دانشکده مهندسی نساجی – دانشگاه صنعتی اصفهان

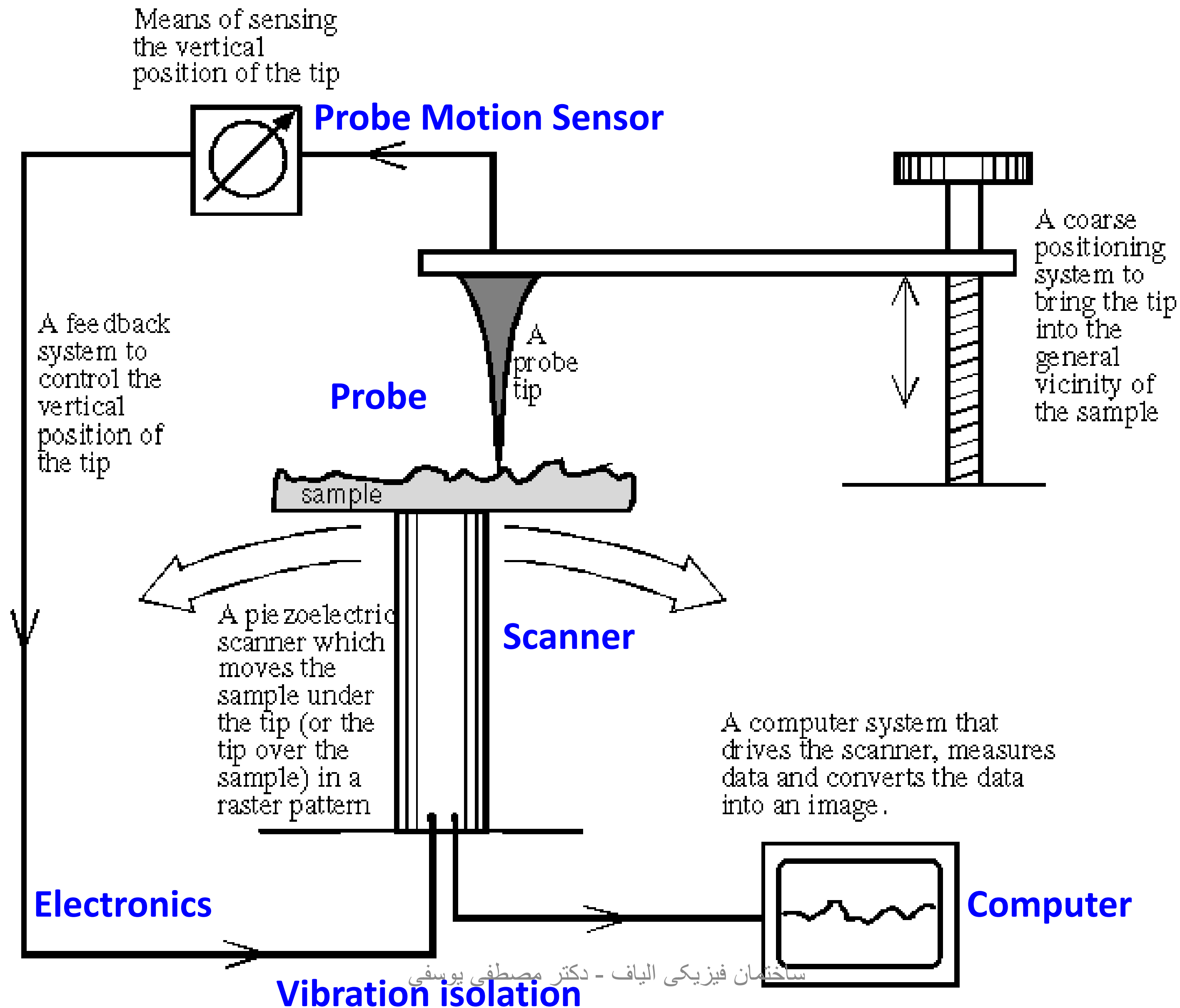
ساختمان فیزیکی الیاف

دکتر مصطفی یوسفی

Scanning Probe Microscopy

Schematic of a generalized SPM

از این میکروسکوپ ها برای مطالعه سطح مواد در مقیاس اتمی تا میکرونی استفاده می شود.



Basic Principles of SPM (STM & AFM)

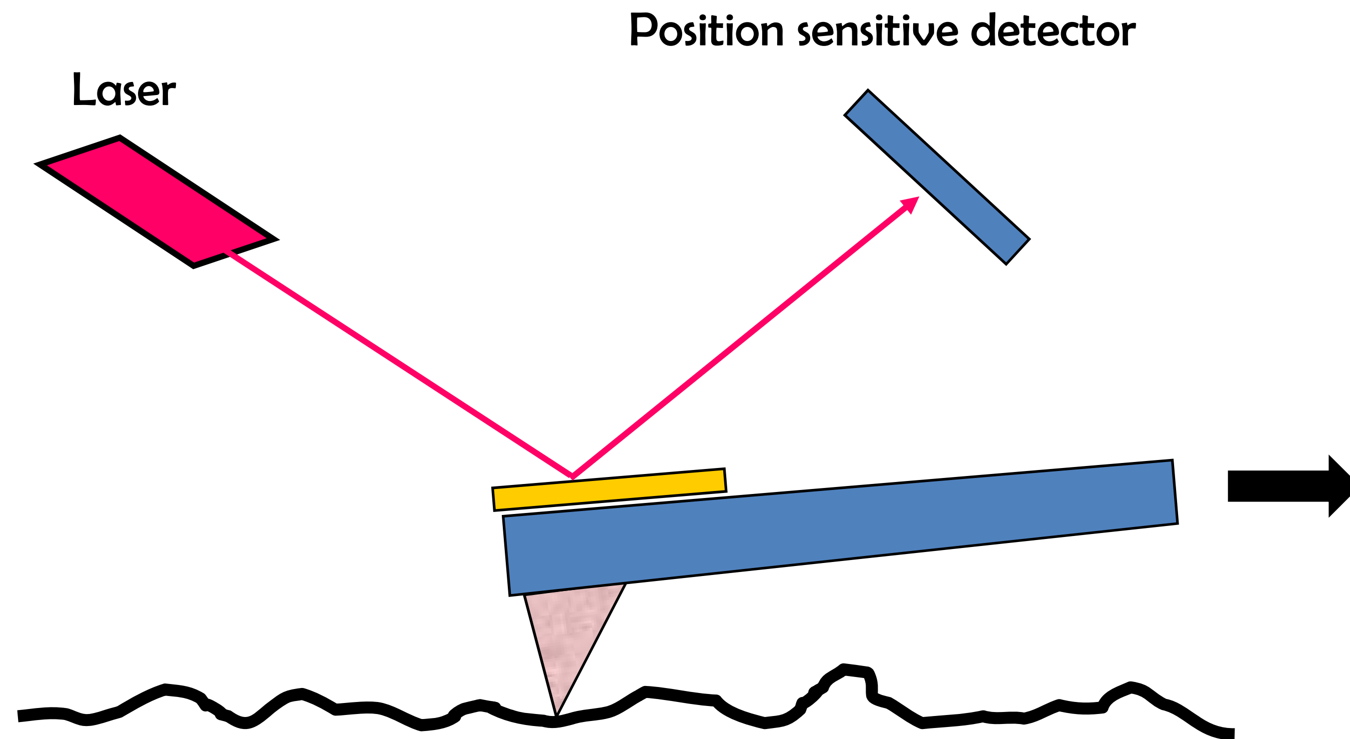
SPM دارای تیغه بسیار تیزی می باشد که در فاصله چند نانومتر بالای نمونه قرار می گیرد. وقتی تیغه سطح نمونه را جارو می کند، پستی و بلندی های سطح باعث انتقال سیگنال به تیغه می شود و در نهایت یک نقشه سه بعدی از سطح نمونه حاصل می شود.

انواع تیغه ها که برای حس کردن سطح نمونه استفاده می شوند عبارتند از:

electron tunneling current (**STM**),
interatomic forces (van der Waals force, **AFM**),
magnetic force (MFM),
capacitive coupling (SCM),
electrostatic force (EFM),
thermal coupling (**SThM**), etc.

سیگنال های تیغه بستگی به برهم کنش نیروهای بین تیغه و سطح دارد و می تواند به پستی و بلندی های در حد ۰.۱ آنگستروم هم حساس باشد.

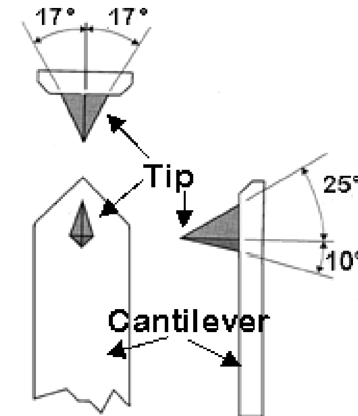
Scanning Probe Microscopy



Braille for Scientists

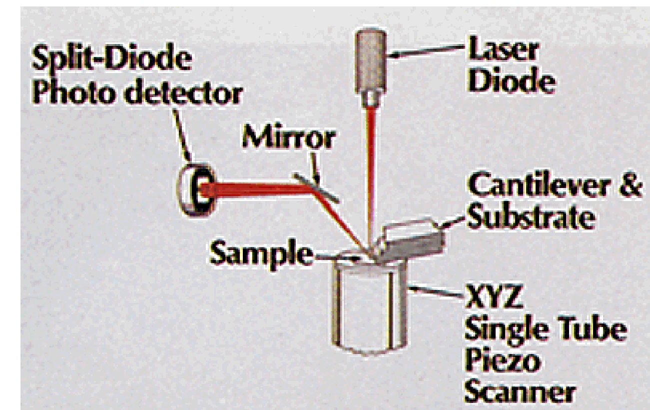
اجزاء اصلی SPM

•Scanning System



•Probe (tip)

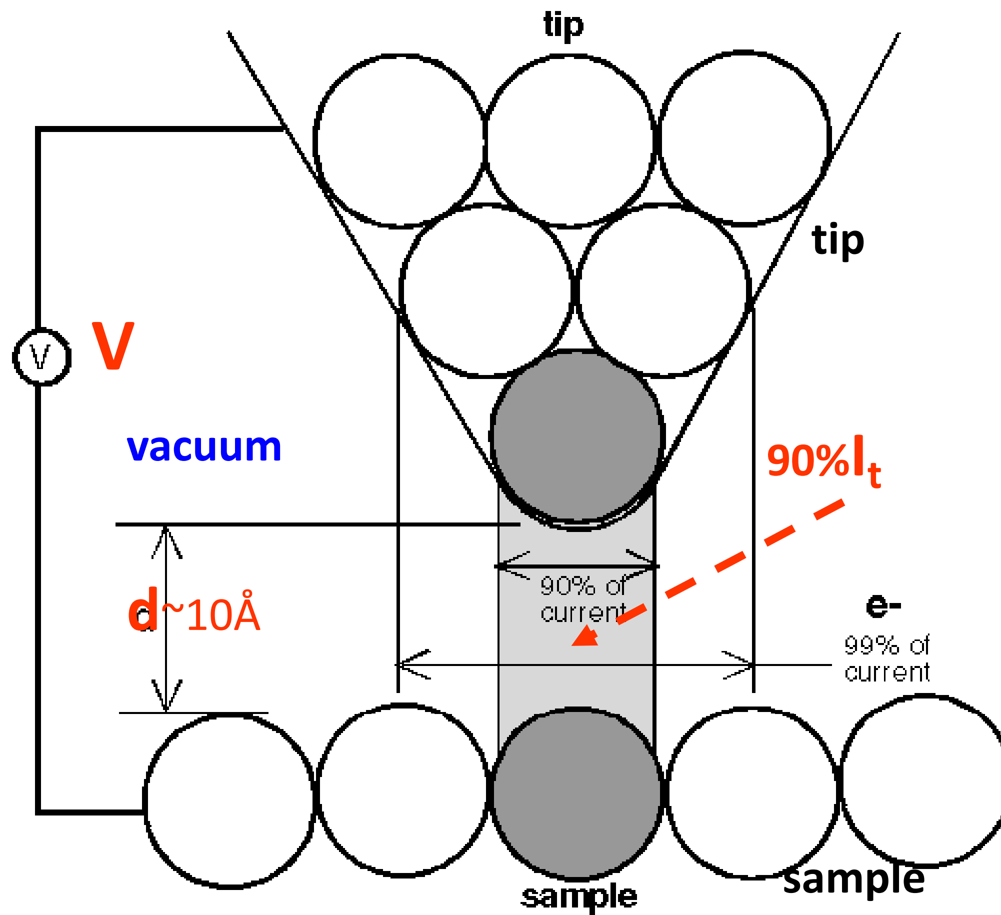
•Probe Motion Sensor



Scanning Tunneling Microscopy

- In 1981, the Scanning Tunneling microscope was developed by Gerd Binnig and Heinrich Rohrer – IBM Zurich Research Laboratories in Switzerland (Nobel prize in physics in 1986).
- This instrument works by scanning a very sharp metal wire tip over a sample very close to the surface. By applying an electric current to the tip or sample, we can image the surface at an extremely small scale – down to resolving individual atoms.

Scanning Tunneling Microscope(STM)



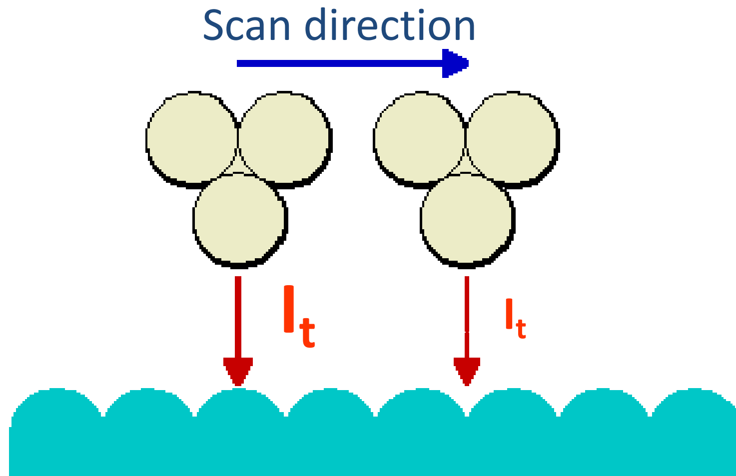
$$I_t = Ve^{-Cd}$$

STM دارای یک تیغه تیز هادی می باشد. بین تیغه و نمونه اختلاف پتانسیل وجود دارد. وقتی تیغه به فاصله حدود ۱۰ نانومتری سطح نمونه می رسد، جریان تونلی الکترونی بین نمونه و تیغه برقرار می شود.

For tunneling to take place, both the sample and the tip must be **conductors** or **semiconductors**.

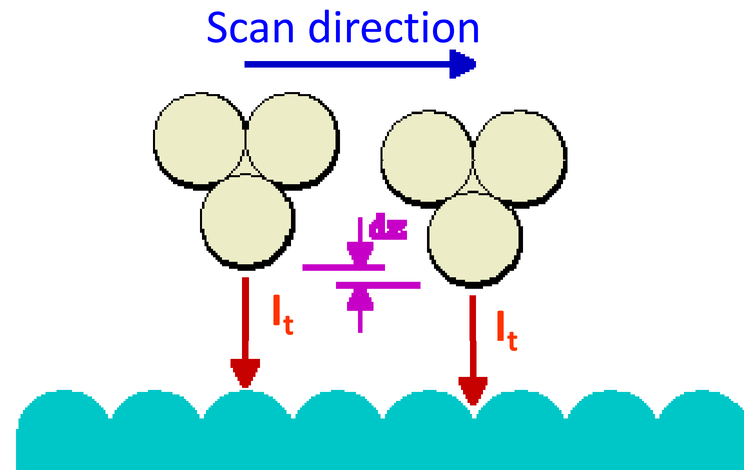
Two Scanning Modes in STM-2

Imaging of surface topology can be done in one of two ways:



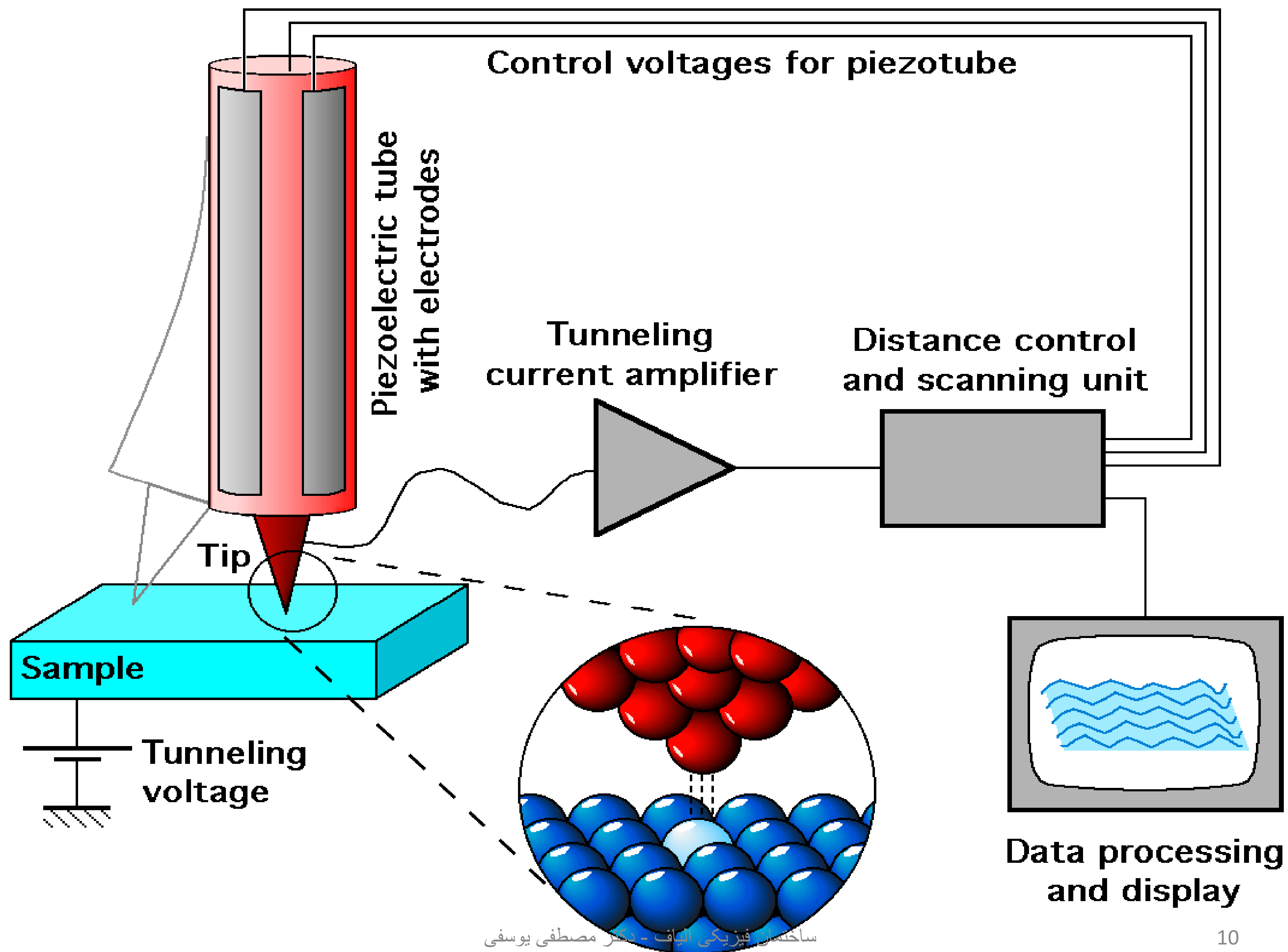
constant height mode

در هنگام جارو شدن سطح نمونه توسط تیغه، جریان تونلی اندازه گیری می شود. با محاسبه جریان نسبت به موقعیت تیغه تصویر به وجود می آید

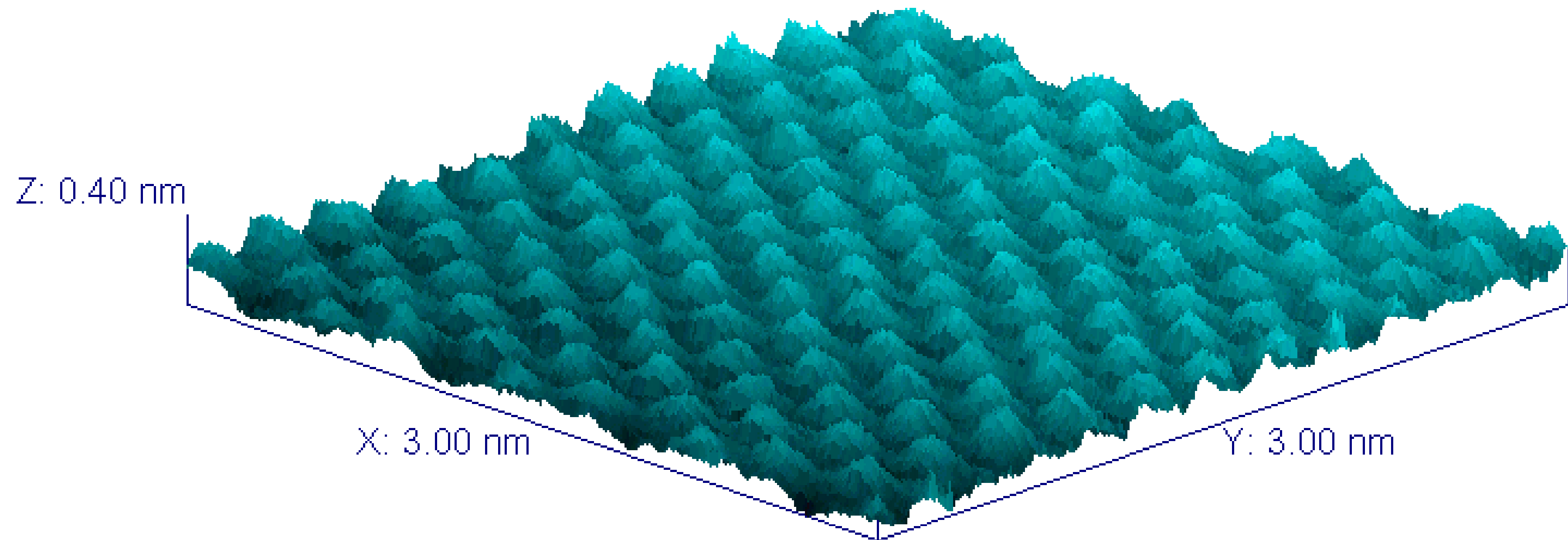


constant current mode

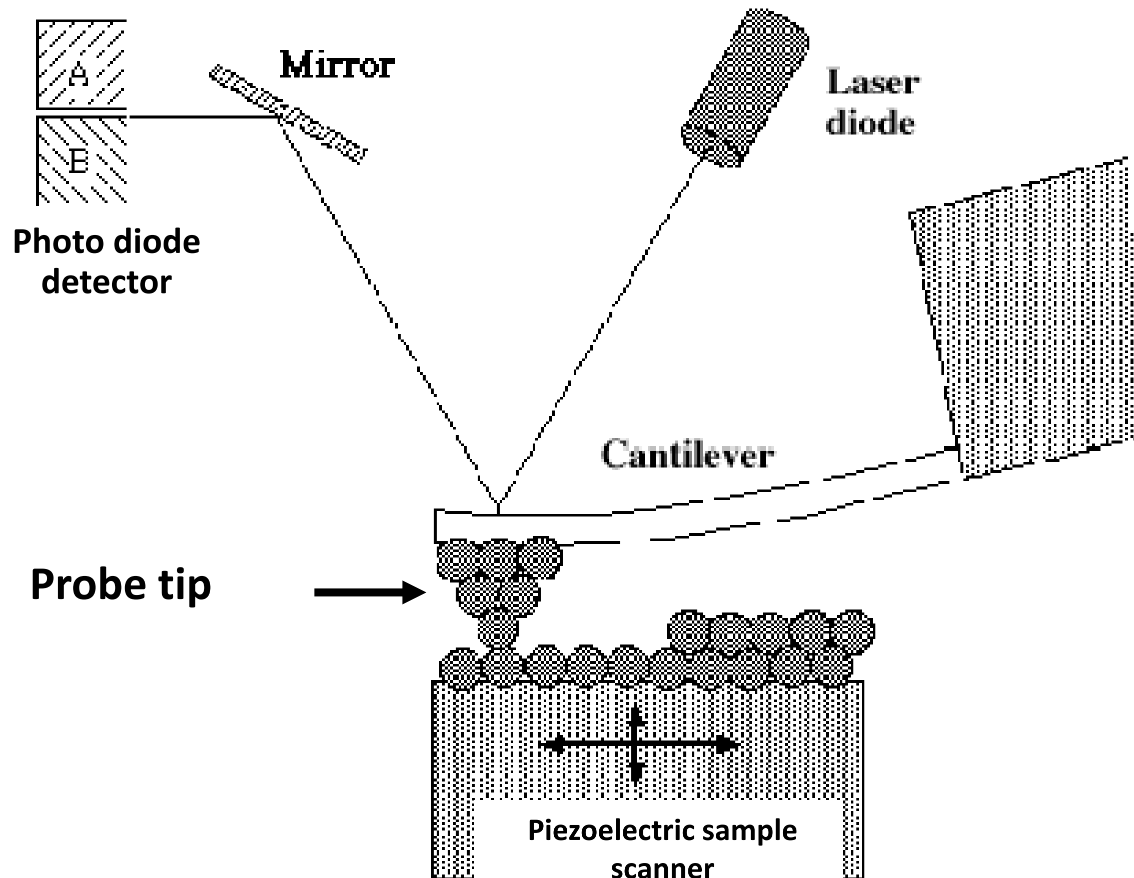
در هنگام جارو شدن سطح نمونه توسط تیغه، جریان تونلی با ثابت تغییر ارتفاع نمونه ثابت نگه داشته می شود. با اندازه گیری تغییرات ارتفاع تیغه و موقعیت تیغه تصویر به وجود می آید.


Control voltages for piezotube
Piezoelectric tube
with electrodes
Tunneling
current amplifier
Distance control
and scanning unit
Tip
Sample
Tunneling
voltage
Data processing
and display

Graphite - magnified



Atomic Force Microscope (AFM)



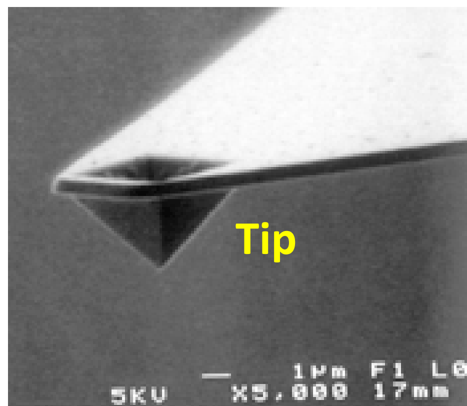
Optical lever detection of cantilever deflection

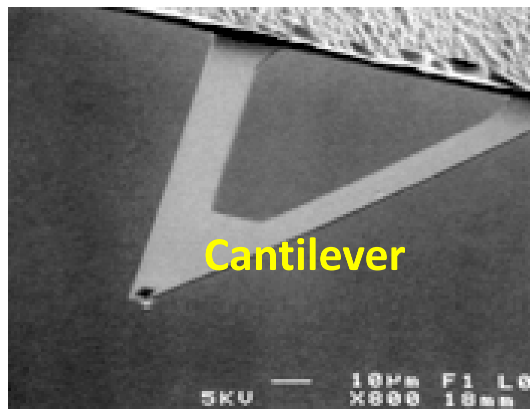
در AFM نیرو های بین اتمی
بین تیغه و نمونه نقش اصلی
را دارند.

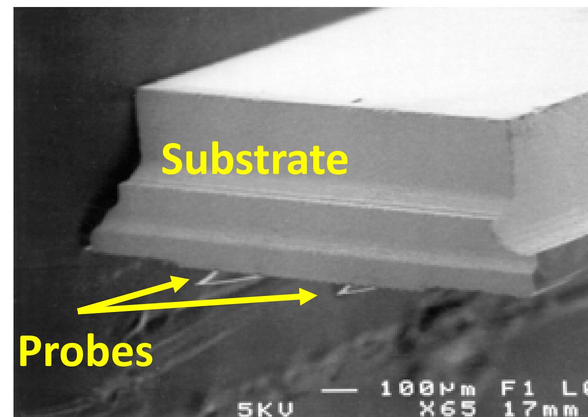
AFM senses interatomic forces that occur between a probe tip and a sample.

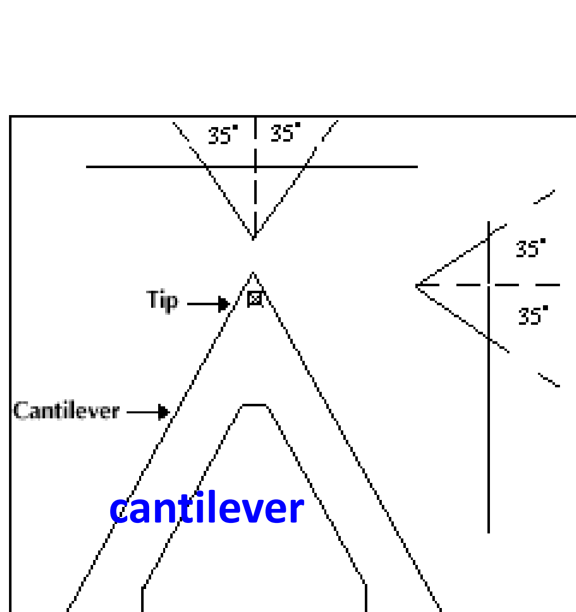
نقشه سه بعدی سطح با رسم ارتفاع سطح نمونه در مقابل موقعیت تیغه به دست می آید.

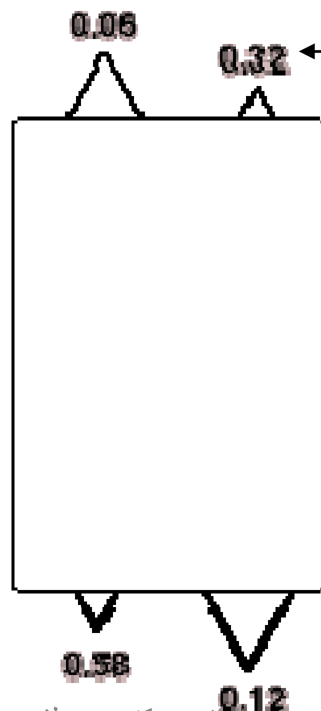
Silicon Nitride-Contact Mode AFM Probe







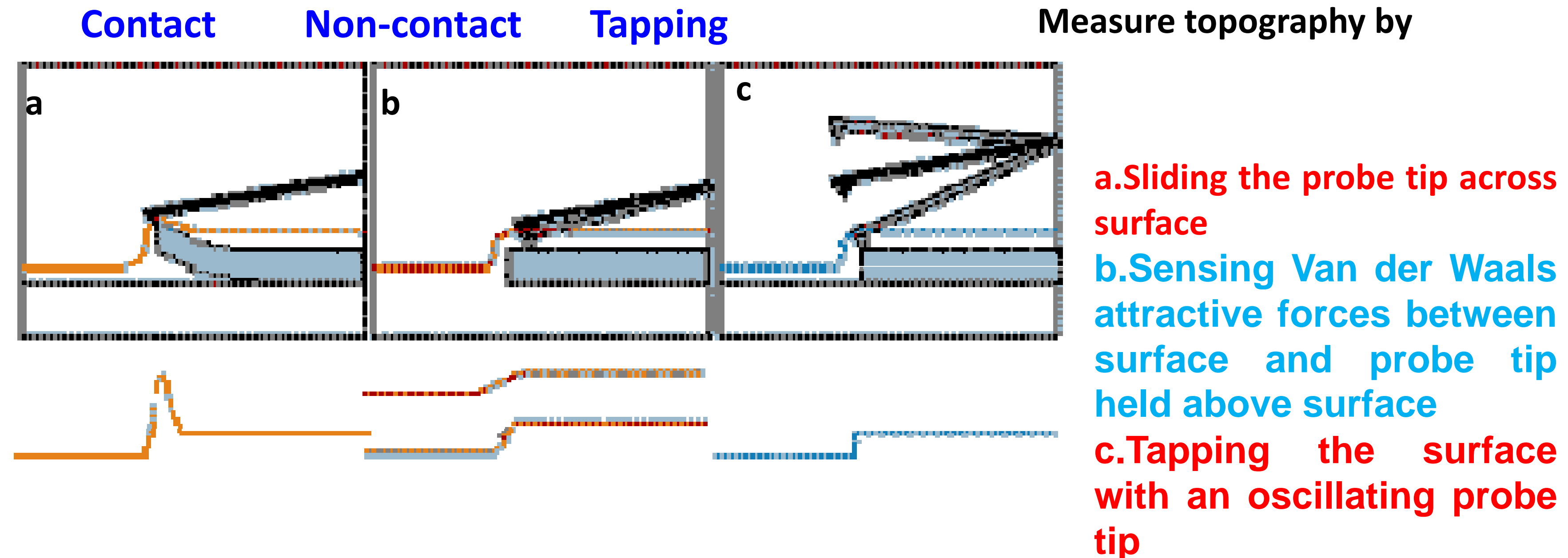




خواص و ابعاد تیفه نقش اصلی را در تعیین حساسیت و قدرت تفکیک AFM دارد.

The properties and dimensions of the cantilever play an important role in determining the sensitivity and resolution of the AFM.

Contact, Non-Contact and TappingMode AFM

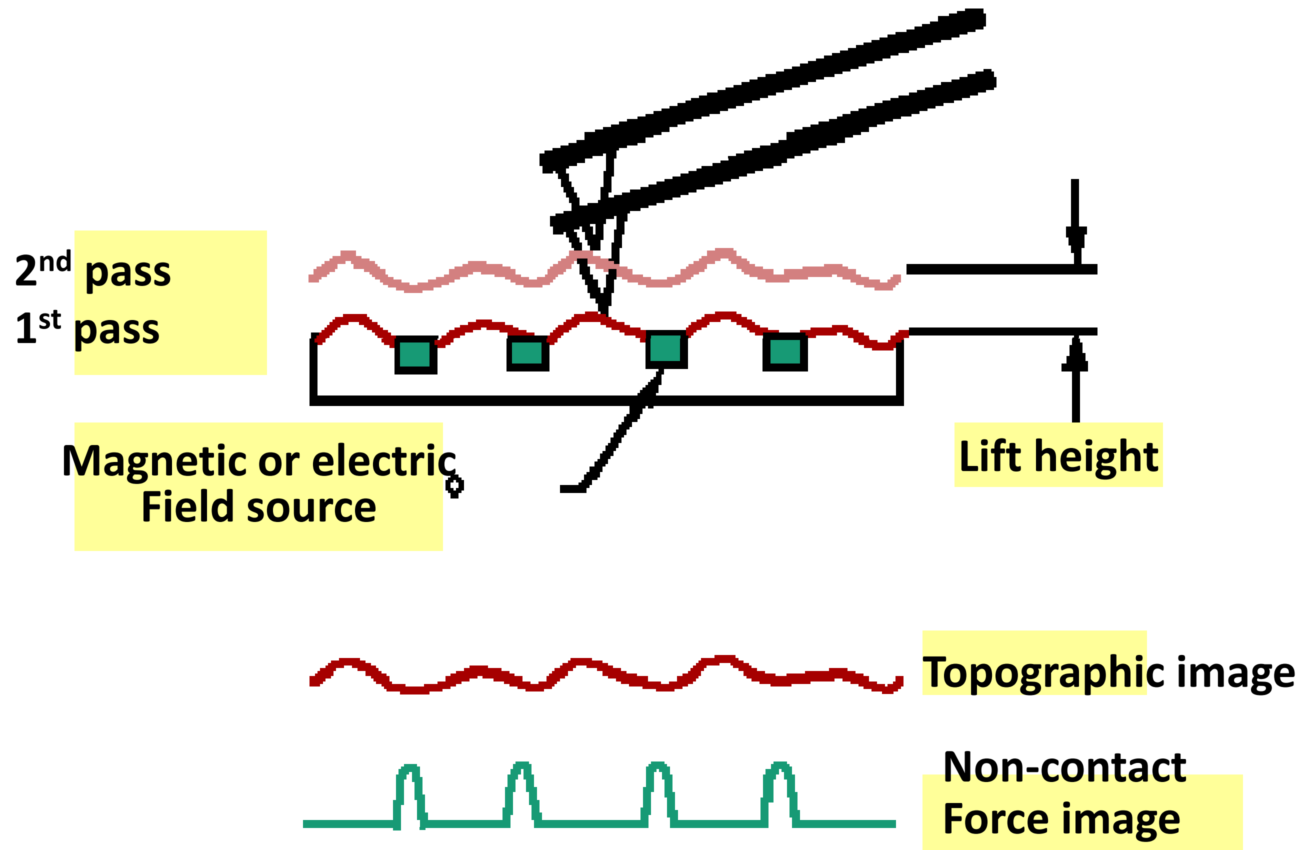


Contact mode imaging is heavily influenced by frictional and adhesive forces which can damage samples and distort image data.

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

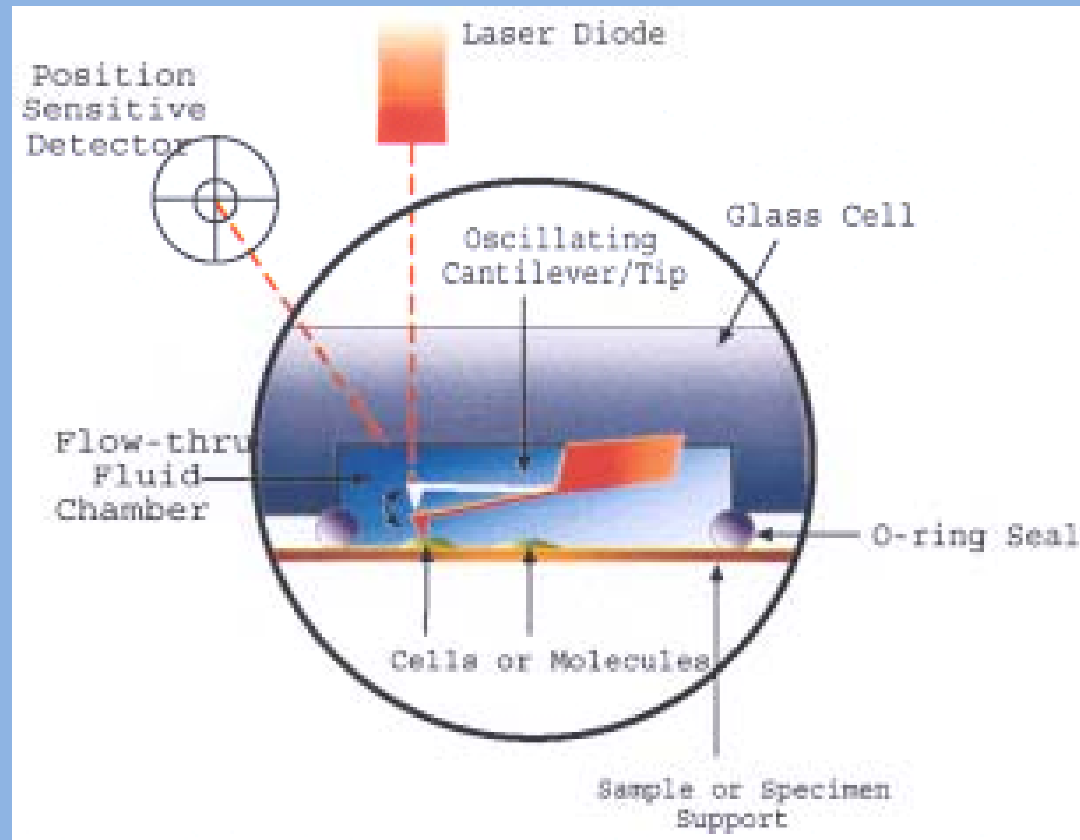
TappingMode imaging eliminates frictional forces by intermittently contacting the surface and oscillating with sufficient amplitude to prevent the tip from being trapped by adhesive meniscus forces from the contaminant layer. The graphs under the images represent likely image data resulting from the three techniques.

LiftMode AFM



LiftMode is a two-pass technique for measurement of magnetic and electric forces above sample surfaces. On the first pass over each scan, the sample's surface topography is measured and recorded. On the second pass, the tip is lifted a user-selected distance above the recorded surface topography and the force measurement is made.

Image Insulating Surfaces at High Resolution in Fluid - **AFM**



Fluid cell for an AFM which allows imaging in an enclosed, liquid environment.

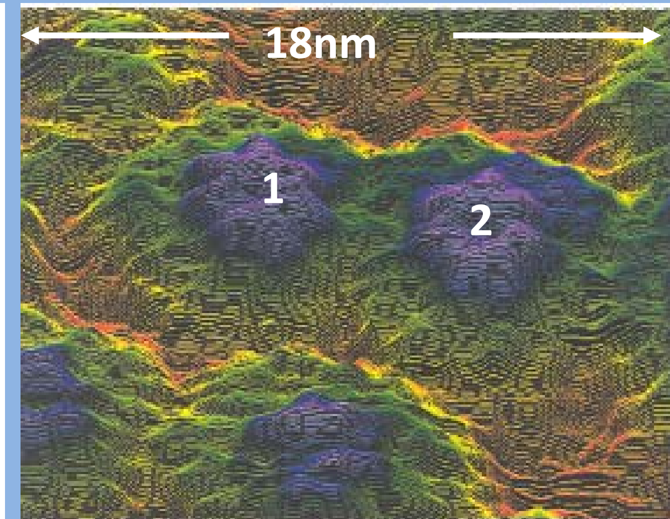


Image of two GroES molecules positioned side-by-side in fluid, demonstrating 1nm lateral resolution and 0.1nm vertical resolution. Entire molecule measures 84Å across and a distinct 45Å "crown" structure protrudes 8Å above remaining GroES surface.

Advanced SPM Techniques

- **Lateral Force Microscopy (LFM)**

  measures **frictional forces** between the probe tip and the sample surface

- **Magnetic Force Microscopy (MFM)**

  measures **magnetic gradient** and distribution above the sample surface; best performed using LiftMode to track topography

- **Electric Force Microscopy (EFM)**

  measures **electric field gradient** and distribution above the sample surface; best performed using LiftMode to track topography

- **Scanning Thermal Microscopy (SThM)**

  measures **temperature distribution** on the sample surface

Advanced SPM Techniques

- **Scanning Capacitance Microscopy (SCM)**

  measures carrier (dopant) concentration profiles on semiconductor surfaces

- **Nanoindenting/Scratching**

  measures mechanical properties of thin films and uses indentation to investigate hardness, and scratch or wear testing to investigate film adhesion and durability

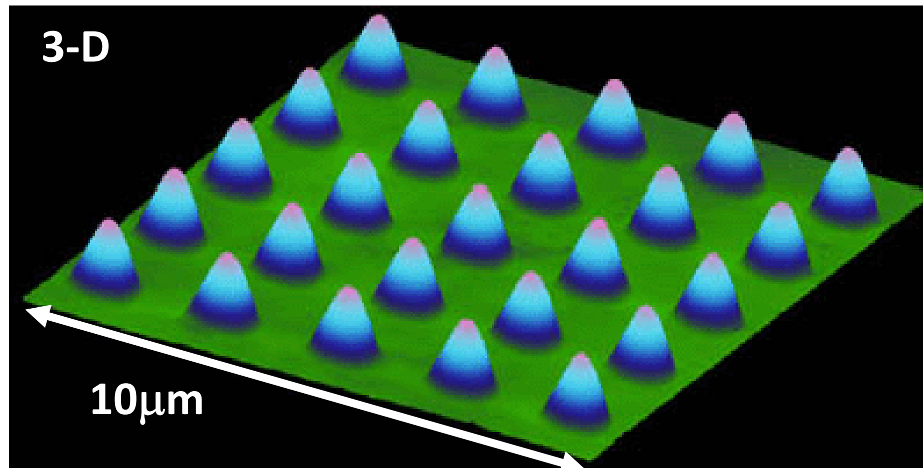
- **Phase Imaging**

  measures variations in surface properties (stiffness, adhesion, etc.) as the phase lag of the cantilever oscillation relative to the piezo drive and provides nanometer-scale information about surface structure often not revealed by other SPM techniques

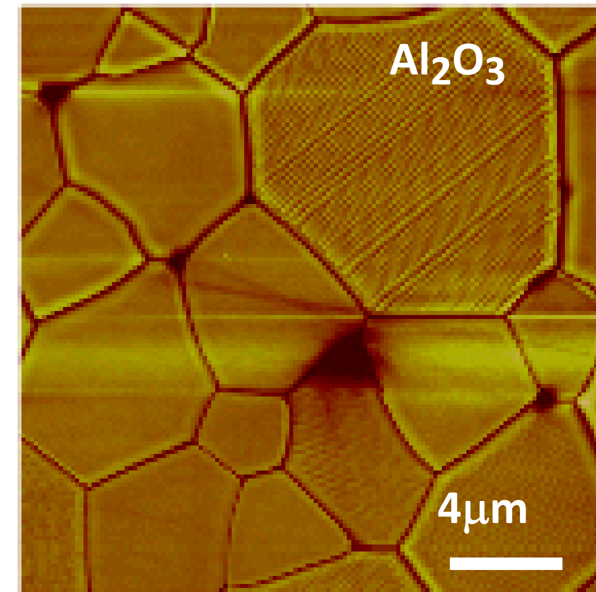
- **Lithography**

  Use of probe tip to write patterns

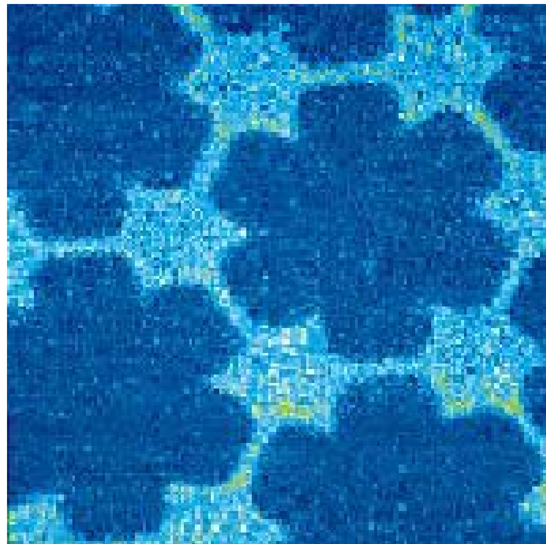
Examples of AFM Images



80nm tall elevated features in a Si/Si_3N_4 substrate



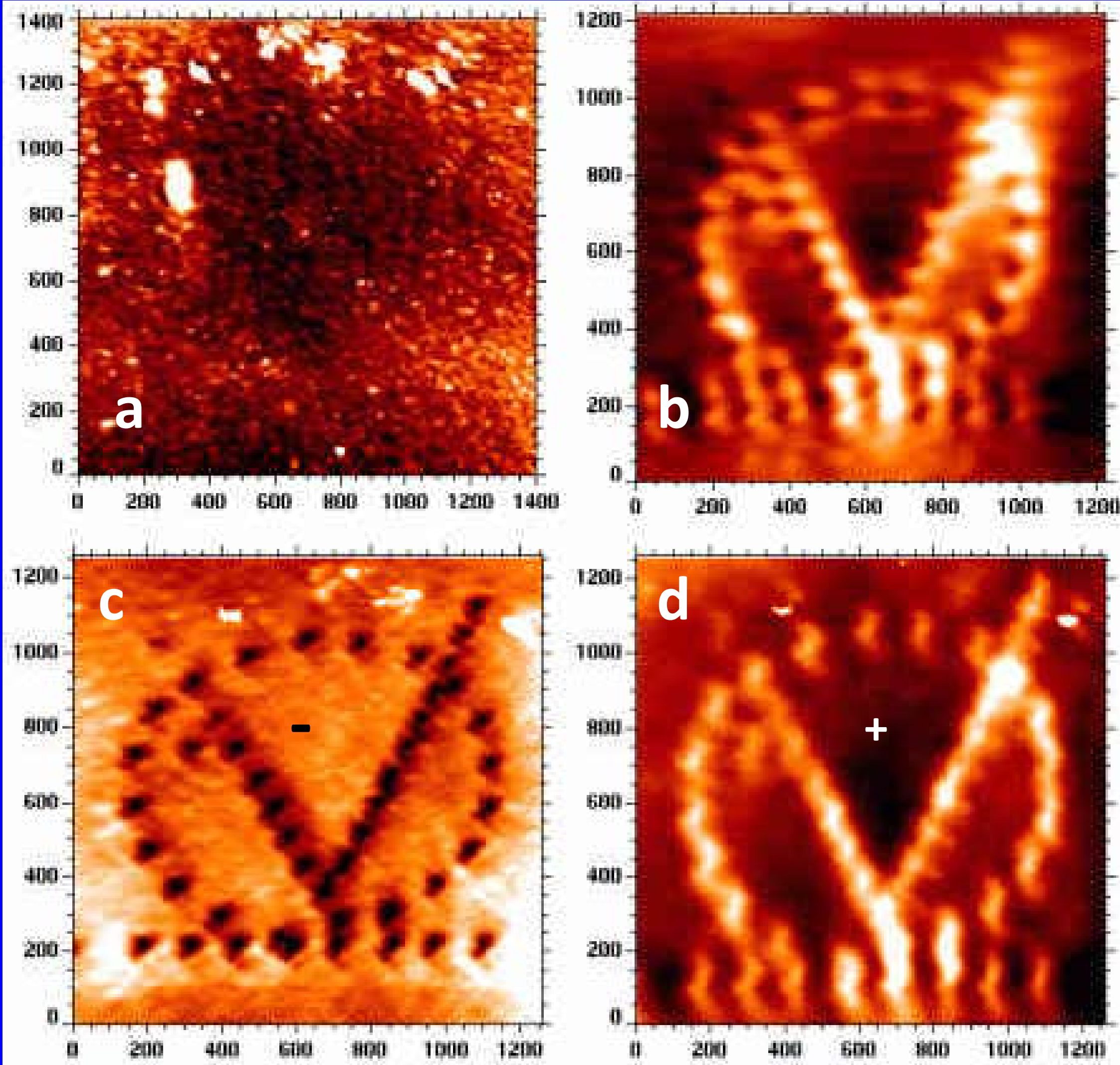
Grain growth studies



Lateral force map of a patterned, monolayer, organic film deposited on a gold substrate. The strong contrast comes from the different frictional characteristics of the two materials. 30 µm scan.

Writing/Reading on Ferroelectric Materials

AFM/Electric Force Microscopy (EFM) Mode :

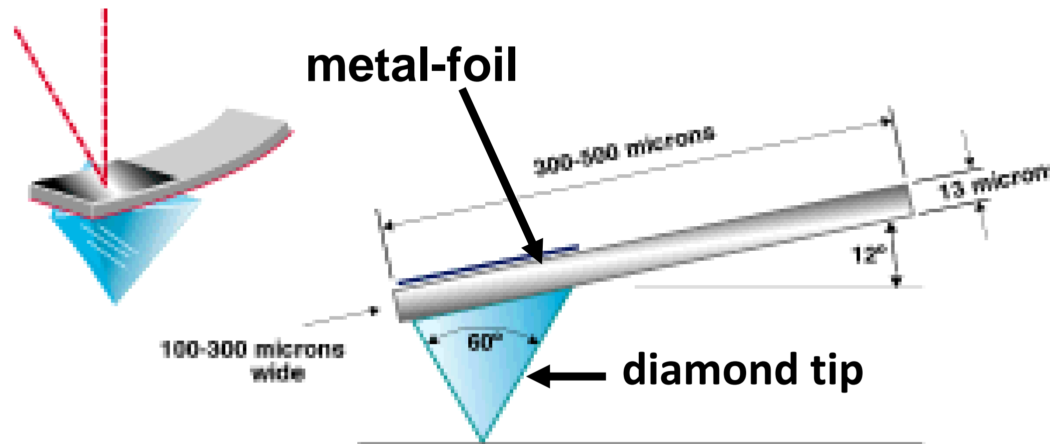


a. Initial surface was first imaged in non-contact mode without a bias voltage at the tip.
b. Imaging of the same surface area yields both dark and bright spots indicating the presence of positive and negative gradients.
c. Image was acquired with -1.5 V at the tip. The features appear black, due to a repulsive electro-static force interaction.
d. The opposite contrast is observed here, where a positive bias of 1.5 V was applied to the cantilever tip.

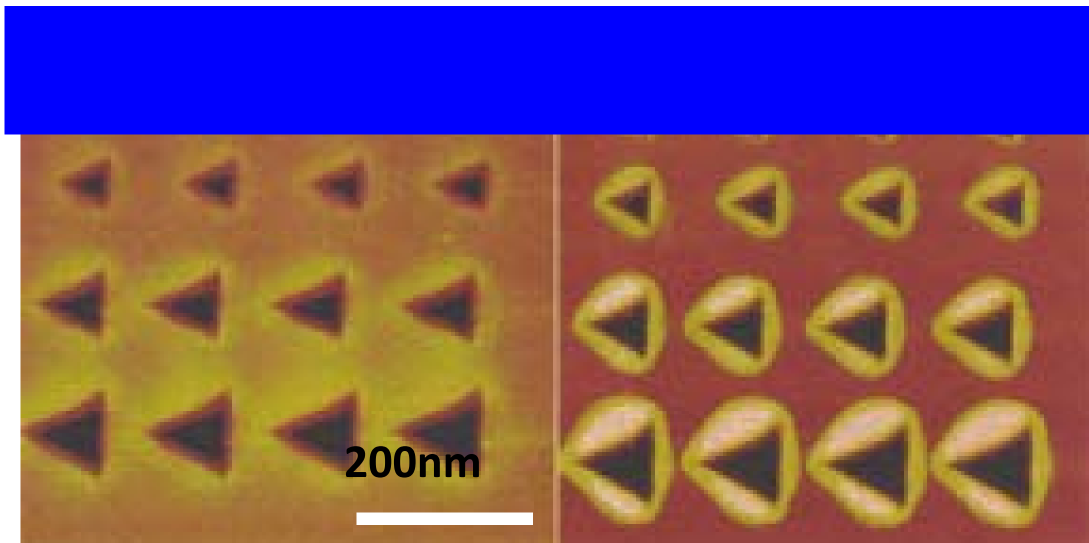
$LaTiO_{3.5}$

polarization

Nanoindentation



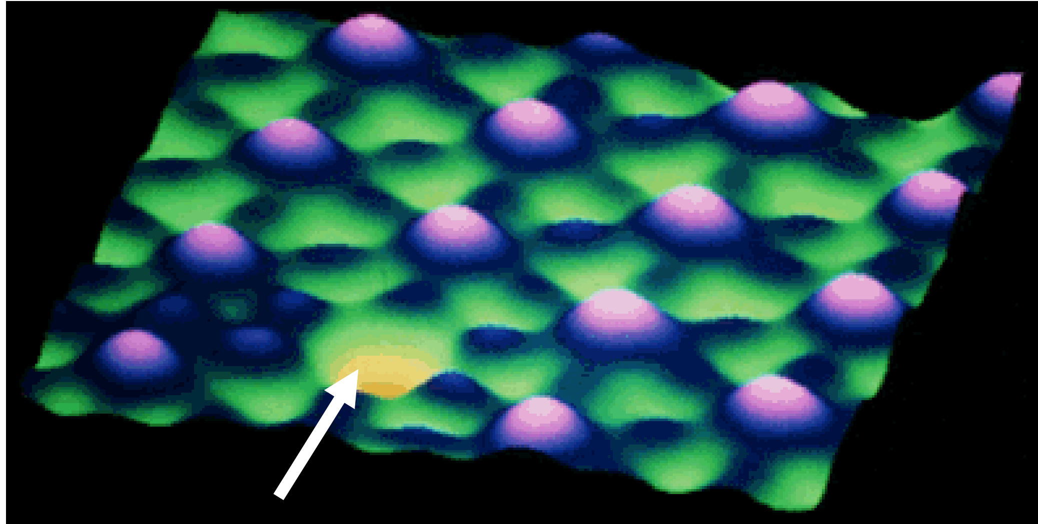
Using a diamond tip to indent a surface and immediately image the indentation. Using indentation cantilevers, it is possible to indent various samples with the same force in order to compare hardness properties.



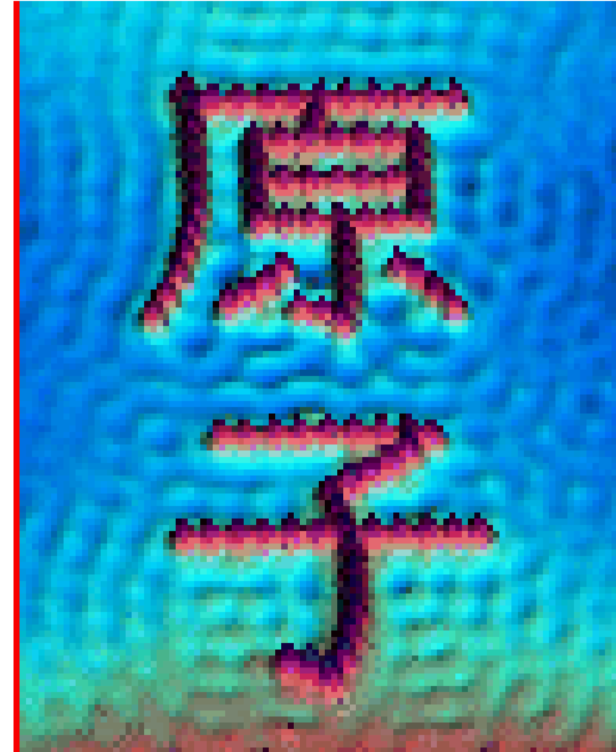
Indentations on two different diamond-like carbon films using three different forces (23, 34, and 45μN) with four incidents made at each force to compare difference in hardness.

Indentation depths are deeper for the softer thin film (right).

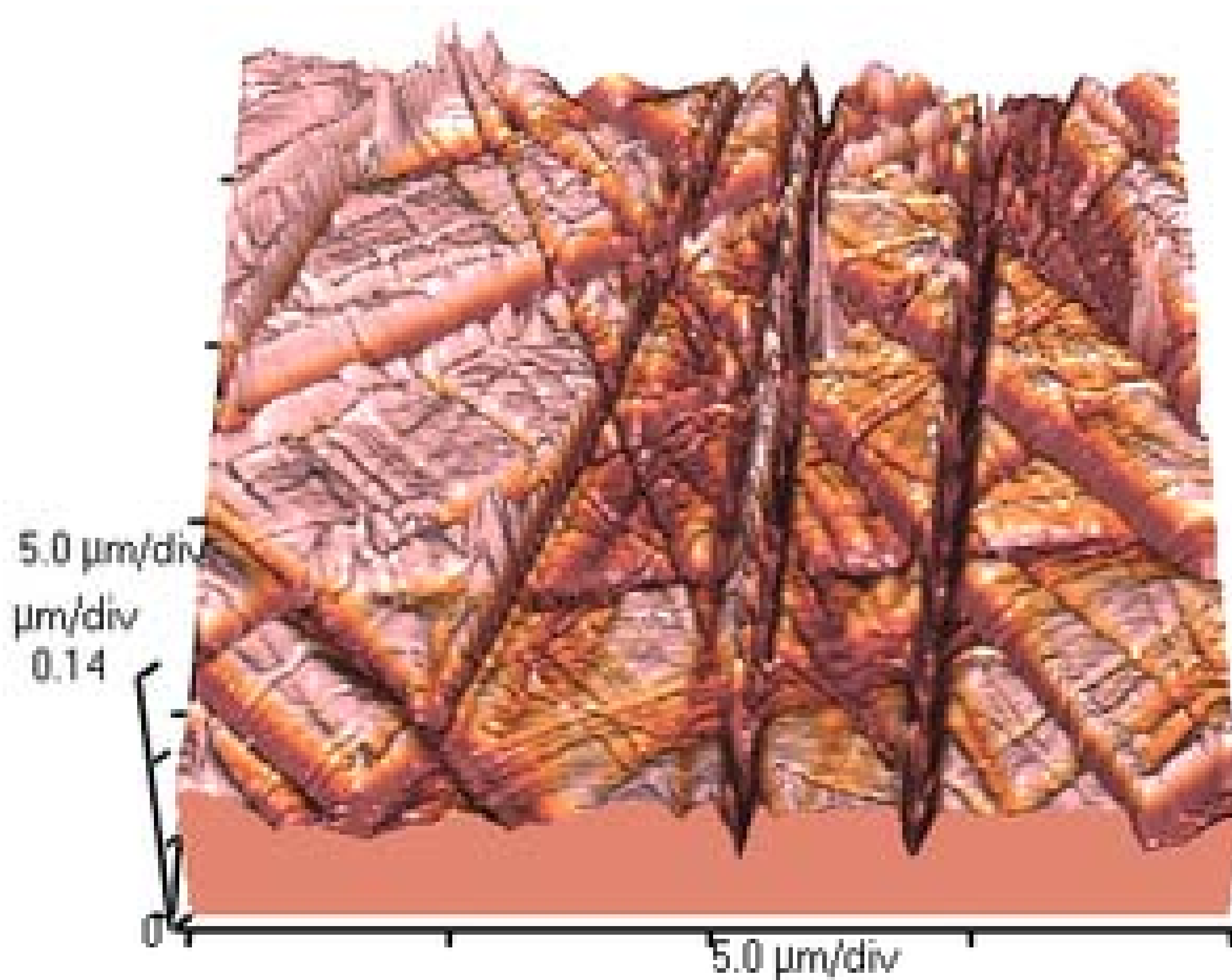
STM - Seeing Atoms



STM image showing single-atom defect in iodine adsorbate lattice on platinum. 2.5nm scan



Iron on copper (111)



Atomic force microscope topographical scan of a glass surface. The micro and nano-scale features of the glass can be observed, portraying the roughness of the material.
Constructed at the Nanorobotics Laboratory at Carnegie Mellon University (http://nanolab.me.cmu.edu).

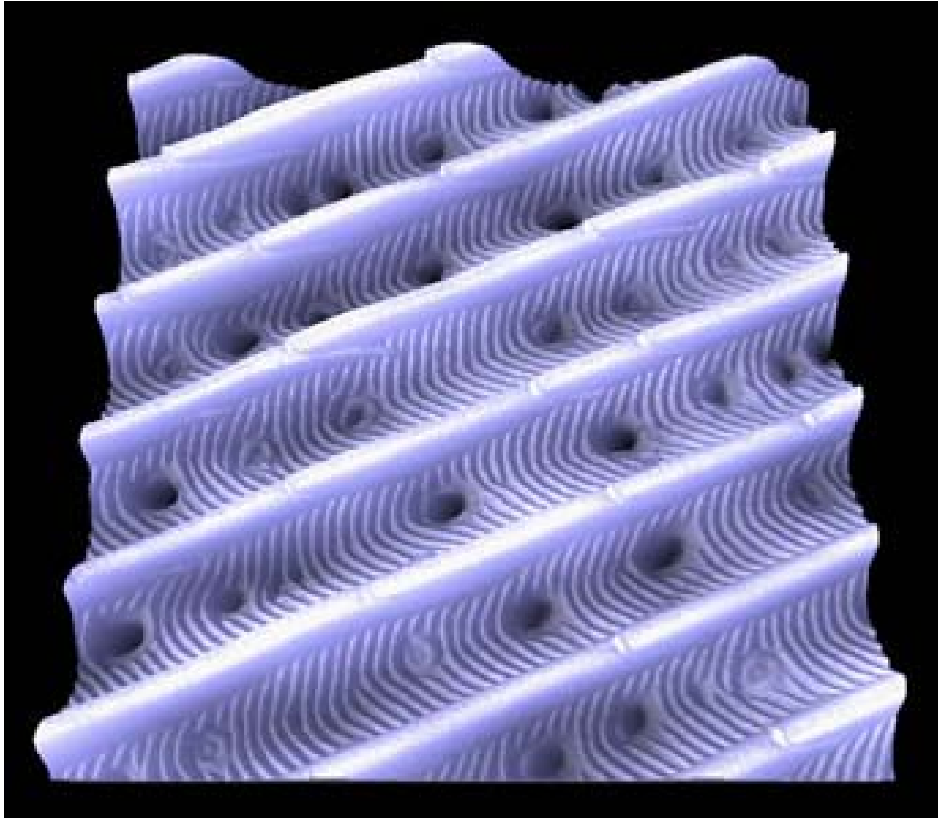


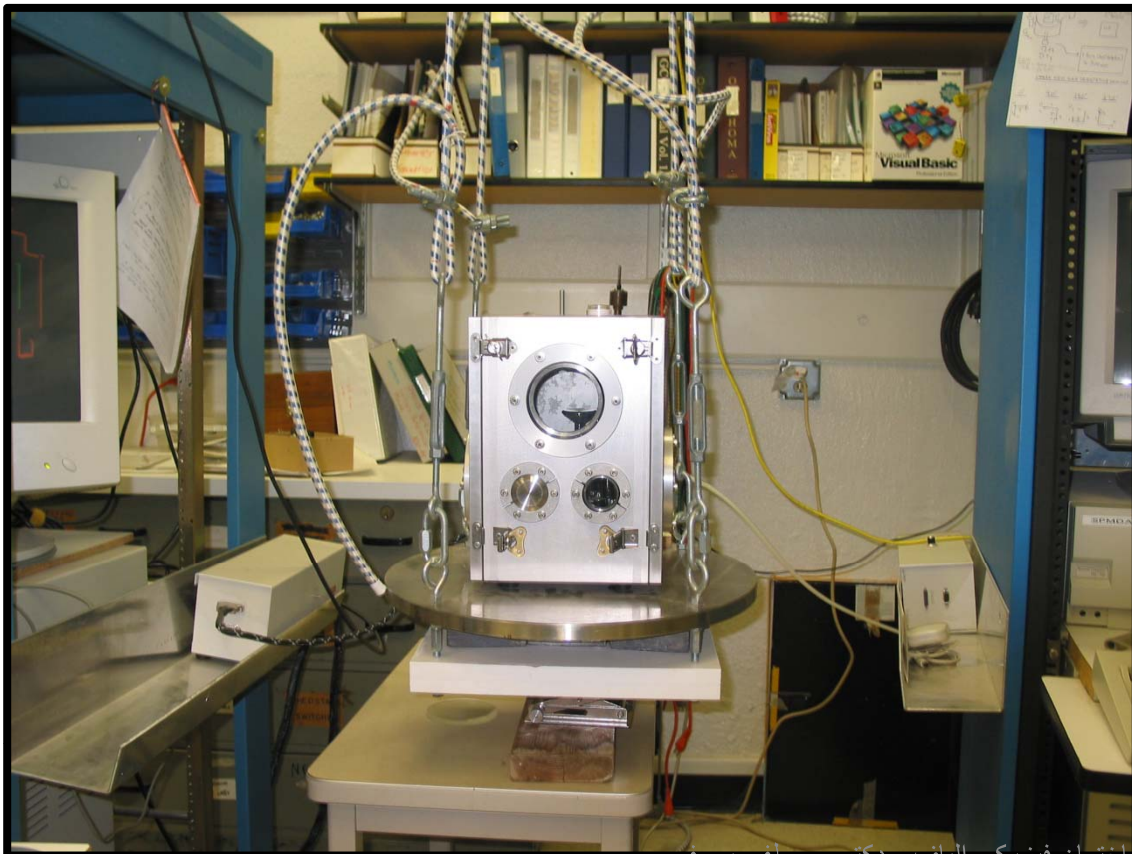
image (left, 3D plot) and
orresponding optical
cope image (above, bright
field) of a

height image (left, 3D plot) and corresponding optical microscope image (above, bright field) of a moth wing scale

intermittent contact mode
scan field 10 µm * 10 µm
z-range 0 - 1.7 µm

AFM

commercial Topometrix Explorer AFM.



مزایای میکروسکوپ های SPM

- ارزانتر بودن
- عدم نیاز به خلاء
- عدم نیاز به روکش نمودن نمونه
- اندازه و ابعاد کمتر
- معایب؟