Spring 2008 MSAE E4990y

Introduction to STM and AFM

Lecture 2

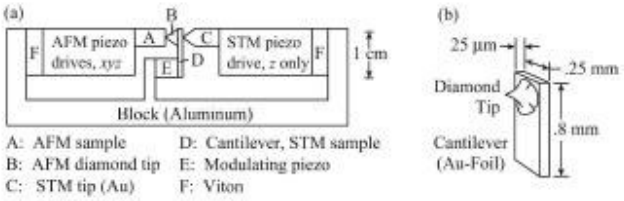
Basics of Atomic Force Microscope

January 28, 2008

Outline

- The invention of AFM
- The road to atomic resolution
- Modes of operation
  - Static force detection
  - Dynamic force detection
    - Amplitude modulation
    - Frequency modulation
    - Higher harmonics detection
- Role of covalent bond in achieving atomic resolution
- Examples

The invention of AFM (1)



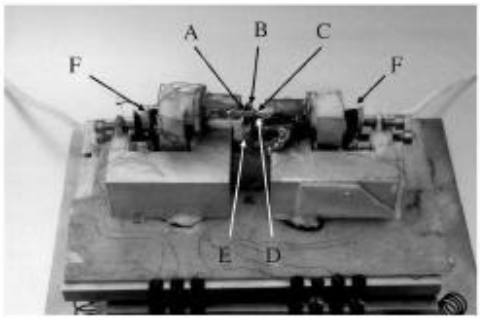
A: AFM sample
B: AFM diamond tip
C: STM tip (Au)
D: Cantilever, STM sample
E: Modulating piezo
F: Viton

Figure 1 in the first paper on AFM.

Common elements with STM: piezoelectric scanner, feedback system, computer control and display system, vibration isolation.

Unique elements: cantilever, modulating piezo, second tip to detect displacement of the cantilever.

The invention of AFM (2)



A: AFM sample
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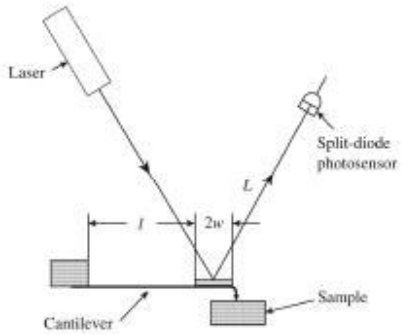
The Creators of AFM

Calvin Quate Gerd Binnig Christoph Gerber

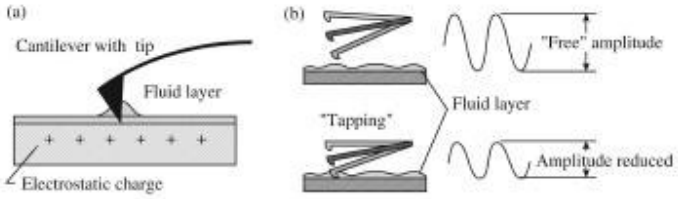
The Static Force Detection in AFM



Optical beam deflection method with a laser and a split photodiode.

The tip is dragging over the surface, prone to tip and sample damage.

The Tapping-Mode AFM (1)



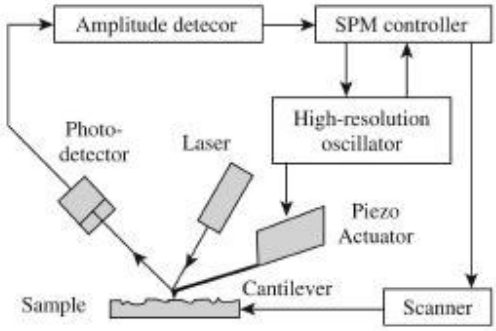
(a) Because of the water film and static charge, inaccuracy would occur.

(b) In the tapping mode, the cantilever is let to vibrate at its resonance frequency.

The force between the tip and the sample causes a reduction of vibrational amplitude, which is taken as the signal for feedback.

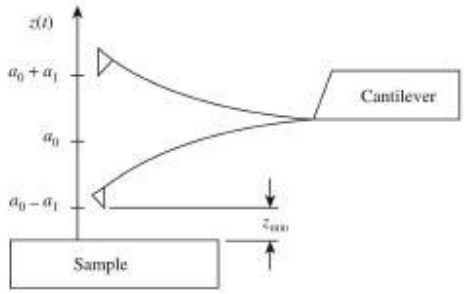
The damage to the tip and the sample is reduced, but not eliminated.

The Tapping-Mode AFM (2)



The cantilever is actuated by a bimorph piezo, and its vibrational amplitude is typically detected by the beam-deflection method.

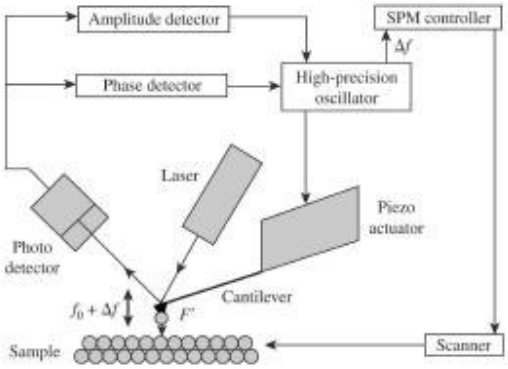
The Non-Contact (Frequency-Modulation) AFM (1)



In non-contact mode of AFM, the tip is probing the attractive force between the tip and the sample, without making a contact – without having the repulsive force.

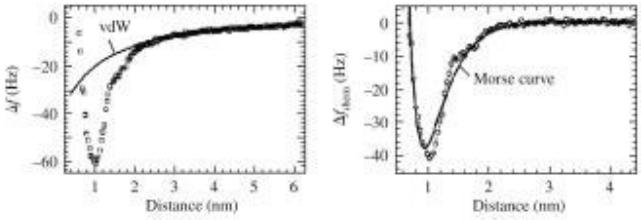
The shift of the resonance frequency of the cantilever is taken as the signal.

The Non-Contact (Frequency-Modulation) AFM (2)



The vibrational amplitude of the cantilever is detected. The feedback system is to maintain a constant amplitude while adjusting the frequency of actuating it.

The Non-Contact (Frequency-Modulation) AFM (3)

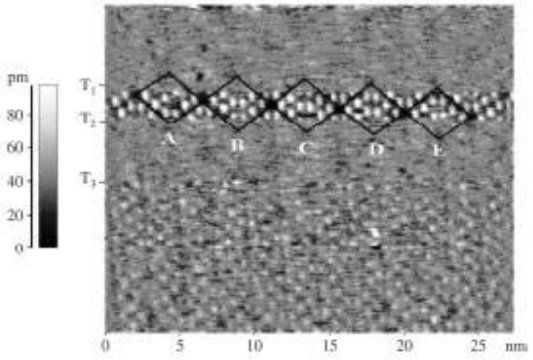


A typical atomic force curve has three components: the long-range, slow-varying van der Waals force; the attractive chemical bond force, and the repulsive force due to the Pauli exclusion principle.

The van der Waals force does not provide atomic resolution.

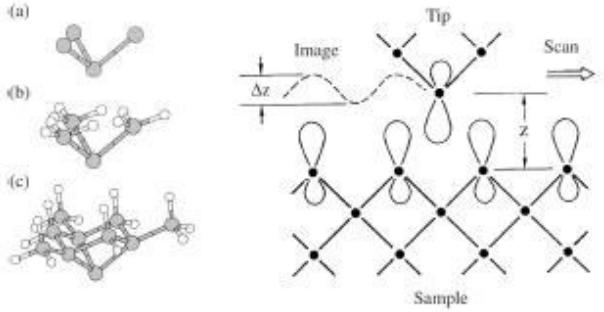
The chemical-bond force can provide atomic resolution, but it depends on the atomic orbital at the apex of the tip.

The Non-Contact (Frequency-Modulation) AFM (4)



The first recorded (and published) atomic-resolution image using non-contact AFM, showing the effect of tip electronic states.

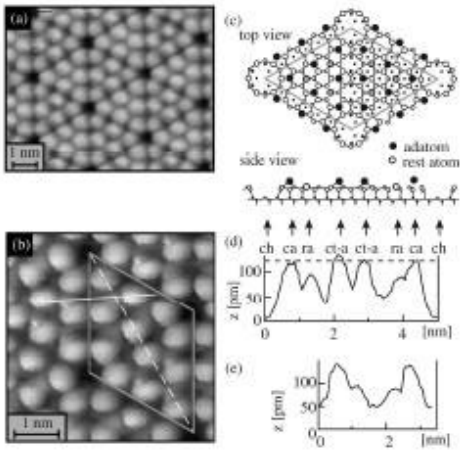
The Non-Contact (Frequency-Modulation) AFM (4)



The origin of atomic resolution of NC-AFM is the interaction of the dangling bond at the tip apex and the dangling bonds on the silicon surface.

AFM may achieve higher resolution than STM (1)

An NC-AFM image of the Si(111)-7X7 surface, showing more details than a typical STM image.

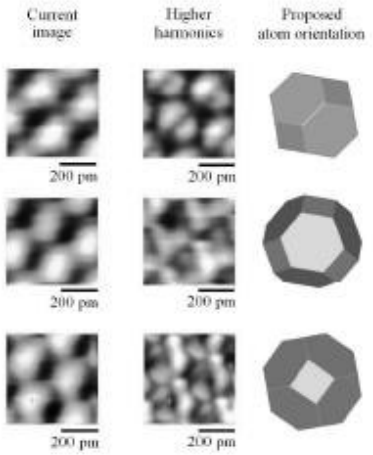


Not only the adatoms are resolved, but also the rest atoms are resolved.

AFM may achieve higher resolution than STM (2)

Simultaneously obtained STM and AFM images show that AFM could get more subatomic details than typical STM images.

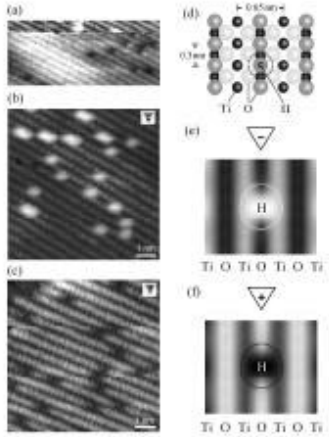
It is because the force signal could have more contrast (positive and negative, slower depth dependence) than the tunneling signal of the same configuration.



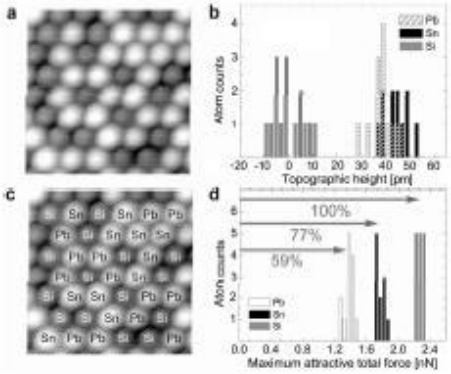
AFM could rely on the ionic force between atoms

Both the tip and the sample are TiO2. The tip could end with a Ti atom, or end with an O atom. The images of TiO2 with the two tips are completely different.

Sometimes, a switch of the tip apex from a negative ion to a positive ion could see a reversal of image resolution.

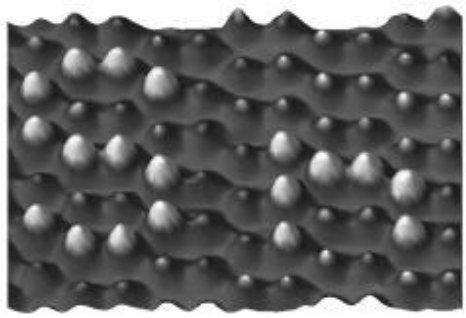


AFM could identify the chemical nature of atoms



The details of the force-distance curve at the atoms (force spectroscopy) could provide information about the chemical identity of the individual atoms.

AFM could also perform atom manipulation



A symbol of tin is assembled using NC-AFM on a Ge(111)-c(2×8) surface using 18 tin atoms.