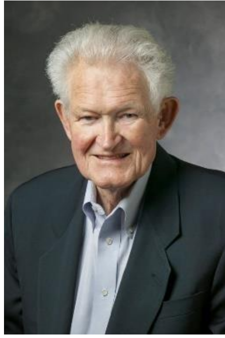
AFM

ANDERSON CAIRES

TEM

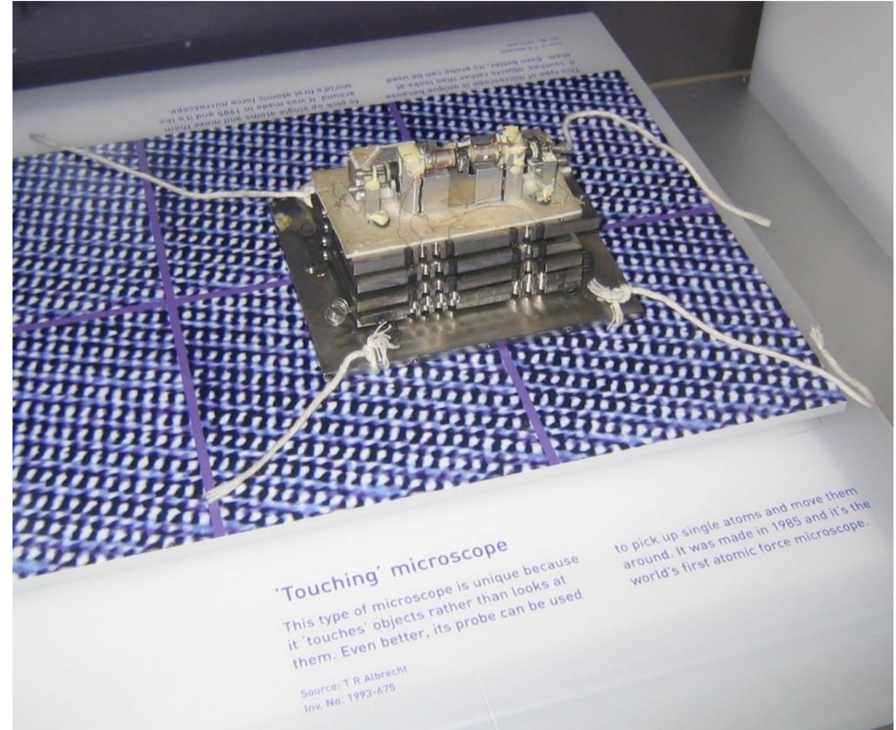
AFM

Primeiro Microscópio de Força Atômica (AFM)



Binnig, Calvin Quate and Christoph Gerber
1986

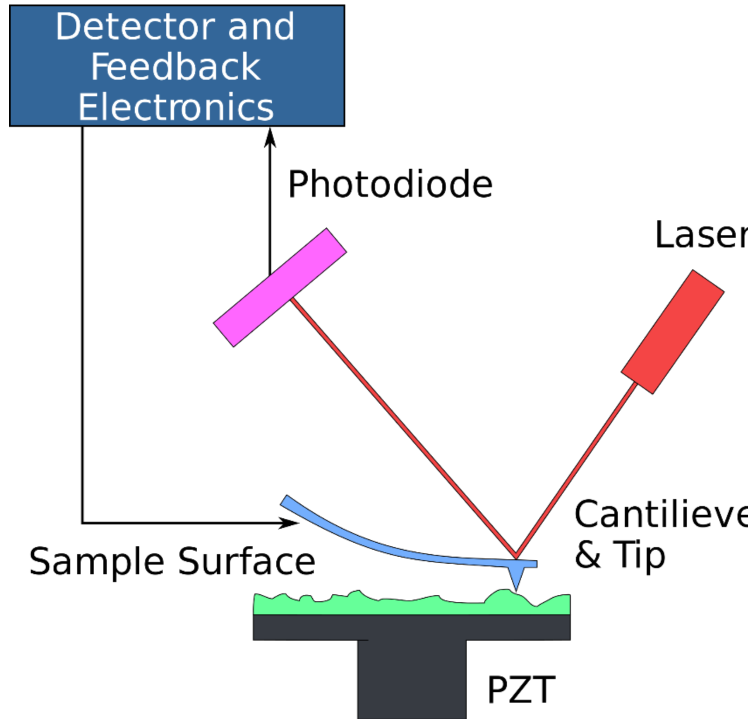
“Com objetivo de medir forças menores que 1µN entre a superfície da ponteira (tip) e a superfície da amostra"

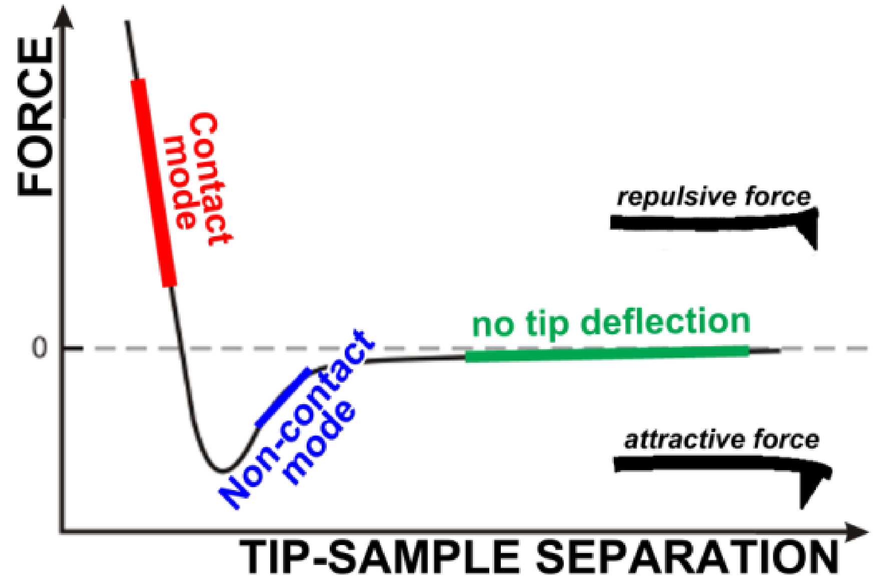


Springer Handbook of Nanotechnology,Bhushan, B., Ed. Springer ,2004, p.361,isbn=3-540-01218-4

https://pt.wikipedia.org/wiki/Microsc%C3%B3pio_de_for%C3%A7a_at%C3%B4mica#cite_note-1

Atomic Force Microscopy (AFM): Princípios básicos





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http://www.intechopen.com/source/html/42103/media/image2.png

Atomic Force Microscopy (AFM): Princípios básicos

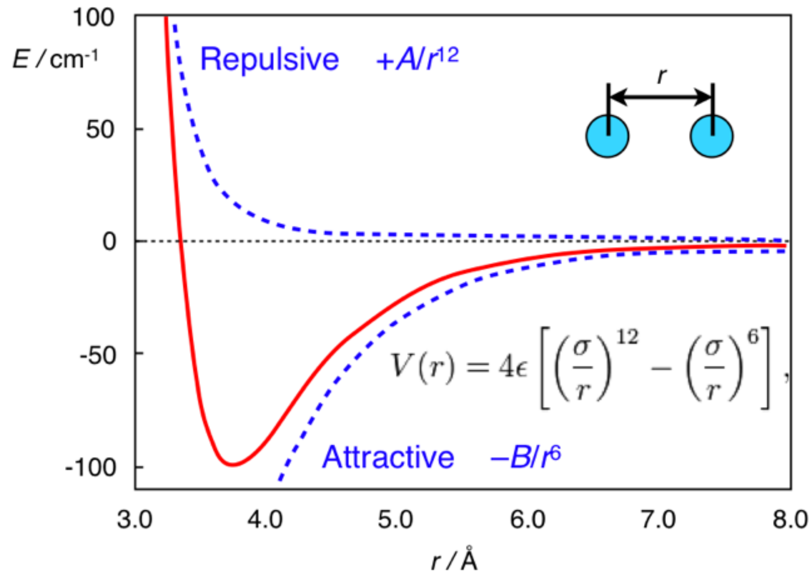
LENNARD-JONES potential

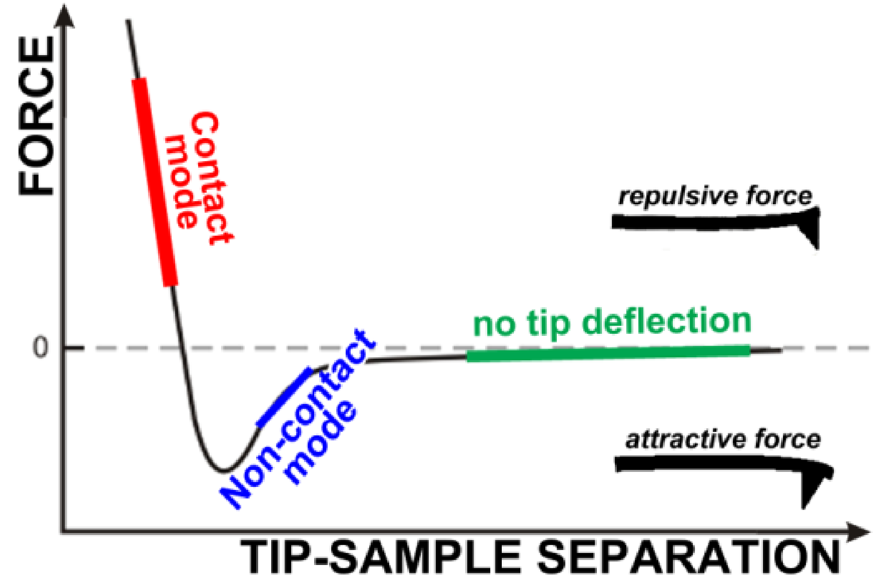
$$V(d) = 4\varepsilon\left(\underbrace{\left(\frac{\sigma}{d}\right)^{12}}_{\substack{\text{repulsion} \\ \text{(short range)}}} - \underbrace{\left(\frac{\sigma}{d}\right)^{6}}_{\substack{\text{attraction} \\ \text{(long range)}}}\right)$$

$$\varepsilon, \sigma = \text{const}$$

Em grandes distâncias, as interações são predominantemente atrativas, devido às forças de Van der Waals. Se aproximarmos ainda mais a ponta com a superfície, as interações são repulsivas devido a repulsão entre os orbitais eletrônicos dos átomos da superfície da amostra e os da ponta do microscópio de força atômica.

Atomic Force Microscopy (AFM): Princípios básicos





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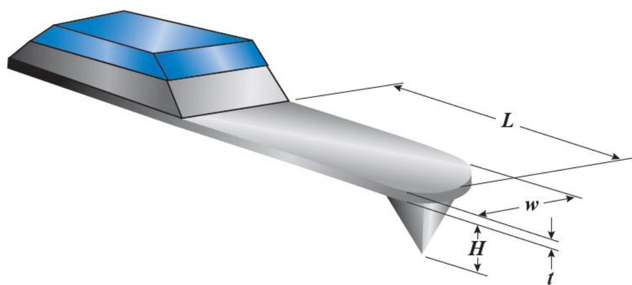
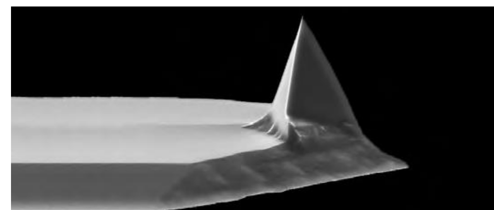
http://www.intechopen.com/source/html/42103/media/image2.png

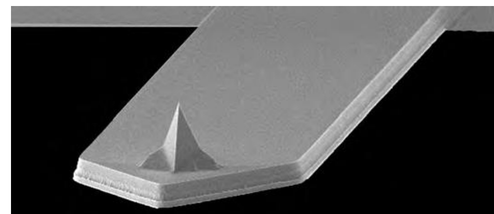
The Modern AFM

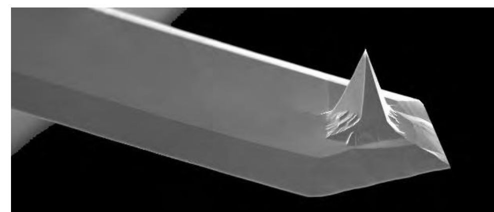
The Modern AFM

Cantilever









Contato

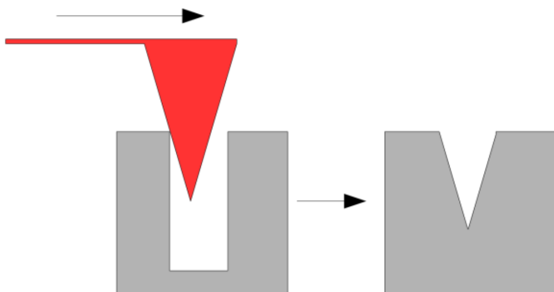
Não-contato

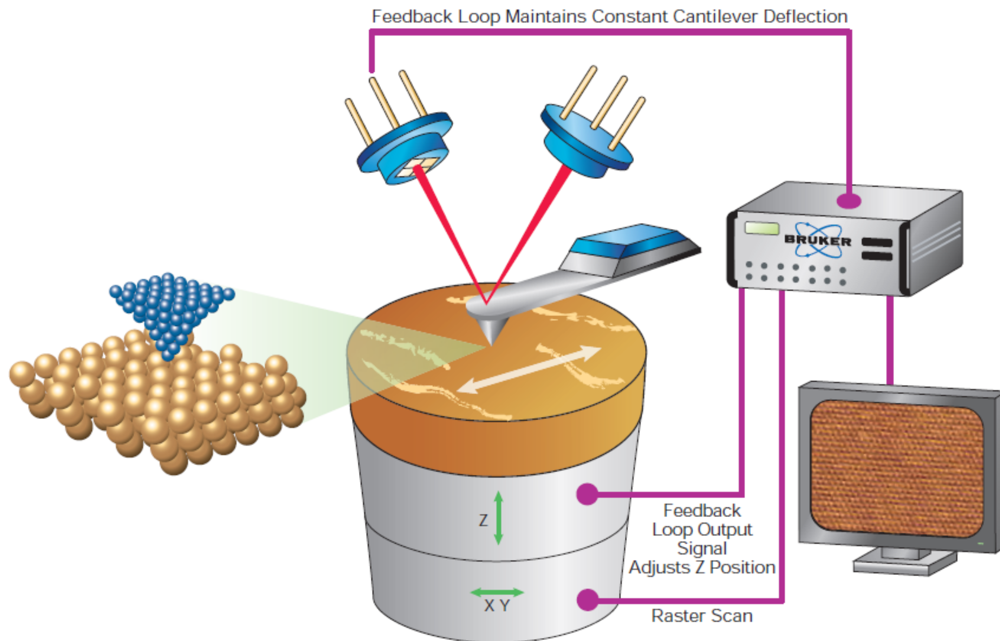
Tapping

Modo contato

Este método é especialmente indicado para amostras rígidas. A compressão e as forças geradas pelo modo contato podem causar danos a amostras.

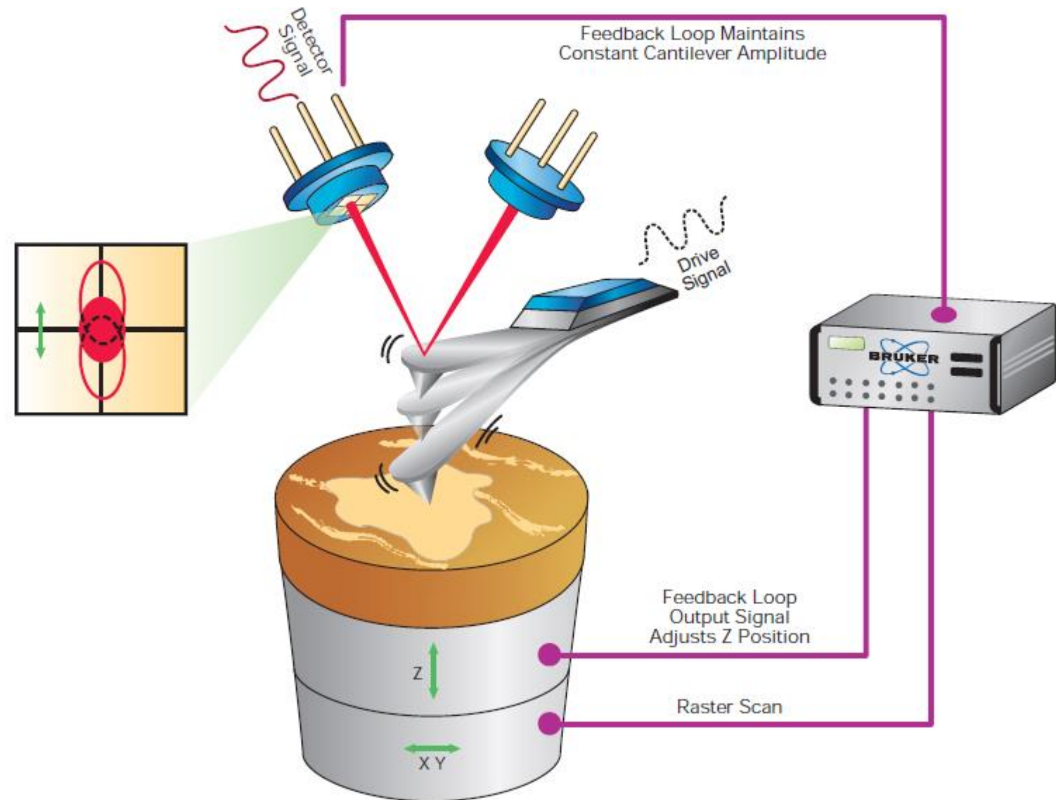
Amostras rugosas – Muitos artefatos





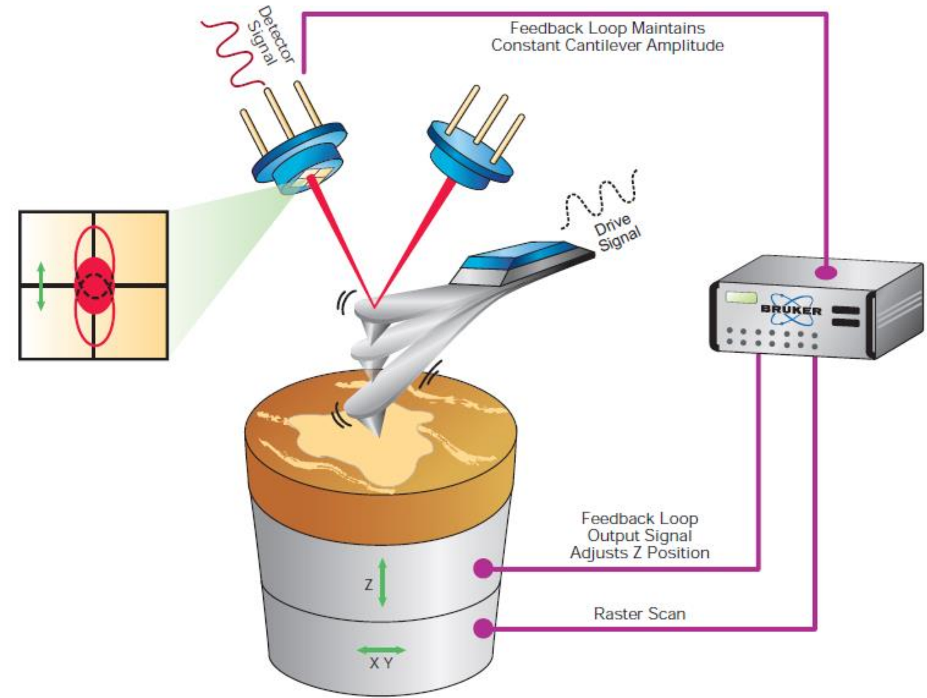
Modo não contato

O método de não contato é usado preferencialmente em amostra moles. Porém a grande distância entre a ponta e a amostra traz uma limitação na resolução da imagem.

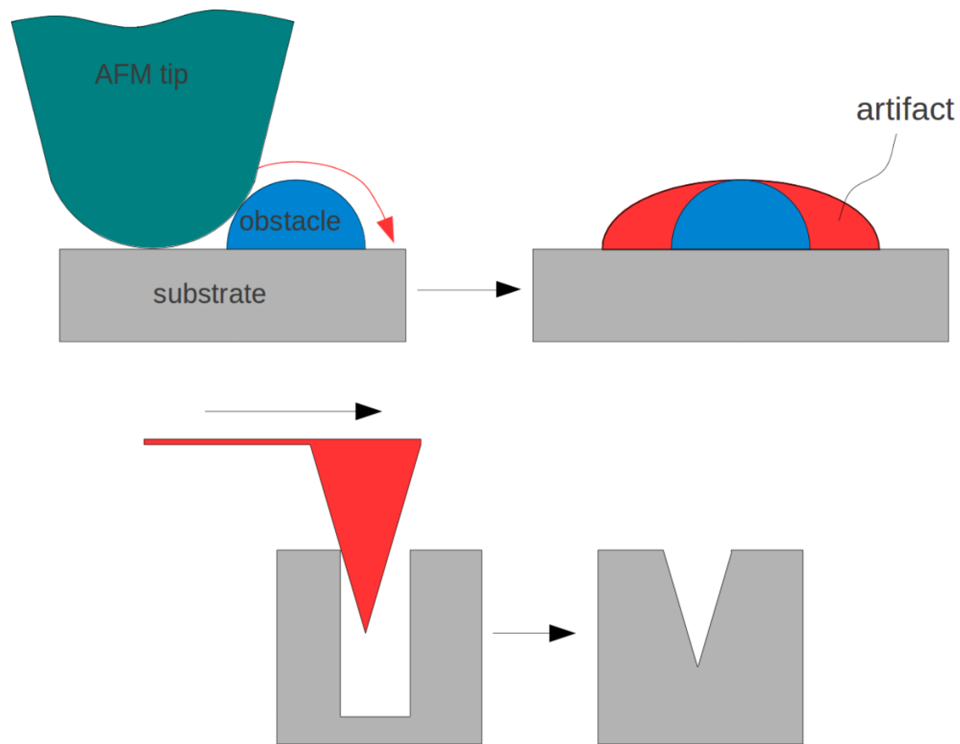


Tapping Mode

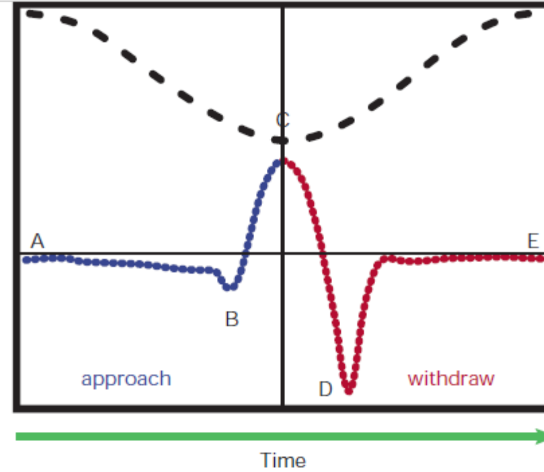
O método de tapping ou contato intermitente é utilizado para contornar as restrições presentes nos modos de contato e de não-contato. **O modo de contato intermitente é utilizada em materias biológicos, polímeros e amostras demasiadamente rugosas, pois estes são maleáveis e deformáveis pela ponta.**

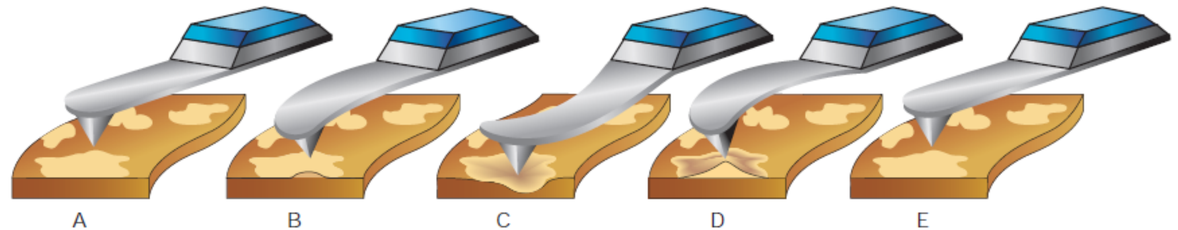


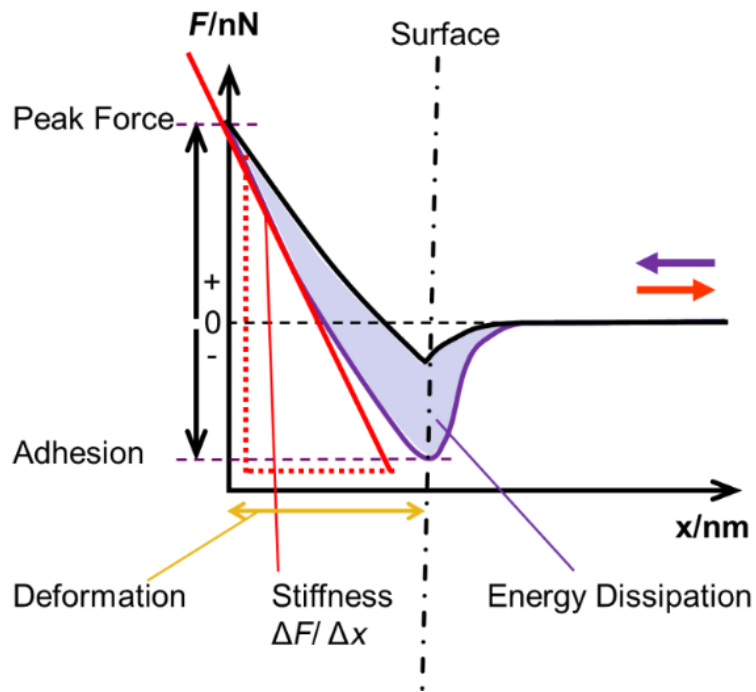
AFM Artefatos



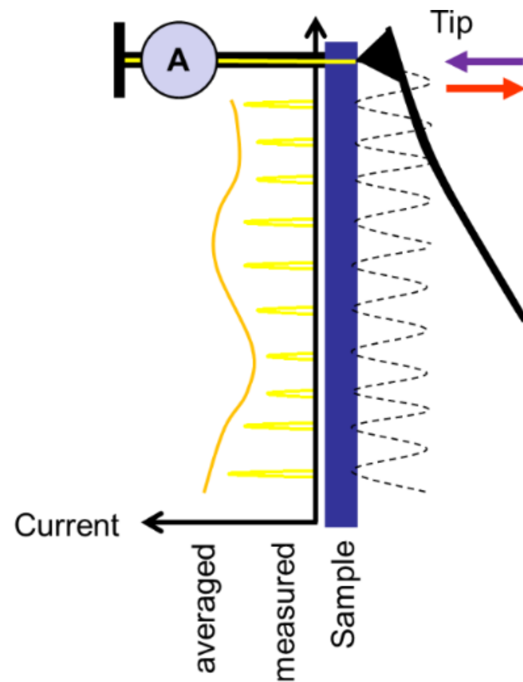
PeakForce Tapping







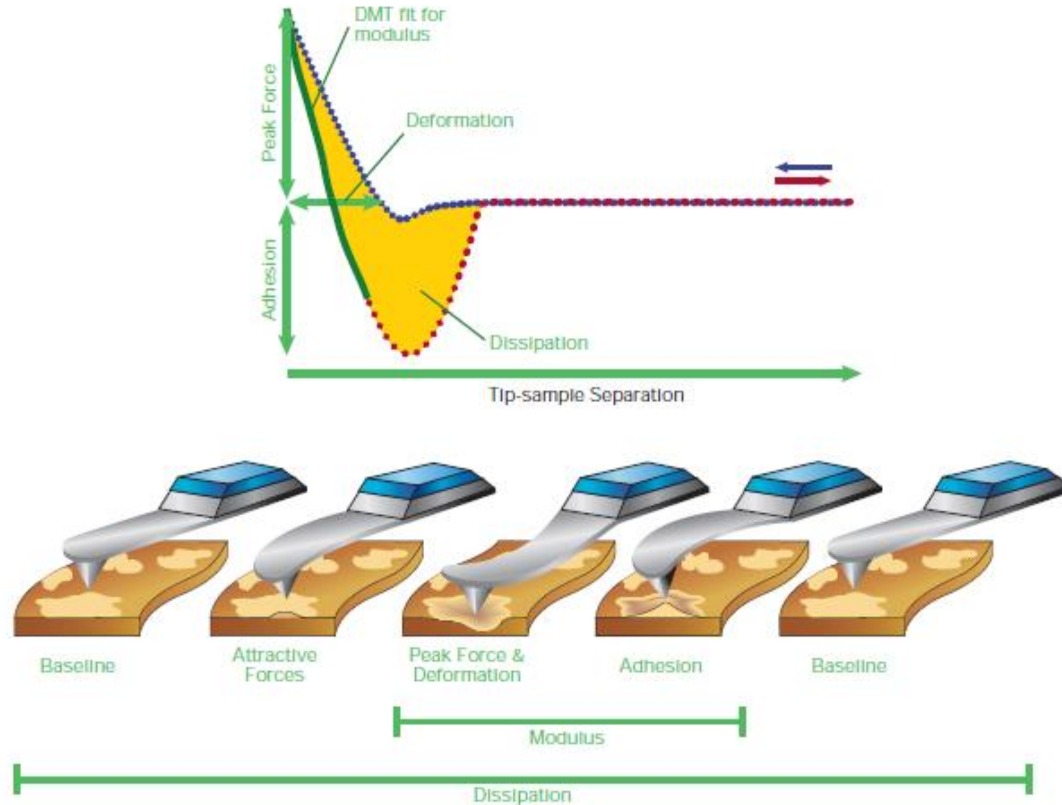
F/nN
Surface
Peak Force
+
0
-
Adhesion
x/nm
Deformation
Stiffness
ΔF/ Δx
Energy Dissipation



Tip
A
Current
averaged
measured
Sample

QNM

Quantitative Nanomechanical Mapping



Quantitative Nanomechanical Mapping

Adhesion: The peak force below the baseline.

Deformation: The maximum deformation of the sample (defined as the distance from the base of the **Deformation Fit Region** position to the peak interaction force position) caused by the probe.

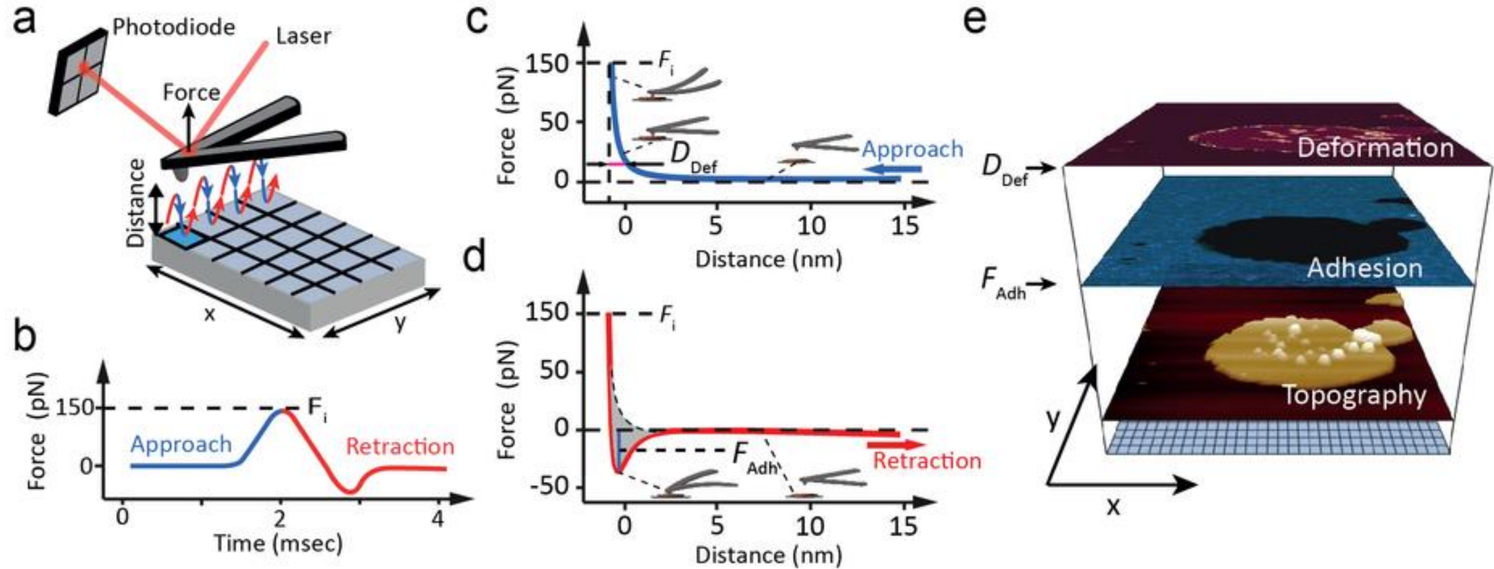
DMT Modulus:

$$F_{tip} = \frac{4}{3}E^{*}\sqrt{Rd^{3}} + F_{adh}$$

Dissipation:

$$W = \int_{0}^{T} \bar{F} \bullet \bar{v}dt = \int \bar{F} \bullet d\bar{Z}$$

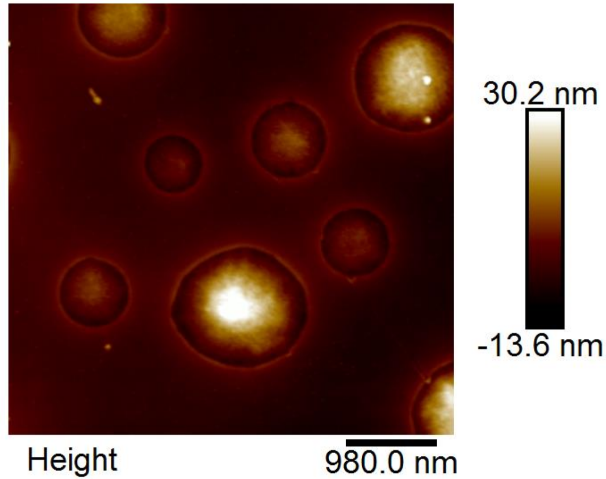
Quantitative Nanomechanical Mapping

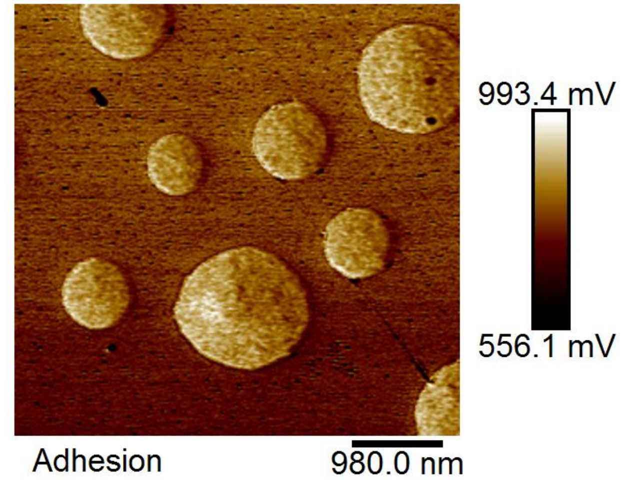


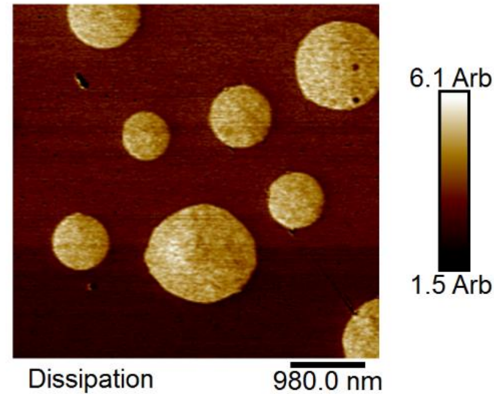
Nature Methods 12, 2015, 845–851

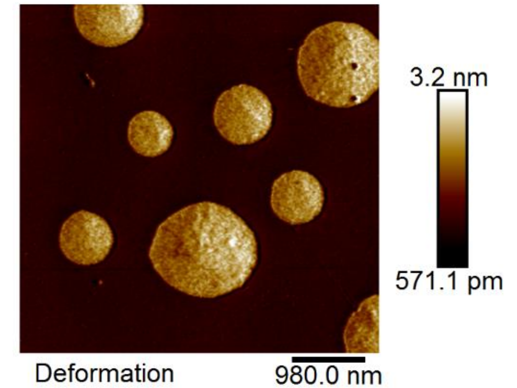
Quantitative Nanomechanical Mapping

PS+LDPE blend









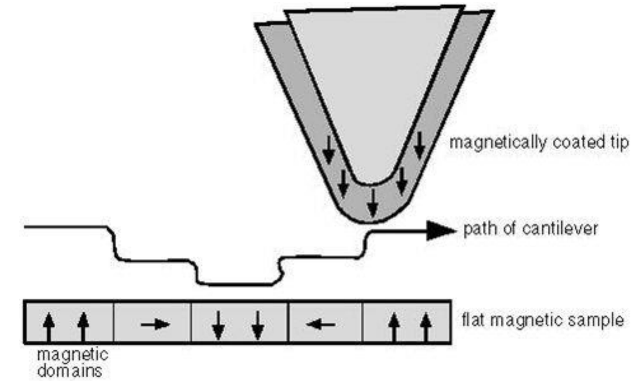
LasMAT

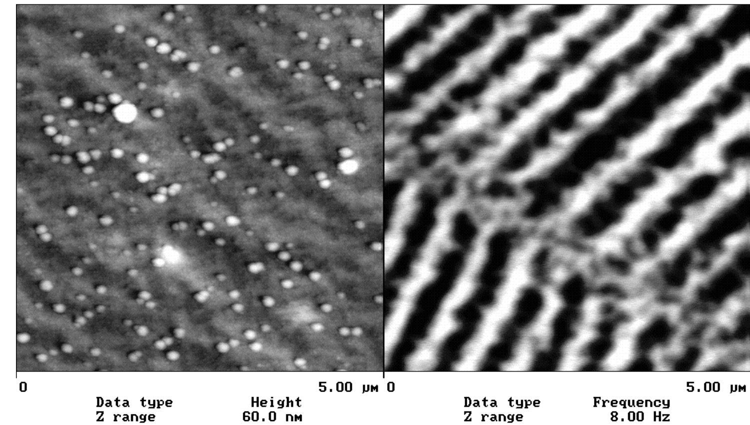
CeNano²I

MFM

Microscopia de força magnética

In the absence of magnetic forces, the cantilever has a resonant frequency *f0*. This frequency is shifted by an amount Δf proportional to vertical gradients in the magnetic forces on the tip.





Microscopia de força magnética

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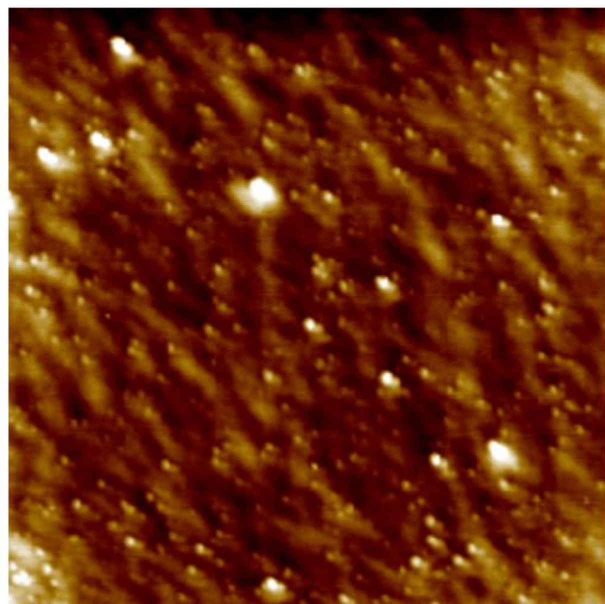

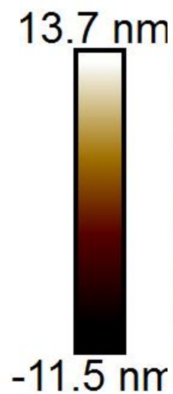

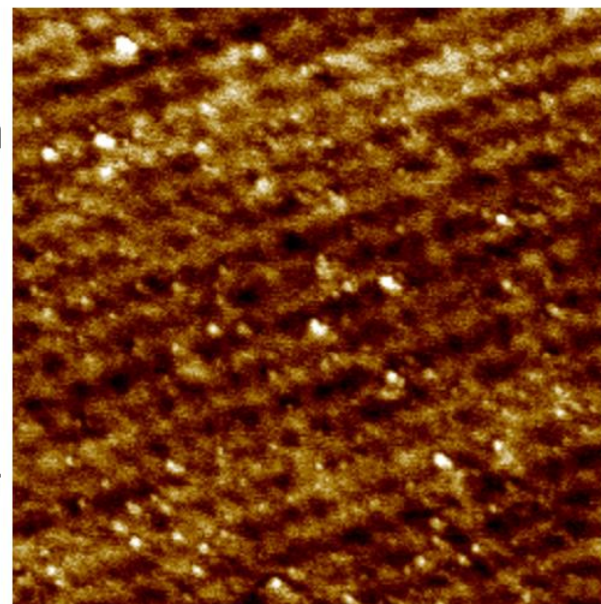

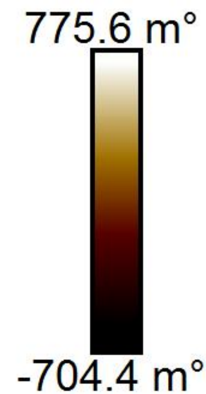

Microscopia de força magnética

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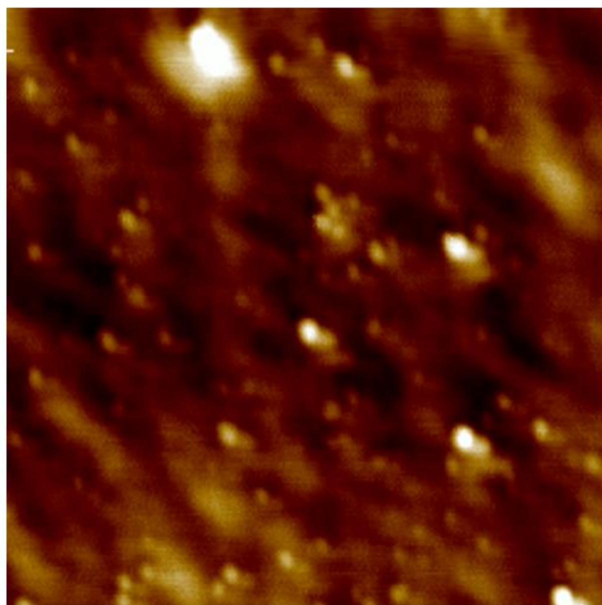
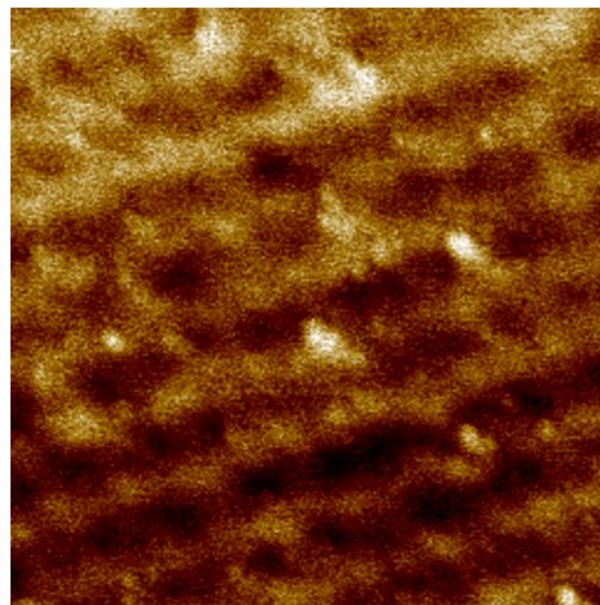
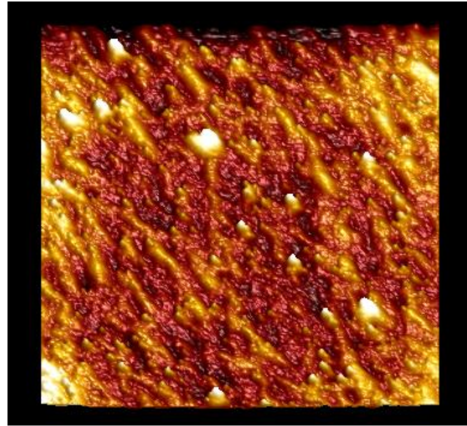
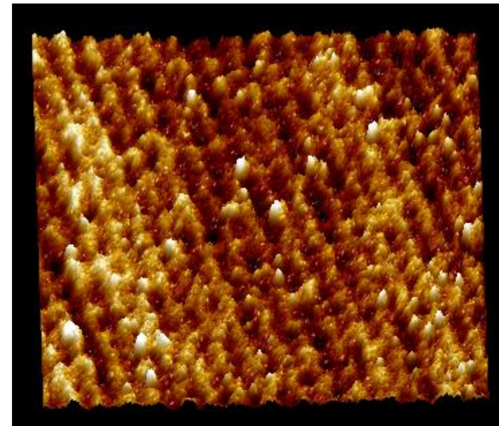
CeNano²I

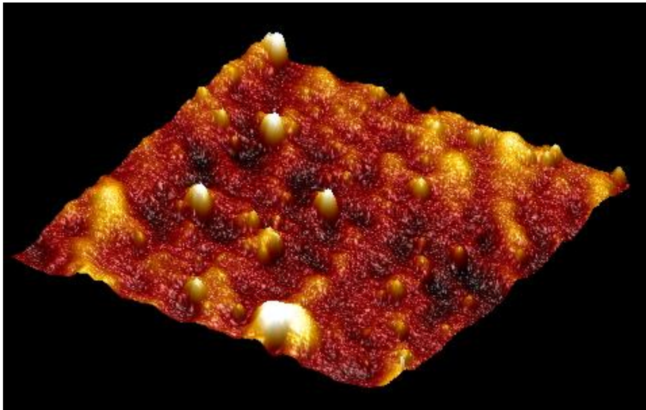


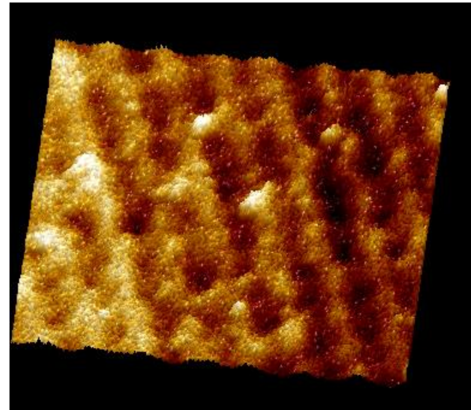


Microscopia de força magnética









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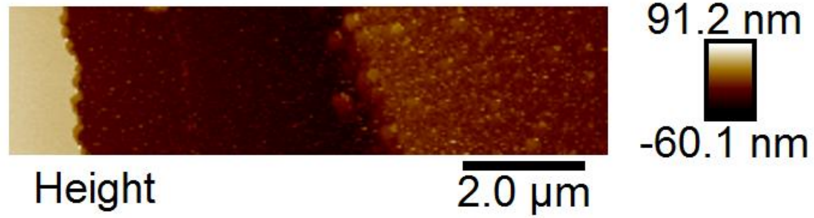
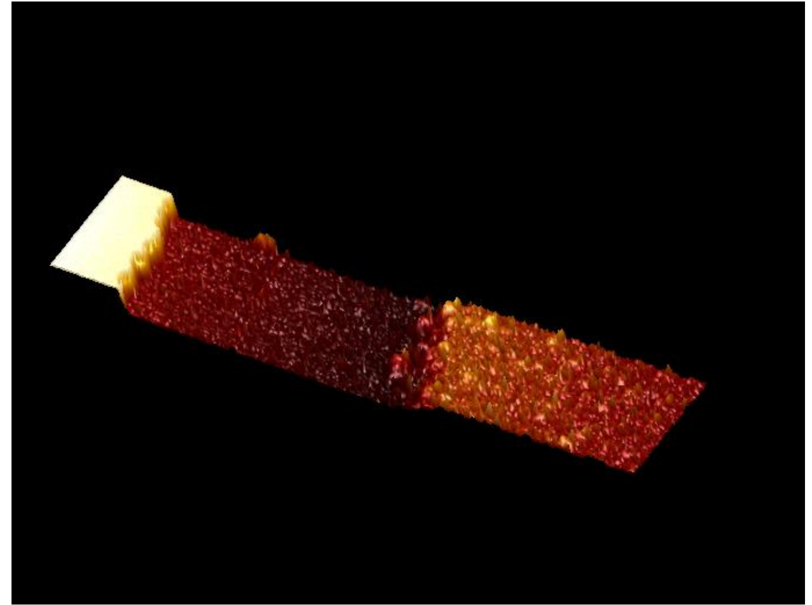
EFM

Microscopia de força elétrica



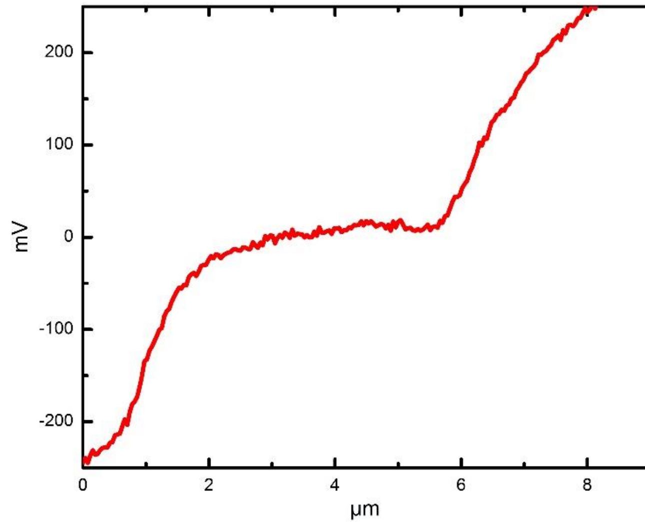


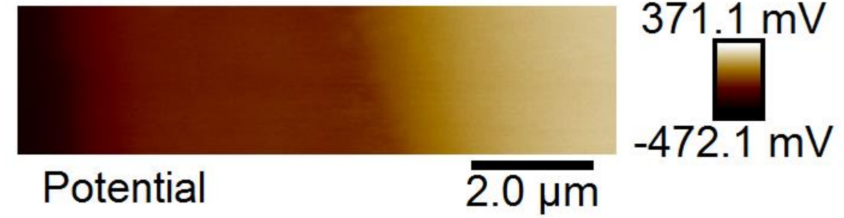
LAS MAT

CeNano^{2}I

Microscopia de força elétrica

LasMat
CeNano²I



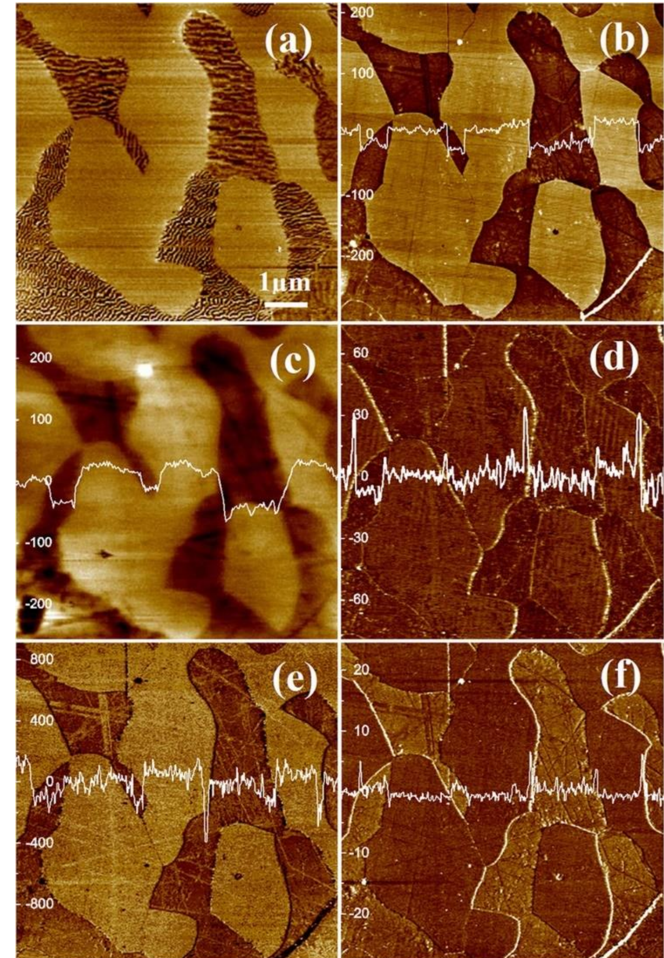


Aplicação em metalurgia

Ferrite and austenite phases in a duplex stainless

(a) A MFM image of the duplex stainless steel; (b) An AFM topography image (c) EFM potential mapping; (d) Adhesion mapping (nN); (e) Modulus (GPa) mapping; and (f) Deformation mapping (nm).

Nature Scientific Reports 6, 20660 (2016)

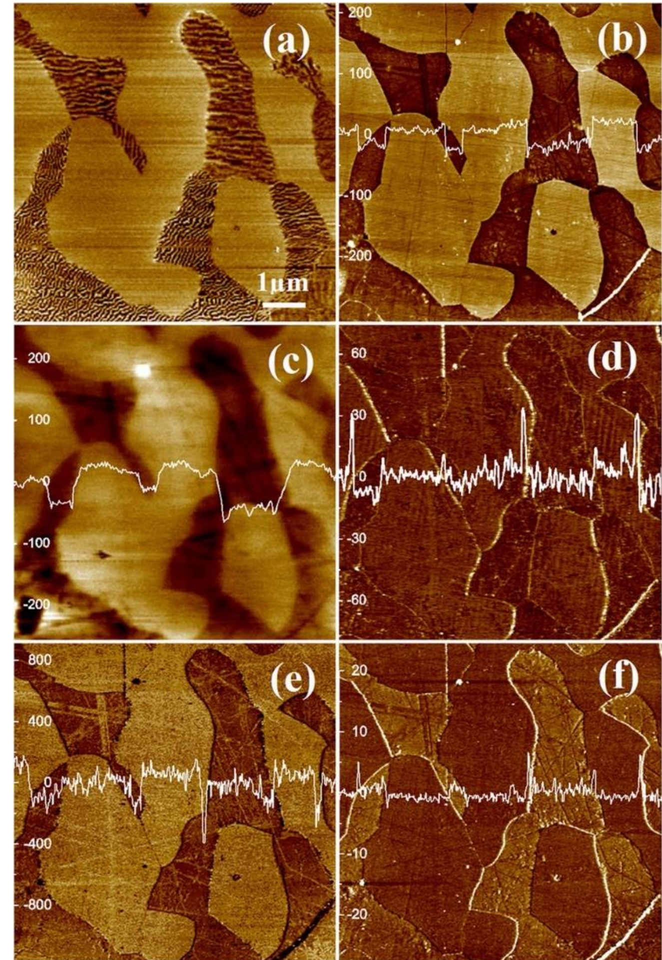


Aplicação em metalurgia

The ferrite phase has a striped appearance due to its ferromagnetic behavior, while the paramagnetic austenite phase shows a uniform appearance.

Topography (Fig. 2(b)) of the same area reveals that austenite (lighter) is higher than ferrite (darker). The difference in height is caused by the electrochemical polishing during which the ferrite phase dissolved faster than austenite due to its relatively lower corrosion resistance.

Nature Scientific Reports 6, 20660 (2016)

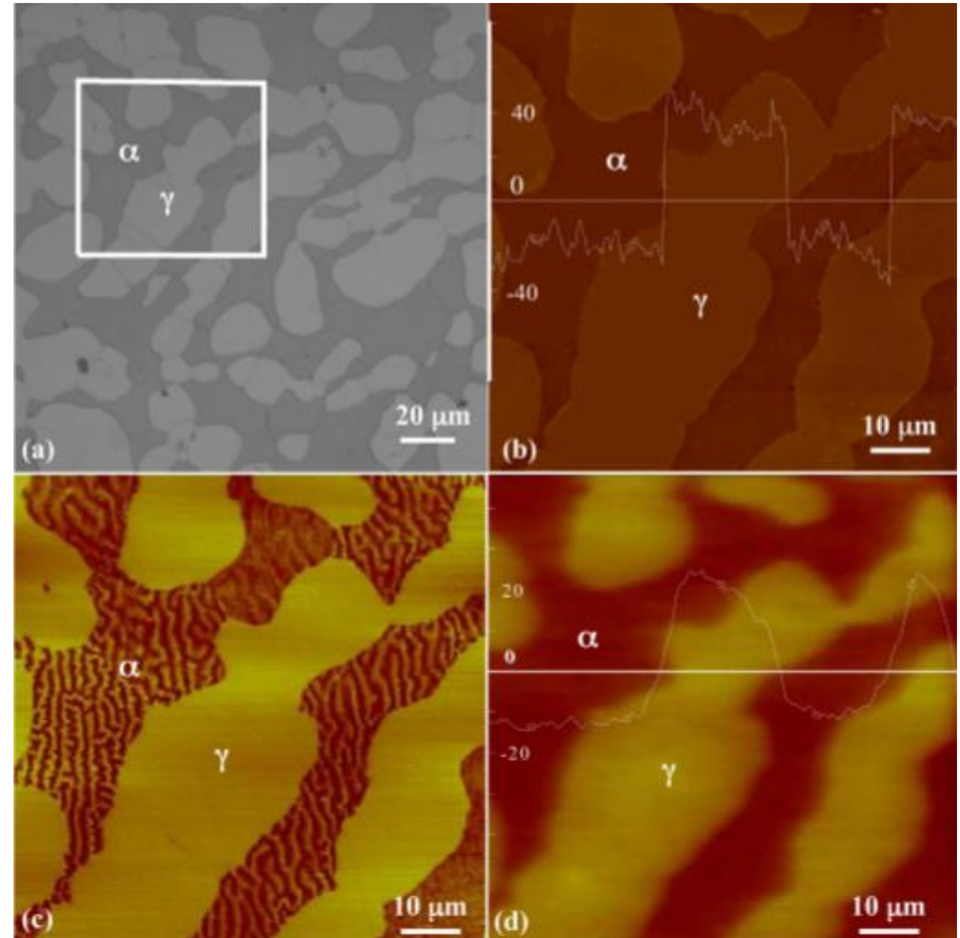


Aplicação em metalurgia

Ferrite and austenite phase identification in duplex stainless steel

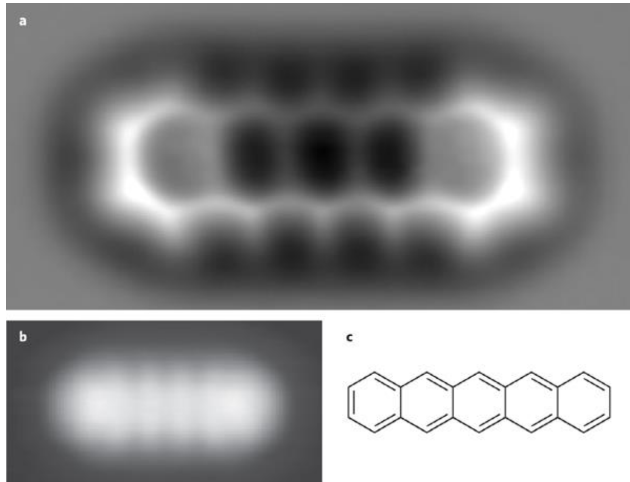
Ferrite (α) - Austenite (γ) phases

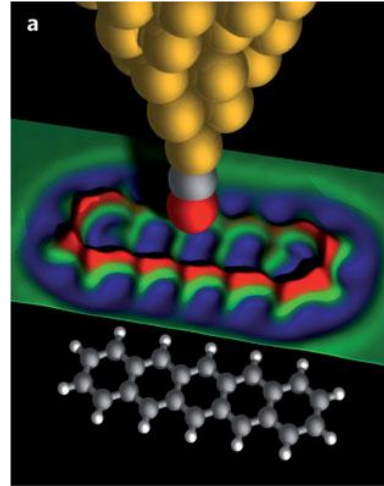
(a) Optical image duplex stainless steel surface; (b) AFM topography (c) MFM image; (d) EFM potential map.

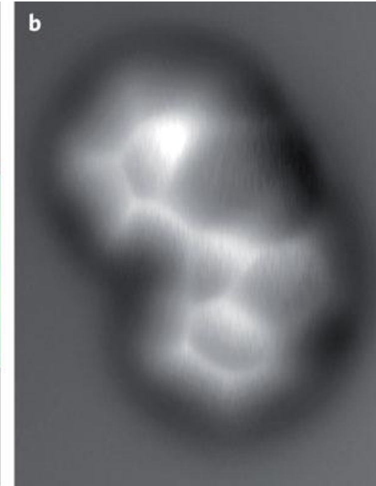


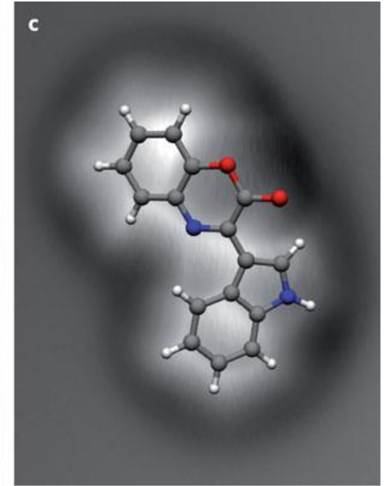
L.Q. Guo et al. /Applied Surface Science 287 (2013) 499– 501

Molecular imaging: The tip of what can be seen



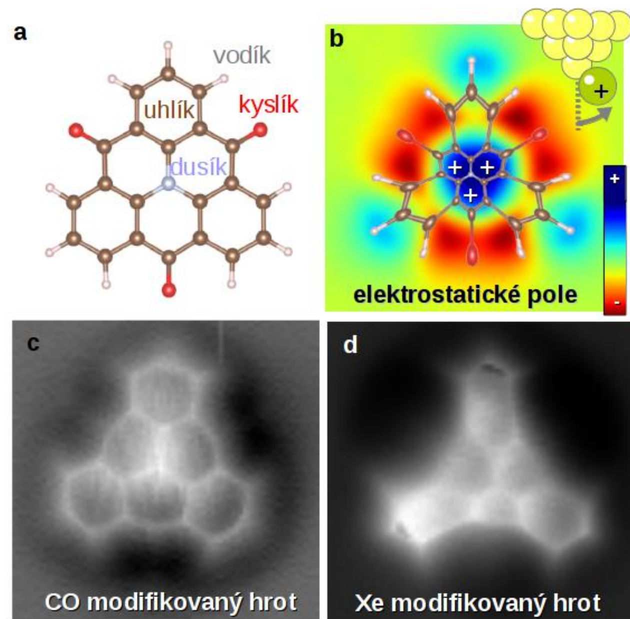


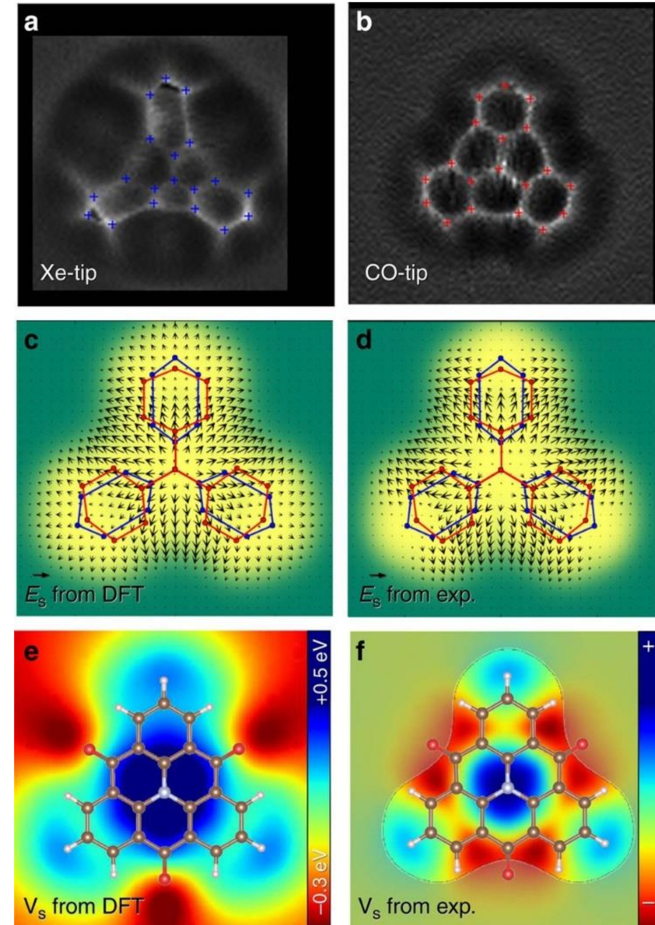




Nature Chemistry 3, 2011, 273–278

Molecular imaging





Nature Communications 7, 11560 (2016)

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