

Microscopia alla nanoscala



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Microscopia alla nanoscala

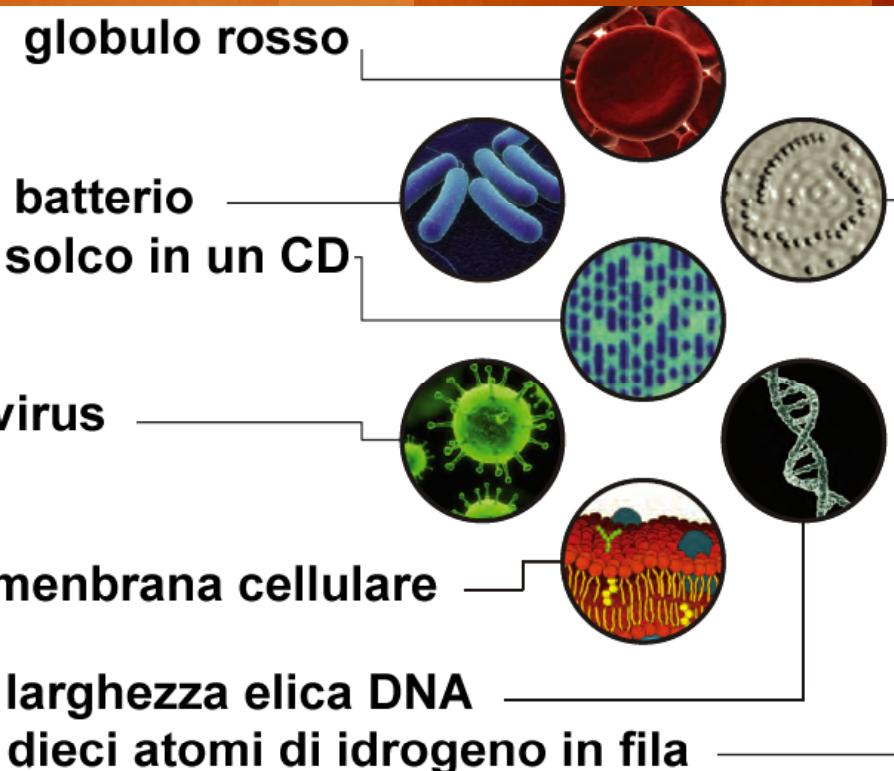


Microscopio ottico

Microscopia alla nanoscala

NanoLab Le nanoscienze in laboratorio
Modena 06/12/2011

- 14 9,200 nanometers: globulo rosso
- 15 4,600 nanometers
- 16 2,300 nanometers
- 17 1,100 nanometers: batterio
- 18 570 nanometers: solco in un CD
- 19 290 nanometers
- 20 140 nanometers
- 21 70 nanometers: virus
- 22 35 nanometers
- 23 18 nanometers
- 24 9 nanometers: membrana cellulare
- 25 4.5 nanometers
- 26 2.3 nanometers: larghezza elica DNA
- 27 1.1 nanometers: dieci atomi di idrogeno in fila



Scanning Probe
Microscopy, SPM

AFM



STM

Scanning Probe Microscopy, SPM ?

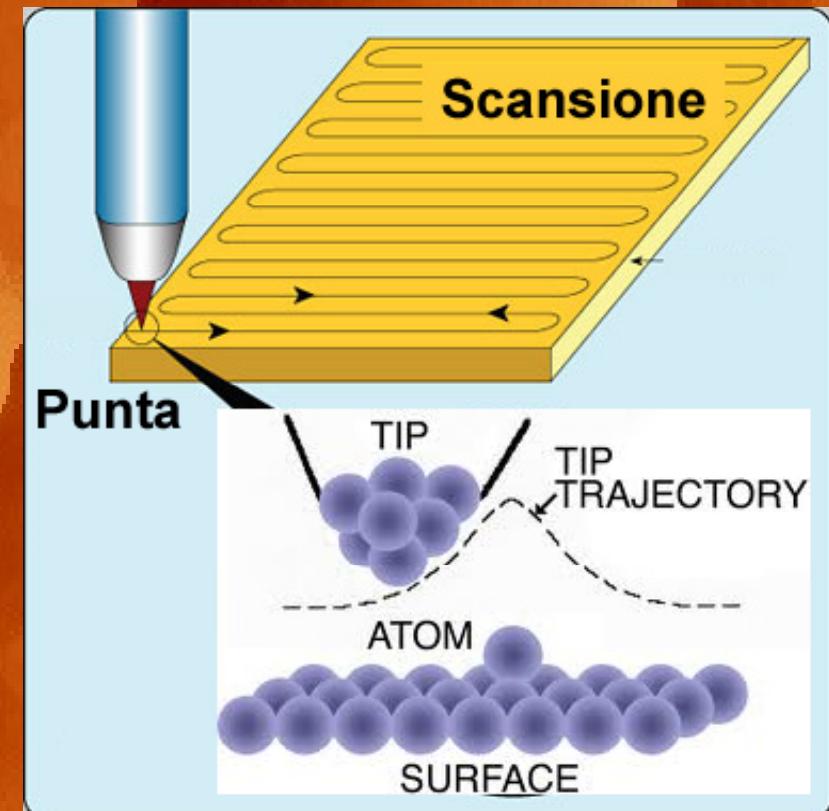
Immagine microscopica

ottenuta con una punta

che opera una scansione

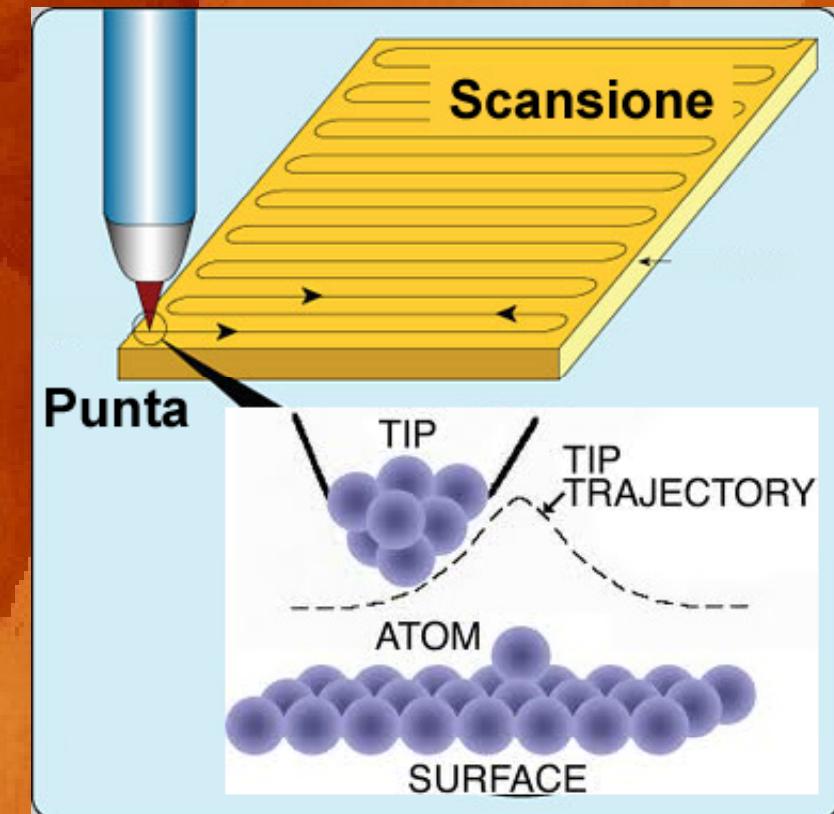
regolare sulla superficie

*Un insieme di tecniche di
microscopia che si sono sviluppate
negli ultimi 30 anni*



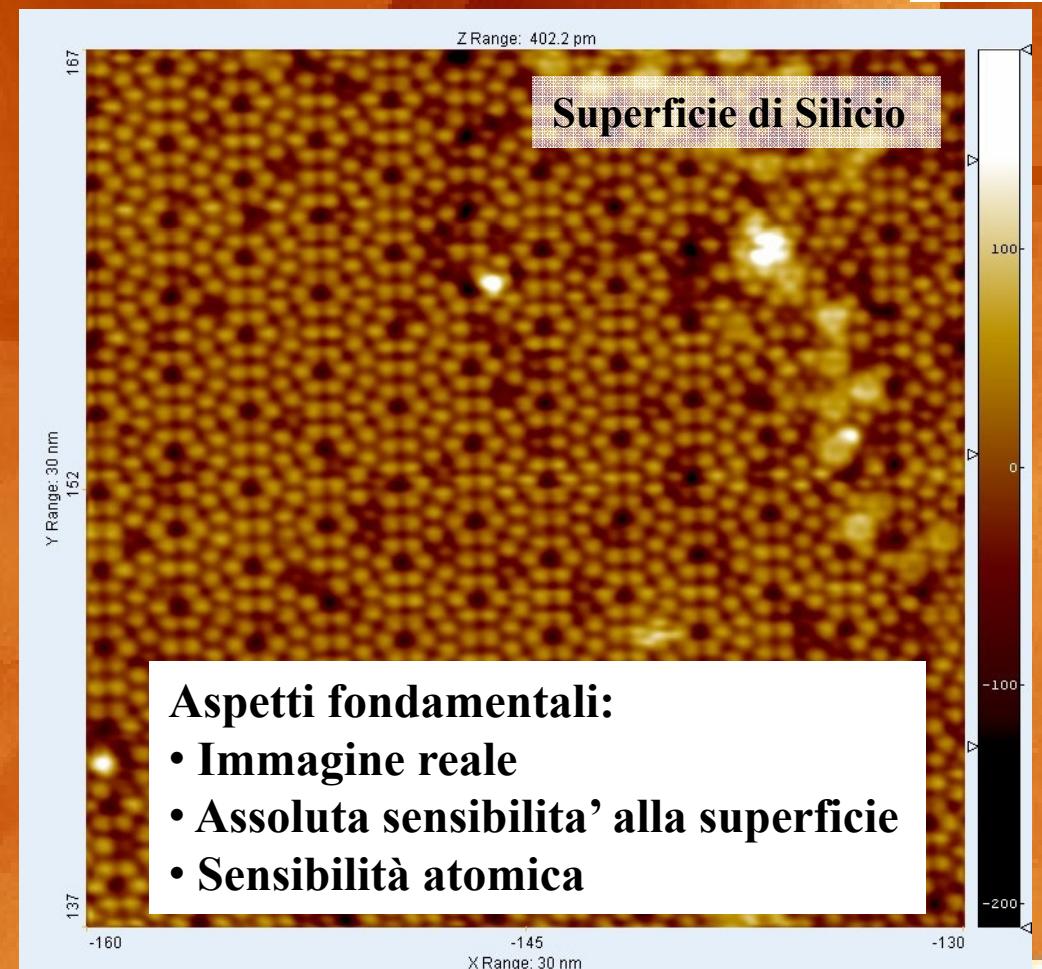
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Caratteristiche fondamentali:

- **movimenti e stabilità $\leq 1 \text{ \AA}$** → soluzioni comuni a tutte le tecniche (piezoelettrici)
- **“sentire” la superficie** → differenti tecniche usano diverse “interazioni”



Aspetti fondamentali:

- Immagine reale
- Assoluta sensibilità alla superficie
- Sensibilità atomica

STM Microscope

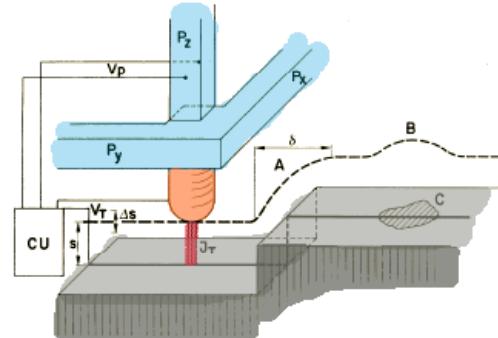


FIG. 1. Principle of operation of the scanning tunneling microscope. (Schematic; distances and sizes are not to scale.) The piezodrives P_x and P_y , scan the metal tip M over the surface. The control unit (CU) applies the appropriate voltage V_p to the piezodrive P_z for constant tunnel current J_T at constant tunnel voltage V_T . For constant work function, the voltages applied to the piezodrives P_x , P_y , and P_z yield the topography of the surface directly, whereas modulation of the tunnel distance s by Δs gives a measure of the work function as explained in the text. The broken line indicates the z displacement in a y scan at (A) a surface step and (B) a contamination spot, C , with lower work function.

Surface Studies by Scanning Tunneling Microscopy

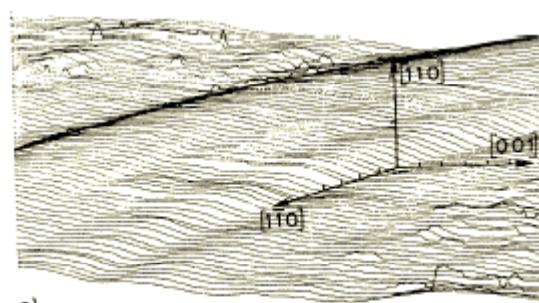
G. Binning, H. Rohrer, Ch. Gerber, and E. Weibel

IBM Zurich Research Laboratory, 8803 Rüschlikon-ZH, Switzerland

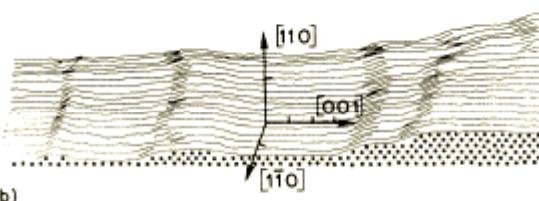
(Received 30 April 1982)

Surface microscopy using vacuum tunneling is demonstrated for the first time. Topographic pictures of surfaces on an *atomic scale* have been obtained. Examples of resolved monoatomic steps and surface reconstructions are shown for (110) surfaces of CaIrSn_4 and Au.

PACS numbers: 68.20.+t, 73.40.Gk

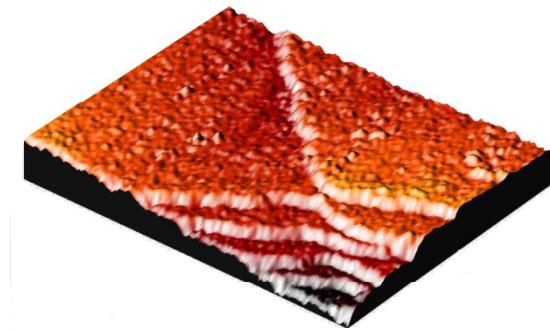


a)



b)

FIG. 3. Two examples of scanning tunneling micrographs of a Au (110) surface, taken at (a) room temperature, and (b) 300°C after annealing for 20 h at the same temperature (and essentially constant work function). The sensitivity is 10 Å/div everywhere. Because of a small thermal drift, there is some uncertainty in the crystal directions in the surface. In (a), the surface



**STM Image
Gold Atomic Steps**

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Il Nobel per la Fisica 1986 è stato dedicato alla miscroscopia

Prof. H. Rohrer

Prof. G. Binning

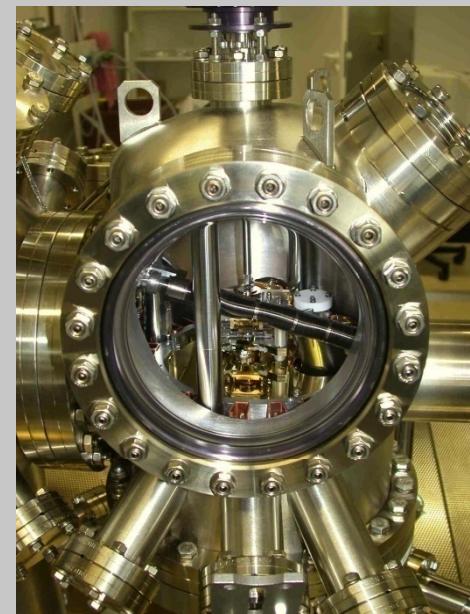
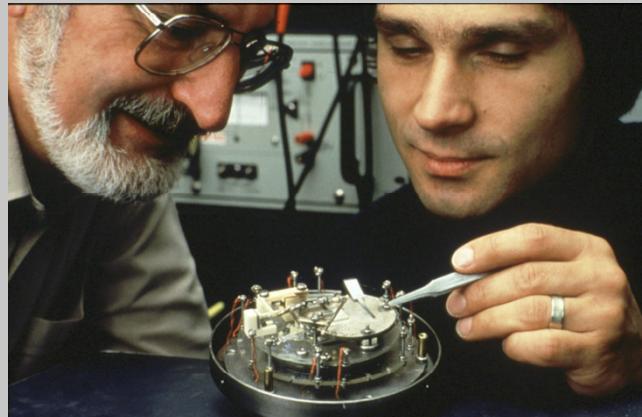
"for their design of the scanning tunneling microscope"

and

Prof. Ernst Ruska

"for the design of the first electron microscope"

http://www.nobelprize.org/nobel_prizes/physics/laureates/1986/



Scanning Tunneling Microscope

- *Sistema in Vuoto*
- *Corrente di tunneling*
- *Campione conduttore*

2.1 Tunneling: A Quantum-Mechanical Effect

17

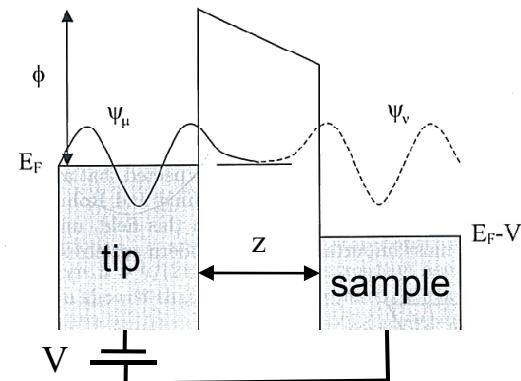


Fig. 2.2. One-dimensional tunneling junction. The wave functions of tip and sample overlap. When a bias voltage is applied, electrons can flow from the tip to the sample (tunneling into empty states of the sample) or from the sample to the tip (tunneling from filled states of the sample). The barrier height is approximately determined by the work function.

tunneling current I_t can be calculated by taking into account the density of states of the sample, $\rho_s(E_F)$, at the Fermi edge:

$$I_t \propto V \cdot \rho_s(E_f) \cdot e^{-1.025 \cdot \sqrt{\Phi} \cdot z} \quad (2.2)$$

where the barrier height Φ is in eV and z in angstrom units. With a typical barrier height of $\Phi = 5$ eV, which corresponds to the work function of gold, the tunneling current decays by an order of magnitude when the vacuum gap is changed by 1 Å.

AFM Microscope

Per poter osservare anche superfici non conduttrici la punta STM misura il movimento di una leva metallica che spinge una punta sul campione

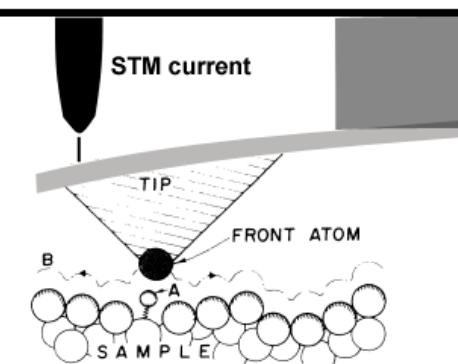


FIG. 1. Description of the principle operation of an STM as well as that of an AFM. The tip follows contour B, in one case to keep the tunneling current constant (STM) and in the other to maintain constant force between tip and sample (AFM, sample, and tip either insulating or conducting). The STM itself may probe forces when a periodic force on the adatom A varies its position in the gap and modulates the tunneling current in the STM. The force can come from an ac voltage on the tip, or from an externally applied magnetic field for adatoms with a magnetic moment.

Atomic Force Microscope

G. Binnig^(a) and C. F. Quate^(b)

Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305

and

Ch. Gerber^(c)

IBM San Jose Research Laboratory, San Jose, California 95193

(Received 5 December 1985)

The scanning tunneling microscope is proposed as a method to measure forces as small as 10^{-18} N. As one application for this concept, we introduce a new type of microscope capable of investigating surfaces of insulators on an atomic scale. The atomic force microscope is a combination of the principles of the scanning tunneling microscope and the stylus profilometer. It incorporates a probe that does not damage the surface. Our preliminary results *in air* demonstrate a lateral resolution of 30 Å and a vertical resolution less than 1 Å.

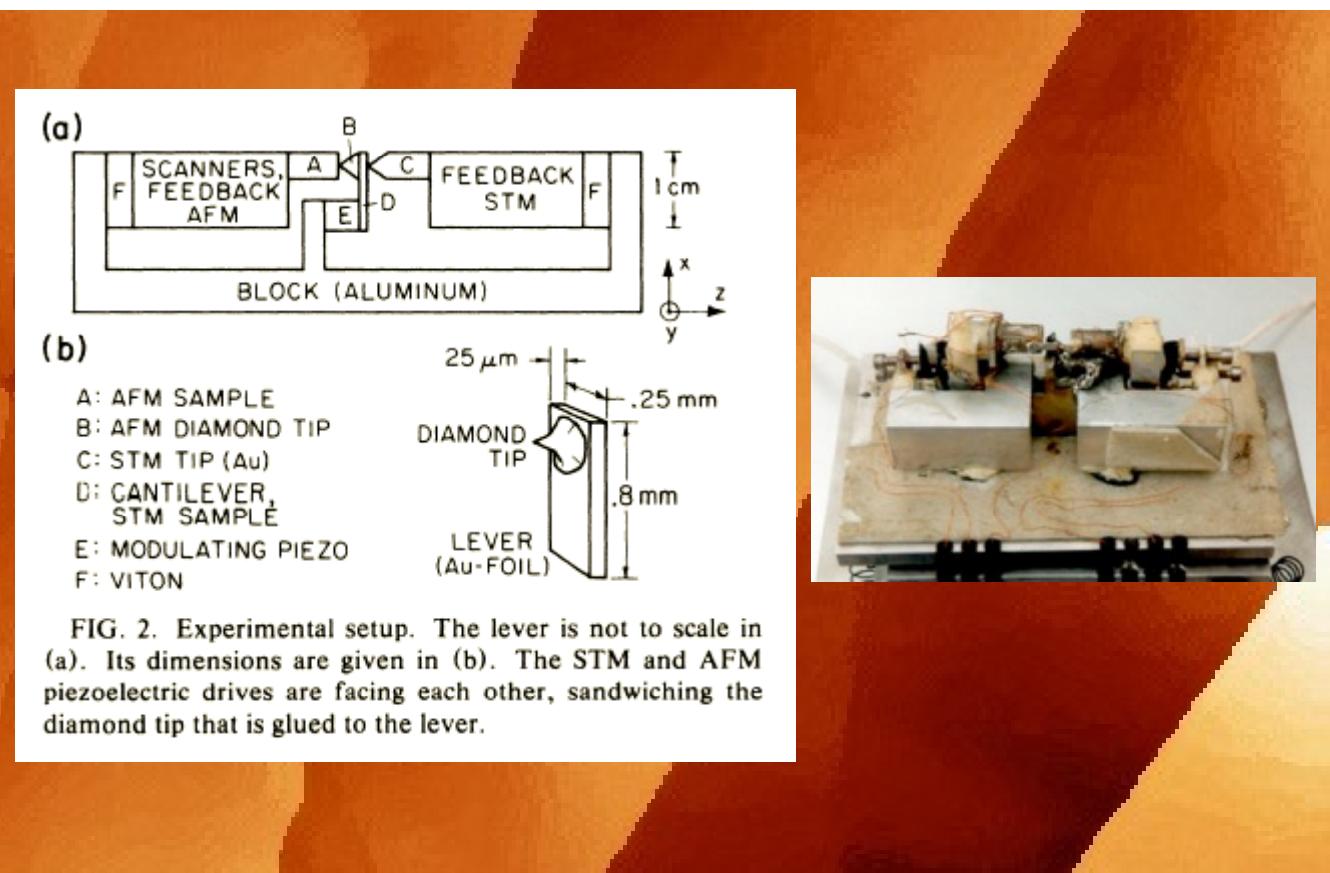
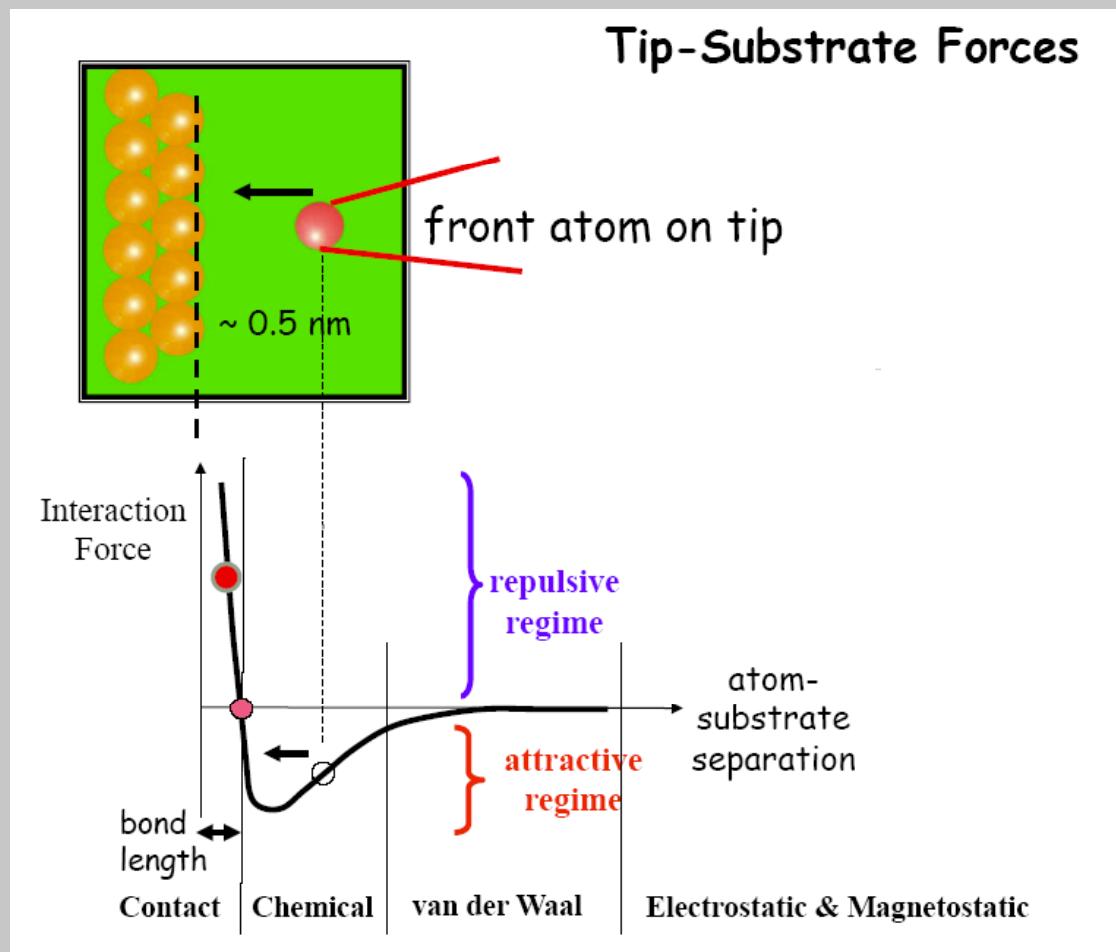
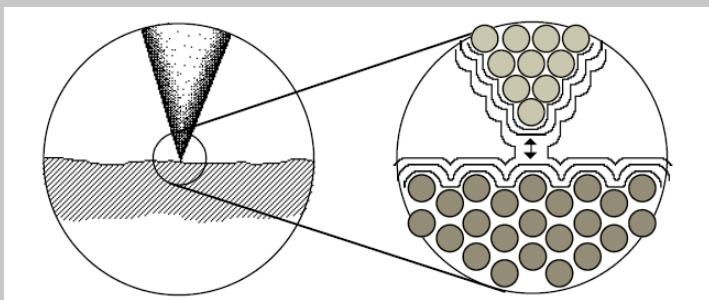


FIG. 2. Experimental setup. The lever is not to scale in (a). Its dimensions are given in (b). The STM and AFM piezoelectric drives are facing each other, sandwiching the diamond tip that is glued to the lever.

Atomic Force Microscope

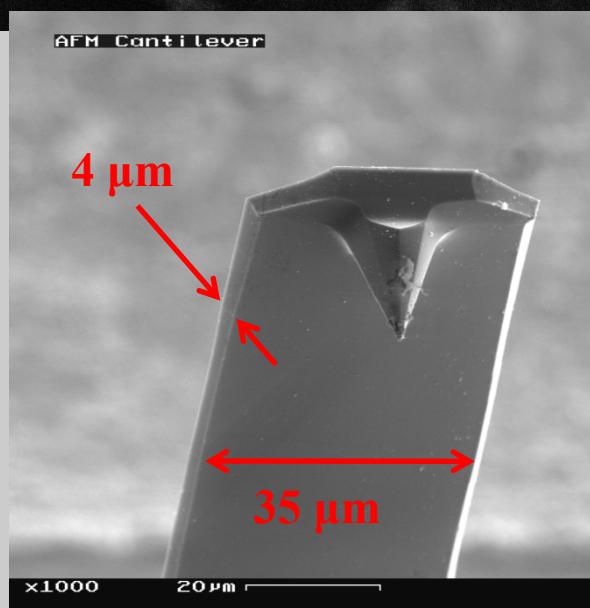
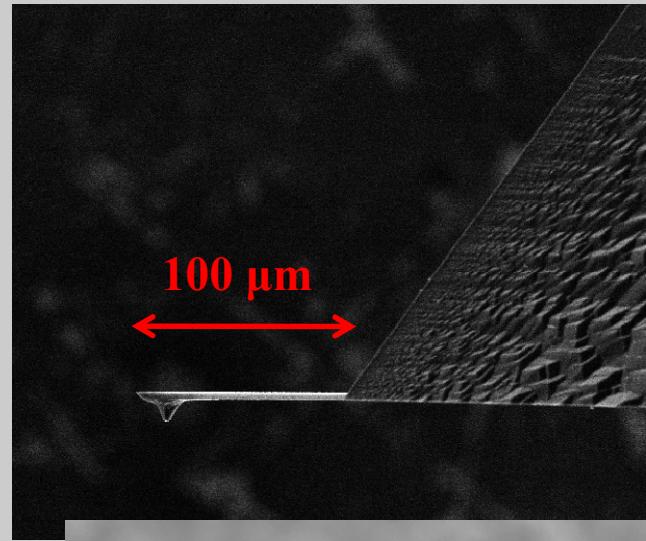
Alla scala dei nanometri esiste sempre una forza di attrazione o repulsione tra punta e campione risultante da diversi effetti elettromagnetici



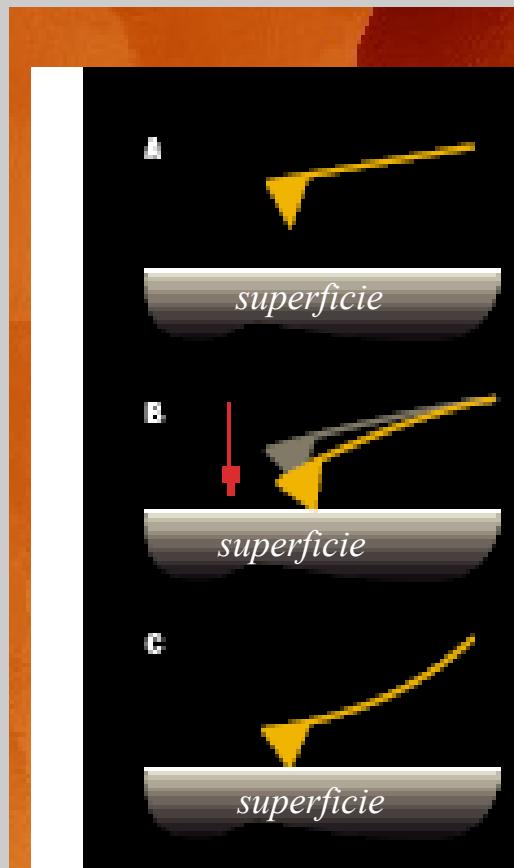
Ron Reifenberger; Arvind Raman (2010),
"ME 597/PHYS 570: Fundamentals of Atomic Force
Microscopy (Fall 2010),"
<http://nanohub.org/resources/9598>.

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Leve di dimensioni micrometriche in Silicio integrate con punte nanometriche sono sensibili a queste forze e si deflettono in prossimità o in contatto con la superficie.

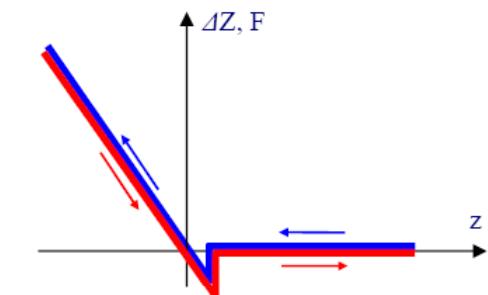


Curva forza-distanza

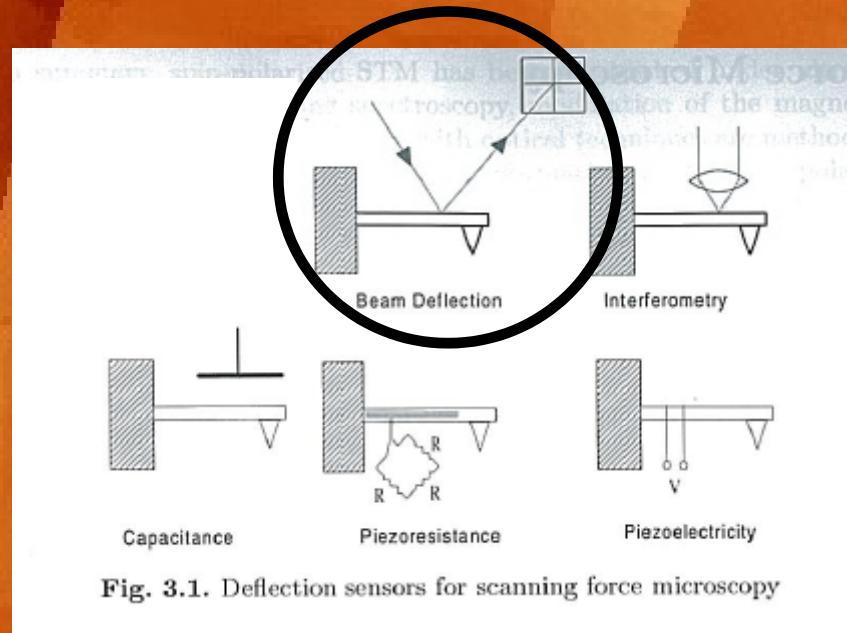
$$F \approx 1/N \quad (\text{max attraction})$$

$$F = -k\Delta z \quad (\text{elastic force})$$

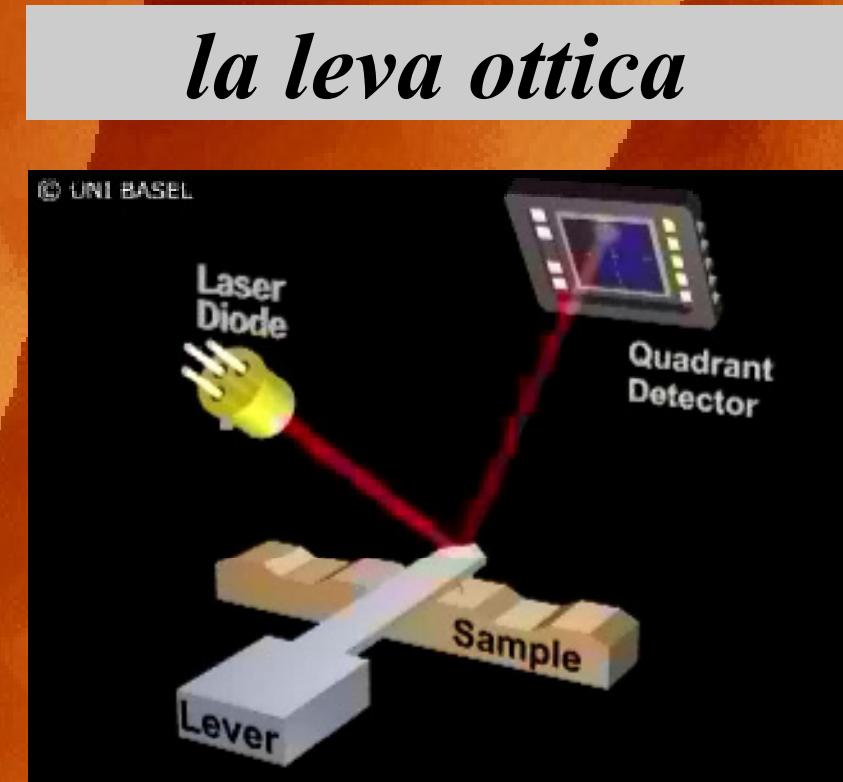
$$k \approx 1\text{N/m} \rightarrow \Delta z \approx 1\text{nm}$$



Come evidenziare il movimento della punta che corrisponde al profilo della superficie ?



Tutti questi metodi non richiedono di operare in **vuoto** !!

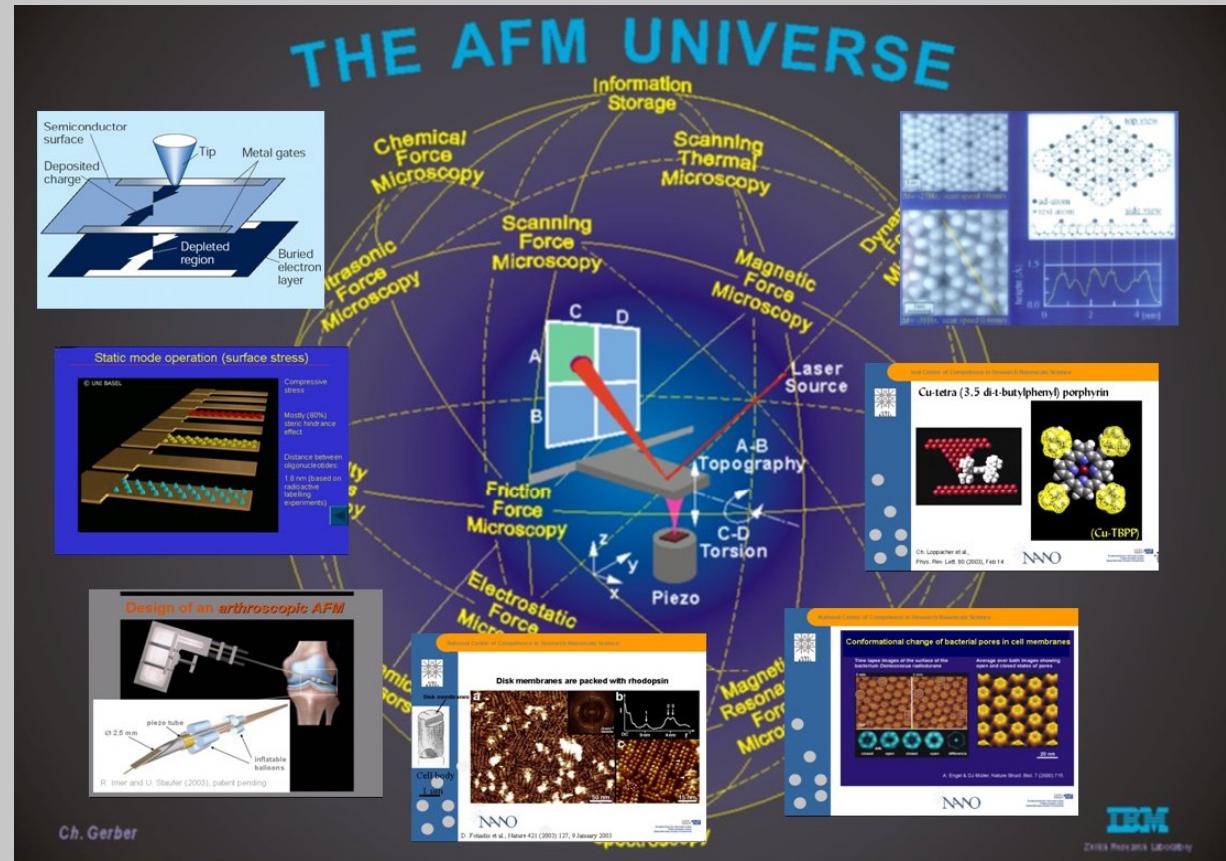
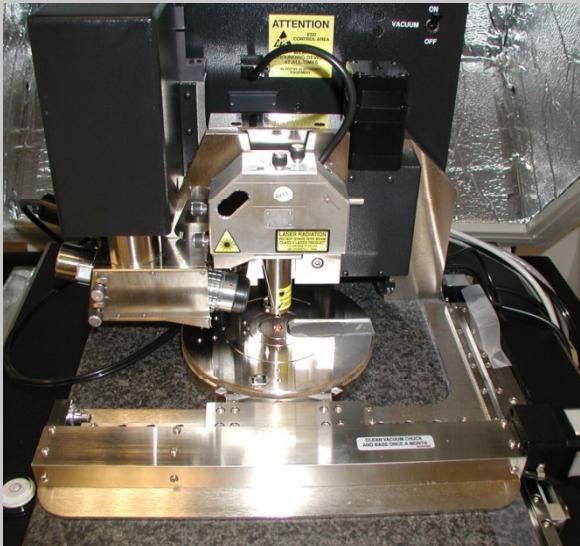


<http://www.nano-world.org/frictionmodule/content/0300reibungsmikroskopie/?lang=en>

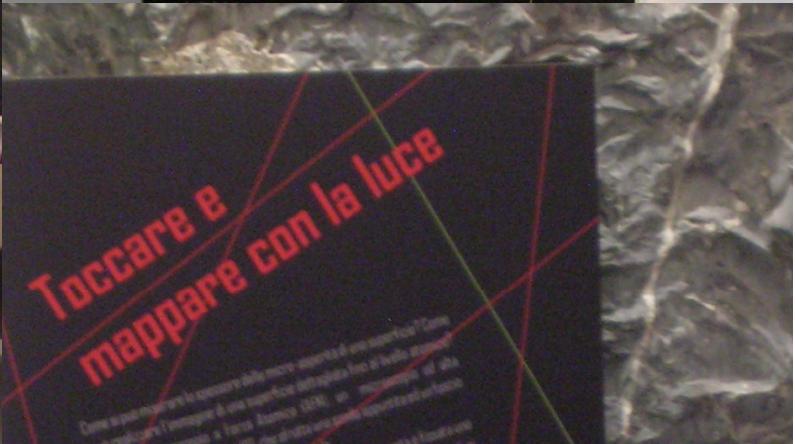
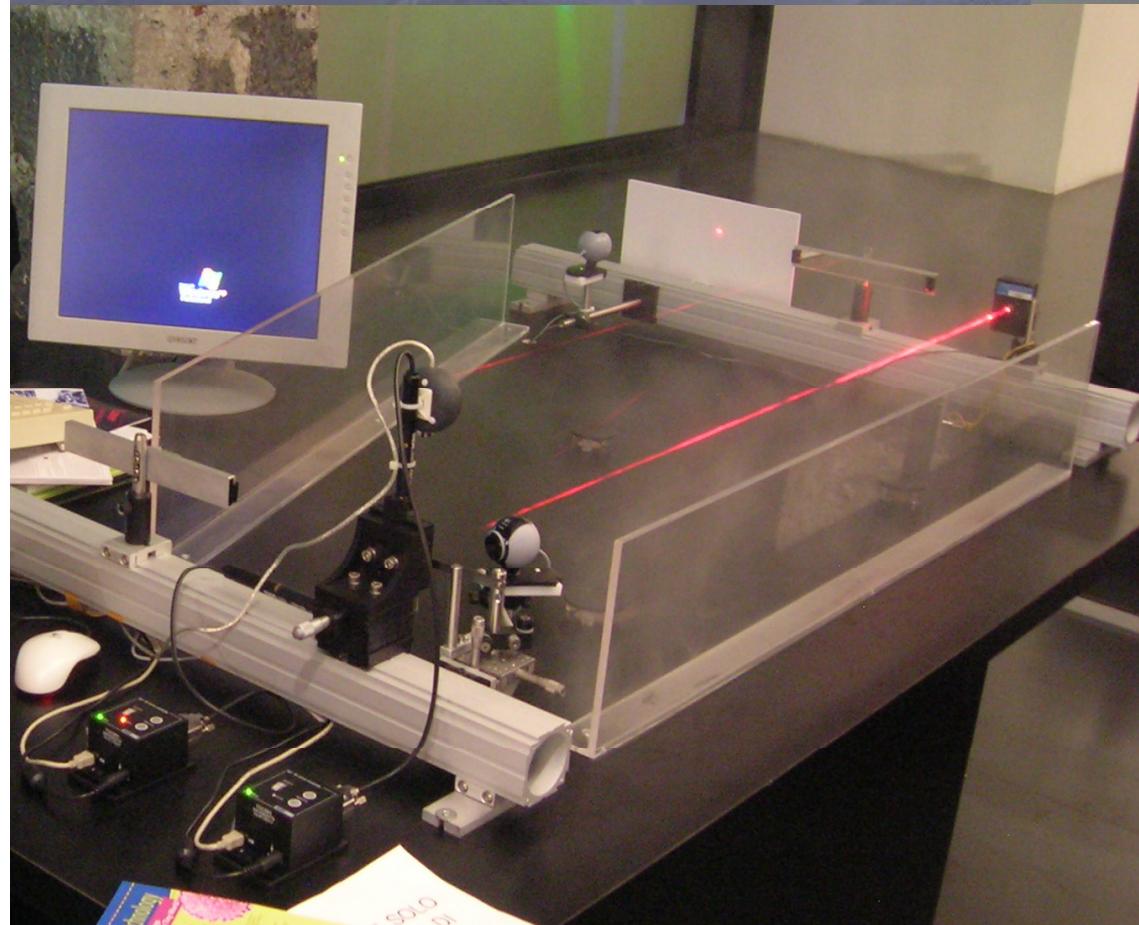
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Atomic Force Microscope



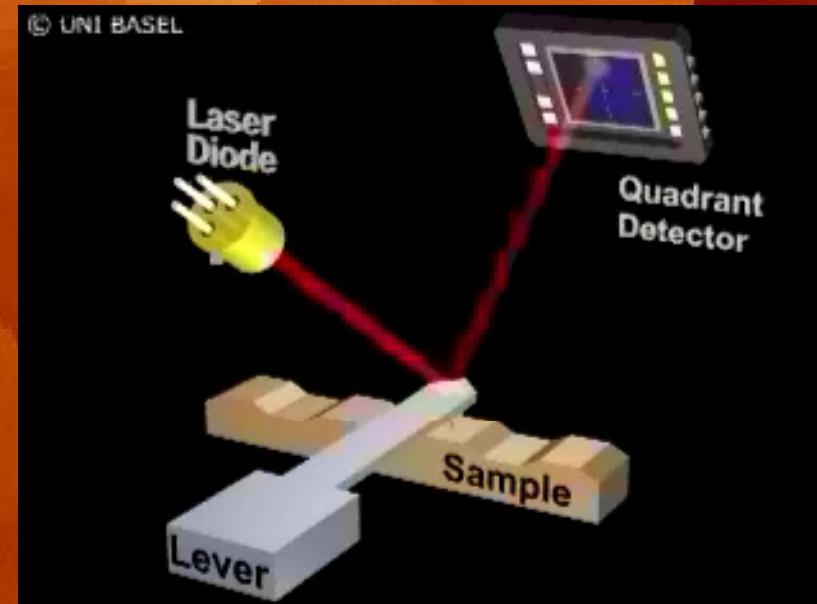
- *Forza di attrazione o repulsione*
- *Sistema in Vuoto, Aria, Liquido*
- *Campione metallico o isolante*
- *Campioni biologici in liquido*



Contributi:

CNR, Ist. NanoScienze and Gruppo PSC
Dip. di Fisica, Univ. Modena e Reggio
Progetto Lauree Scientifiche

la leva ottica



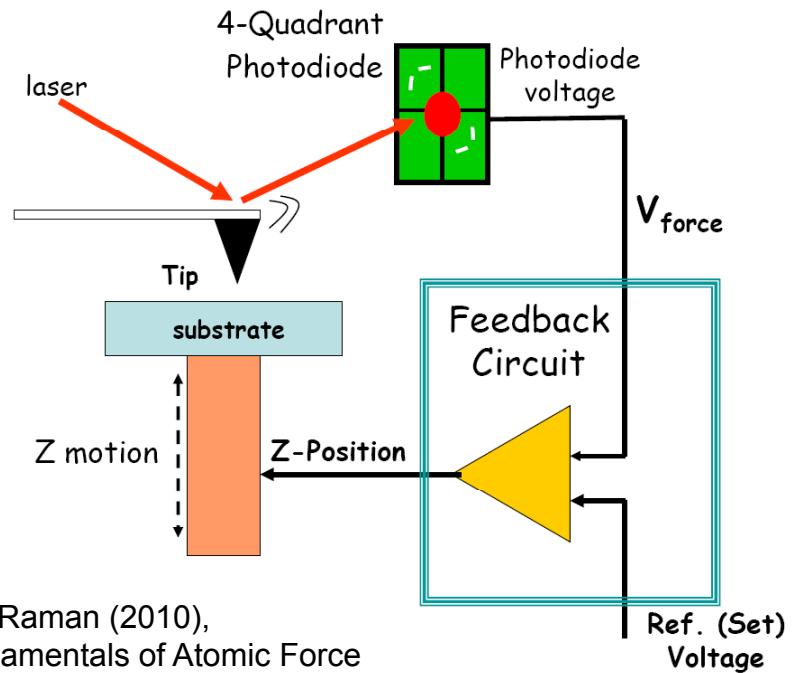
<http://www.nano-world.org/frictionmodule/content/0300reibungsmikroskopie/?lang=en>

Effettivamente il microscopio AFM lavora **sempre**, come anche il microscopio STM, utilizzando il metodo del **feedback**!



Ron Reifenberger; Arvind Raman (2010),
"ME 597/PHYS 570: Fundamentals of Atomic Force
Microscopy (Fall 2010),"
<http://nanohub.org/resources/9598>.

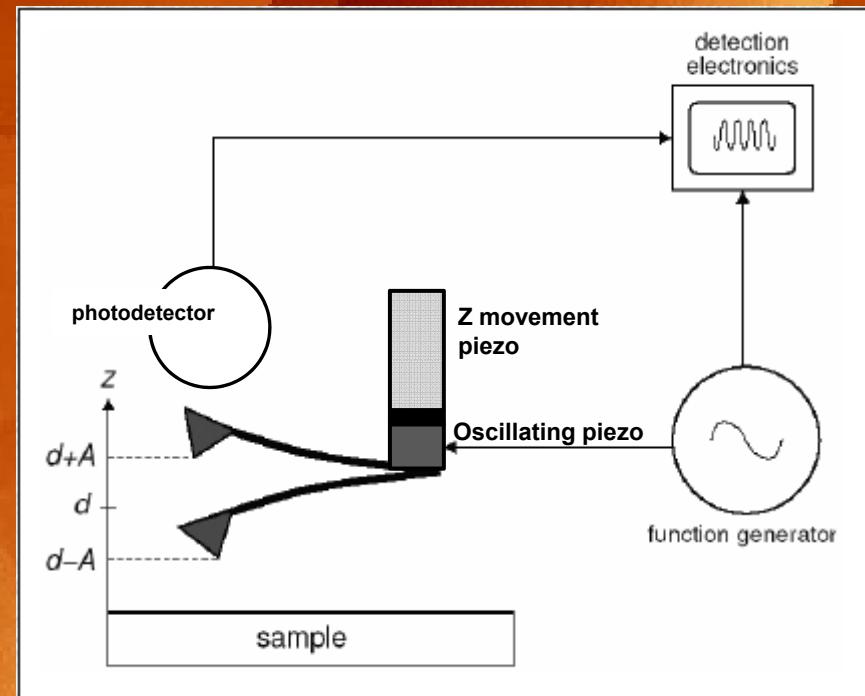
Maintaining a constant force



Microscopia alla nanoscala

Effettivamente il microscopio AFM lavora quasi sempre in modalità dinamica

La descrizione del sistema, punta in interazione con una superficie, diventa più complessa ma "gestibile". Si passa dalla equazione statica di una molla a quella di un oscillatore armonico forzato e smorzato dove lo smorzamento è in parte dovuto alla interazione punta superficie.



$$m\ddot{z} + k z + \frac{m\omega_0}{Q}\dot{z} = F_{ts} + F_0 \cos(\omega t) \quad (2.2)$$

where F_0 and ω are the amplitude and angular frequency of the driving force, respectively; Q , ω_0 and k are the quality factor, angular resonance frequency and force constant of the free cantilever, respectively. F_{ts} contains the tip–surface interaction forces. In the absence of tip–surface forces, Eq. (2.2) describes the motion of a forced harmonic oscillator with damping.

La soluzione dell'equazione del moto di un oscillatore armonico forzato e smorzato e' ancora una oscillazione armonica.

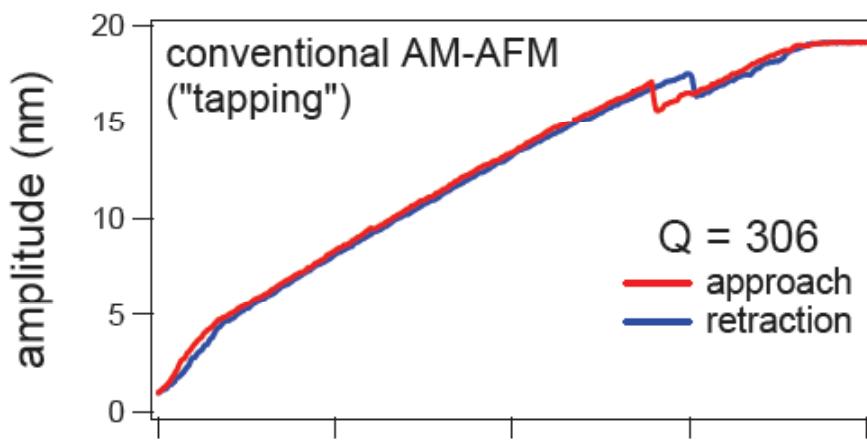
$$z(t) = z_0 + A(\cos(2\pi f t + \varphi))$$

Sia la frequenza f che l'ampiezza A dipendono dall'interazione $F(z)$.

Frequenza

$$\frac{\Delta f}{f} = -\frac{1}{2k} \frac{\partial F}{\partial z} . \quad (\text{per piccole ampiezze } A)$$

Aampiezza



Minore probabilita' di danneggiare il campione poiche' il contatto e' intermittente o assente.

Si minimizzano gli effetti di forze laterali (attrito).

FM-AFM oppure Non Contact AFM
e' la modalita' di lavoro in cui il feedback e' sulla frequenza f .

- utilizzata in vuoto
- raggiunge risoluzione atomica

AM-AFM oppure Tapping AFM
e' la modalita' di lavoro in cui il feedback e' sulla frequenza A .

- utilizzata in aria e liquido
- utilizzata su campioni biologici
- non raggiunge risoluzione atomica

Misure di forze di attito in contatto

The optical AFM system is aligned so that radiation of the semi-conductor laser is focused on the probe console, and the reflected beam hits the center of a photosensitive area of a photodetector. Four-section semi-conductor photodiodes are applied as position-sensitive photodetectors.

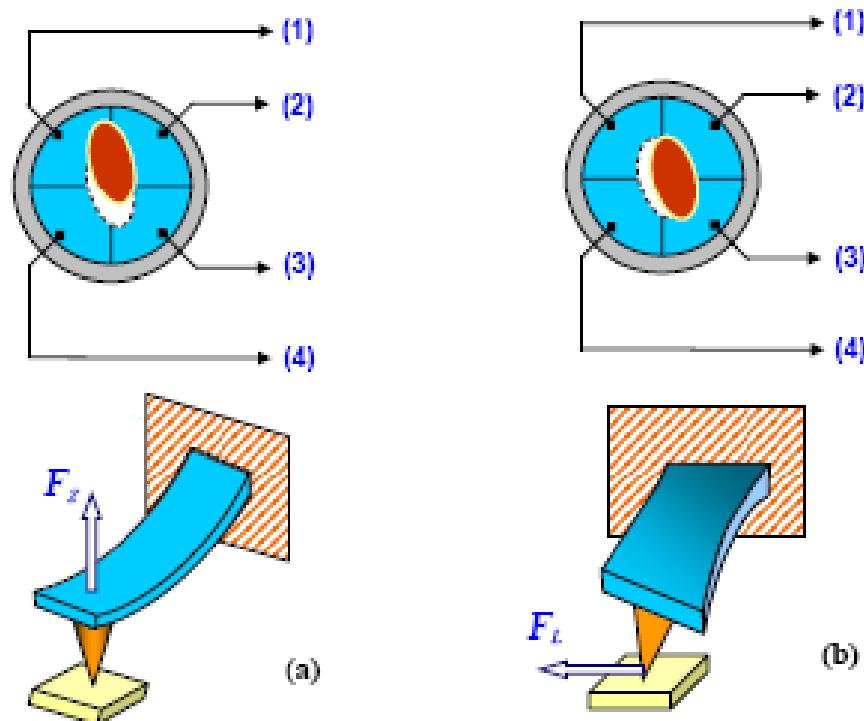


Fig. 63. Conformity between the types of bending deformations of the probe console and the change of exposure spot position on the photodiode