrostatic and/or surface tension forces from the adsorbed gas layer pull the scanning tip toward the surface. It can damage samples and distort image data. Therefore, contact mode imaging is heavily influenced by frictional and adhesive forces compared to non-contact or tapping mode.

Non-contact imaging generally provides low resolution and can also be hampered by the contaminant layer which can interfere with oscillation.

Tapping Mode AFM was developed as a method to achieve high resolution without inducing destructive frictional forces both in air and fluid. With the TappingMode technique, the very soft and fragile samples can be imaged successfully. Also, incorporated with *Phase Imaging*, the tapping mode AFM can be used to analyze the components of the membrane.

Phase imaging

Phase Imaging is a powerful extension of Tapping Mode Atomic Force Microscopy (AFM) that provides nanometer-scale information about surface structure often not revealed by other SPM techniques. By mapping the phase of the cantilever oscillation during the TappingMode scan, phase imaging goes beyond simple topographical mapping to detect variations in composition, adhesion, friction, viscoelasticity, and perhaps other properties.

In TappingMode AFM, the cantilever is excited into resonance oscillation with a piezoelectric driver. The oscillation amplitude is used as a feedback signal to measure topographic variations of the sample. In phase imaging, the phase lag of the cantilever oscillation, relative to the signal sent to the cantilever's piezo driver, is simultaneously monitored by the Extender Electronics Module and recorded by the NanoScope III SPM controller. The phase lag is very sensitive to variations in material properties such as adhesion and viscoelasticity.

AFM - siły oddziaływania



Do zmiany położenia dźwigienki przyczyniają się oddziaływania kilku rodzajów. Oddziaływaniami, które są najbardziej reprezentatywne dla AFM, są międzyatomowe siły zwane siłami van der Waals'a. Zależność sił van der Waals'a od odległości pomiędzy powierzchnią badanego materiału a ostrzem sondy przedstawia rysunek 1.4.

Na rysunku 1.4 widoczne są dwa tryby pracy AFM, zależne od odległości między próbką a sondą: 1) - tryb kontaktowy (Contact Regime: CR), 2) - tryb bezkontaktowy (Non-Contact Regime: NCR). W przypadku CR dźwigienka jest utrzymywana w odległości mniejszej niż kilka dziesiątych nanometra od powierzchni próbki, zaś siły, jakie występują, są siłami odpychania.

Ad 'tapping mode'

W trybie NCR, system wprowadza dźwigienkę w drgania bliskie jej częstotliwości rezonansowej (na ogół 100-400 kHz), o amplitudzie od kilku do kilkadziesiąt nanometrów. Następnie, kiedy sonda zbliża się do powierzchni badanego materiału, system mierzy zmiany w częstotliwości rezonansowej lub amplitudzie drgań dźwigienki. Czulość tego układu detekcji ma podobną rozdzielczość pionową obrazu jak w trybie kontaktowym AFM.

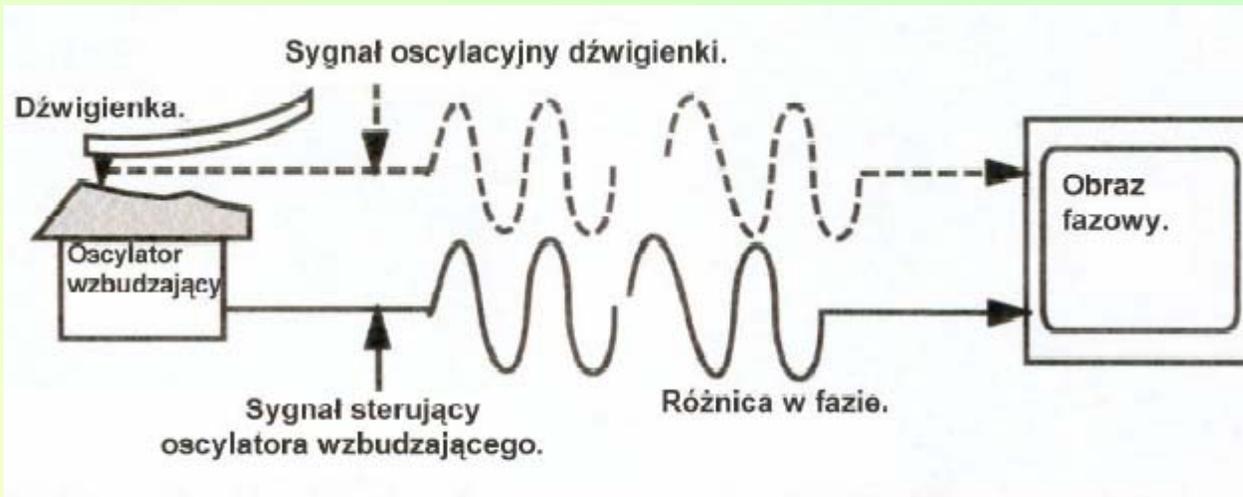
Związek pomiędzy częstotliwością rezonansową dźwigienki a zmianami w topografii próbki może być wyjaśniony w następujący sposób. Częstotliwość rezonansowa dźwigienki zmienia się jak pierwiastek kwadratowy stałej sprężystości dźwigienki. Dodatkowo, stała sprężystości zmienia się wraz z gradientem sił doświadczanym przez dźwigienkę. Ostatecznie gradient sił, który jest pochodną siły w funkcji odległości pokazanej na rysunku 1.4, zmienia się wraz z odległością między sondą a powierzchnią badanego materiału. Tak więc zmiany w częstotliwości rezonansowej dźwigienki mogą być wykorzystane do pomiaru zmiany gradientu sił, które z kolei odpowiadają zmianom w odległości sonda - próbka. Zarejestrowane zmiany tej odległości pozwalają otrzymać mapę topografii badanej powierzchni.

AFM – z modulacją siły (FMM)

Mikroskop z modulacją siły (Force Modulation Microscopy: FMM) jest rozszerzeniem obrazu AFM, o charakterystykę właściwości mechanicznych próbki. Podobnie jak techniki LFM i MFM tak i mikroskop z modulacją siły pozwala na jednoczesne gromadzenie danych dotyczących topografii i właściwości powierzchni próbki.

W trybie FMM sonda AFM skanuje powierzchnię próbki pozostając z nią w kontakcie. System sprzężenia zwrotnego utrzymuje stałe, w pionowym kierunku, wychylenie dźwigienki (podobnie jak podczas trybu stałej siły w AFM). Dodatkowym czynnikiem jest periodyczny sygnał modulujący wychylenie, który jest przykładany do sondy lub do próbki. Amplituda modulacji dźwigienki będąca rezultatem przyłożonego sygnału zmienia się w zależności od lokalnych różnic we właściwościach sprężystych badanego materiału (rysunek 1.11)

AFM – FMM detekcja fazy



Opóźnienie fazowe zmienia się w zależności od lokalnych różnic w mechanicznych właściwościach powierzchni

Wykrywanie fazy polega na badaniu opóźnienia fazowego pomiędzy sygnałem który wprawia dźwigienkę w drgania, a sygnałem pochodzącym od dźwigienki (rysunek 1.13). Zmiana opóźnienia fazowego odpowiada zmianom we właściwościach mechanicznych powierzchni badanego materiału.

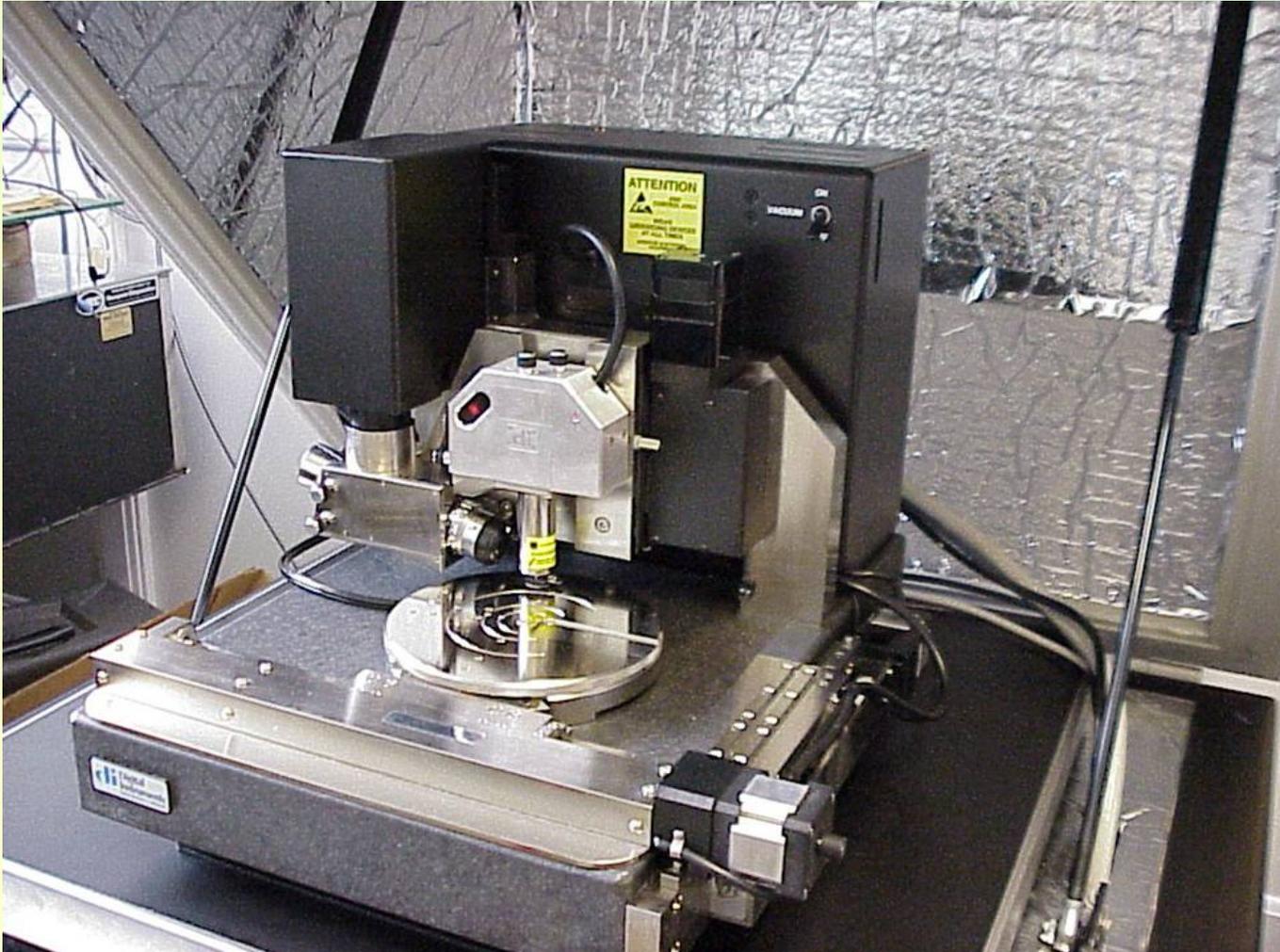
Aparatura



Integrated AFM imaging system. The AFM head is mounted on the optical microscope sitting on the concrete block with the bungee cords. The block is raised to the air for vibration isolation. The two PC's on the left are used for controlling the AFM, while the PC on the right is used for image processing.

<http://www.engineering.ucsb.edu/~ranawera/afm.html>

Aparatura



Released the first commercially available AFM in 1989.

<http://tools.ecn.purdue.edu/~afmlab/afmbasic.htm>

Jak to działa 1 ?

http://block.chem.rpi.edu/html/NSEC_HS/VAFM/



Jak to działa 2 ?

http://block.chem.rpi.edu/html/NSEC_HS/VAFM/



Jak to działa 3 ?

http://block.chem.rpi.edu/html/NSEC_HS/VAFM/

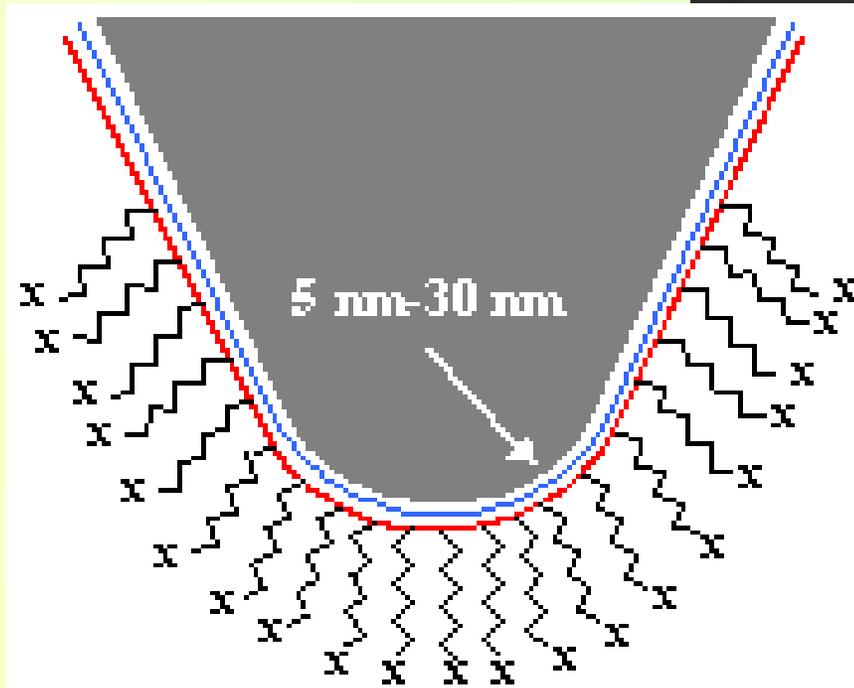
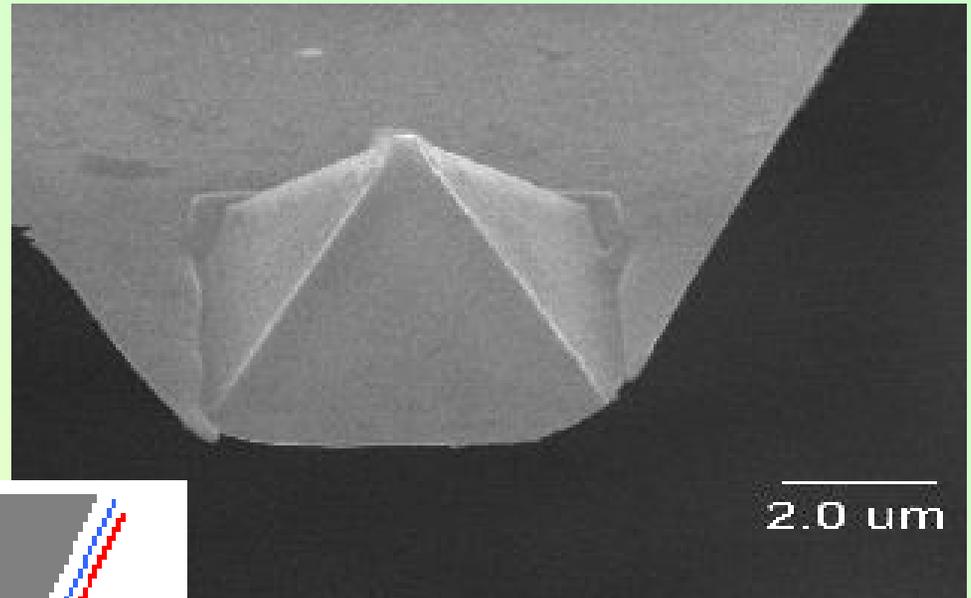


Jak to działa 4 ?

http://block.chem.rpi.edu/html/NSEC_HS/VAFM/

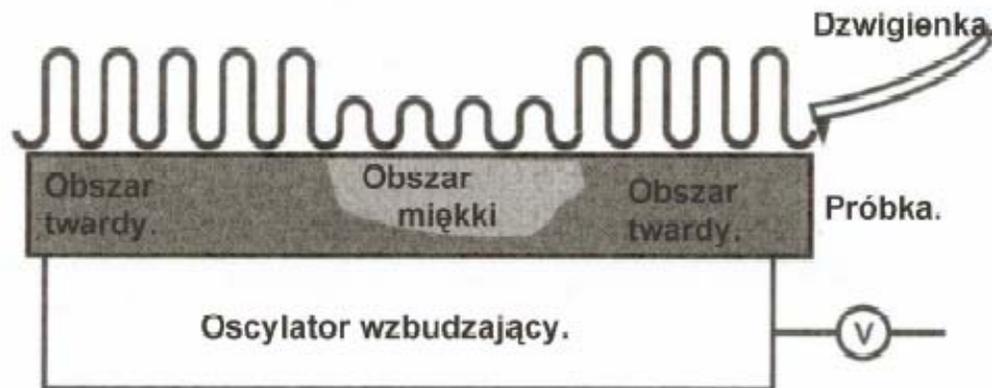


AFM - igła



The tip modification process includes the controlled deposition of very thin metallic films (normally a 5 nm thick chromium layer followed by a 50 nm thick gold layer) onto the probe followed by immersion of the probe in a solution of organic thiol.

AFM -FMM

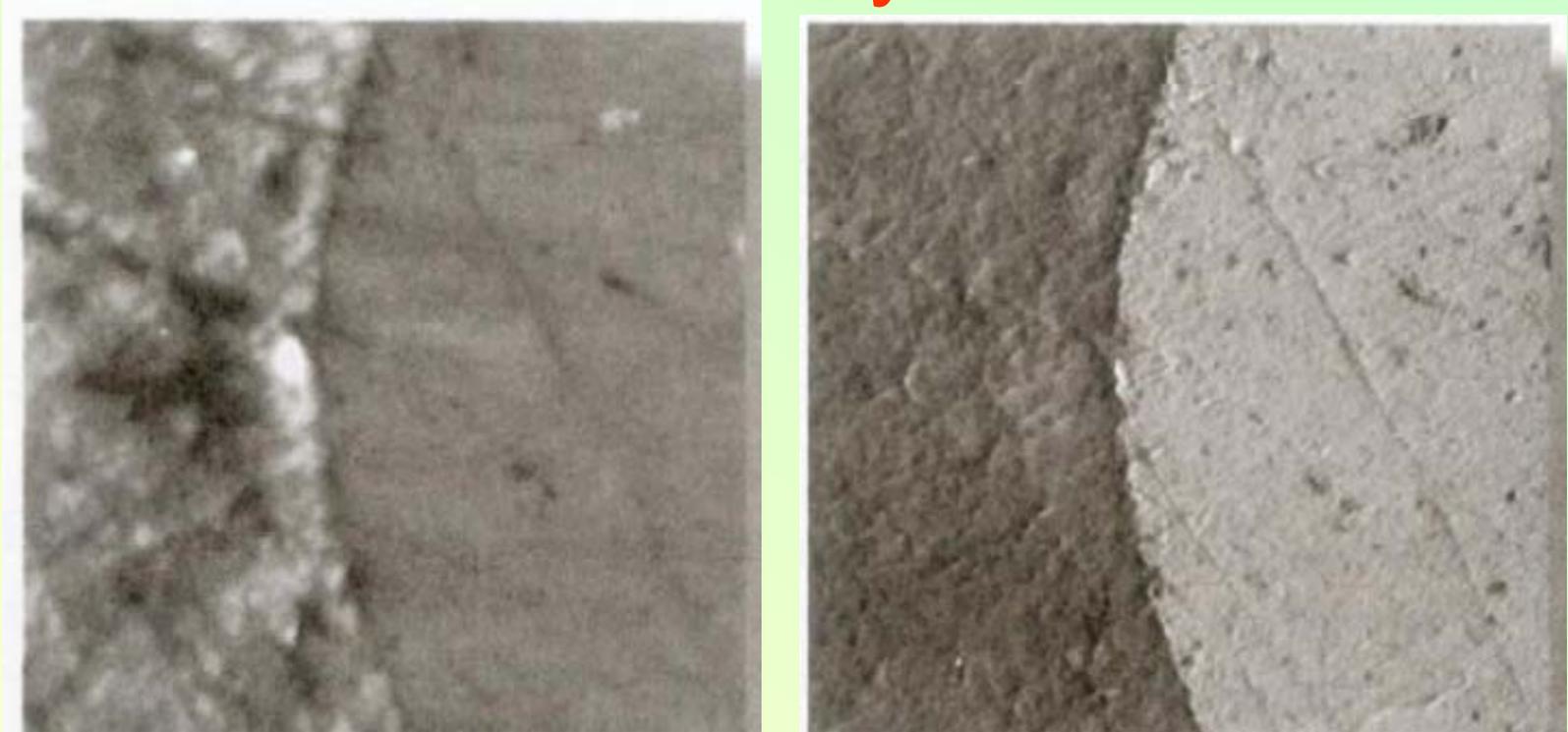


AFM
a
FMM

Rys.1.11 Amplituda drgań dźwigienki zmienia się w zależności od mechanicznych właściwości badanej powierzchni

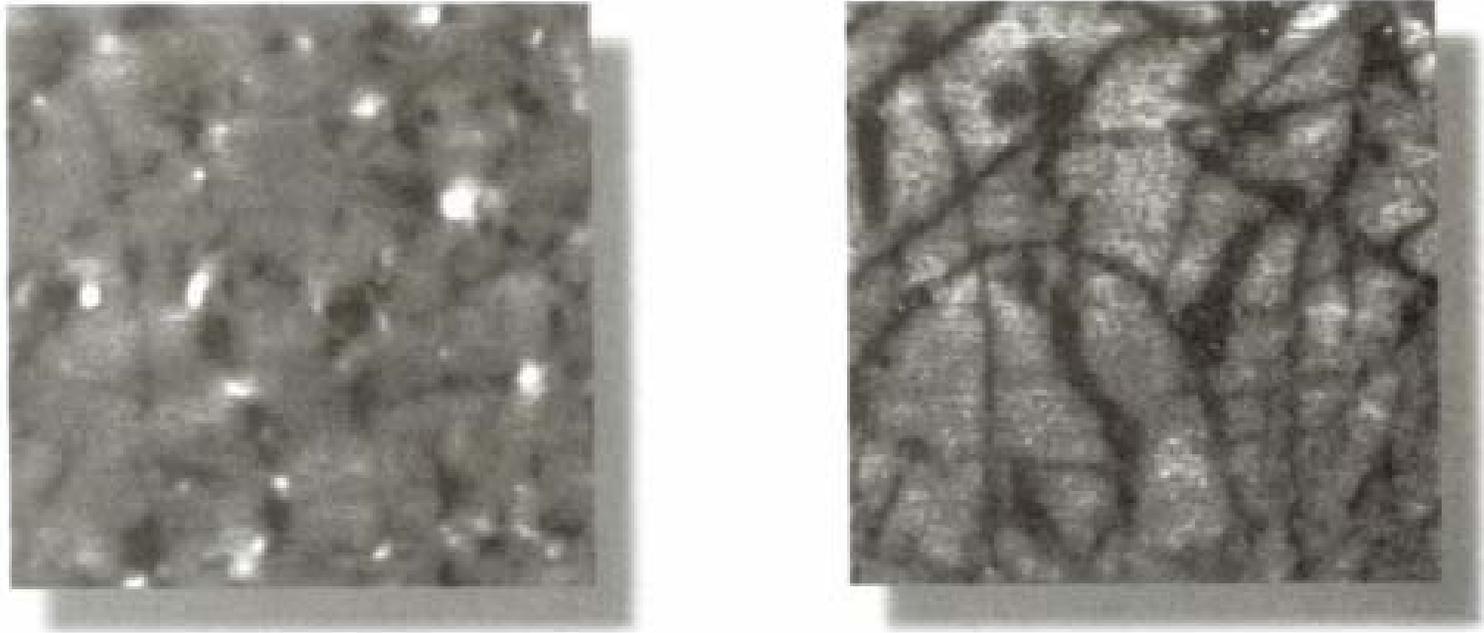
System mikroskopu tworzy obraz zmodulowanej siły z wykorzystaniem zmian w amplitudzie modulacji dźwigienki. Obraz ten jest mapą właściwości sprężystych próbki. Częstotliwość przyłożonego sygnału jest rzędu kilkuset kHz co czyni go szybszym od pętli sprzężenia zwrotnego, stosowanej do wywoływania zmian położenia skanera w pionie. Dzięki temu informacja o topografii próbki może być oddzielona od lokalnych zmian w elastycznych właściwościach próbki. Oba typy danych, dotyczących topografii i właściwości sprężystych, są gromadzone jednocześnie. Rysunek 1.12 pokazuje różnicę pomiędzy obrazem AFM a obrazem FMM powierzchni kompozytu z włóknami węglowymi.

AFM - FMM – przykład 1



Rys.1.12 Obrazy kompozytu polimerowego z włóknami węglowymi zbierane jednocześnie jako kontaktowy AFM (z lewej) i FMM (z prawej). Pole widzenia $5\ \mu\text{m} \times 5\ \mu\text{m}$

AFM - FMM – przykład 2



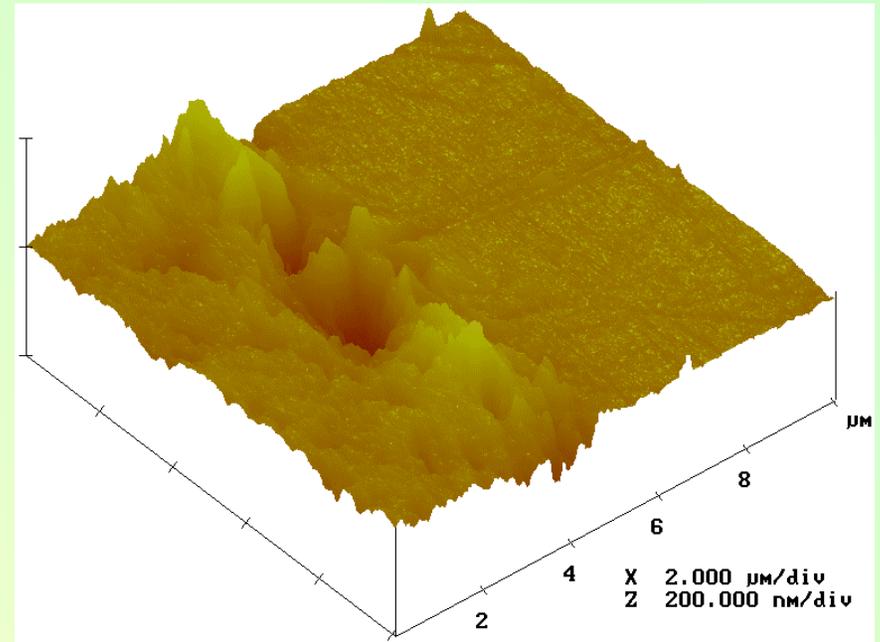
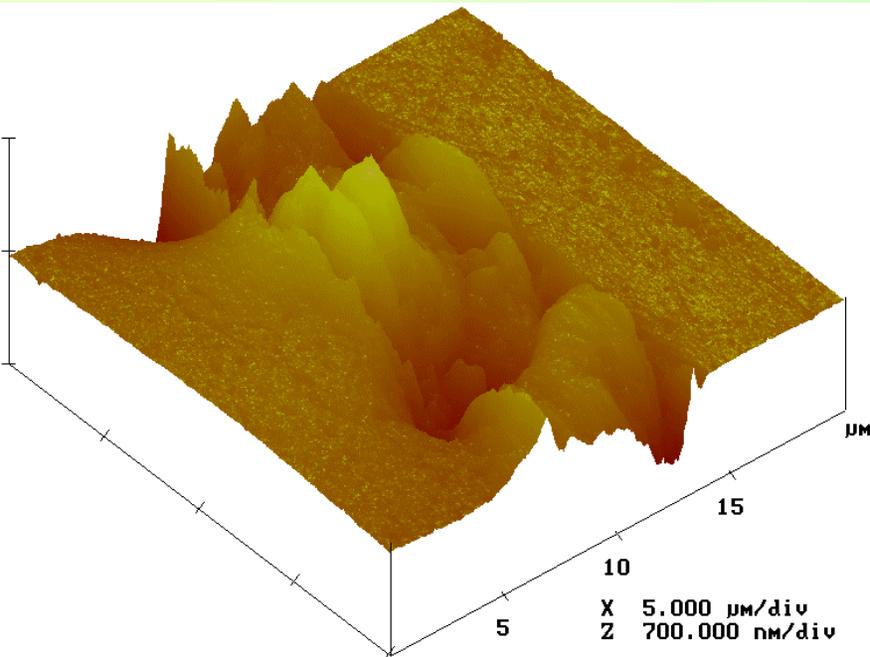
Rys.1.14 Obrazy taśmy samoprzylepnej utworzone jednocześnie z użyciem bezkontaktowego trybu AFM (z lewej) i trybu PDM (z prawej)
Pole widzenia $3\ \mu\text{m} \times 3\ \mu\text{m}$

Przykłady zastosowania AFM

- metale
- ceramiki
- podzespoły elektroniczne
- układy biologiczne

AFM - metale

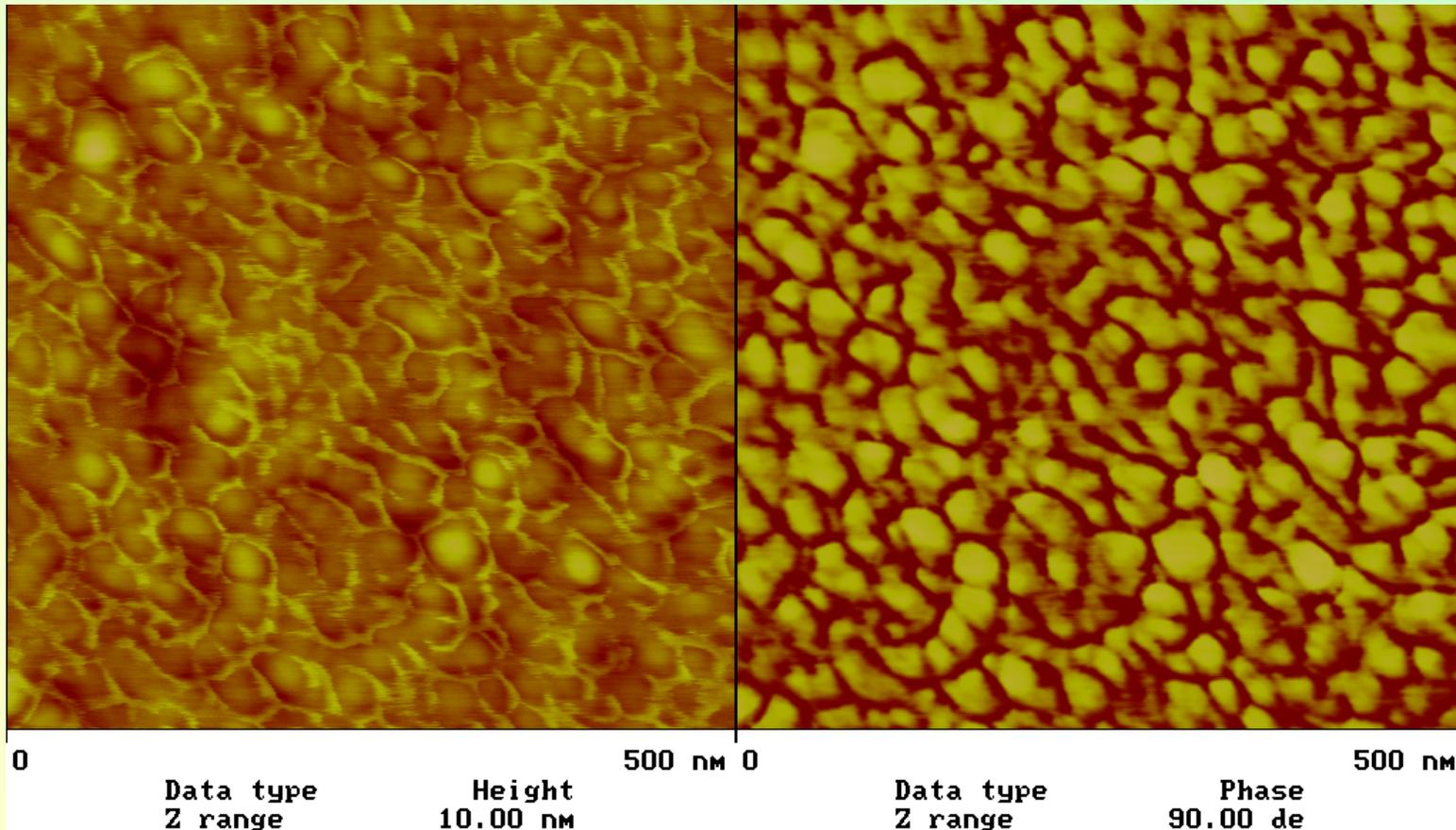
Warstwa na metalu



The samples in the topographic images are cross-sections of polyurethane coatings on steel substrates. The left sample was room-temperature cured while the right sample was heat cured. Although the topography near the interfaces obscures the microstructure, the size of the roughened area in the heat cured sample is significantly smaller than that of the room-temperature cured sample.

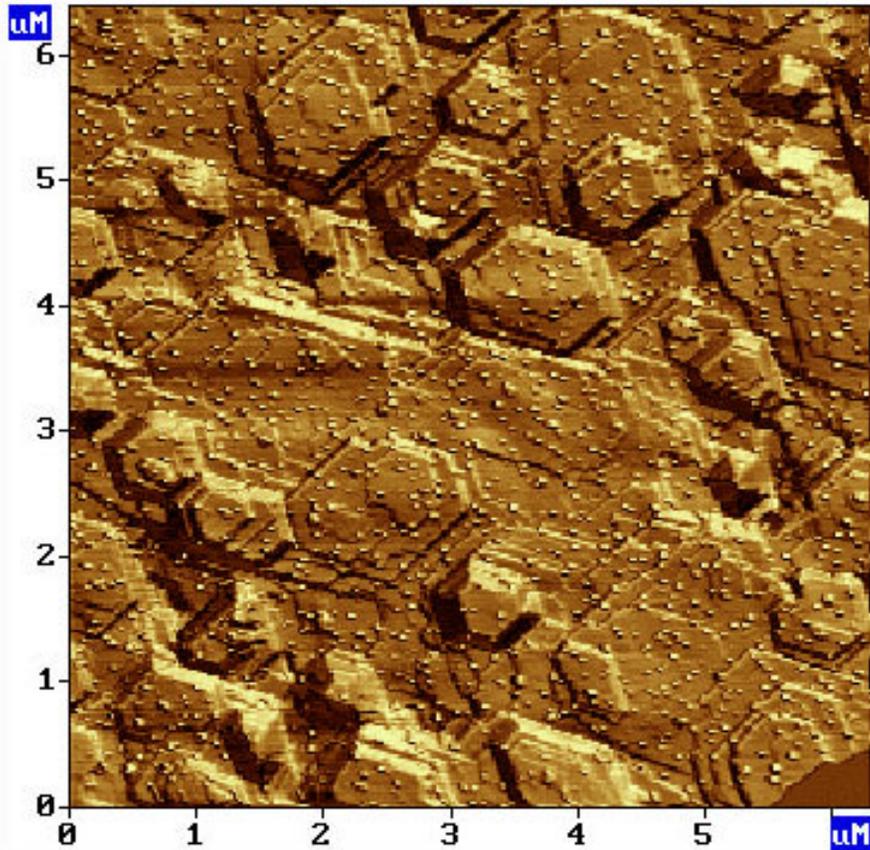
http://www.bfrl.nist.gov/nanoscience/gallery/on_steel.html

Warstwy – cd



Topographic and phase images of [epoxy thin films](#)
An epoxy-amine film was spin cast onto a silicon substrate. The sample was made with a stoichiometric ratio between epoxy and amine.

http://www.bfrl.nist.gov/nanoscience/gallery/on_steel.html

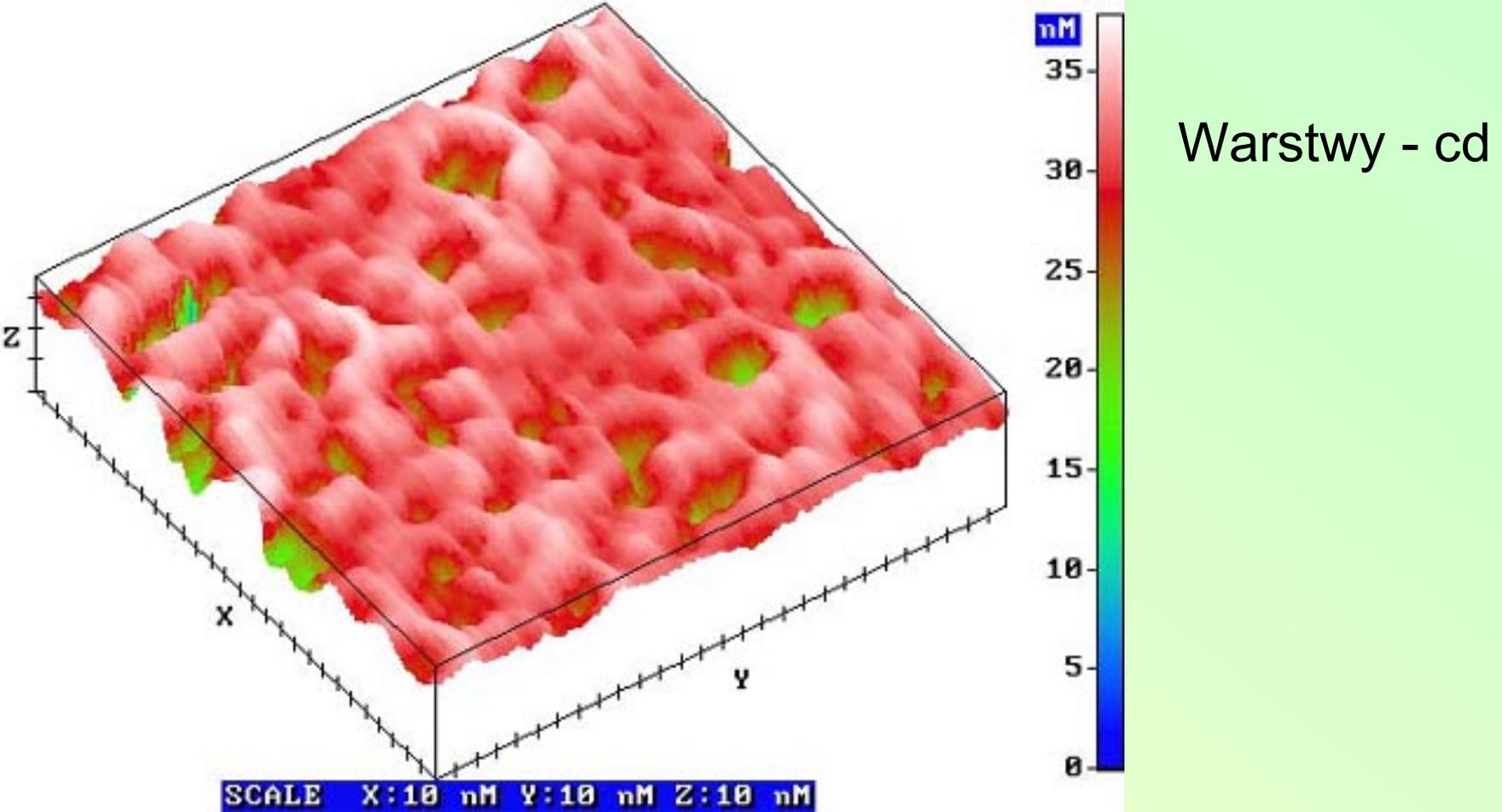


Warstwy - cd

Epitaxial films on silicon

MnAs on Si(111)

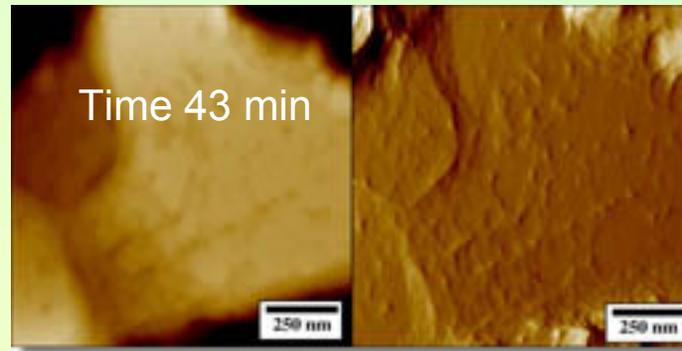
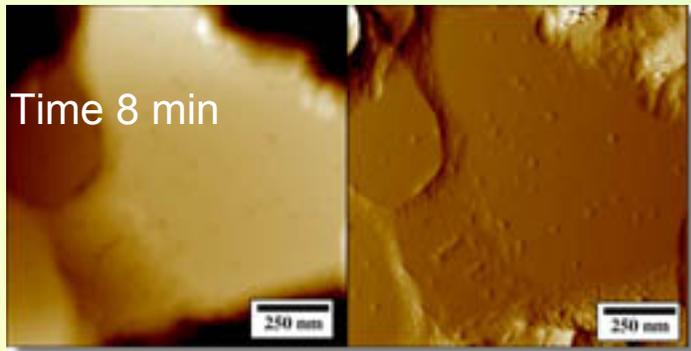
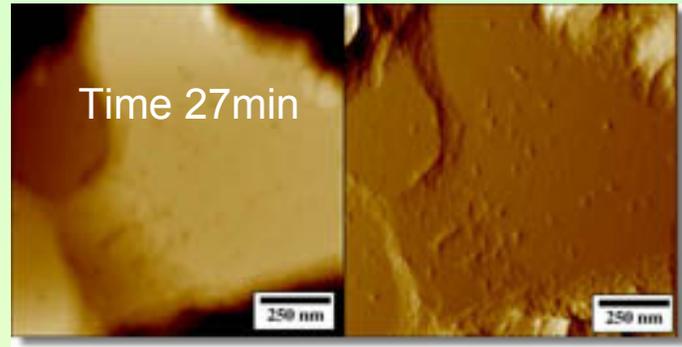
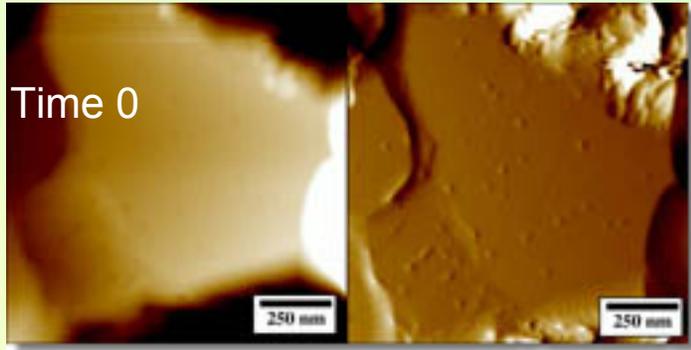
http://www.ntmdt.ru/Scan-gallery/Material_Science/index.html



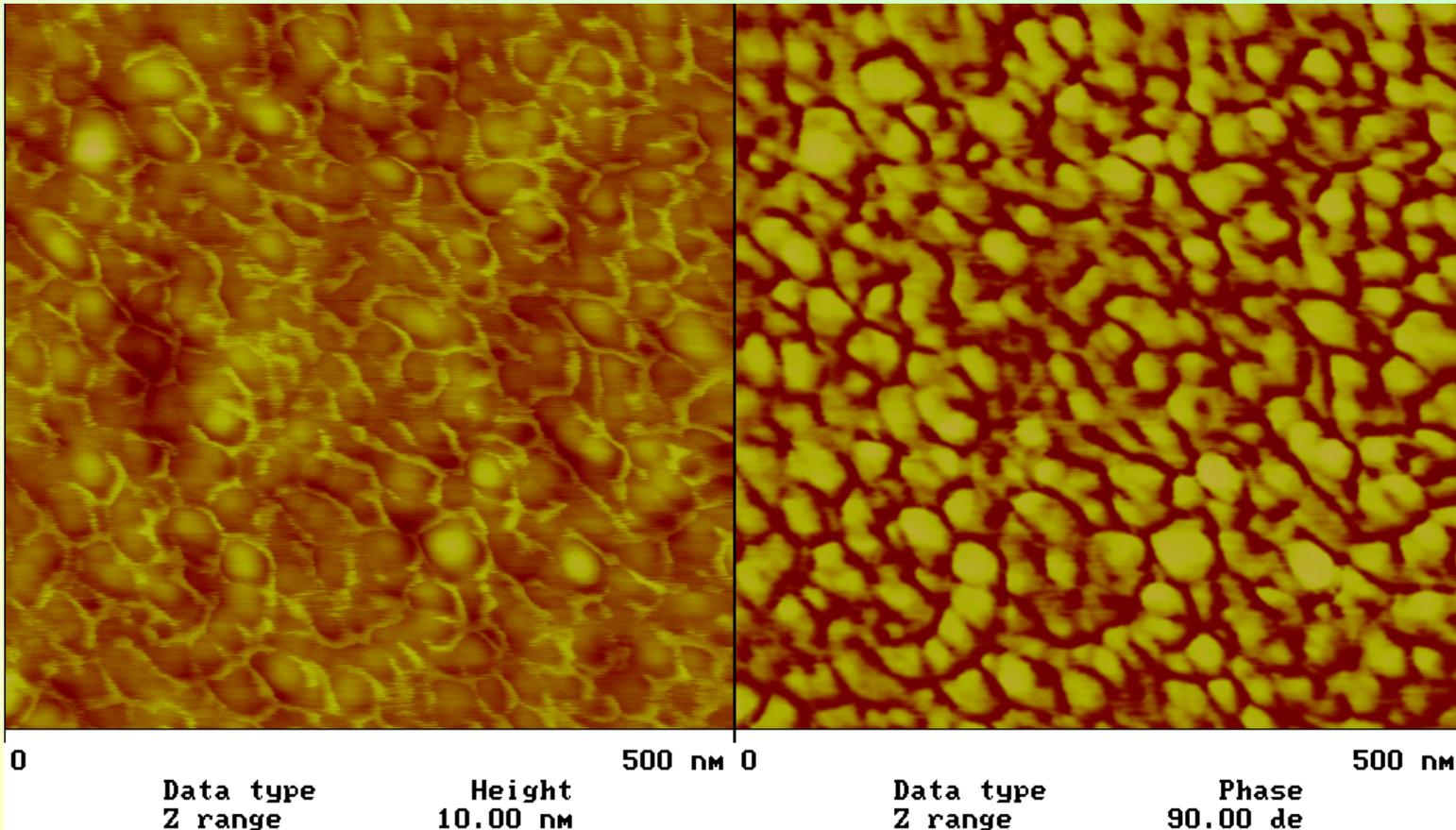
SFM image of diamond-like film on glass.

http://www.ntmdt.ru/Scan-gallery/Material_Science/index.html

AFM - korozija



A time sequence of atomic force microscopy images of the corrosion of aluminum thin films in 0.1M sulfuric acid solution shown in figures 1-8. The onset of corrosion is marked with the formation of 5-10 nm pits across the aluminum terraces - possibly induced by the slow dissolution of the passivating oxide layer. After initial pitting, the corrosion proceeds through a step dissolution process, causing small scale rouging across the sample surface. Left images are Height Plots, z range = 175nm, Right images are Deflection Plots, z range = 5nm

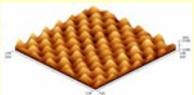
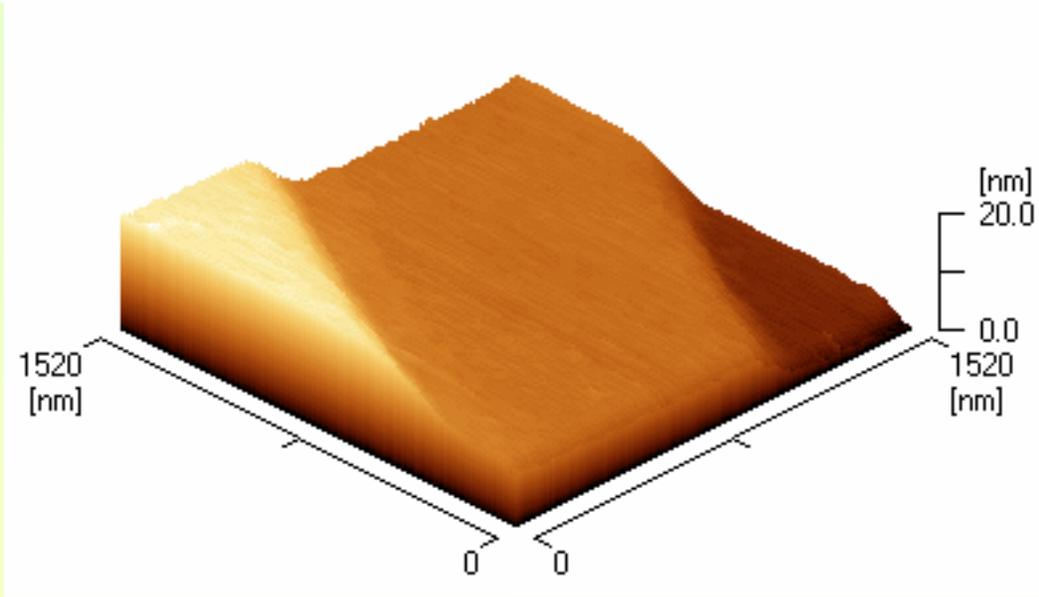
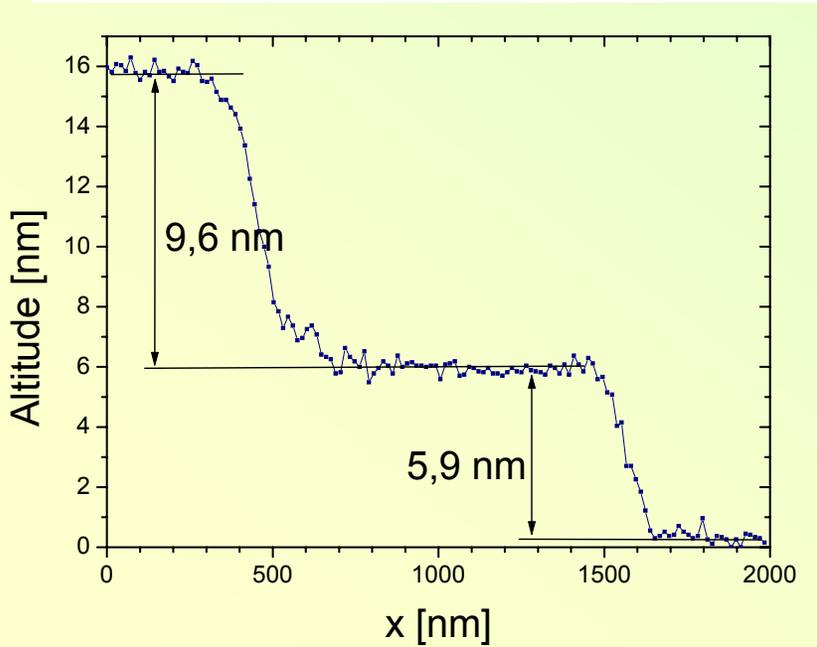
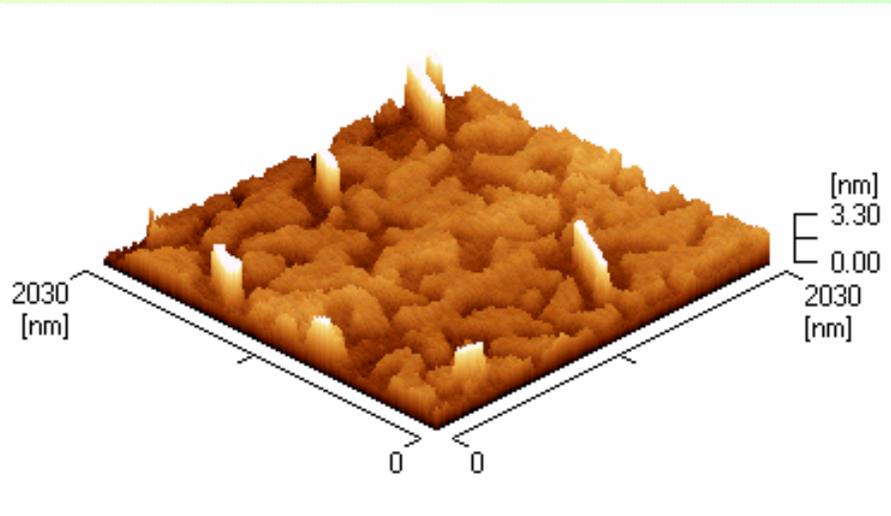


Topographic and phase images of [epoxy thin films](#)
An epoxy-amine film was spin cast onto a silicon substrate. The sample was made with a stoichiometric ratio between epoxy and amine.

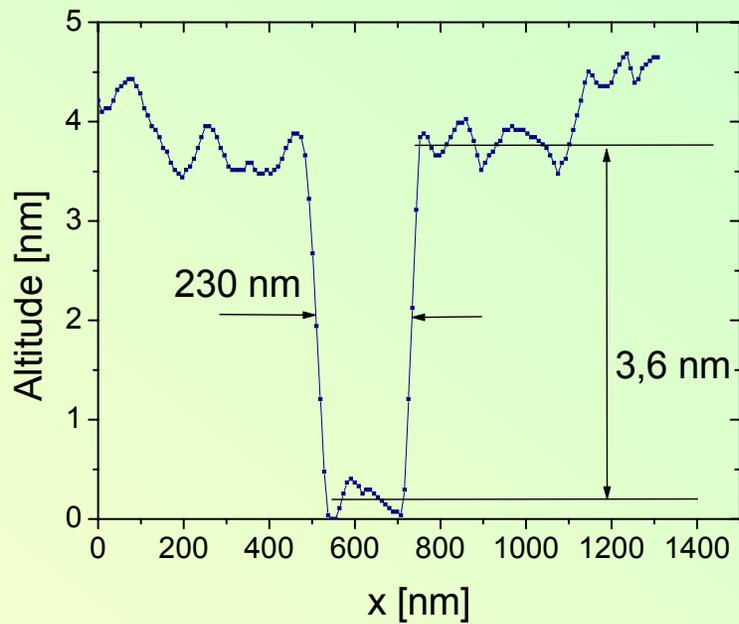
http://www.bfrl.nist.gov/nanoscience/gallery/on_steel.html

AFM - ceramiki

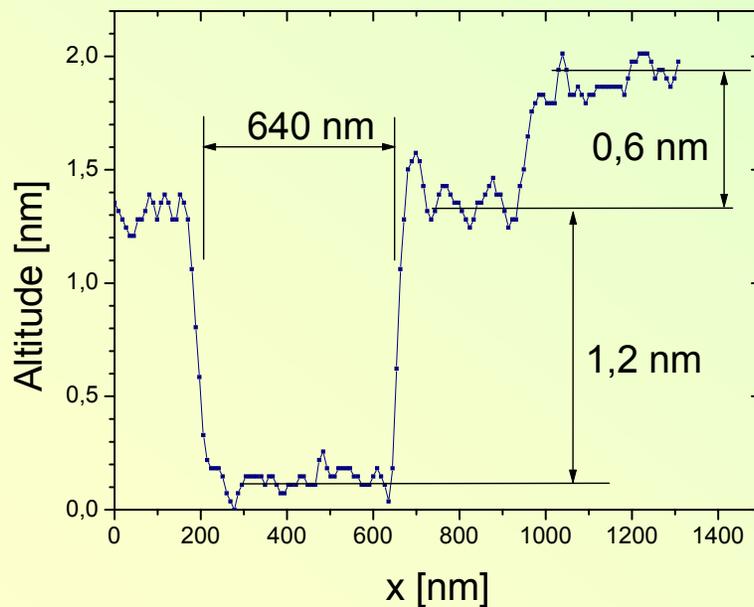
Mikroskop AFM



A-A

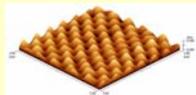
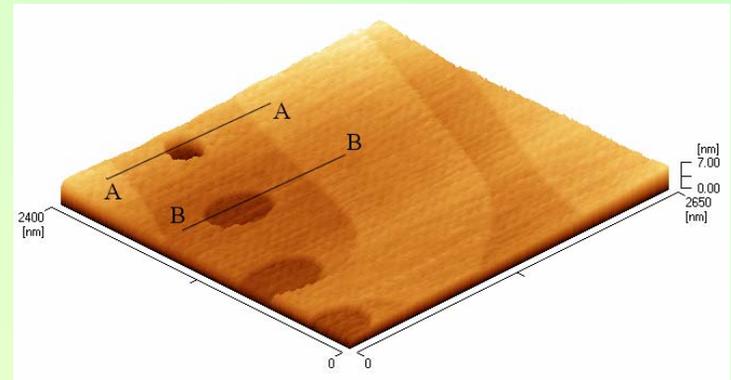


B-B



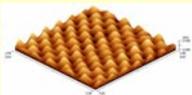
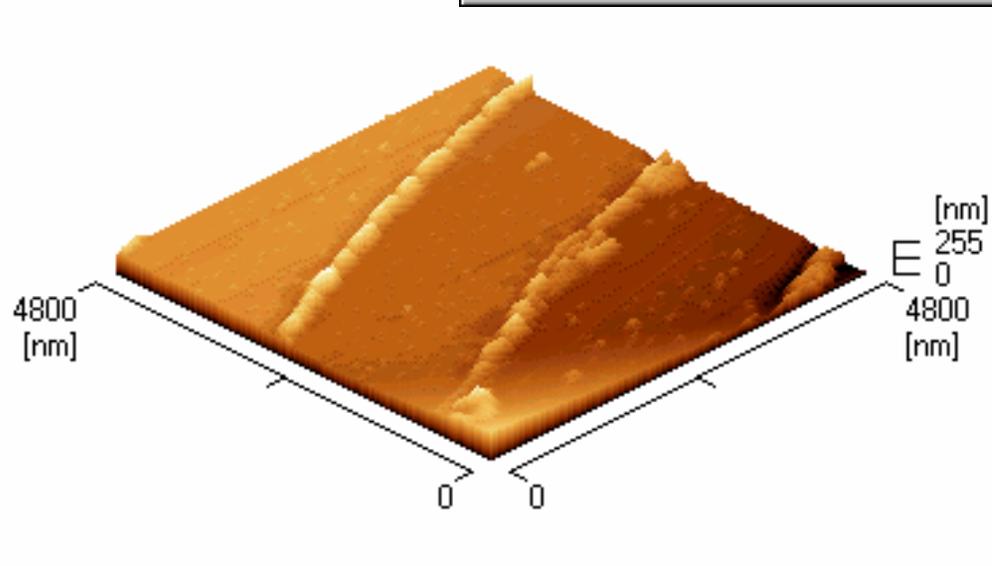
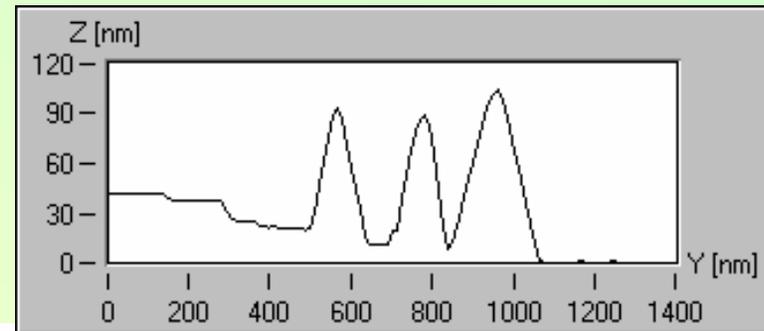
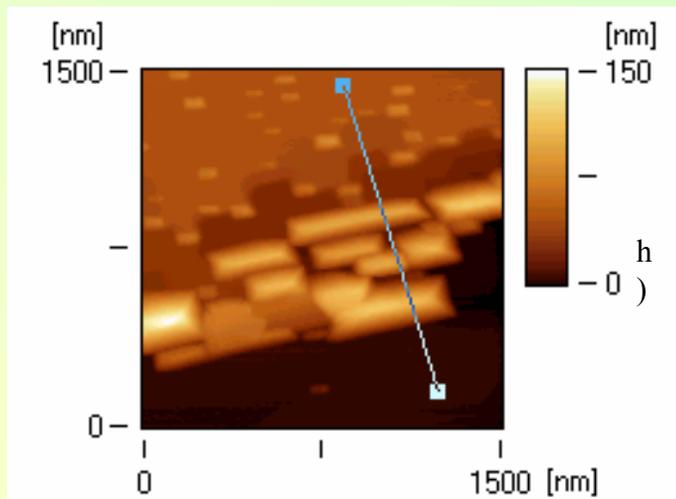
Mikroskop AFM

$\text{Nd}_{2-x}\text{Ce}_x\text{CuO}_{4-y}$

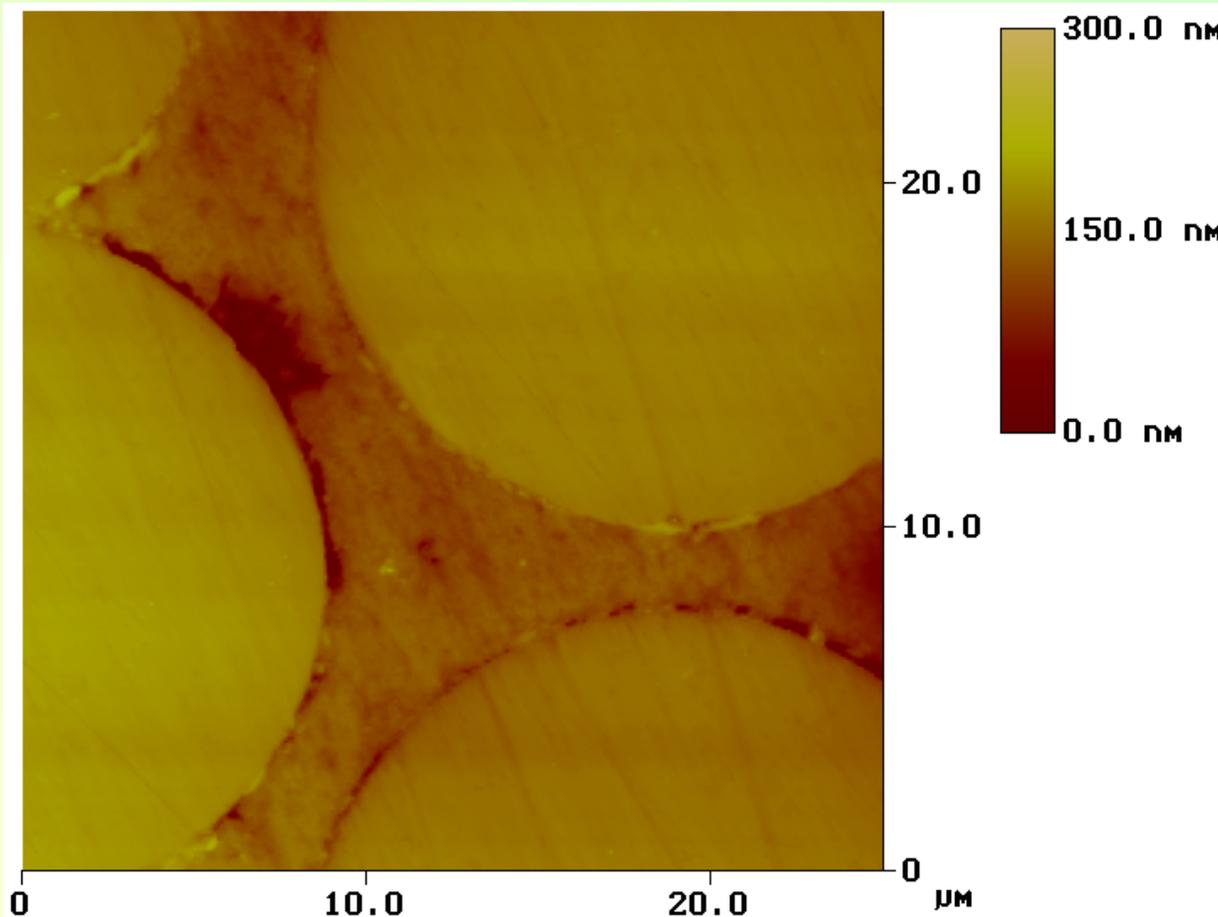


Galeria AFM

Mikroskop AFM



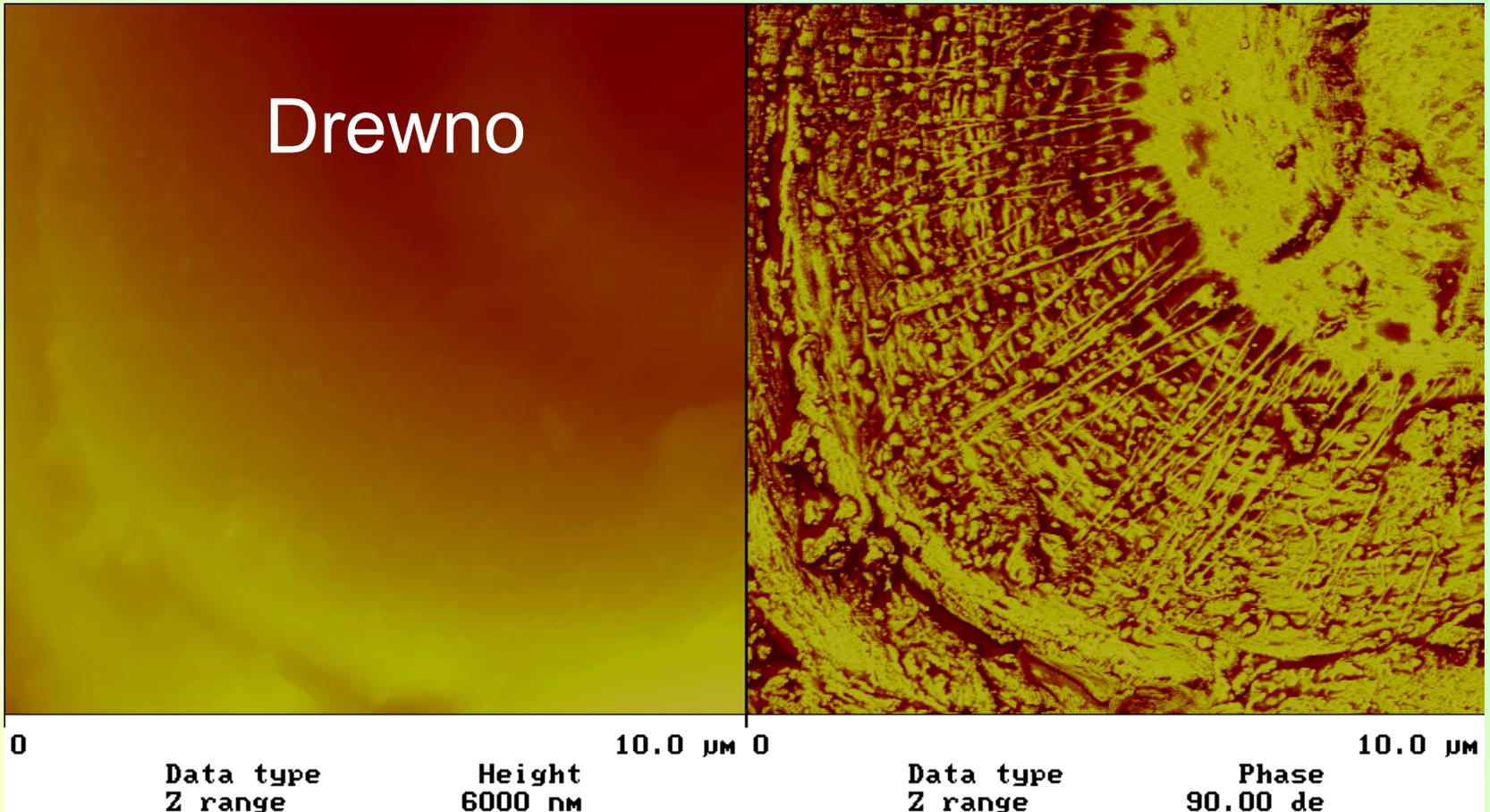
Kompozyty



The glass fiber-reinforced epoxy composite shown in this image was exposed to a moist environment. Interfacial debonding, which caused a reduction in the strength of this material, can be observed between the glass fibers and the epoxy matrix in this AFM topographic image.

<http://www.bfrl.nist.gov/nanoscience/gallery/frp.html>

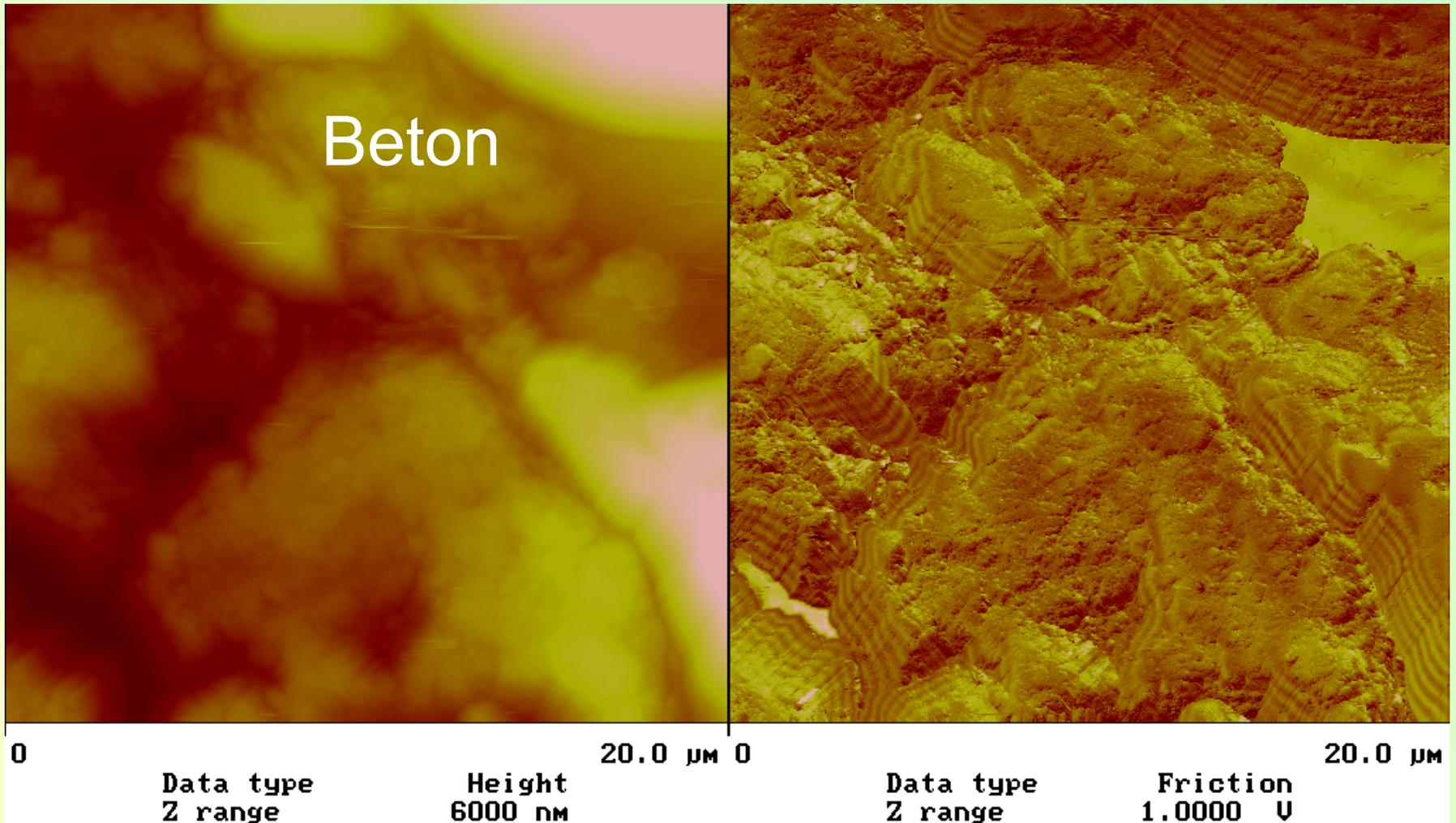
Drewno



The detailed microstructure of the wood particle is much more easily observed in the phase image compared to the topographic image

http://www.bfrl.nist.gov/nanoscience/gallery/wood_image.html

Beton

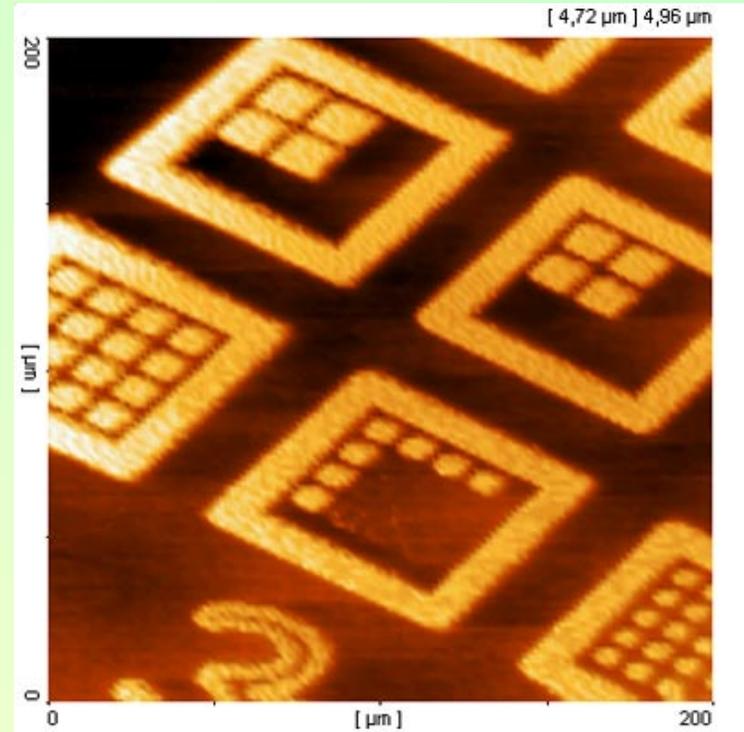


- Topographic and friction contrast images of a [short fiber-reinforced concrete](http://www.bfrl.nist.gov/nanoscience/gallery/concrete.html) cross-section, in which an interphase region with different friction characteristics is observed next to a fiber. An interphase region with different friction characteristics is observed next to the fiber in the upper right hand corner of the phase image

<http://www.bfrl.nist.gov/nanoscience/gallery/concrete.html>

AFM - podzespoły

AFM – podzespoły elektroniczne



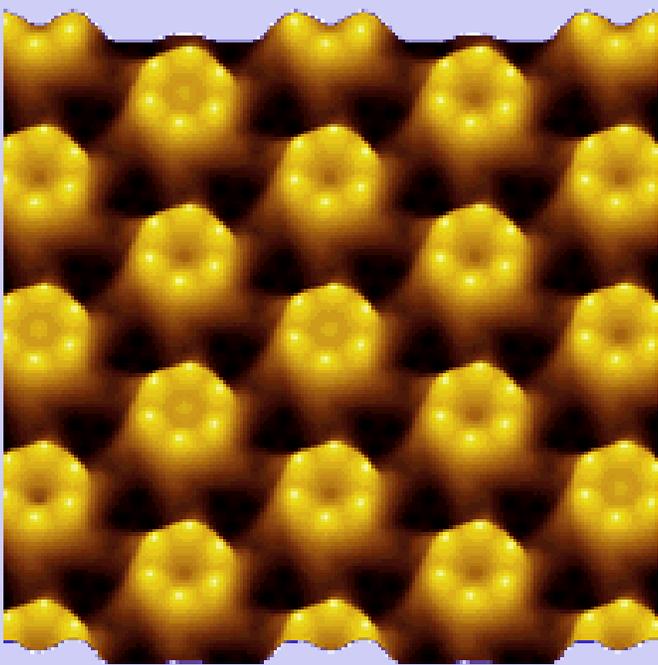
Wafer

<http://www.dme-spm.dk/App/Semiconduc.htm>

The needs for AFM is becoming evident in this area, because it makes it possible to measure and image even sub-micron details on the wafers and thereby heighting the degree of quality control and increase yields.

AFM – układy biologiczne

AFM - biologia 1



Protein surface layer of D. Radiodurans. Courtesy of Digital Instruments.



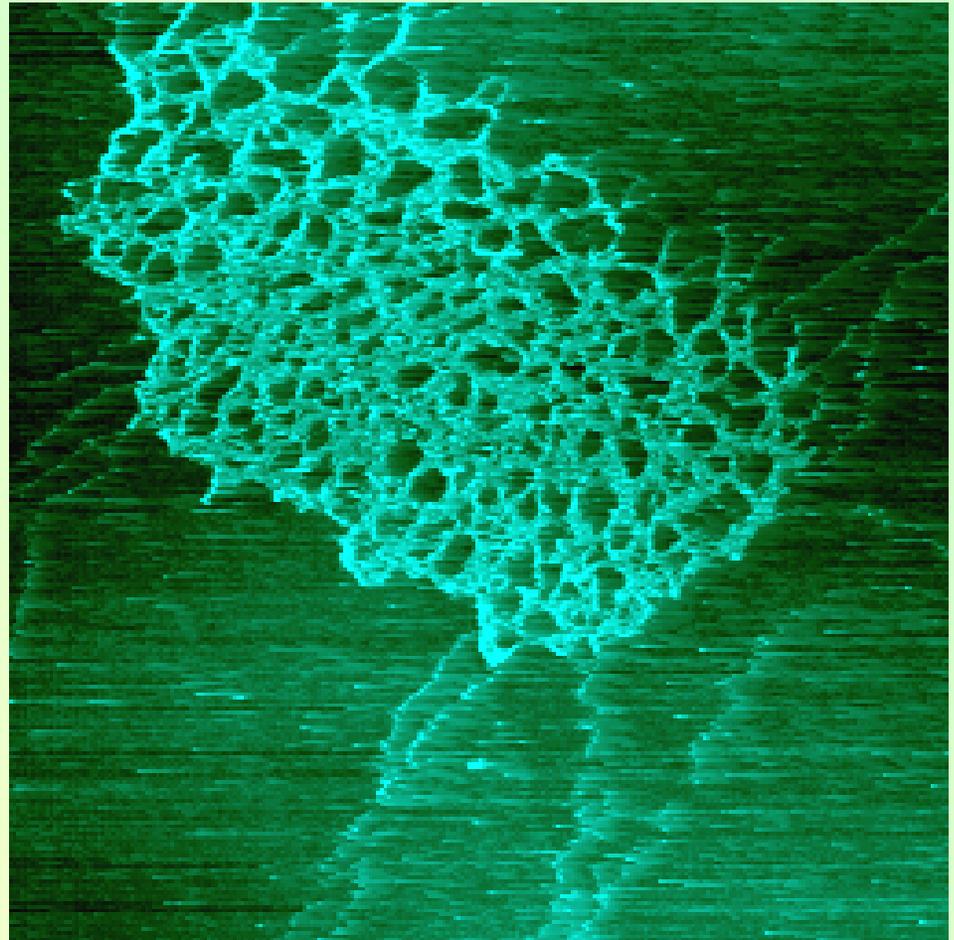
Human Chromosomes. Thanks to Digital Instruments for the picture.

One of the advantages of AFM is that it can image the non-conducting surfaces. So it was immediately extended to the biological systems, such as analyzing the crystals of amino acids and organic monolayers. Applications of AFM in the biosciences include: DNA and RNA analysis; Protein-nucleic acid complexes; Chromosomes; Cellular membranes; Proteins and peptides; Molecular crystals; Polymers and biomaterials; Ligand-receptor binding.

<http://www.chembio.uoguelph.ca/educmat/chm729/afm/applicat.htm>

AFM-biologia 2

AFM image of a typical aggregate formed by Hylan. Hylan is therapeutic product used in the treatment of osteoarthritis for visco-supplementation of the synovial fluid in joints. It is derived from the polysaccharide hyaluronic acid by chemical cross-linking of the polymer chains. The cross-linking results in aggregated structures which are highly stable. Image size: 1.9 microns x 1.9 microns



<http://www.ifr.ac.uk/spm/spmimages/hylan.html>

AFM

Waterchestnut cell wall

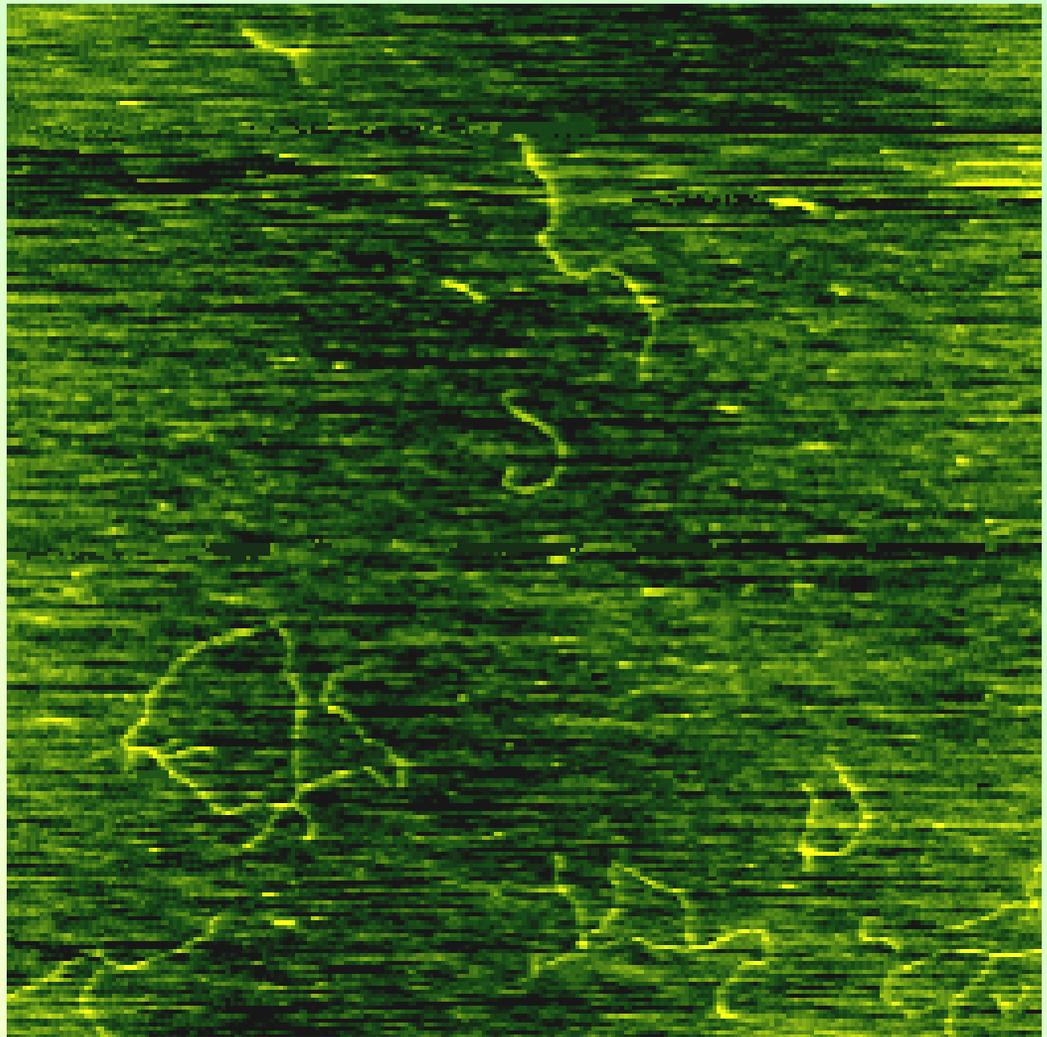
AFM error signal image of wet waterchestnut cell wall on mica, scanned in air. The strands in the image are cellulose microfibrils. Image size: 1 x 1 micron.



<http://www.ifr.ac.uk/spm/spmimages/cwall02.html>

AFM-guma

AFM image of single molecules of the polysaccharide xanthan gum. Image size: 4 microns x 4 microns

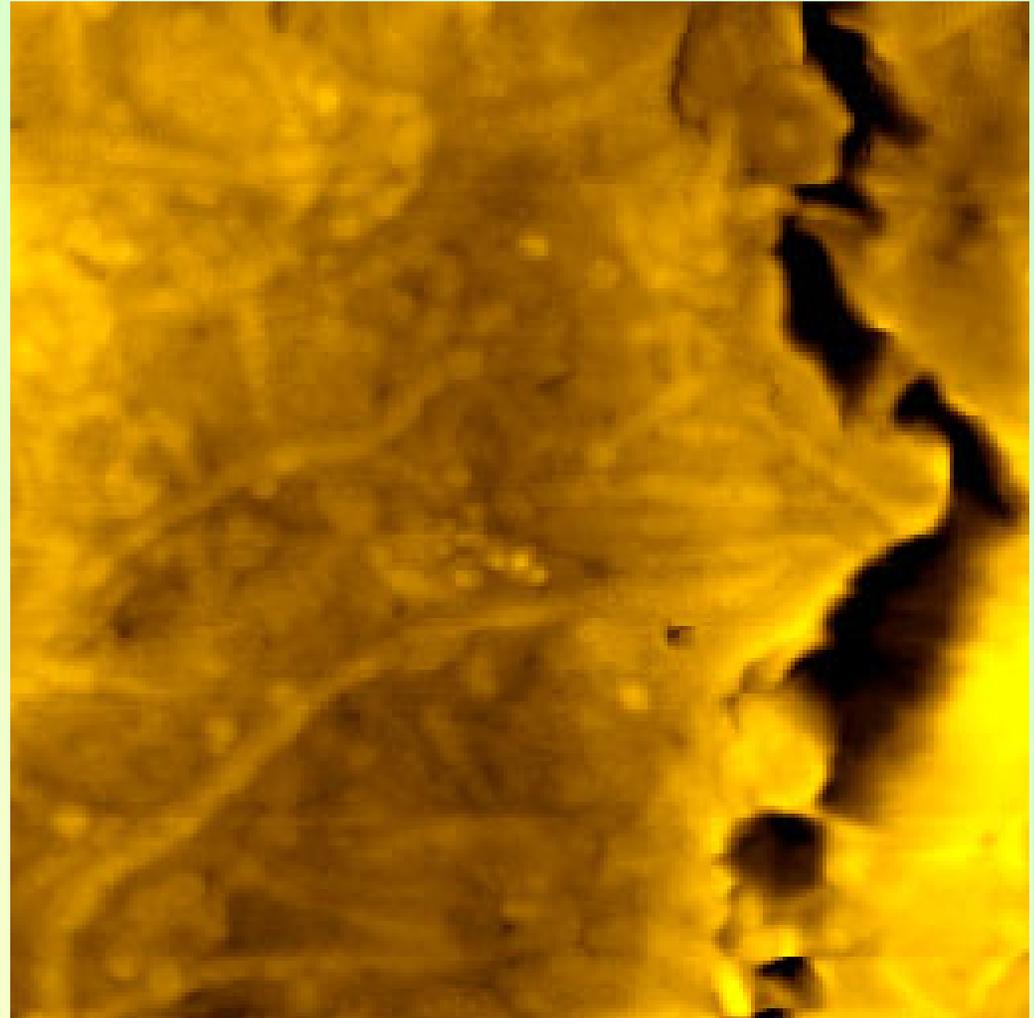


<http://www.ifr.ac.uk/spm/spmimages/hylan.html>

AFM

HT29 colorectal carcinoma

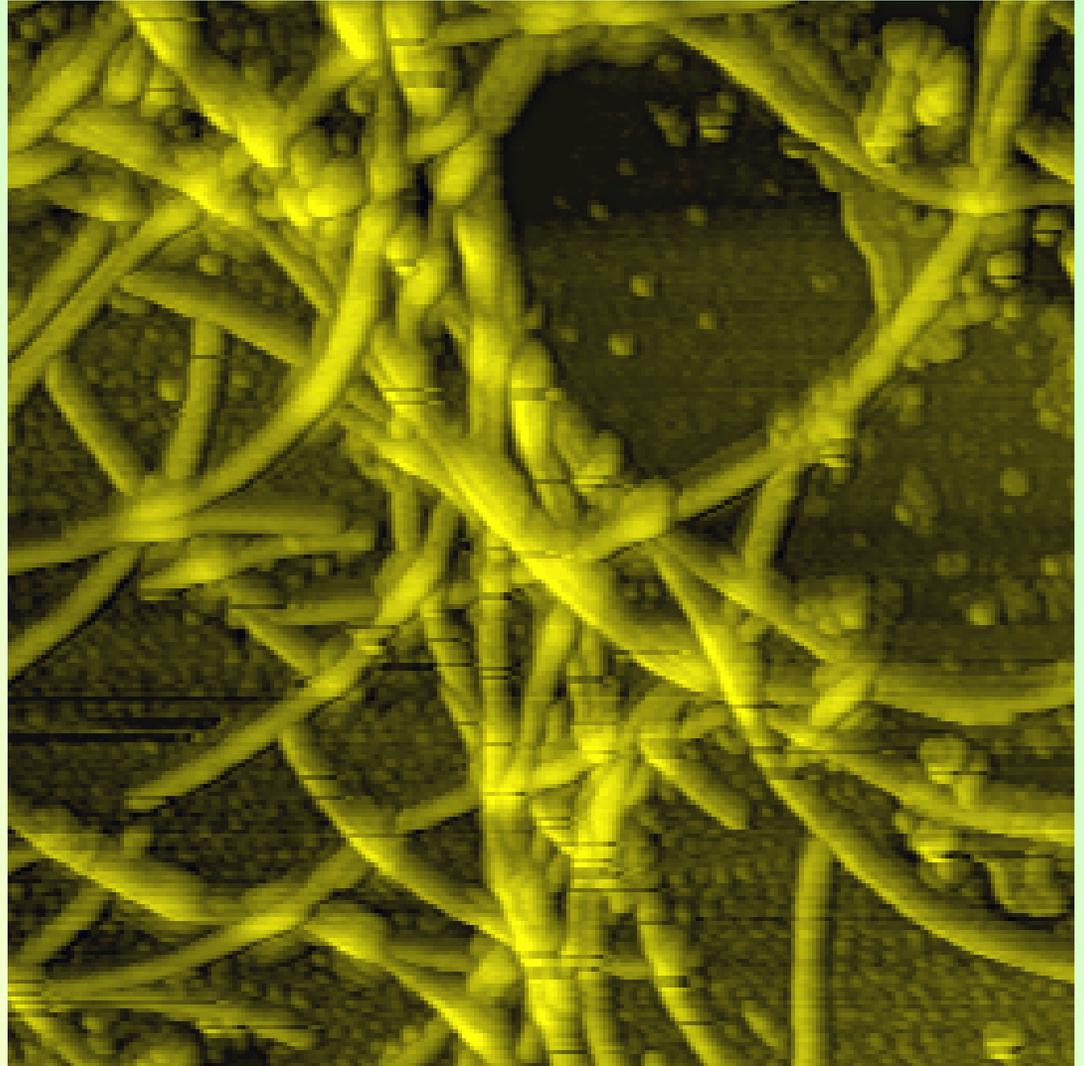
Low magnification AFM image of a boundary between two HT29 colorectal carcinoma cells. Note the cell processes visible on the surface of the cell on the left. Scanned under butanol in contact (dc) mode. Scan size: 4.5 x 4.5 microns.



<http://www.ifr.ac.uk/spm/spmimages/Colon25.html>

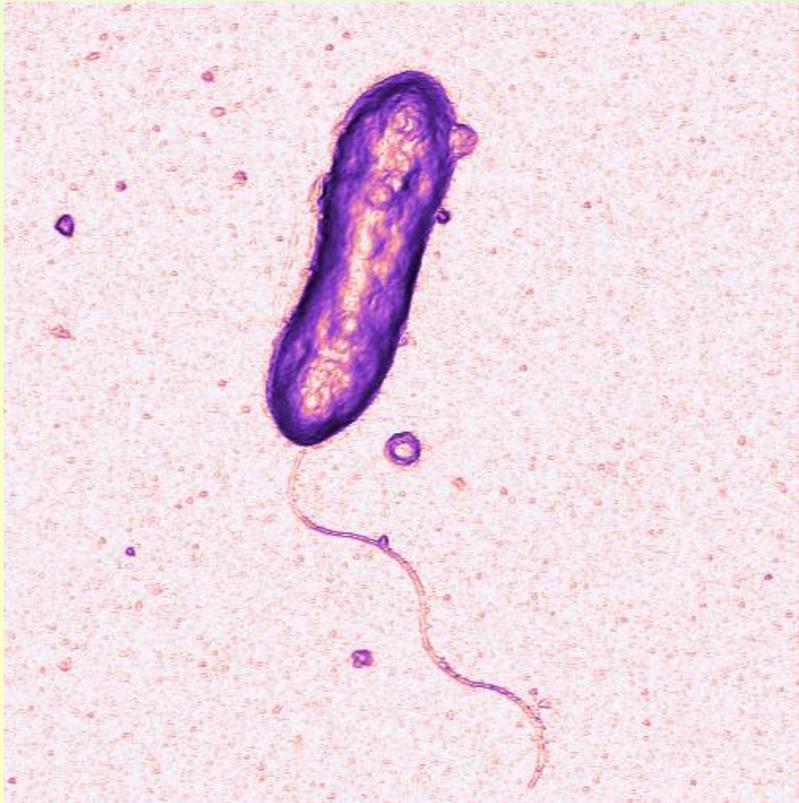
AFM-bakterie

True non-contact AFM image of a tangle of *Pseudomonas putida* bacterial flagellae. Note the bright cross-over points are clearly resolved when imaging in non-contact mode. This is because the forces acting on the sample are very much less than in contact mode. Imaged on mica and scanned in air. Image size: 2 x 2 microns.

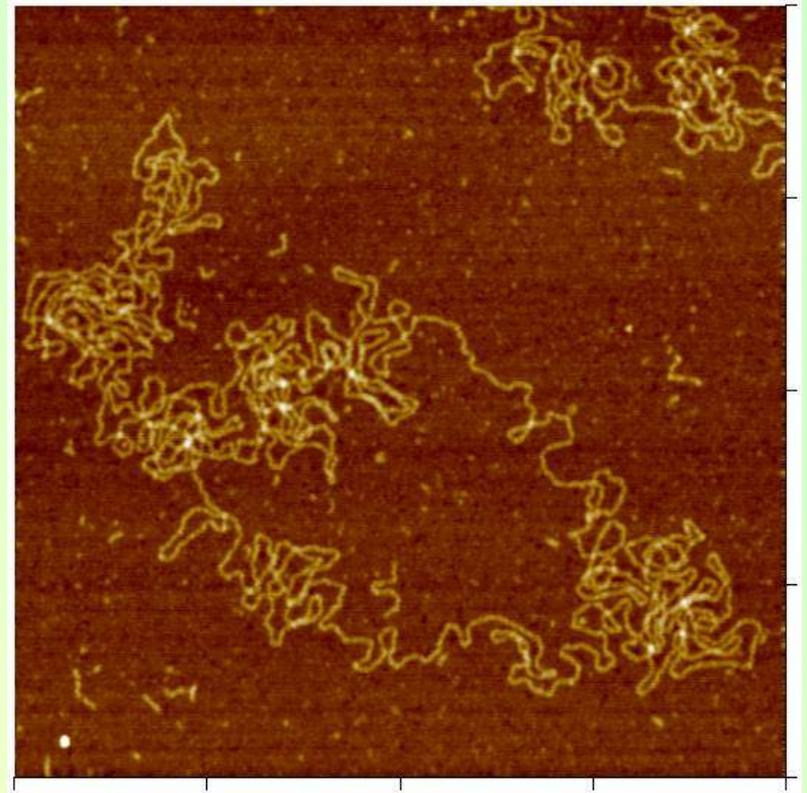


<http://www.ifr.bbsrc.ac.uk/spm/spmimages/bfilm06.html>

Galeria AFM

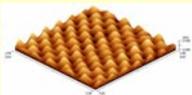


„tajemnicza” bakteria

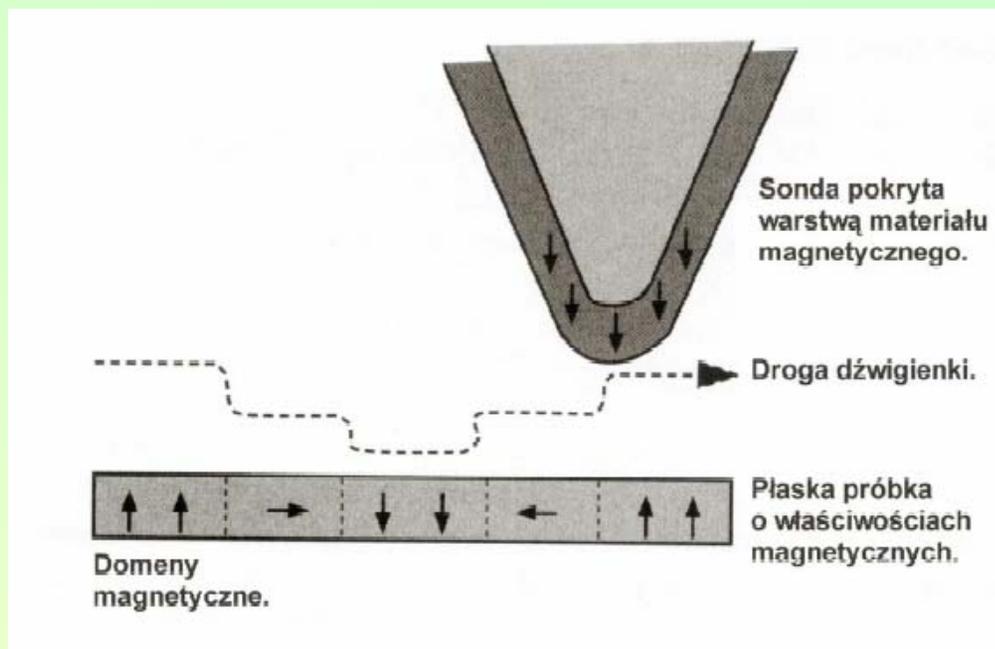


DNA na mice

Department of Pharmacology, University of Cambridge

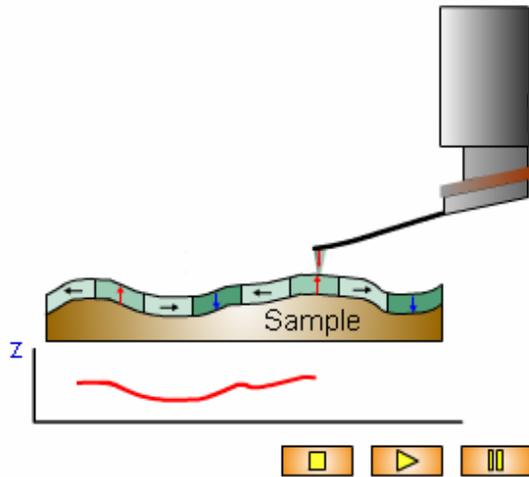


Mikroskop sił magnetycznych (MFM)



Mikroskop Sił Magnetycznych (Magnetic Force Microscopy: MFM) pozwala na zobrazowanie różnic sił magnetycznych działających na sondę w różnych punktach powierzchni badanego materiału. W przypadku MFM, jego skanująca sonda pokryta jest cienką warstwą ferromagnetyka. Mikroskop ten pracuje w trybie bezkontaktowym wykrywając zmiany w częstotliwości rezonansowej dźwigienki. Zmiany te są indukowane przez zależność pola magnetycznego od odległości sonda - próbka. MFM może być wykorzystywany do uzyskiwania obrazów struktur domen magnetycznych występujących naturalnie lub sztucznie "zapisanych" w materiale magnetycznym przez człowieka (rys. 1.7 i 1.8).

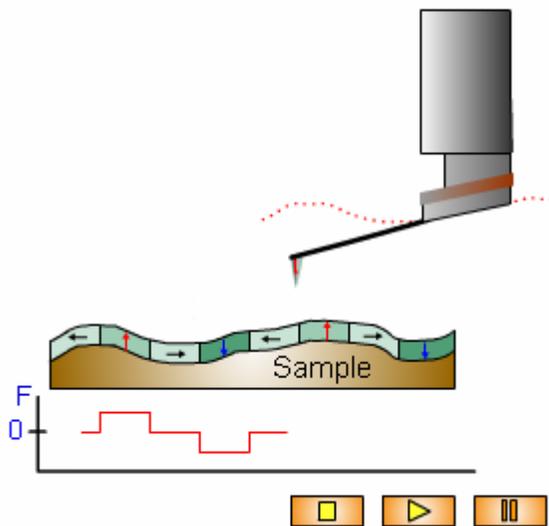
1-st pass. Sample profile acquisition.



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www.ntmdt.com

2-nd pass. Magnetic Force profile acquisition.



Copyright © NT-MDT, 2002

www.ntmdt.com

http://www.ntmdt.ru/SPM-Techniques/Principles/SFM/Many-pass_techniques/DC_MFM_mode53.html

Magnetic Force microscopy (MFM) [1,2] is an effective tool for magnetic investigations on submicron scale. Image obtained by MFM is the space distribution of some parameter characterizing magnetic probe-sample interaction, i.e. interaction force, amplitude of vibrating magnetic probe etc. The magnetic probe is standard silicon cantilever (or silicon nitride cantilever) coated by magnetic thin film. MFM measurements enable the high resolution investigation of magnetic domain structure, reading and recording information in magnetic media, magnetization reversal processes etc.

In magnetic investigations on submicron scale first of all one must separate the magnetic image from the topography. To solve this problem the magnetic measurements are executed by means of two-pass method. In the first pass the topography is determined in Contact or Semicontact mode. In the second pass the cantilever is lifted to a selected height for each scan line (or after topography measurement), and scanned using the stored topography (without the feedback). As a result the tip-sample separation during second pass is kept constant. This tip-sample separation must be large enough to eliminate the Van der Waals' force. During second pass the short-range Van der Waals' force vanishes and the cantilever is affected by long-range magnetic force. Both the height-image and the magnetic image are obtained simultaneously with this method. In the DC MFM during second pass the deflection (DFL) of a non-vibrating cantilever is detected. DFL is caused by the magnetic interaction between the tip and the sample (similarly to contact mode). The magnetic force acting on the cantilever can be obtained by multiplying the deflection of the cantilever by the cantilever force constant. Due to a small size of the magnetic cantilever it is possible to consider it as a point magnetic dipole.

Magnetyczne nośniki informacji

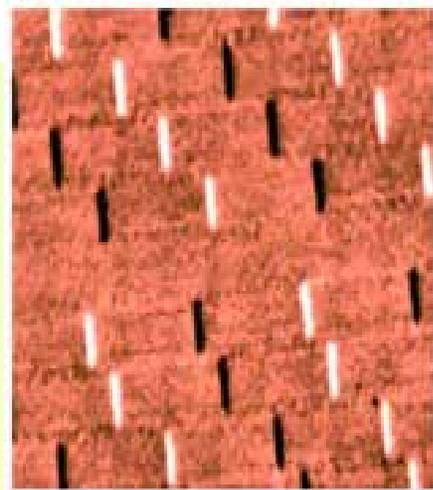


Obraz MFM
powierzchni płyty
kompaktowej

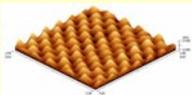
Galeria AFM



Twardy dysk
 $10\ \mu\text{m} \times 10\ \mu\text{m}$

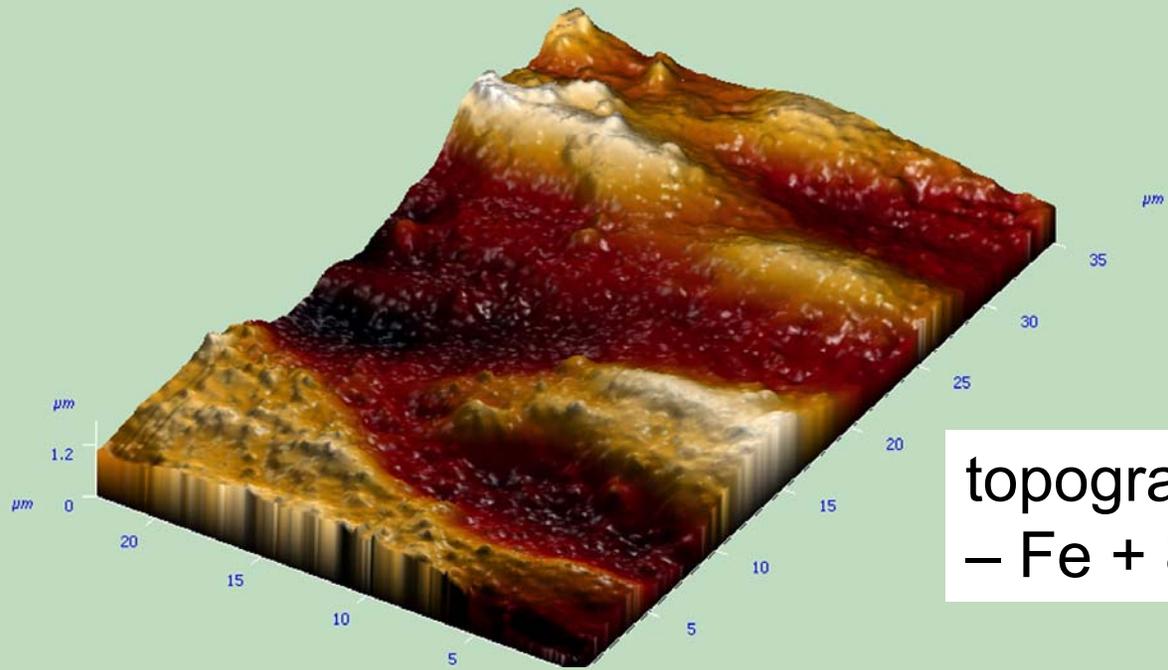


Twardy dysk
pojedyncze bity (MFM)
 $30\ \mu\text{m} \times 30\ \mu\text{m}$

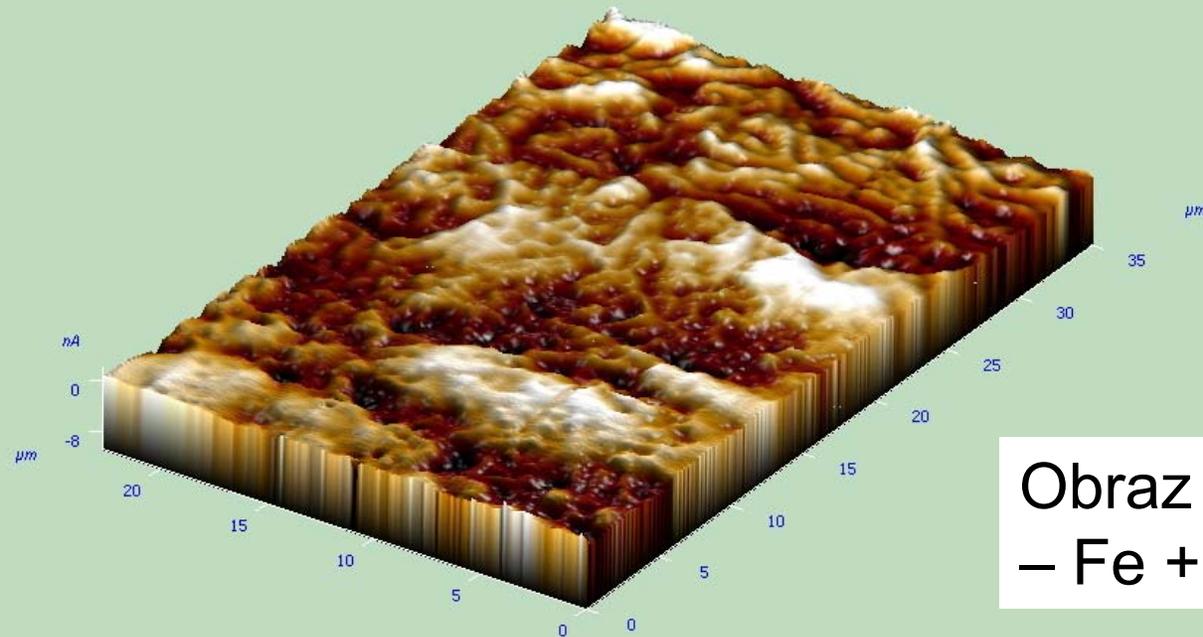


Metale – topografia i obraz magnetyczny

Fe80

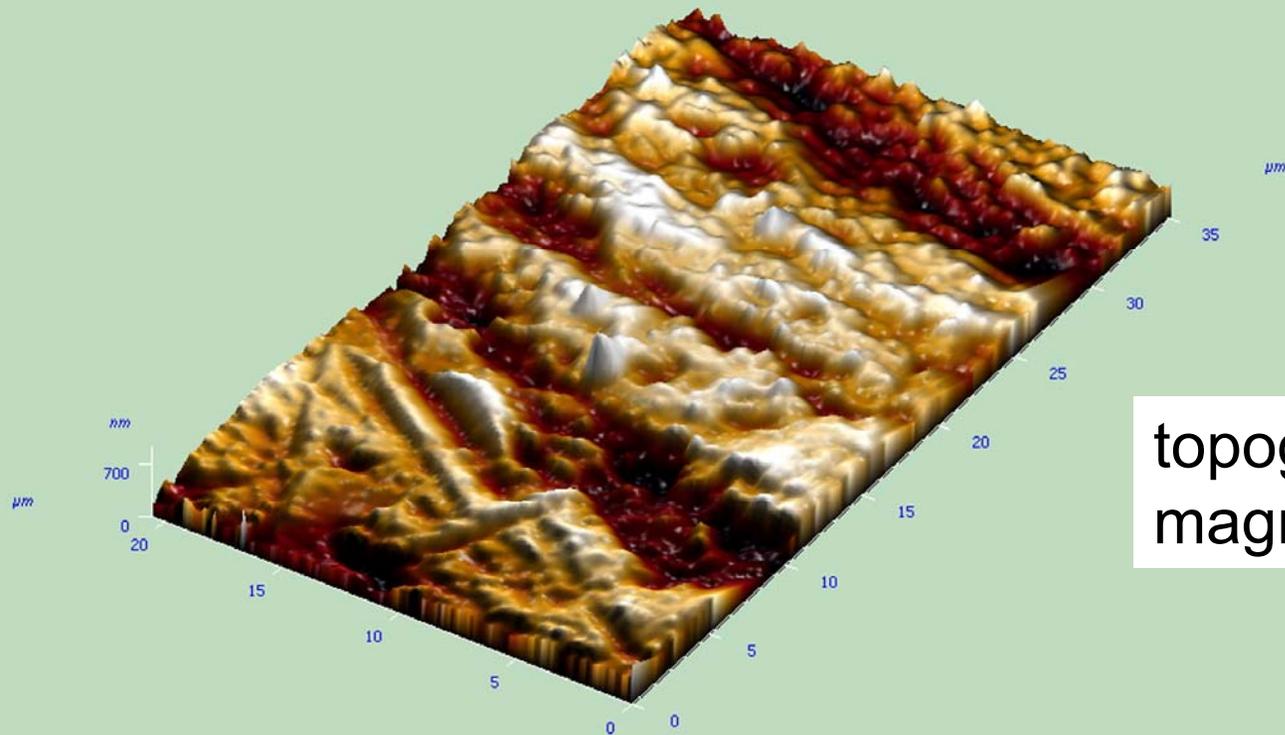


topografia blaszki
– Fe + 80 pp C



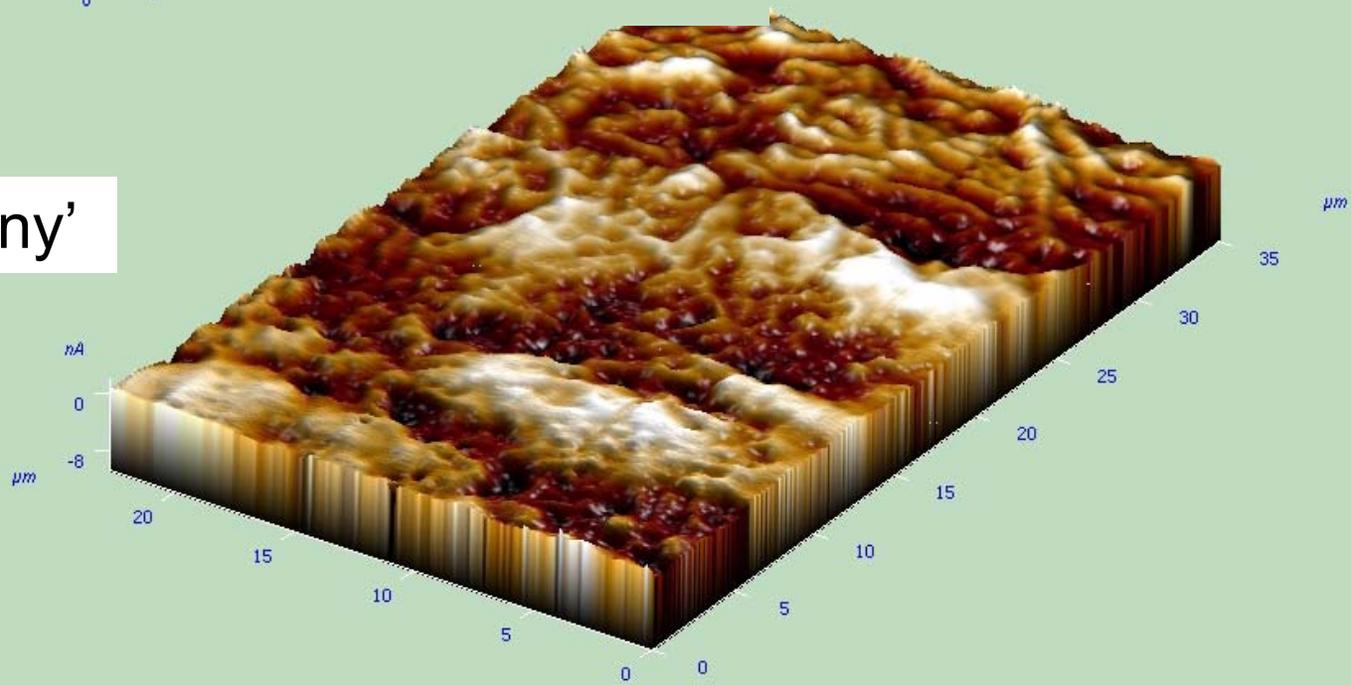
Obraz 'magnetyczny'
– Fe + 80 pp C

stal

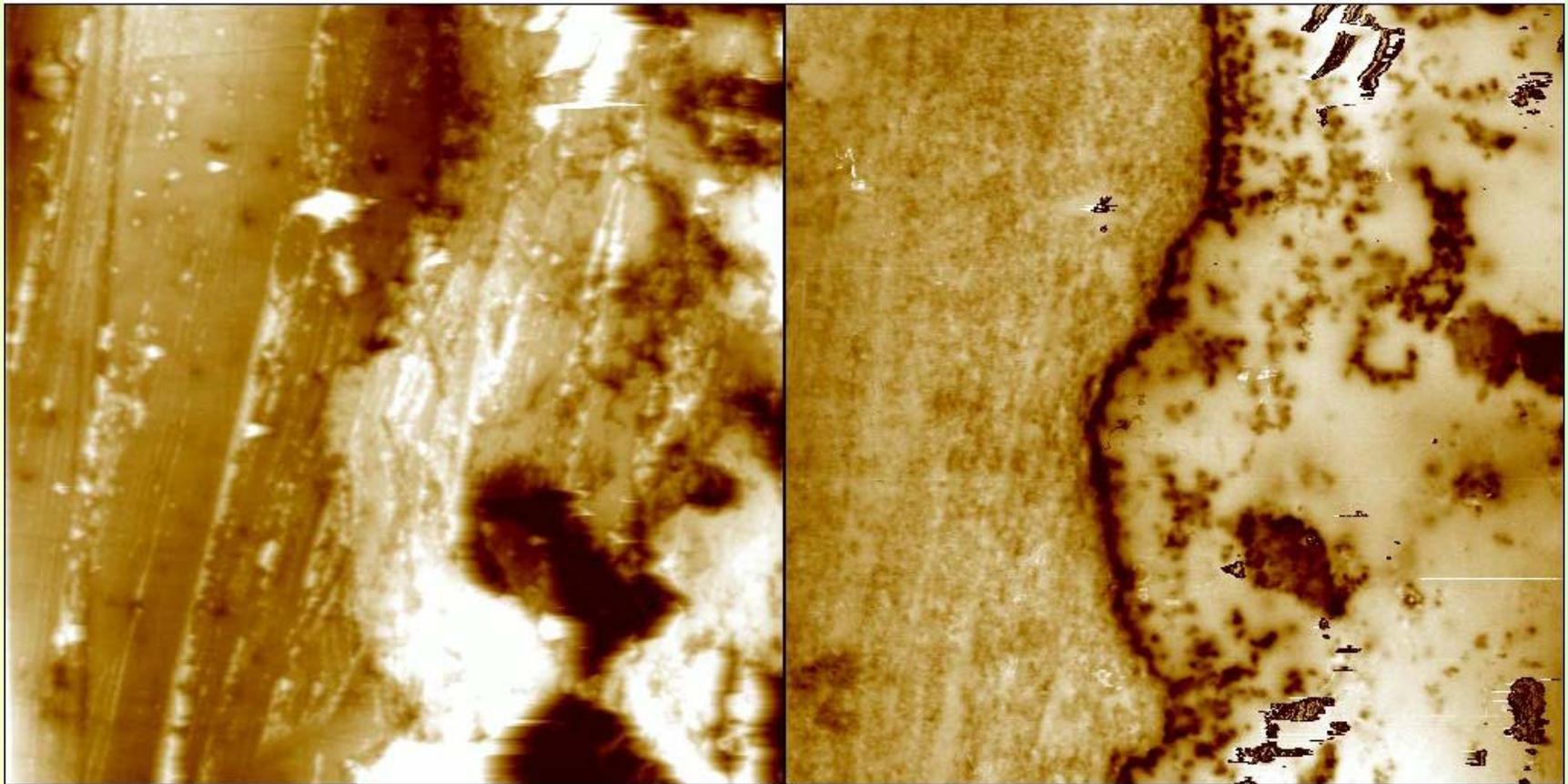


topografia blaszki stali magnetycznej

Obraz 'magnetyczny'



Eksplotowana stal austenityczna + zgorzelina



0 70.0 μm 0

Data type
Z range
Height
735.1 nm

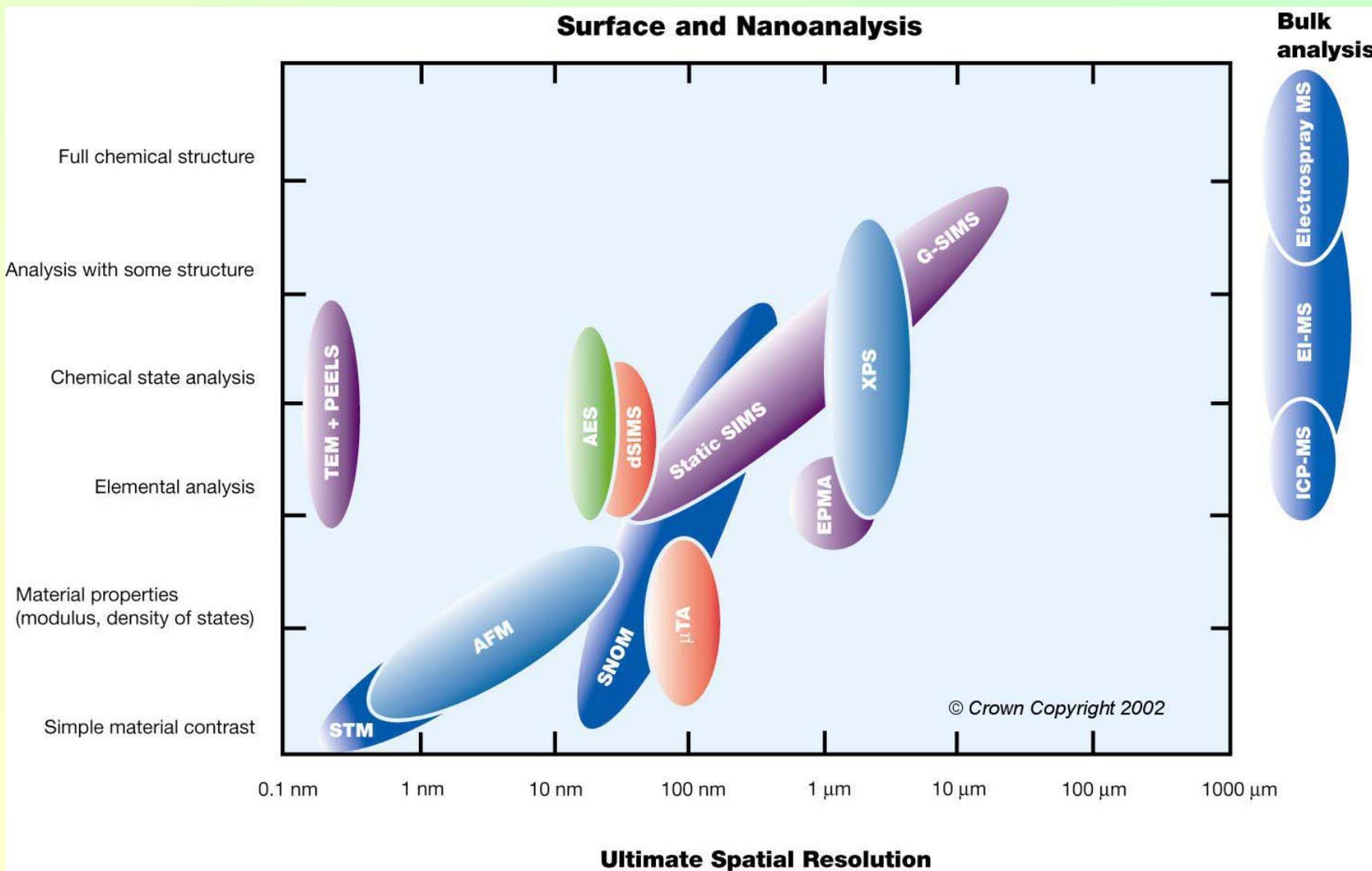
0 70.0 μm

Data type
Z range
Phase
17.52 $\%$

pr2_mfm_ziarno.004pop

Widoczne fazy ferromagnetyczne (brązowe)

Ocena AFM i innych technik mikroskopowych



- **AFM - Atomic Force Microscopy**
- **AES - Auger Electron Spectroscopy**
- **XPS - X-ray Photoelectron Spectroscopy**
- **SSIMS - Static Secondary Ion Mass Spectrometry**
- **GSIMS** is a new variant of static SIMS developed at NPL using two spectra
- **SNOM - Scanning Near Field Optical Microscopy.**

AFM a STM

It's interesting to compare AFM and its precursor -- Scanning Tunneling Microscope. In some cases, the resolution of STM is better than AFM because of the exponential dependence of the tunneling current on distance.

The force-distance dependence in AFM is much more complex when characteristics such as tip shape and contact force are considered. STM is generally applicable only to conducting samples while AFM is applied to both conductors and insulators. In terms of versatility, needless to say, the AFM wins. Furthermore, the AFM offers the advantage that the writing voltage and tip-to-substrate spacing can be controlled independently, whereas with STM the two parameters are integrally linked.

AFM a SEM i TEM

AFM versus SEM:

Compared with Scanning Electron Microscope, AFM provides extraordinary topographic contrast direct height measurements and unobscured views of surface features (no coating is necessary).

AFM versus TEM:

Compared with Transmission Electron Microscopes, three dimensional AFM images are obtained without expensive sample preparation and yield far more complete information than the two dimensional profiles available from cross-sectioned samples.

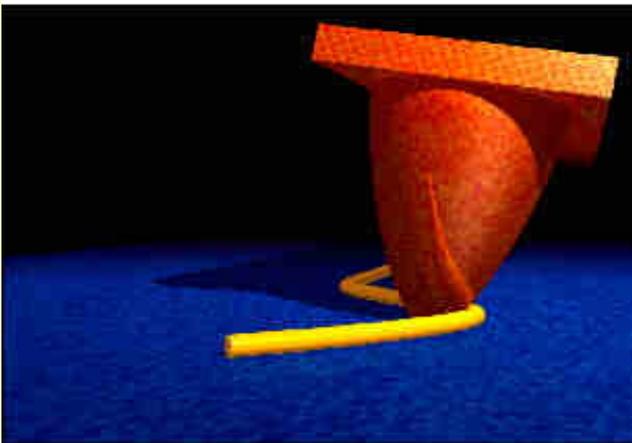
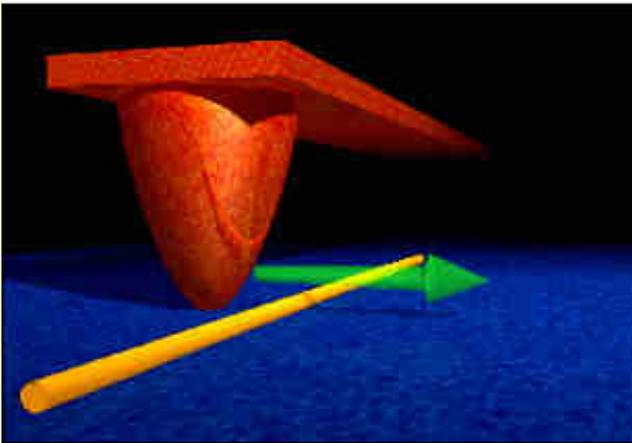
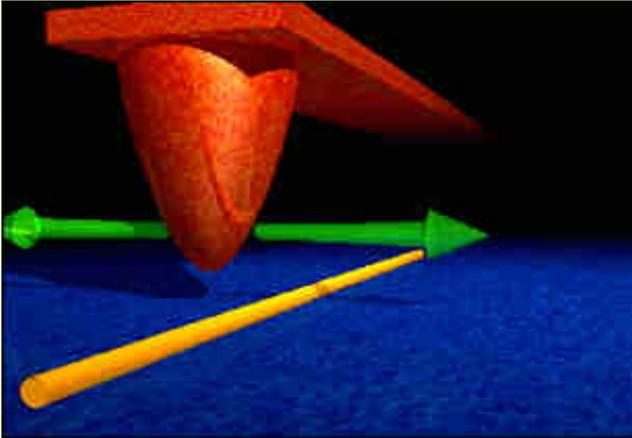
Supplement

AFM - manipulacja

The AFM is first used in "non-contact" mode to obtain an image of the nanotube by scanning the AFM tip, shown in red in the schematic on the left, just above the surface.

The AFM tip is then brought down to the surface and is used like a tiny plow to move the nanotube.

Because of the strong interaction between the nanotube and the surface via van der Waals forces, the bent Nanotube stays where it has been placed and maintains its shape, rather than snapping back to its preferred straight configuration.

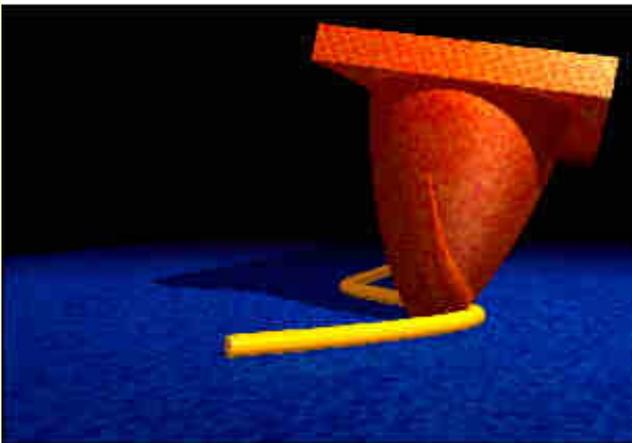
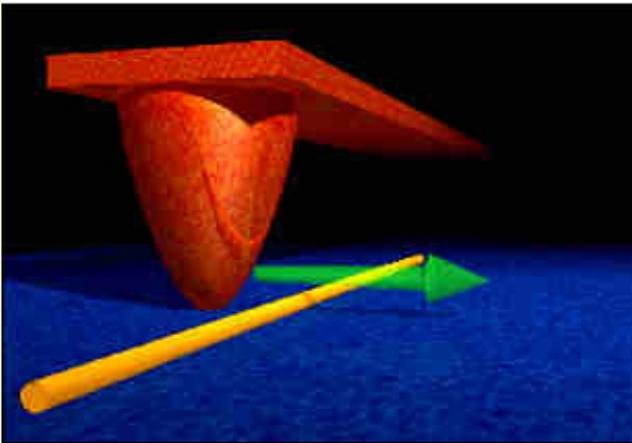
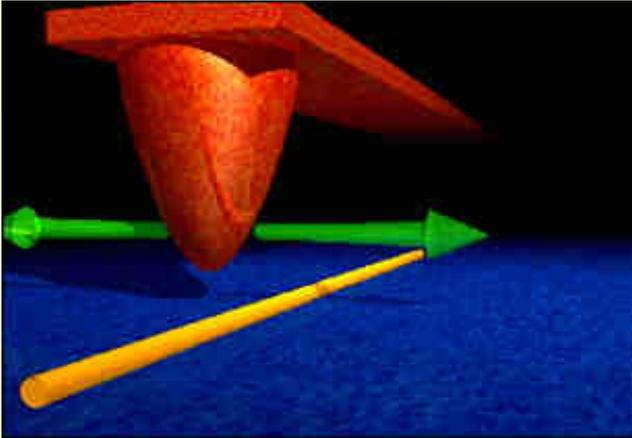


AFM – manipulacja 2

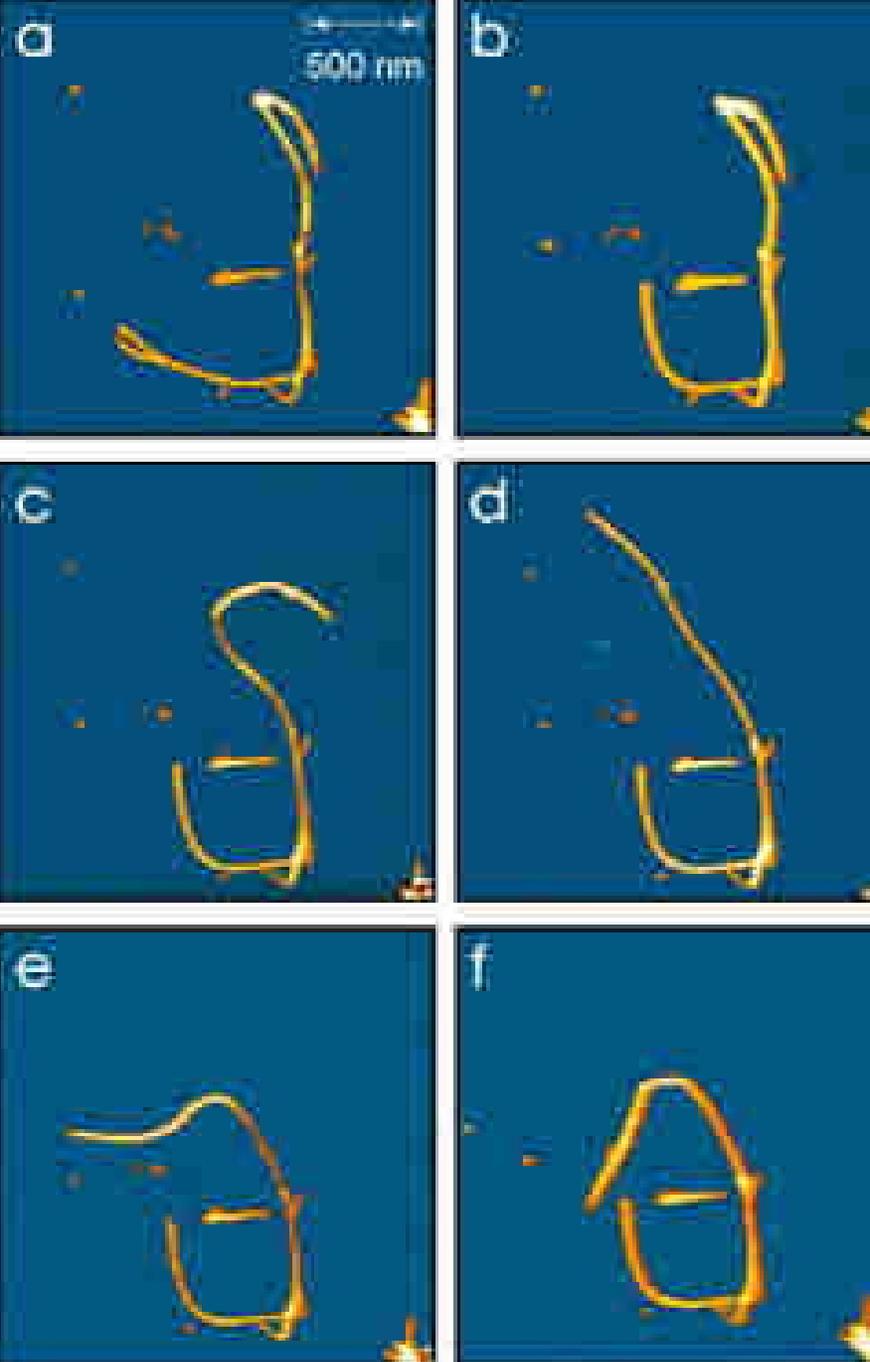
The AFM is first used in "non-contact" mode to obtain an image of the nanotube by scanning the AFM tip, shown in red in the schematic on the left, just above the surface.

The AFM tip is then brought down to the surface and is used like a tiny plow to move the nanotube.

Because of the strong interaction between the nanotube and the surface via van der Waals forces, the bent Nanotube stays where it has been placed and maintains its shape, rather than snapping back to its preferred straight configuration.



AFM – manipulacja 3



On the left we show another example of how a nanotube can be manipulated to form complex shapes: the 6 frames are a series of AFM images of a nanotube (orange) on a silicon substrate (blue). Not all steps are shown. The AFM tip is used to create the Greek letter "theta" from a 2.5 micron long nanotube.