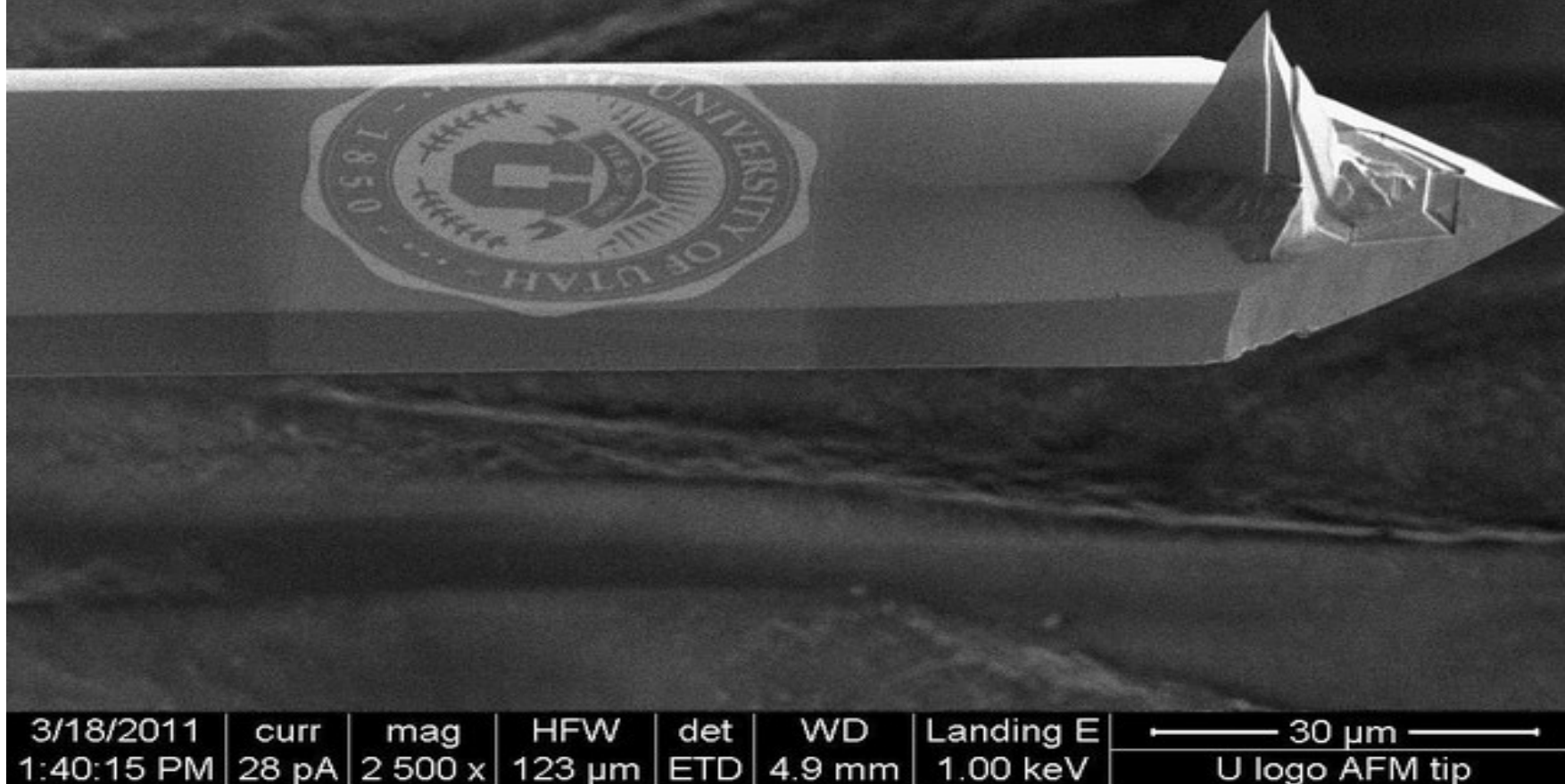


Introduzione al microscopio a Forza Atomica



Microscopia Ottica



Galileo
Microscope
(circa late 1600s)



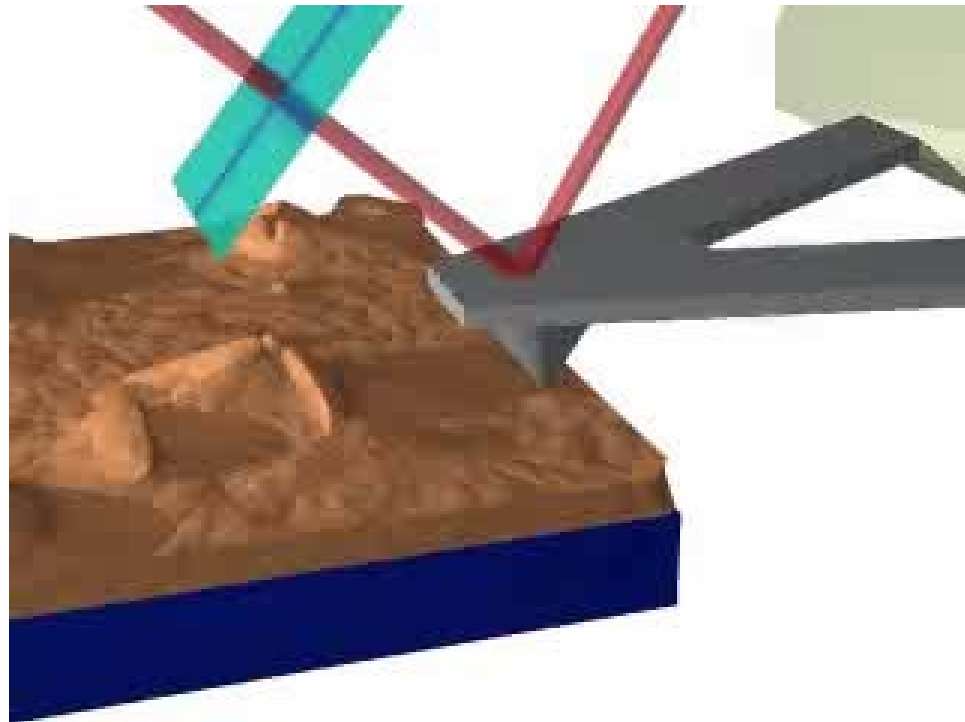
**Dist. tra due atomi in un
cristallo: 1-5 Å**

**Lungh. d'onda della luce:
4000-7000 Å**

$$1 \text{ Å} = 10^{-10} \text{ m} = 0.0000000001 \text{ m}$$

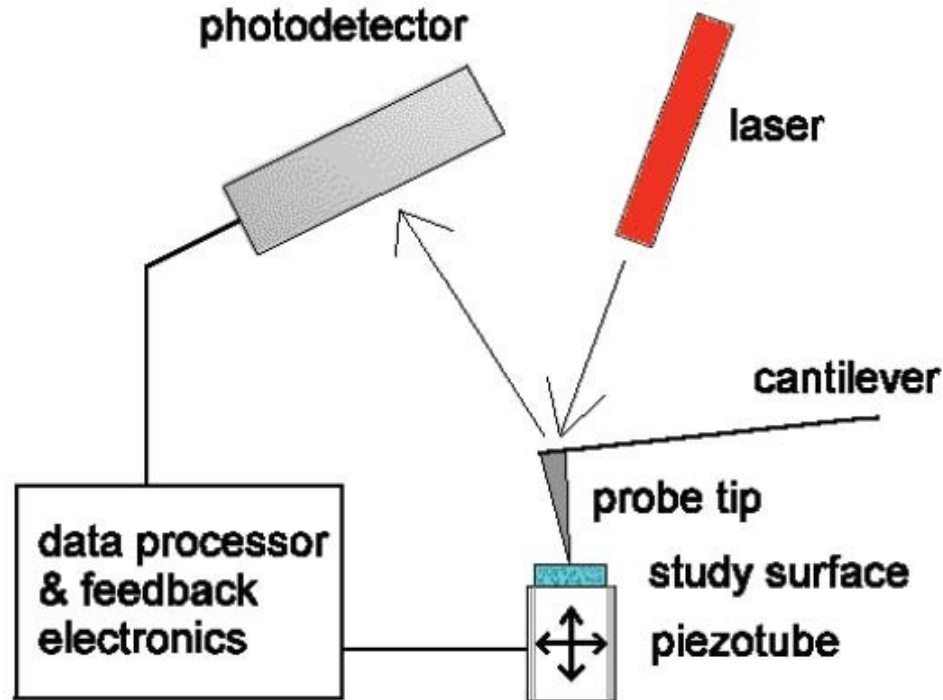


La leva e la punta: il principio dell AFM



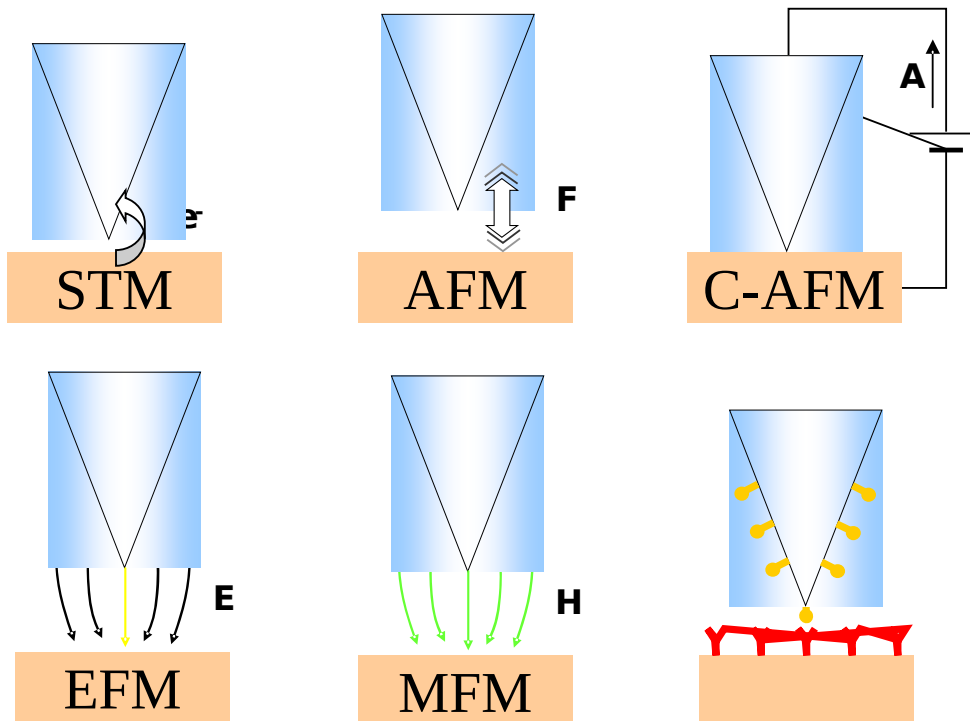
Misura della deflessione

Leva ottica Un fascio laser viene deflesso dal retro del cantilever in un foto-detector sensibile alla posizione

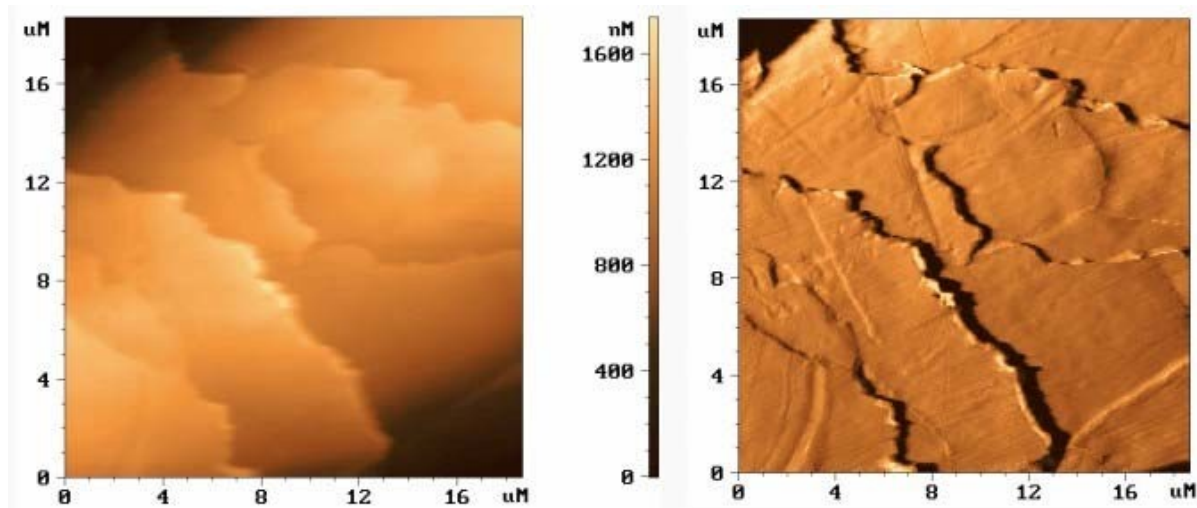


Main advantages of SPMs

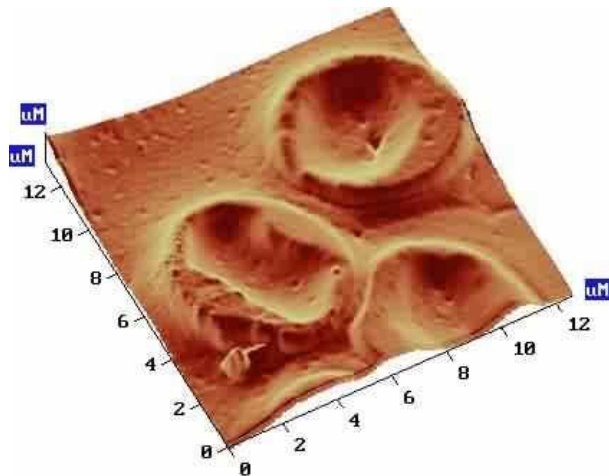
- High vertical resolution ($< 0.1 \text{ \AA}$);
- High lateral resolution;
- Works on conducting, insulating and semiconducting substrates
- Can work in air, vacuum, liquids, etc.
- It is (relatively) cheap, (tens of K€)
- Can be used to monitor different kind of forces: mechanical, electrical, magnetic, “biological”, etc.



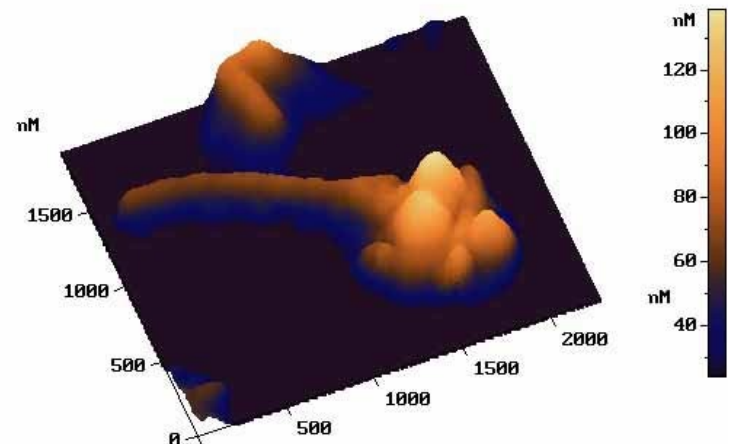
Capello umano



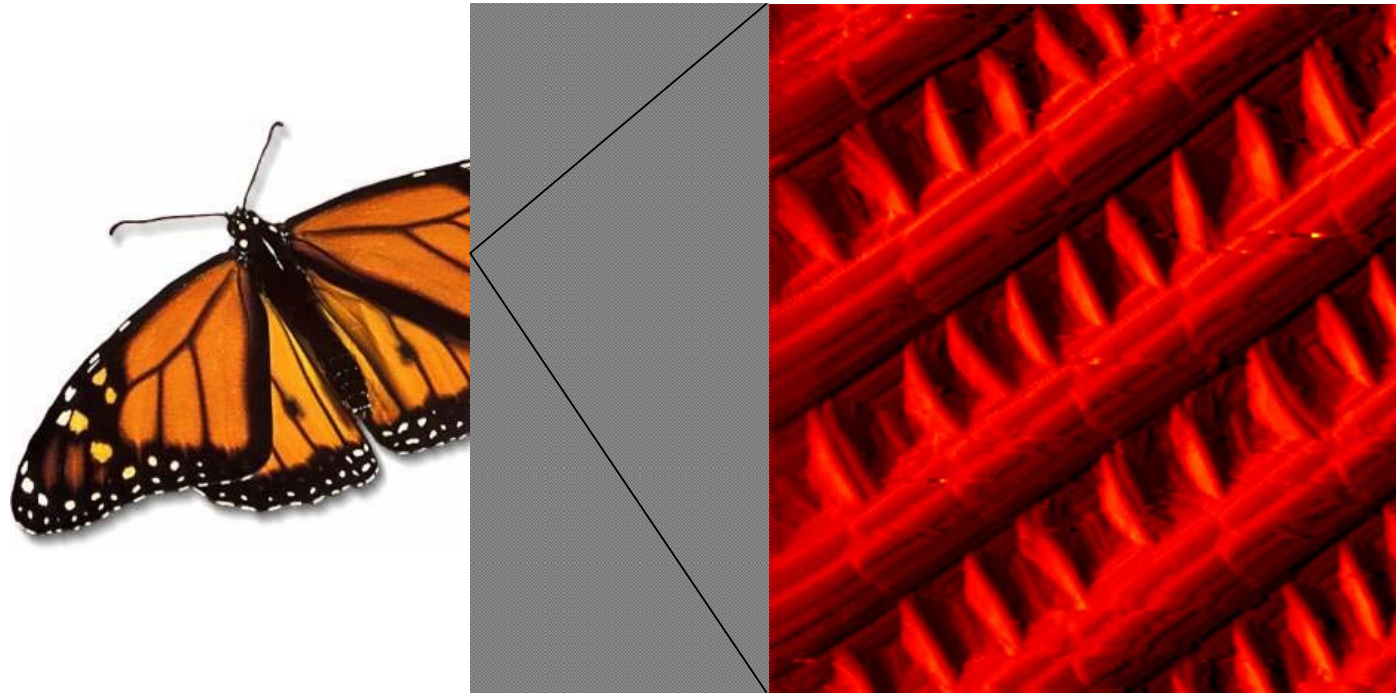
Eritroцити



Virus Ebola



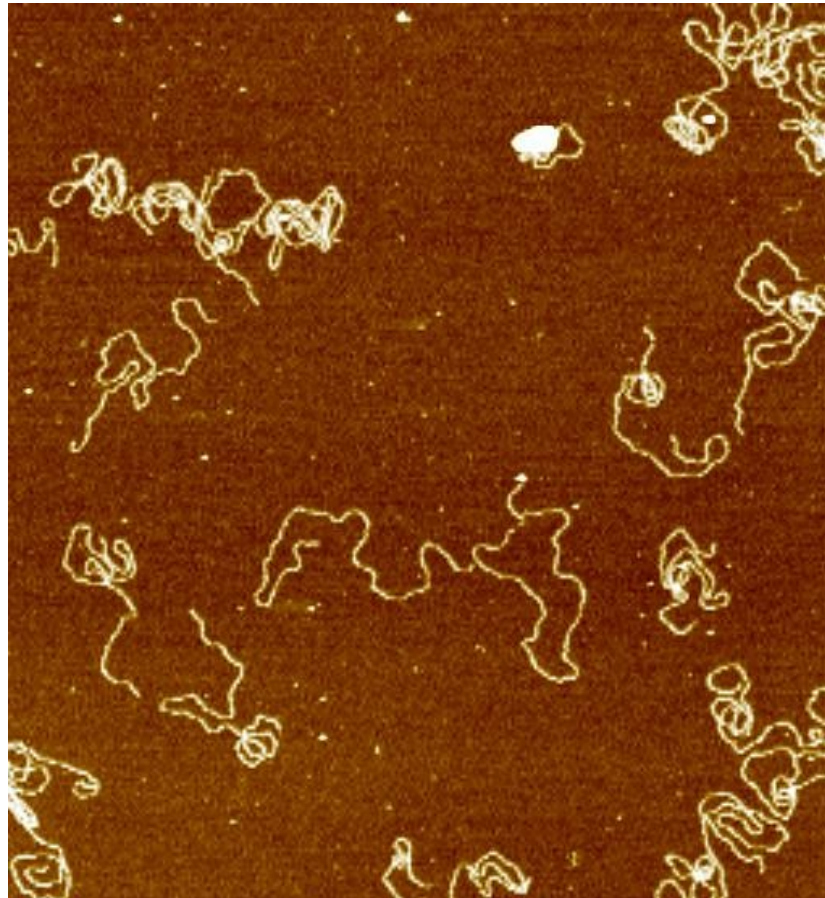
AFM works on many different substrates-1



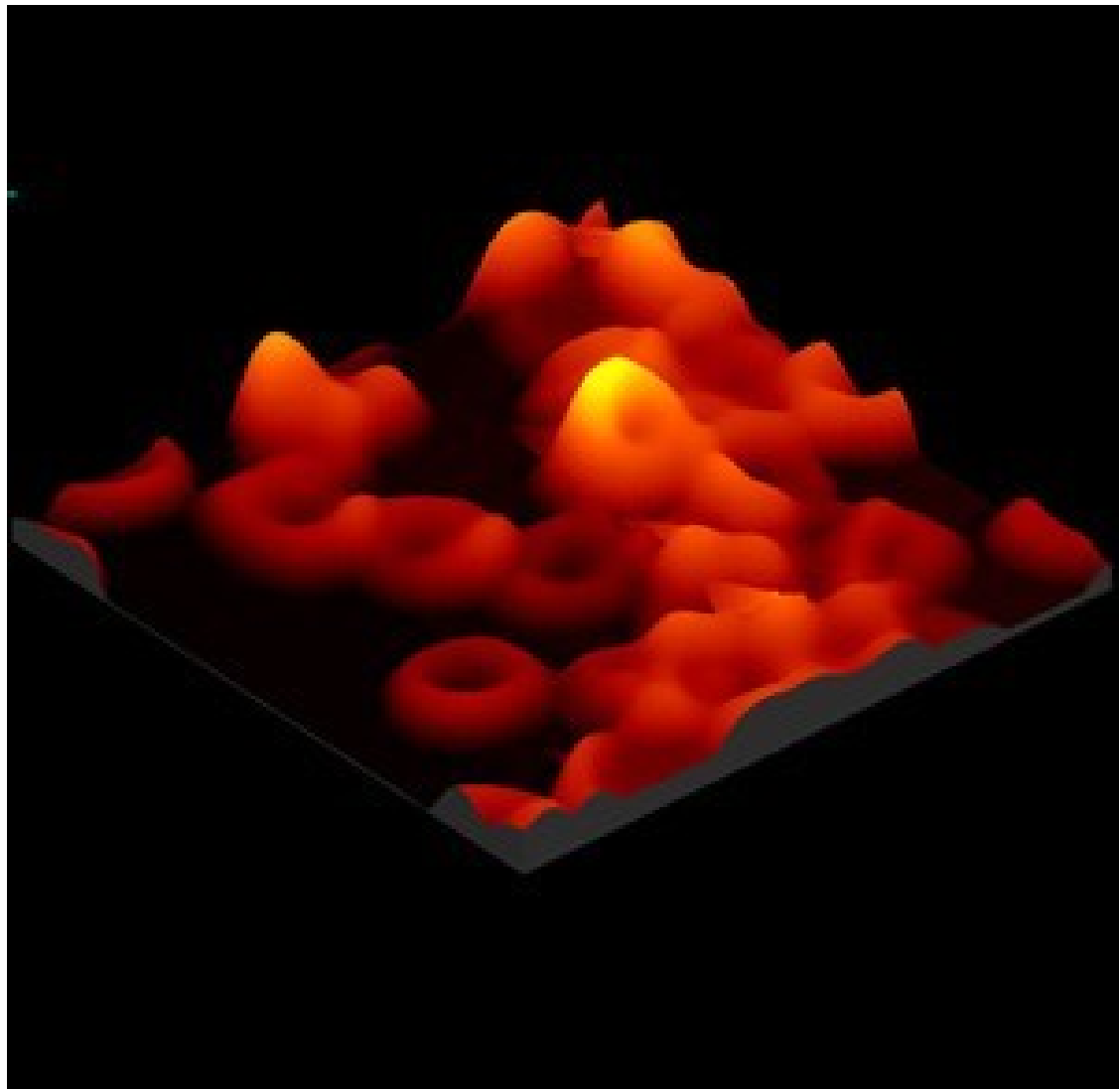
5x5 μm

AFM works in air, vacuum, liquid (in water !)

DNA image taken using tapping mode
under aqueous buffer. 3x3 μm



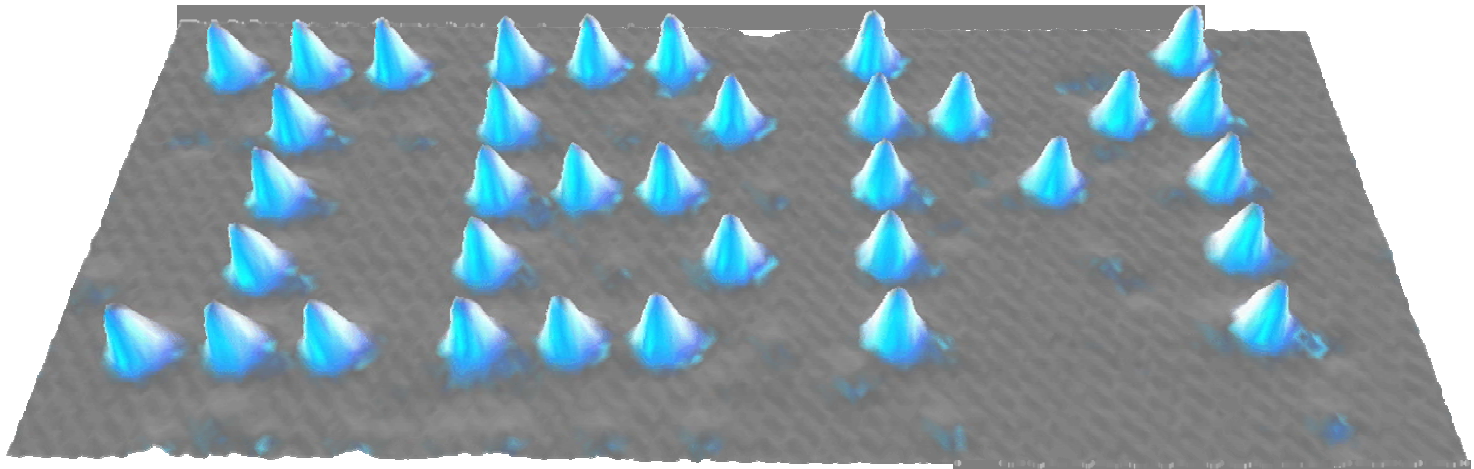
Modo Immagine 3D



height image of eritrociti
contact modescan field $40\text{ }\mu\text{m} * 40\text{ }\mu\text{m}$
z-range $2.1\text{ }\mu\text{m}$

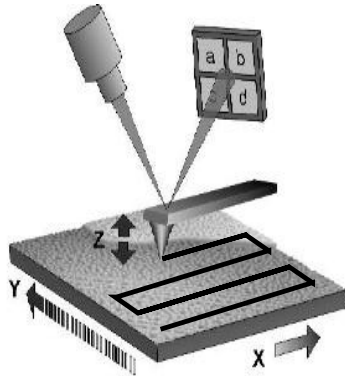
Predictions

“But I am not afraid to consider the final question as to whether, ultimately – in the great future – we can arrange the atoms the way we want; the very *atoms*, all the way down!” – Feynman, 1959



D.M. Eigler, E.K. Schweizer. **Positioning single atoms with a scanning tunneling microscope.** *Nature* 344, 524-526 (1990).

Scanner piezoelettrici

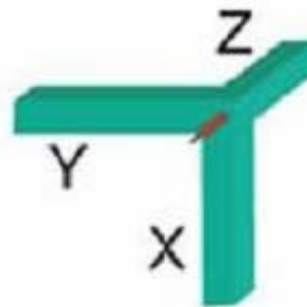


Come controllare su scala nanometrica la movimentazione punta-campione

I materiali ceramici piezoelettrici si deformano (si allungano) quando sono immersi in campo elettrico.

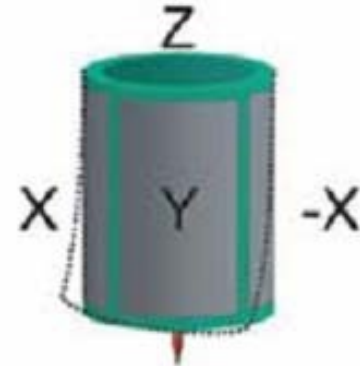


a)



Primi modelli

b)

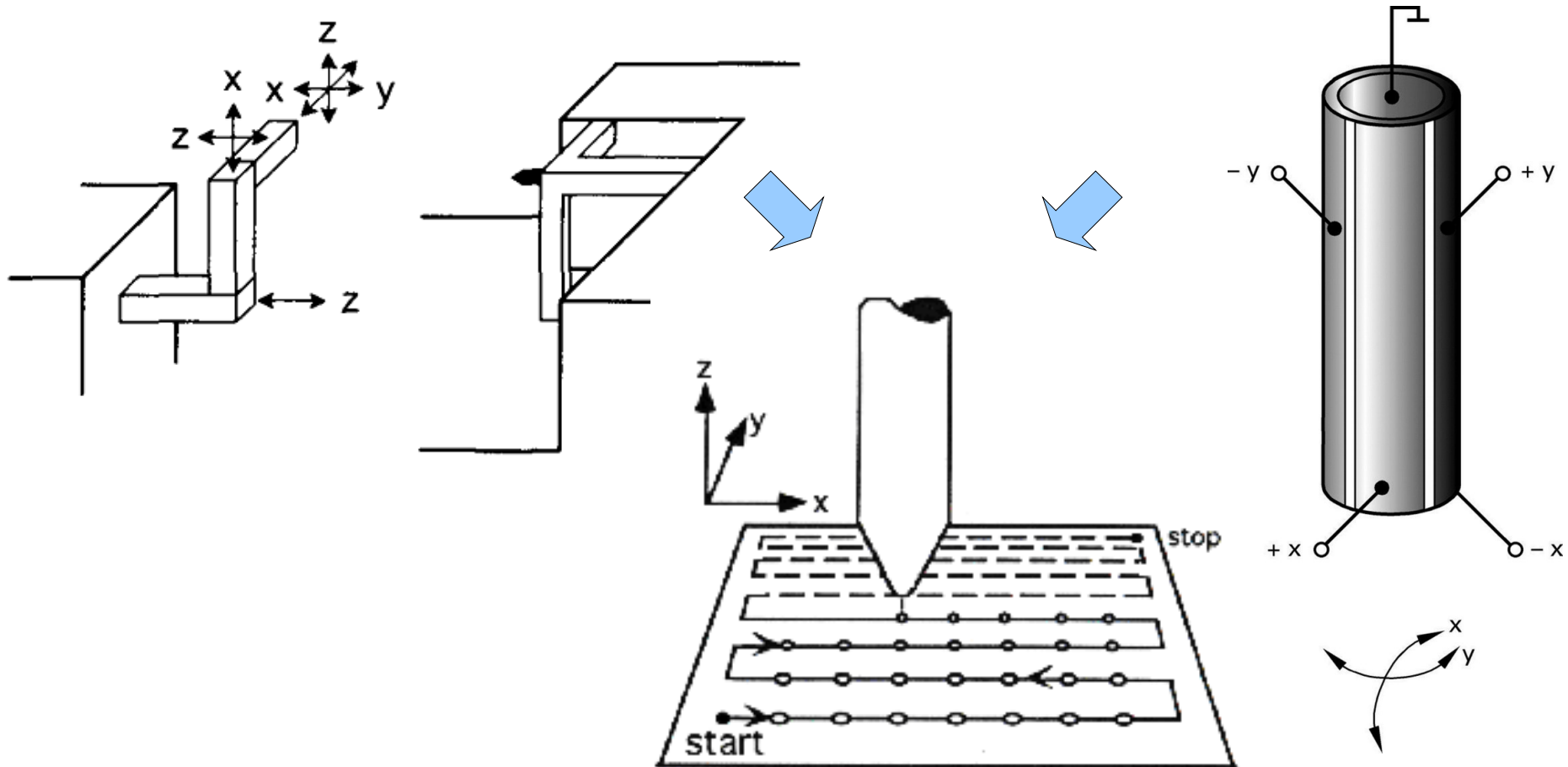


Modelli di uso comune

Piezoelectric actuators

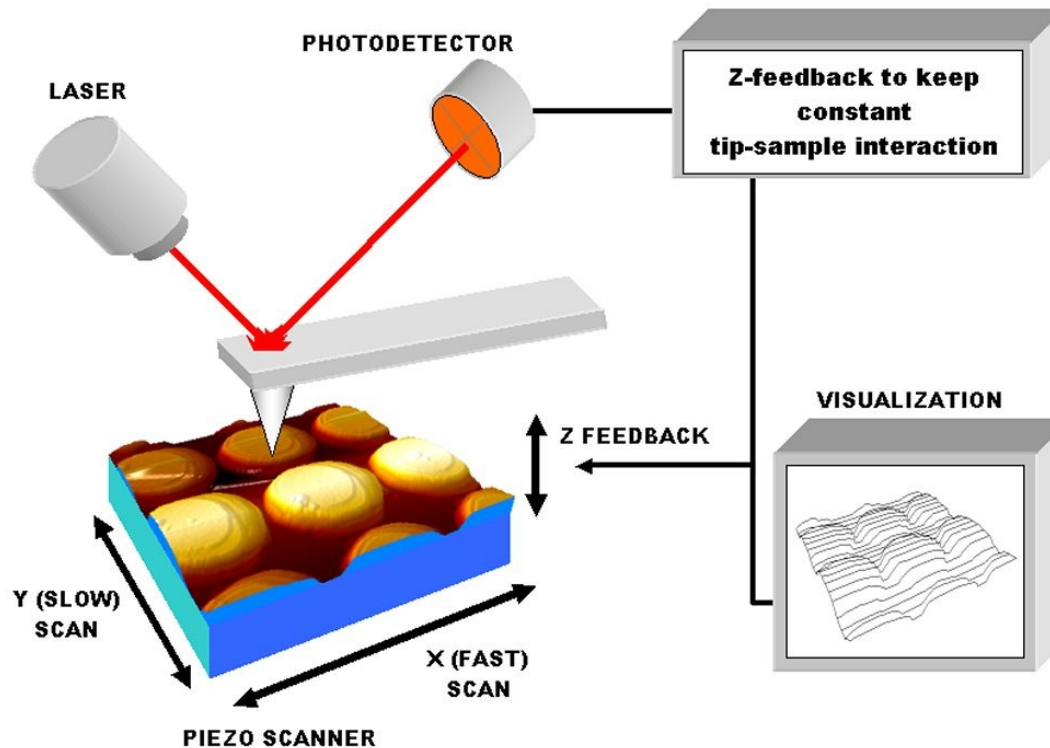
The domains are usually randomly oriented, but can be aligned during poling, a process by which a strong electric field is applied across the material, usually at elevated temperatures.

As very high electric fields correspond to only tiny changes in the width of the crystal (from μm to pm). Piezo crystals the most important tool for positioning objects with extreme accuracy

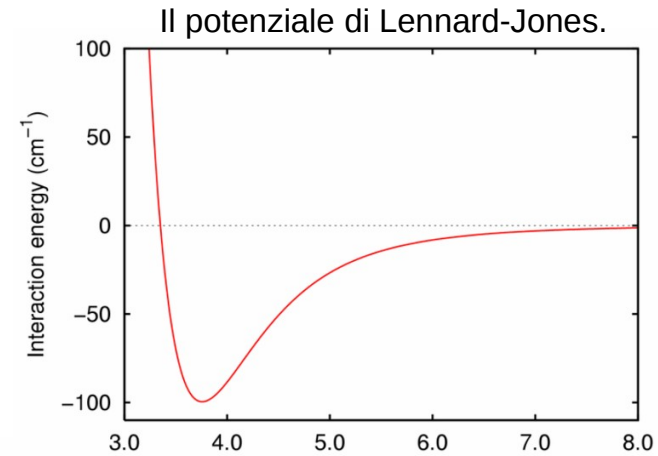
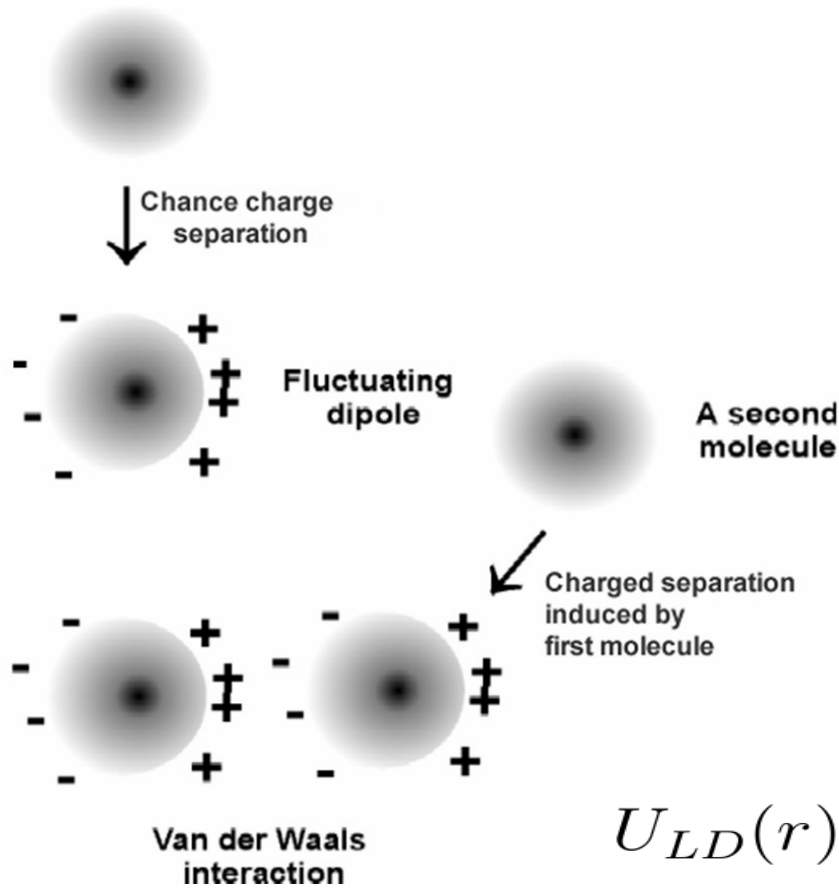


Scanning Force Microscope (SFM)

a.k.a Atomic Force Microscope (AFM)

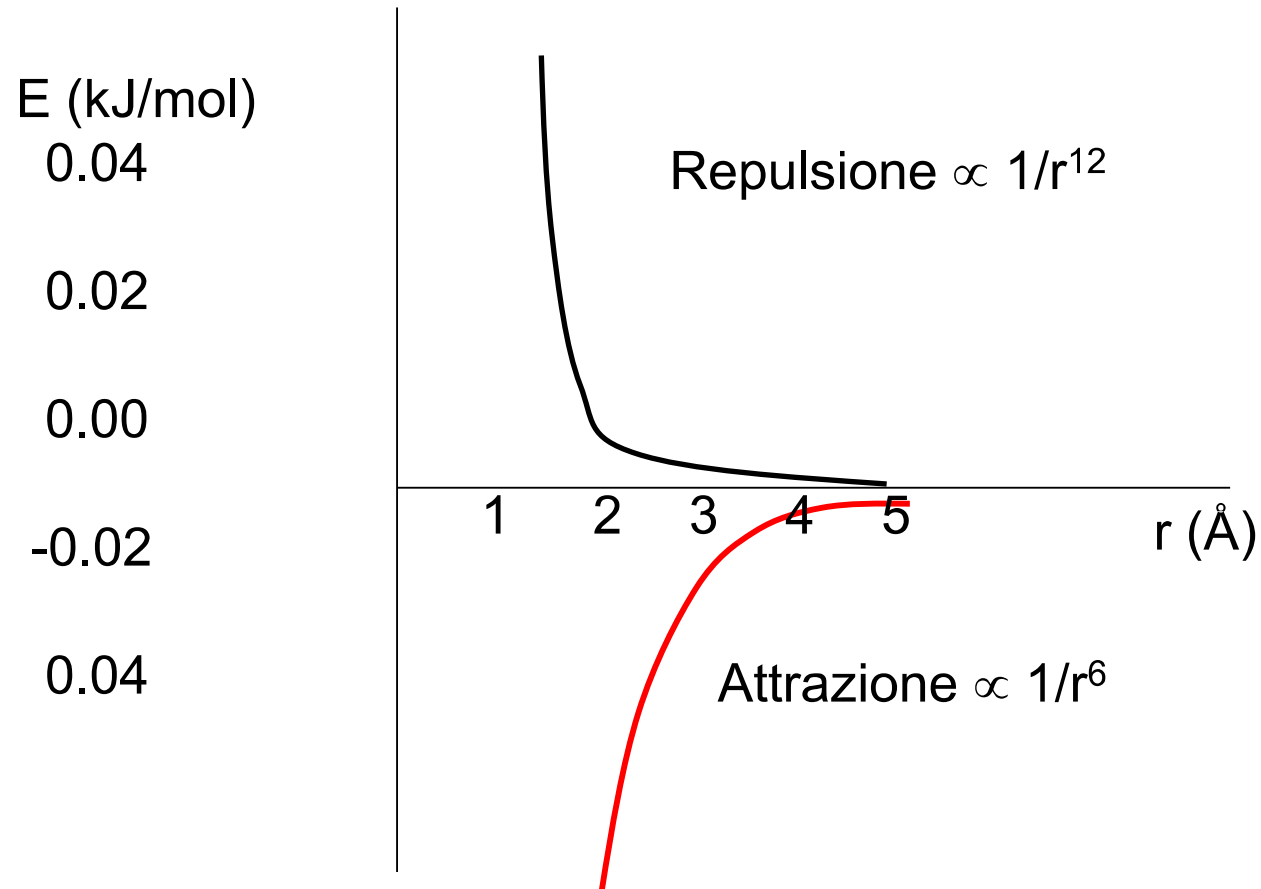


Forze di Van der Waals



$$U_{LD}(r) = U_0 \left\{ -2 \left(\frac{r_0}{r} \right)^6 + \left(\frac{r_0}{r} \right)^{12} \right\}$$

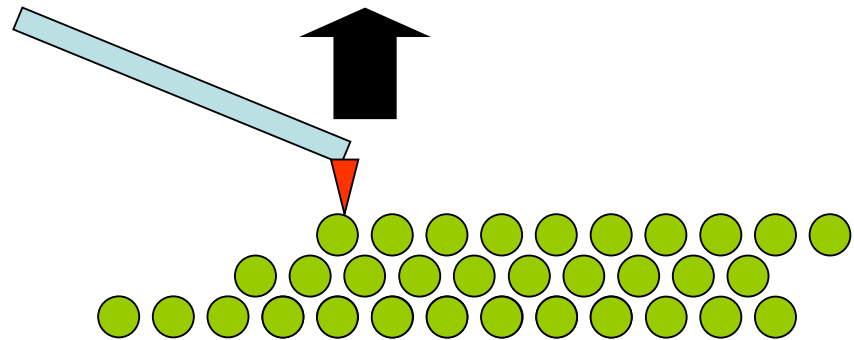
Forze di Van Der Waals



Modalità di Funzionamento

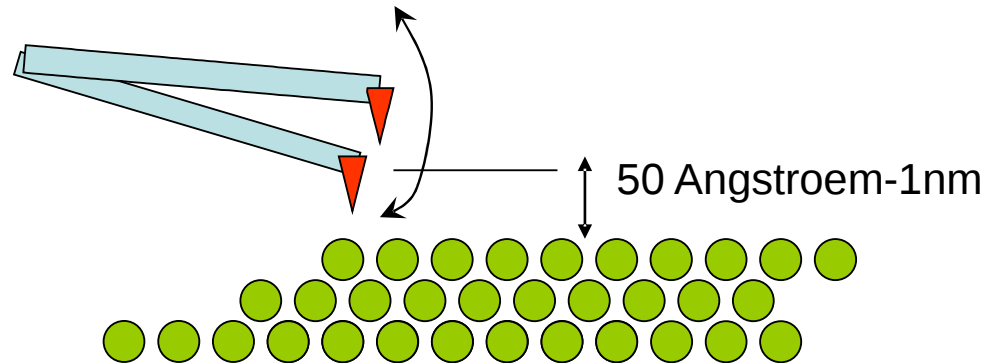
Modi di funzionamento:

Modo di contatto:



Modo di non-contatto:

Sensibile a strati di gas adsorbito
o altri tipi di strati



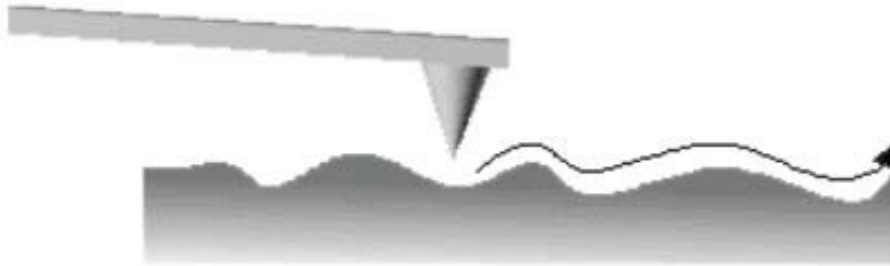
AFM: modalità a contatto

Contatto fisico “continuo” con la superficie del campione

$$F_z = -k \cdot z$$

$K =$ costante elastica

$$k_{\text{cantilever}} < k_{\text{sample}}$$



Vantaggi: elevata risoluzione

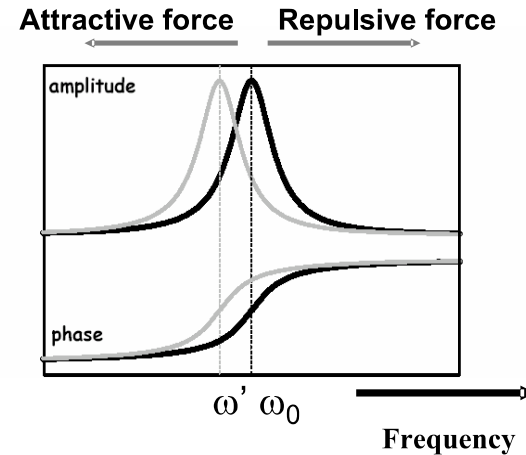
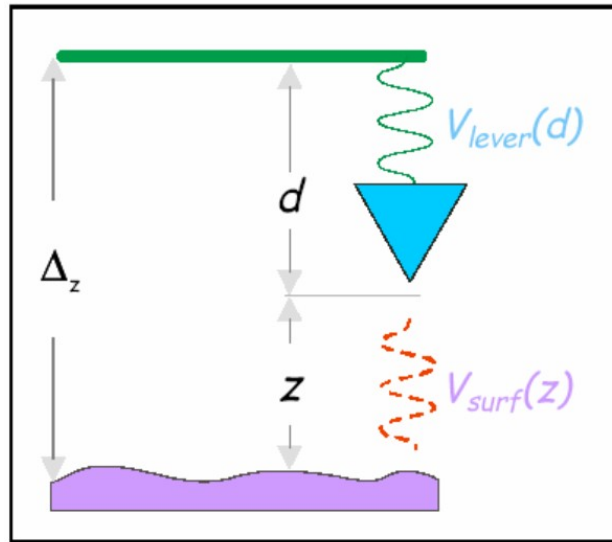
Svantaggi: bassa velocità di scansione

forze di capillarità, frizione, danneggiamento del campione

la punta può trascinare via del materiale

Non indicato per materiali “soffici” (organici, biologici)

AFM: modalità di non-contatto



$$\omega' = \omega_0 \sqrt{1 - \frac{F'(z)}{k}}$$



Variazioni nella frequenza ω_0 corrispondono a variazioni nella distanza punta-cantilever (=topografia della superficie)

- Sistema di feedback (misura alla frequenza di risonanza)
- movimento (x,y) dello scanner



Immagine AFM

AFM: modalità intermittente (Tapping mode™)

La punta vibra “vicino” alla superficie toccandola nel punto più basso di oscillazione

Cantilever ($k = 20 - 80 \text{ N/m}$)

$$k_{\text{interm}} > k_{\text{cont}}$$

Contatto punta-superficie

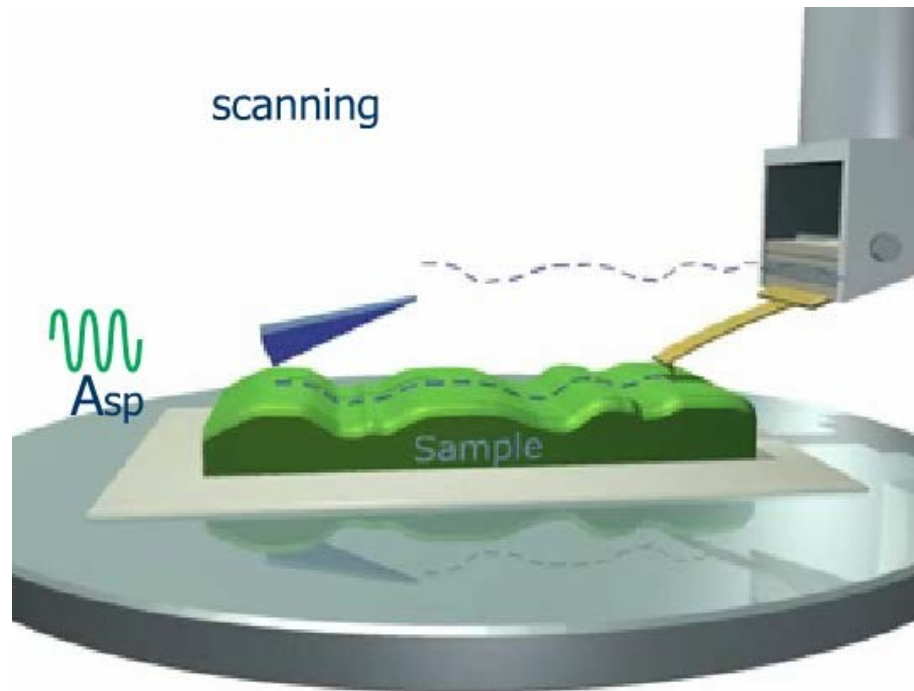


Perdita di energia meccanica



Riduzione dell'ampiezza di oscillazione

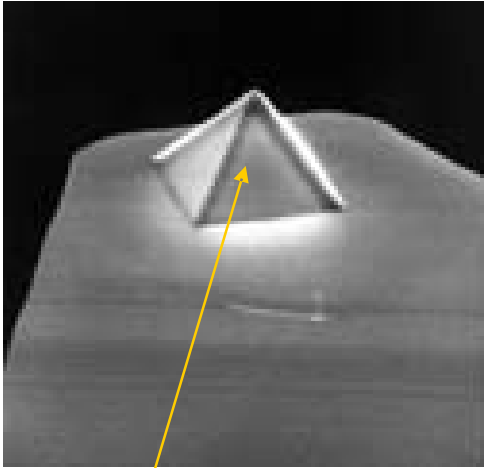
AFM: modalità intermittente



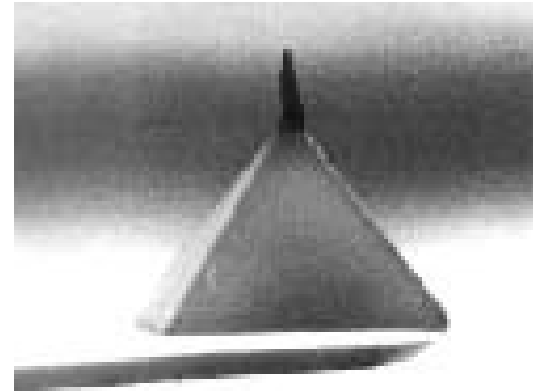
Vantaggi: Alta risoluzione
Riduzione della frizione, riduzione problemi di adesione
Velocità di scansione, ampie zone misurate

Varietà delle punte

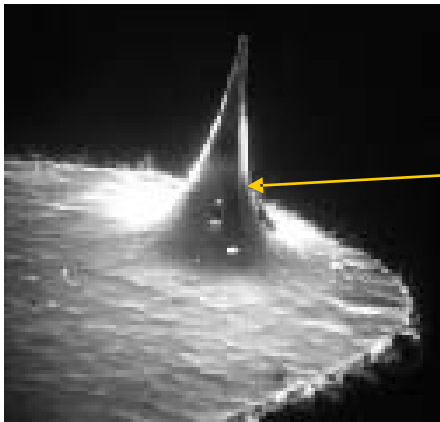
Le punte sono generalmente fatte con Si_3N_4 or Si



3 μm altezza
30 nm di raggio in punta



3 μm altezza
10 nm di raggio in punta



3 μm altezza
10 nm di raggio in punta

Artefatti e risoluzione limite

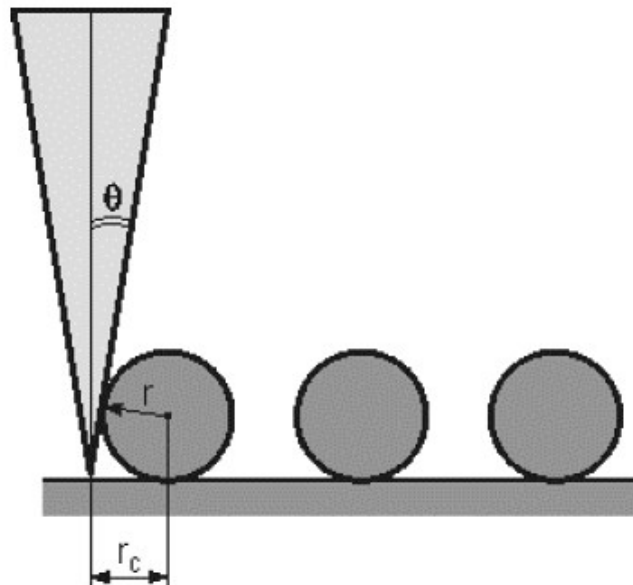


Fig. 2.1. Schematics of the studied object and conical tip in case $R \ll r$

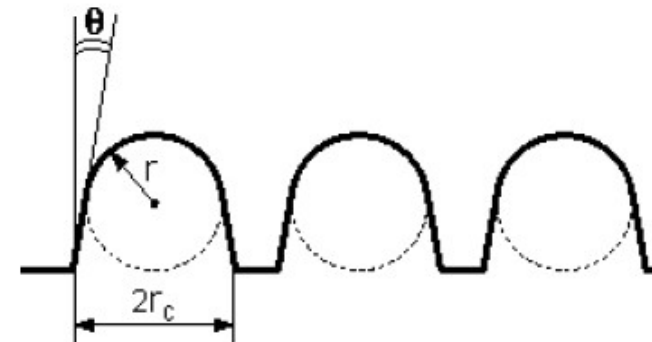


Fig. 2.2. Image profile of objects shown in Fig. 1.

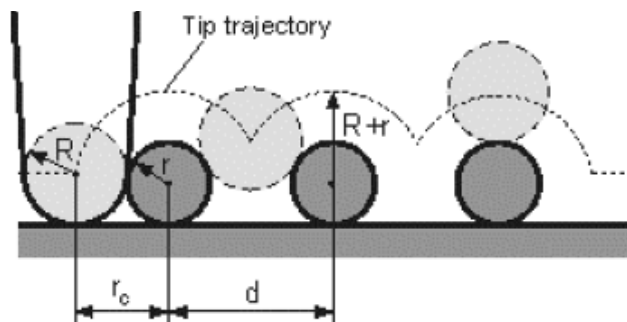


Fig. 2.3. Schematics of the studied object and conical tip in case $R \approx r$. Dotted line represents the tip path.

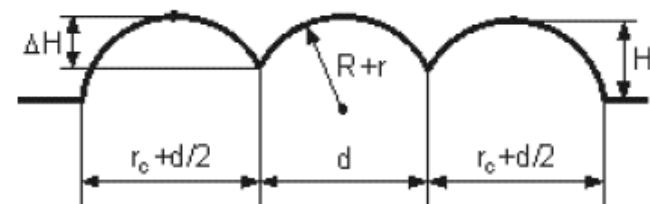
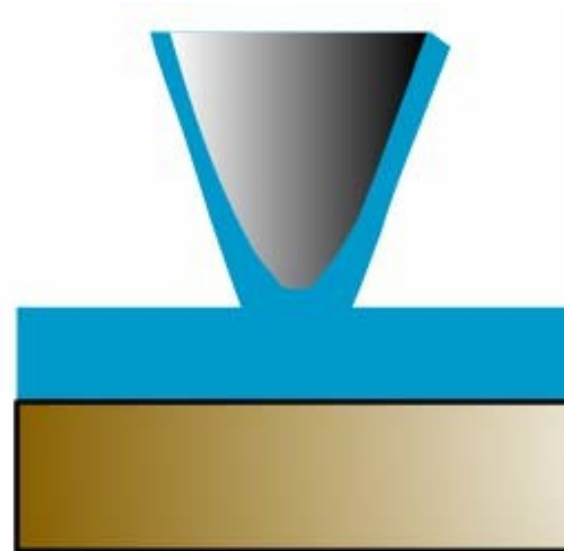
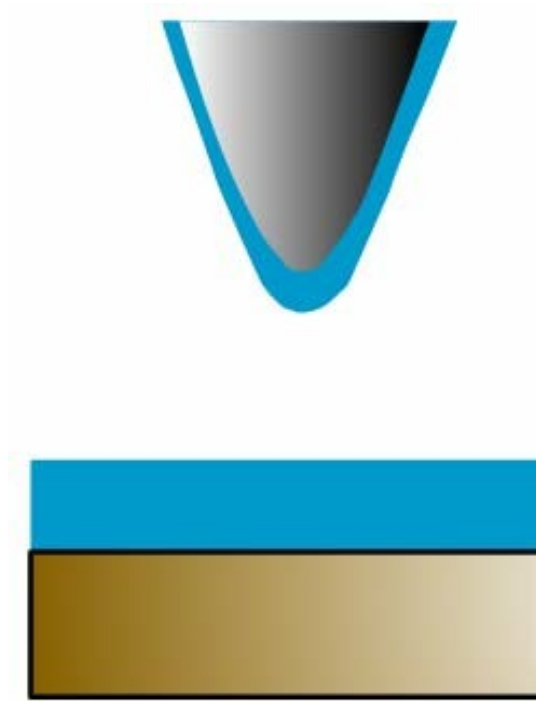


Fig. 2.4. Image profile of objects shown in Fig. 3.

Dimensione della punta

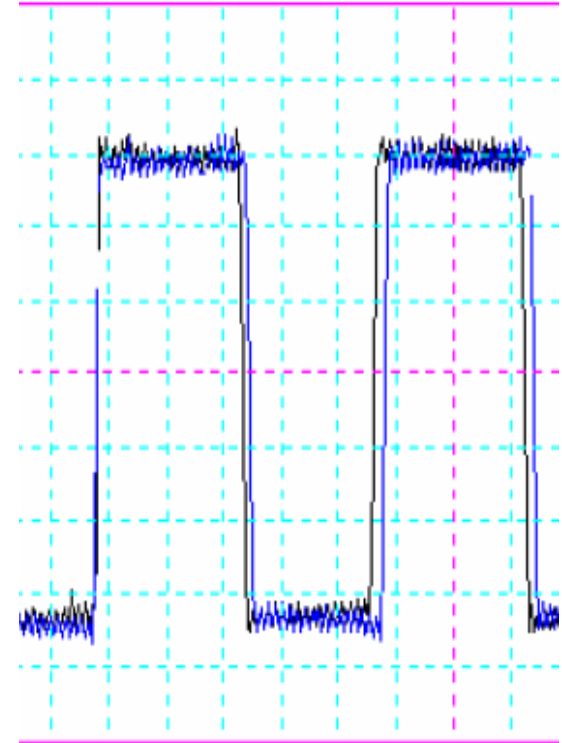
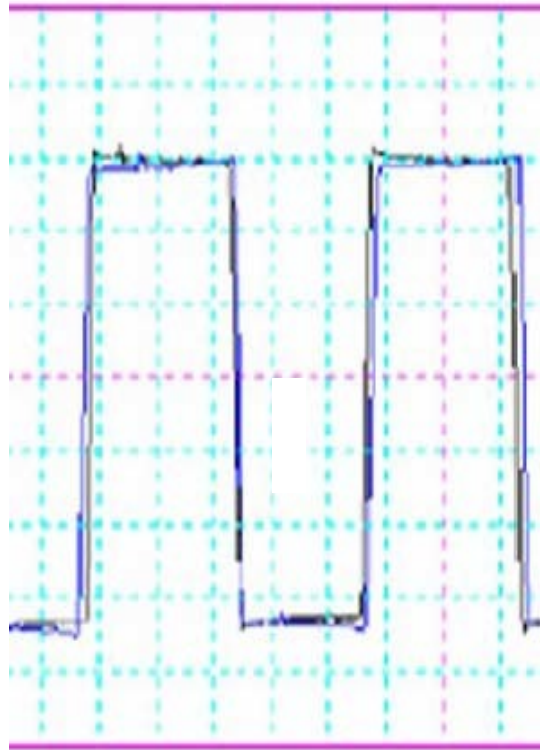
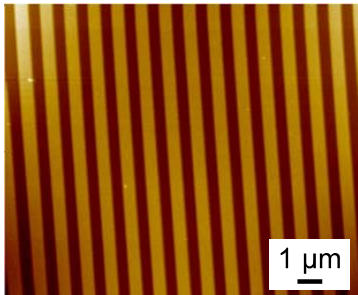
Water meniscus



Artefatti

Gain (Reattività) \longleftrightarrow Rumore

Immagine AFM

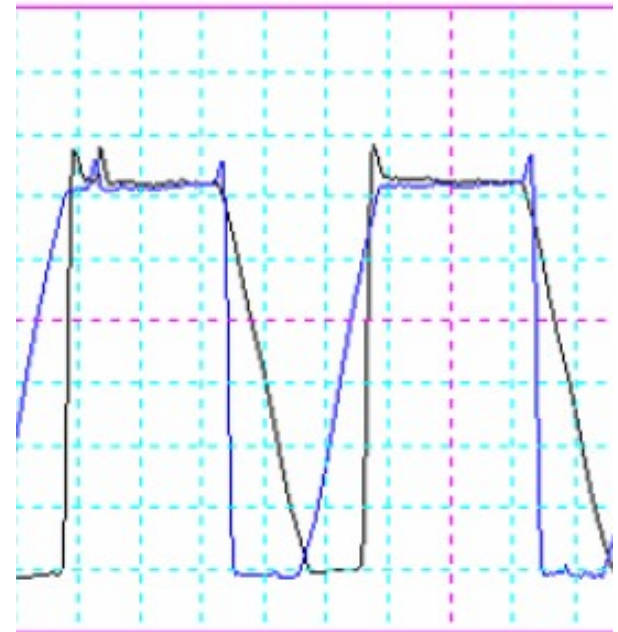
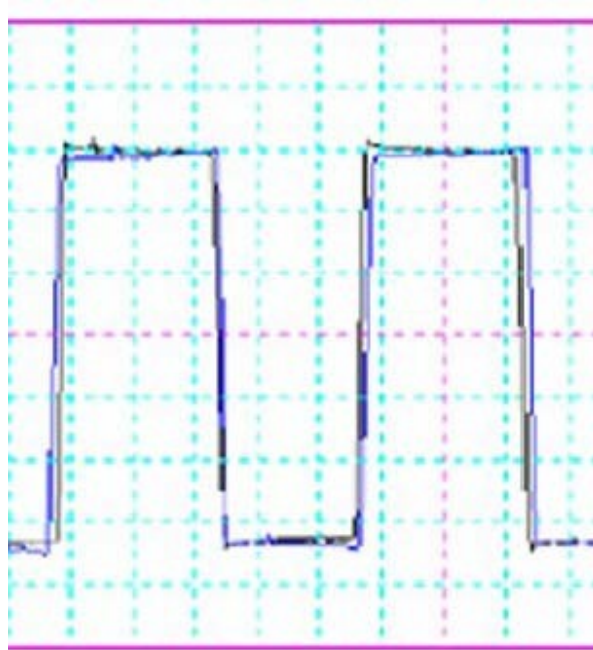
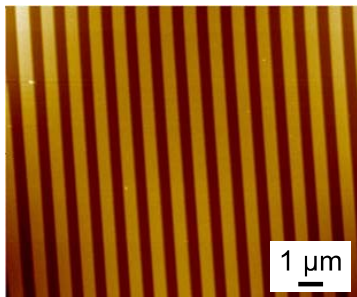


Gain

Artefatti

Velocità di scansione

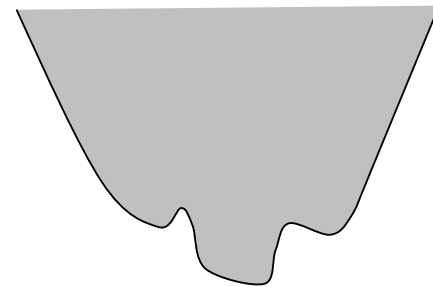
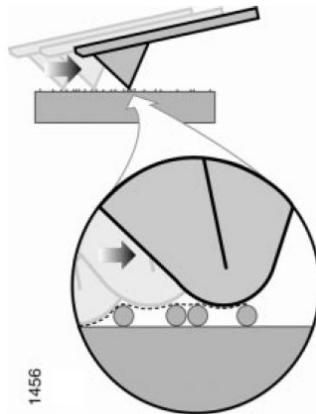
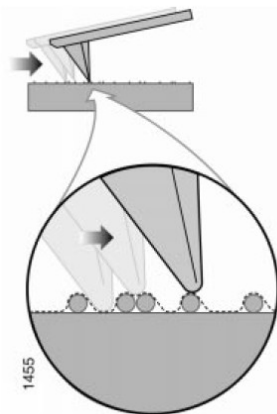
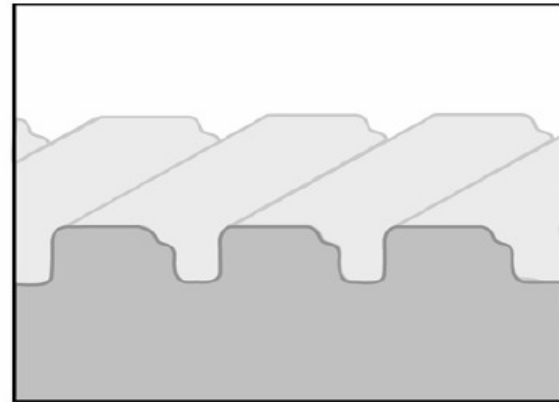
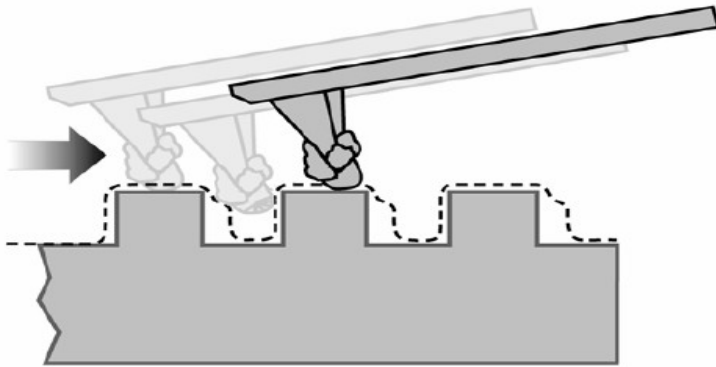
Immagine AFM



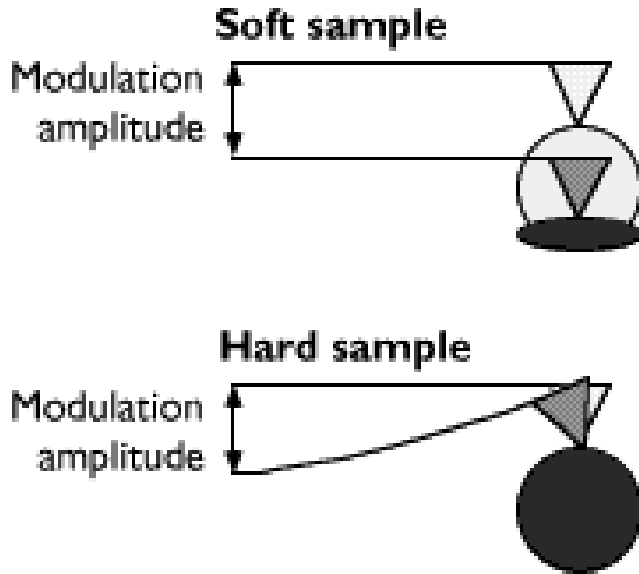
Velocità

Artefatti

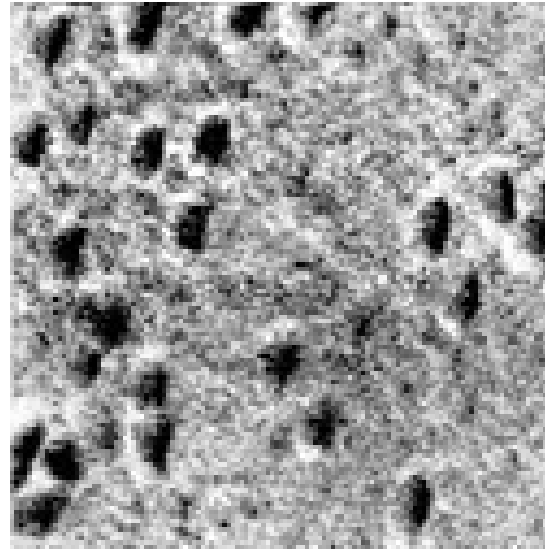
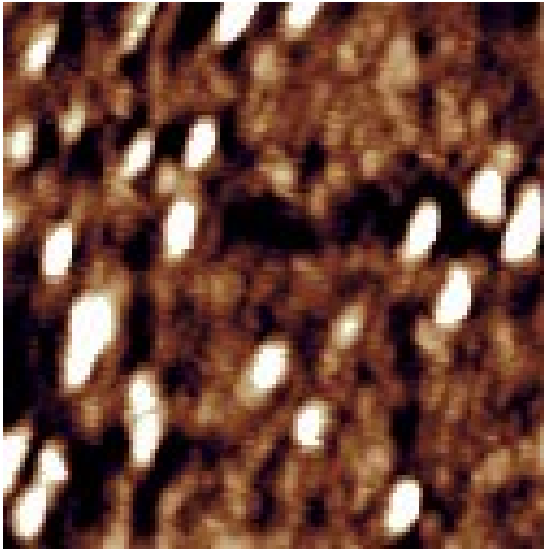
Stato di pulizia della punta



AFM: elasticità del campione



Si può campionare sotto forma di immagine **l'elasticità del campione** spingendo la punta sul campione e misurando la **deflessione risultante** del cantilever.

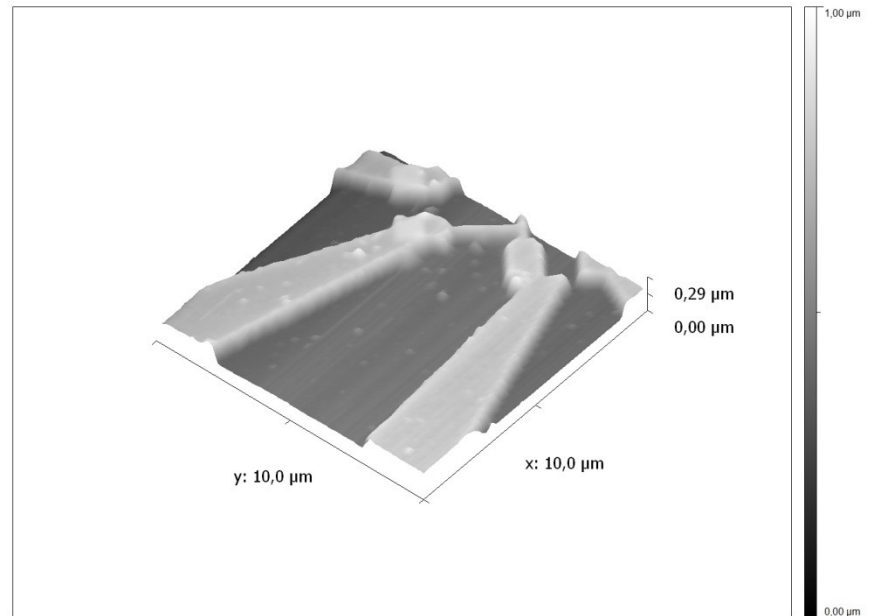


1 x 1 μm immagini di **topografia (sinistra)** ed **elasticità (destra)** di albumina di siero bovino su silicio

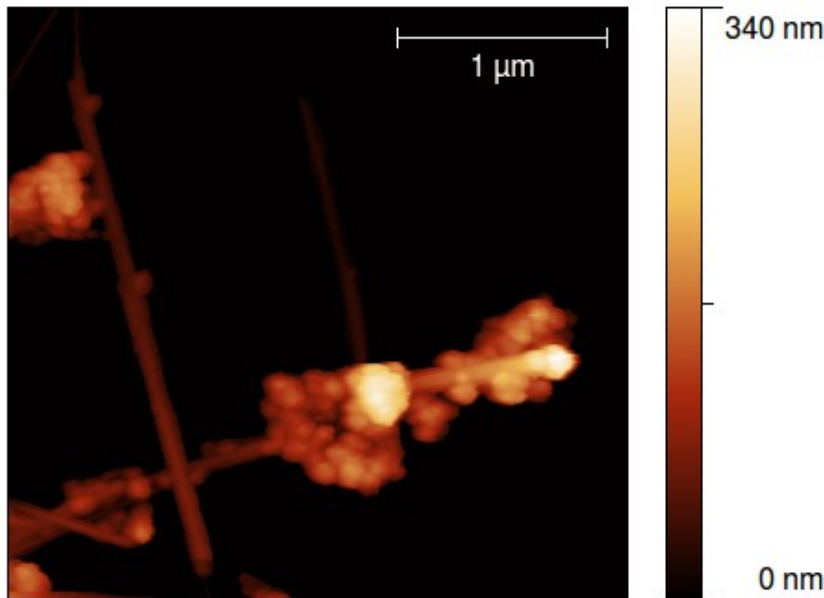
Laboratorio di Microscopia AFM



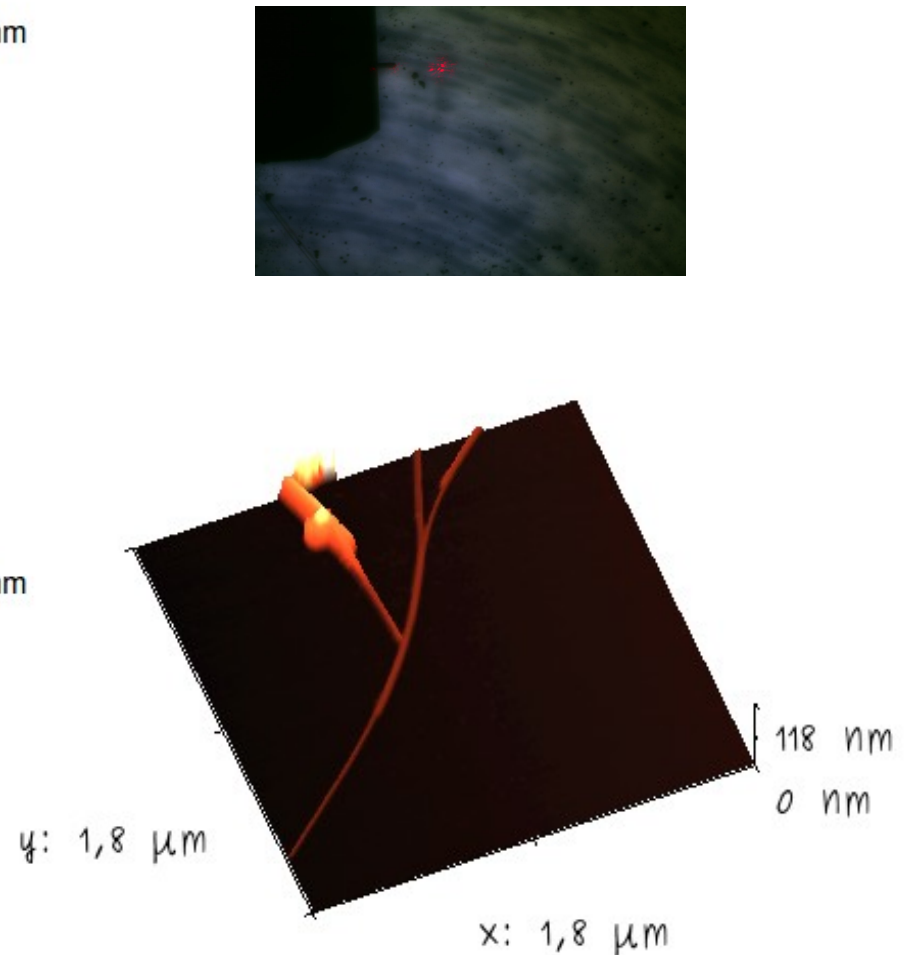
Ape Reasearch



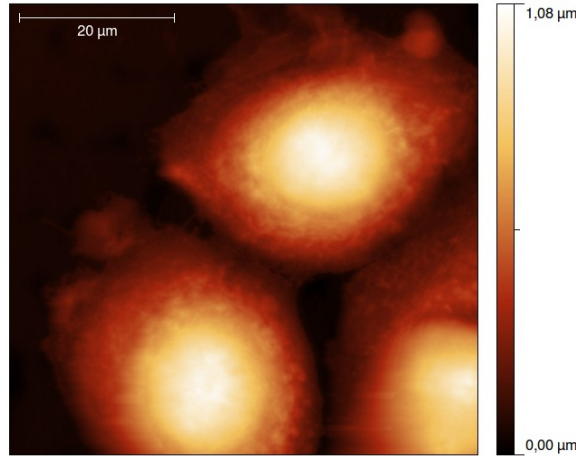
Laboratorio di Microscopia AFM



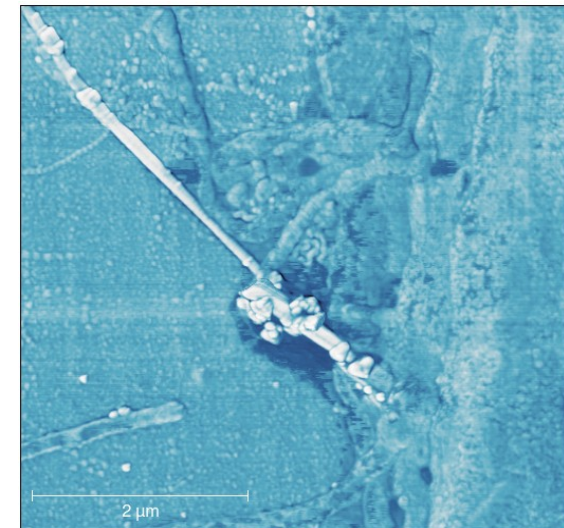
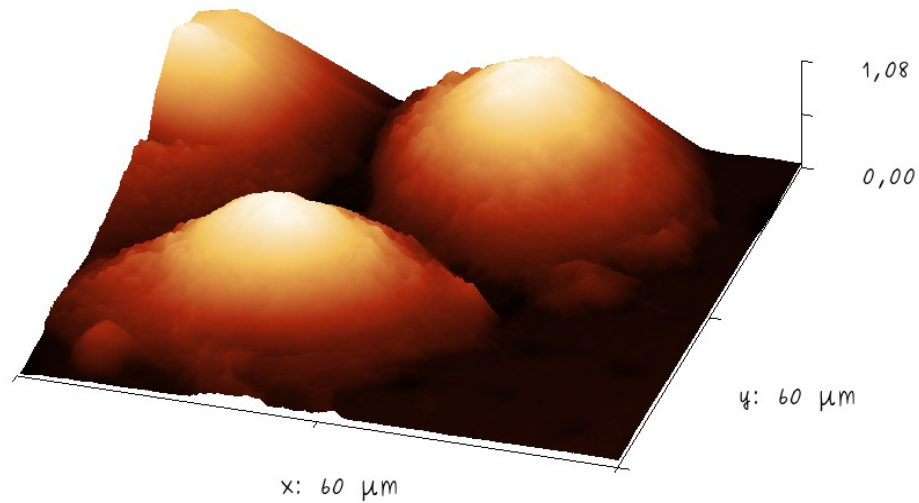
Nanotubi di carbonio a
parete multipla
MWCNT



AFM - Bio



Superficie cellulare
+
MWCNT



Vantaggi della Microscopia a Forza Atomica

- Gli ambienti di lavoro possono essere indifferentemente:
 - **vuoto** (per campioni che necessitano del minore numero di impurità)
 - **aria**
 - **liquidi** (particolarmente interessante per osservazioni in-vivo)
- Non si necessita di particolare preparazione dei campioni:
 - il campione deve essere depositato su una superficie piana (spesso si usano sfoglie di mica)
- La risoluzione è paragonabile a quella di un microscopio elettronico
- Possibilità di elaborare le immagini al computer (immagini 3D)

Conclusioni

- AFM: Microscopia di Forza
- Tre principali metodi (contatto, non-contatto, contatto intermittente)
- La modalità intermittente è un buon compromesso tra risoluzione e velocità. Consente di misurare campioni soffici quali nanstrutture organiche e biologiche
- Procedure e parametri sperimentali per l'acquisizione di una immagine AFM
- Analisi e rimozione degli artefatti

UN MICROSCOPIO AFM NON È UNA SCATOLA NERA!

La comprensione dei meccanismi di interazione punta-campione permette di:

- ottimizzare i parametri sperimentali
- comprendere e analizzare la misura acquisita

