“Técnicas de Sonda: AFM e STM”

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Scanning Tunneling Microscopy (STM)

O **STM** foi inventado por Gerd Binnig e Heinrich Rohrer (Prêmio Nobel de Física 1986), da IBM de Zurich, em 1981

Finalidade: gerar imagens reais de superfícies com resolução atômica.

Princípio Físico: fenômeno de tunelamento - mecânica quântica.

STM

Mecânica Quântica

Matéria: comportamento ondulatório

Probabilidade não nula: $|\psi(x)|^2 \neq 0$ na barreira

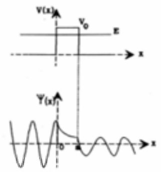
Efeito túnel ou Tunelamento

Probabilidade que um elétron tem para aparecer do outro lado da barreira: equação de **Schrödinger**.

STM

*Densidade de probabilidade de presença da partícula **m** em **x***

$$-\left(\frac{\hbar^2}{2m}\right)\frac{d^2\psi(x)}{dx^2} + V(x)\psi(x) = E\psi(x)$$



$\hbar = \frac{h}{2\pi}$: é a constante de Planck normalizada

m : é a massa do elétron

x : é a variável unidimensional

$\psi(x)$: é a função de onda ($|\psi(x)|^2$

V(x) : é a energia potencial

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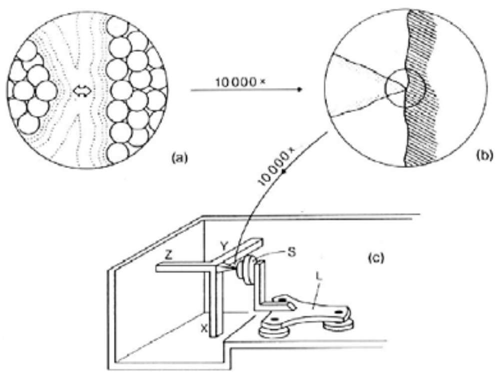
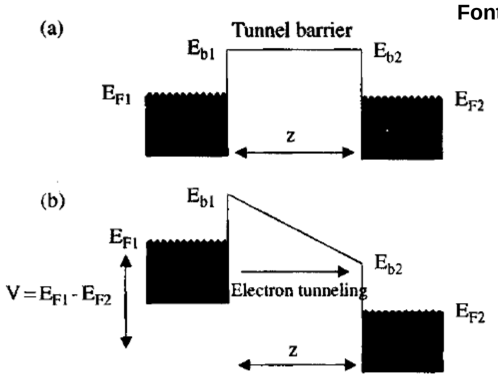


Esquema do STM. ***(a)*** *visualização do ápice da ponta (esquerda) e da superfície da amostra (direita) a uma ampliação de cerca de 108. Os círculos sólidos indicam átomos e as linhas pontilhadas os contornos da densidade dos elétrons. O caminho da corrente de tunelamento é mostrado pela seta.* ***(b)*** *escala reduzida por um fator de 104. A ponta (esquerda) parece tocar a superfície (direita).* ***(c)*** *STM com sistema de cerâmicas piezoelétricas X, Y, Z com a ponta de tunelamento a esquerda e L (motor eletrostático) para posicionamento superficial (irregular) da amostra.*

Fonte: H.-J. Güntherodt, R. Wiesendanger (Eds.), "Scanning Tunneling Microscopy I", Second Edition, Spring-Verlag, 1994.

Fonte: Guozhong Cao



The energy levels in two solids (metals or semiconductors) separated by an insulating or vacuum barrier (a) with no electric field applied between the solids and (b) with an applied electric field. Energies of the electrons in the solids are indicated by the shaded areas up to E_{F1} and E_{F2}, which are the Fermi levels of the respective solids. The applied bias V is $E_{F1} - E_{F2}$, and z is the distance between the two solids. [D.A. Bonnell and B.D. Huey, in *Scanning Probe Microscopy and Spectroscopy*, ed., D. Bonnell, Wiley-VCH, New York, p. 7, 2001.]

STM

• Electrons in the material cannot transfer from one surface to another through the insulator, since there is an energy barrier.
• When a voltage is imposed between the two, the shape of the energy barrier is changed and there is a driving force for electrons to move across the barrier by tunneling, resulting in a smallcurrent when the distance is sufficiently small so that the electron wave functions extended from the two surfaces overlap.

Fonte: Guozhong Cao

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Fonte: Guozhong Cao

The tunneling current, *I*, is given by:

$$I \propto e^{-2kz}$$

where z is the distance between the two metals or the thickness of the insulator and k is given by:

$$k = \frac{\sqrt{2m(V-E)}}{h}$$

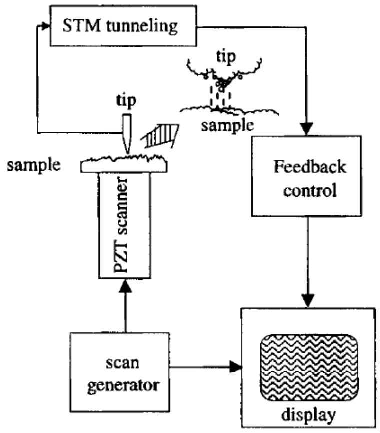
where m is the mass of an electron, h is Planck's constant, E is the energy of electron, and V is the potential in the insulator. Similar discussion is applicable to a tip-planar surface geometry, the configuration of a STM. However, the tunneling current is then given by:

$$I = C \rho_t \rho_s e^{-zk^{\frac{1}{2}}}$$

where z is the distance between the tip and the planar surface or sample, ρ_t is the tip electronic structure, ρ_s is the sample electronic structure, and C is a constant dependent on the voltage applied between the tip and the sample surface. The tunneling current decays exponentially with the tip-sample distance. For example, a 0.1 nm decrease in the distance will increase the tunneling current by one order of magnitude. Such a quantum mechanical property has been utilized in the STM.

STM

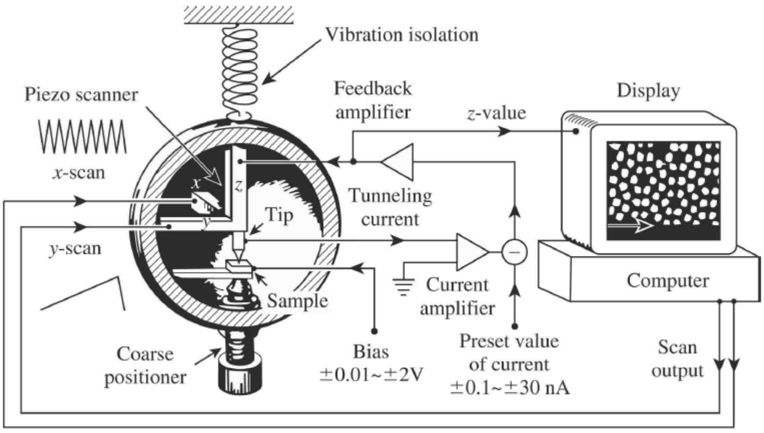
Fonte: Guozhong Cao



Schematic of scanning tunneling microscope. Two operation modes are commonly used. **(i)** Constant current mode, **in** which the distance between the tip and sample surface is kept constant. (ii) Constant voltage mode, in which the tip position **is** held unchanged during scanning the sample surface.

STM

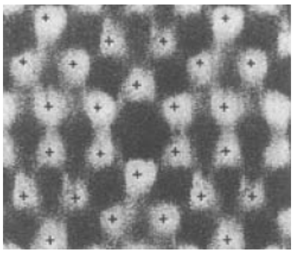
Fonte: C. Julian Chen



The scanning tunneling microscope in a nutshell. The scanning waveforms, applying on the x and y piezos, make the tip raster scan on the sample surface. A bias voltage is applied between the sample and the tip to induce a tunneling current. The z piezo is controlled by a feedback system to maintain the tunneling current constant. The voltage on the z piezo represents the local height of the topography.To ensure stable operation, vibration isolation is essential.

STM

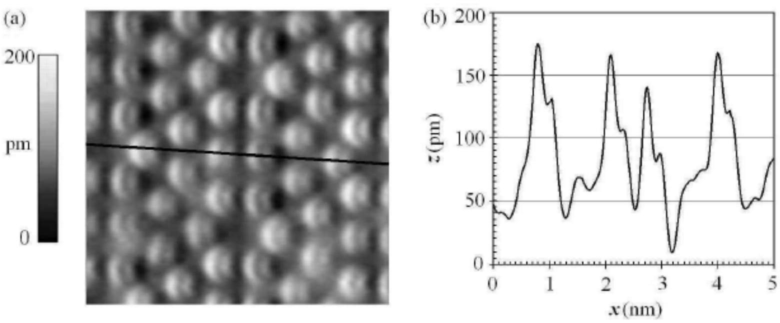
STM imagine of 7 X 7 reconstruction on Si (1 1 1) surface in real space with atomic resolution. (b) Modified adatom model. The underlying top-layer atom positions are shown by dots, and the remaining atoms with unsatisfied dangling bonds carry circles, whose thickness indicates the measured depth. The adatoms are represented by large dots with corresponding bonding arms. The empty potential adatom position is indicated by an empty circle in the triangle of adjacent rest atoms. The grid indicates the 7 X 7 unit cells.



Fonte: G. Binnig, H. Rohrer, C. Gerber, and E. Weibel, Phys. Rev. Lett. 50, 120 (1983).

STM

Fonte: C. Julian Chen



Gray-scale image and contour plot. (a) A 5nm×5nm gray-level topographic image of Si(111)7×7. The bright spots represent protrusions, and the dark spots represent depressions. The z values corresponding to the gray levels are indicated by a scale bar. (b) The topographic contour along a line in (a), for a more quantitative representation.

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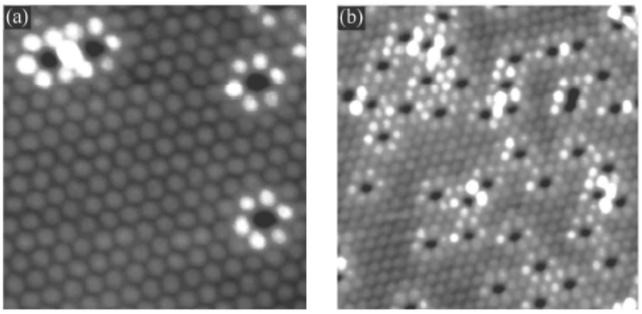
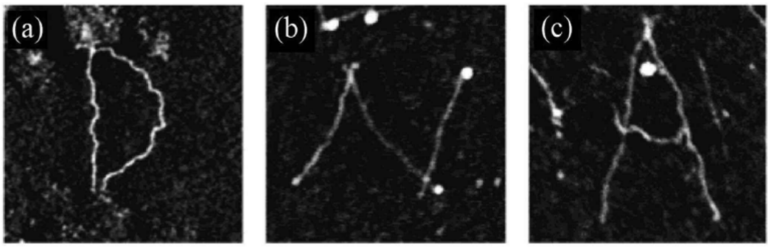


STM topographical images of the Ni-Au system. (a) An image of Ni(111) with 2% Au. The Au atom appears as depressions because of the LDOS at the Fermi level is lower. The Ni atoms surrounding an Au atom appear as protrusions because of the enhancement of LDOS at the Fermi level, indicating a higher chemical reactivity. For the Ni atom between two Au atoms, the LDOS enhancement is even higher. (b) Na image of Ni(111) surface with 7% of Au. The number of Ni atoms with doubly enhanced Fermi-level LDOS is increased.

Fonte: C. Julian Chen citing: Science 279, 1913–1915 (1998).

STM



Manipulating DNA molecules using AFM. A pattern of DNA molecules fabricated by AFM. First, DNA strands are deposited on an AP-mica surface. Second, the AFM tip is positioned to a predefined location of the DNA strand, then pressed hard to cut it. Third, the AFM tip is used to sweep or push the DNA strands to form a designed pattern.

Fonte: C. Julian Chen citing: Nano Letters 2, 55–57 (2002).

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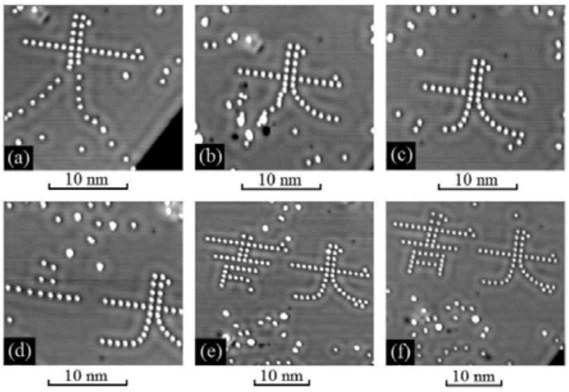
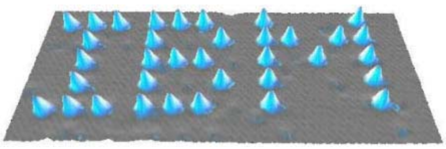
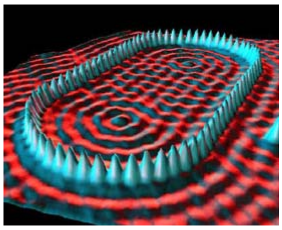


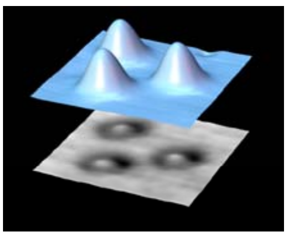
Writing Chinese characters using STM. A sequence of STM images showing the assembly of two Chinese characters from single Ag atoms on a Ag(111) surface. The lateral manipulation technique allows the exact placing of single atoms on desired atomic sites. An assembly involves not only the movement of single atoms but requires also many repair and cleaning steps until the final structure is completed.

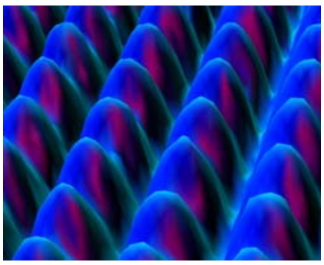
Fonte: C. Julian Chen citing: R. P. Feynman. There's Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics. Lecture at an 1959 APS meeting. The Archives, CaliforniaInstitute of Technology, see www.its.caltech.edu/↑ feynman/plenty.html (1959).

STM: IBM









http://www.almaden.ibm.com

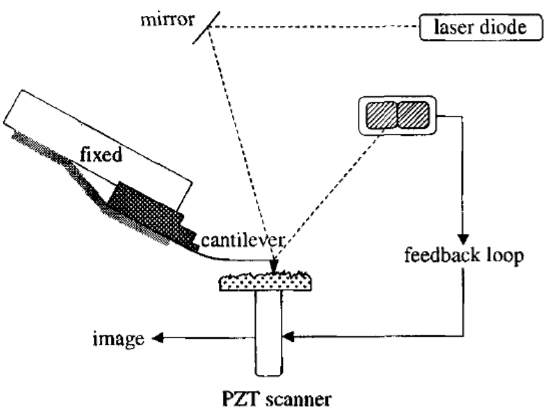
Atomic force microscopy (AFM)

• In spite of atomic resolution and other advantages, STM is limited to an electrically conductive surface since it is dependent on monitoring the tunneling current between the sample surface and the tip.

• AFM was developed as a modification of STM for dielectric materials.

Atomic force microscopy (AFM)

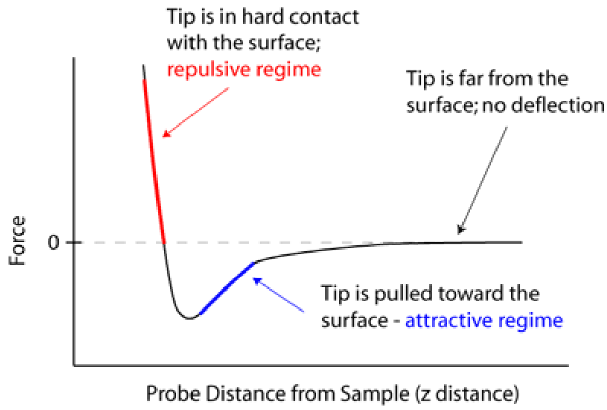
Fonte: Guozhong Cao



Operating principle of an atomic force microscope. The sample is mounted on a scanner, and the cantilever and tip are positioned near the surface with a macroscopic positioning device. Cantilever deflected with a photo diode that records the position of a laser beam that has been reflected off the top of the cantilever.

Atomic force microscopy (AFM)

Fonte: www.nanoscience.com

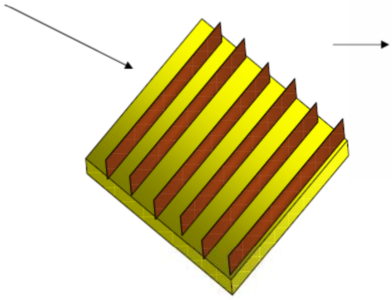


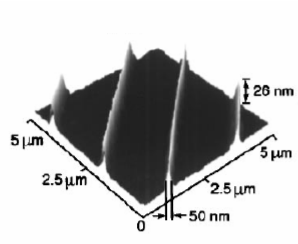
Atomic force microscopy (AFM)

- Contact Mode
- Lateral Force Microscopy
- Noncontact mode
- Dynamic Force / Intermittant-contact / “tapping mode” AFM
- Force Modulation
- Phase Imaging

Atomic force microscopy (AFM)

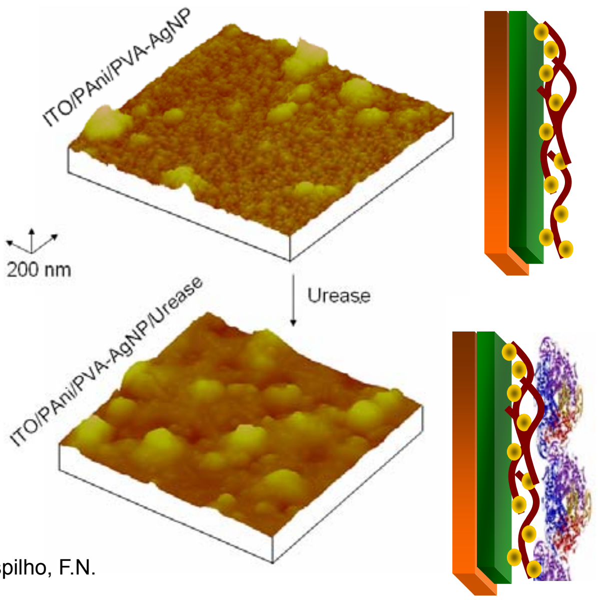
Example



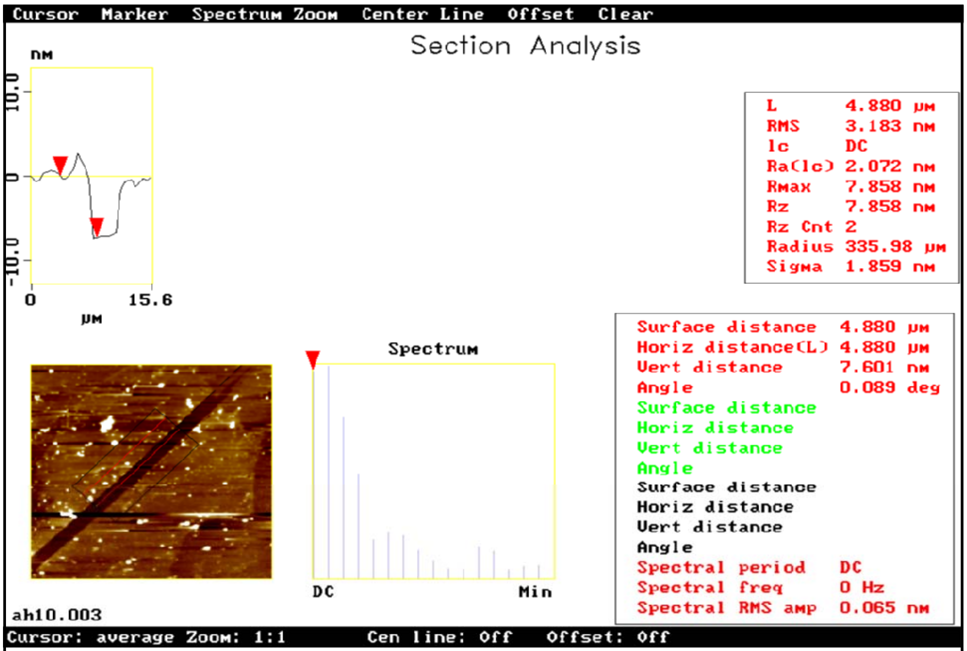


Picture from
Annu. Rev. Mater. Sci. 1998. 28:153–84

Atomic force microscopy (AFM)



Fonte: Crespilho, F.N.



Fonte: Crespilho, F.N.