

Atomic Force Microscope (AFM)

(Absolute) Fundamentals, (very Basic) Operation and (only Some) Applications

NT 70002

AFM

Human
Hair

$$\underline{1 \text{ nm}} = \underline{10^{-9} \text{ m}}$$

very small → How Small ?

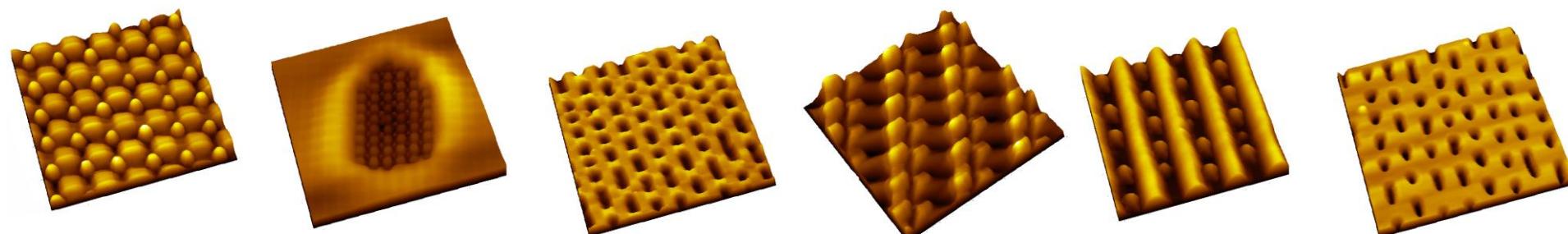
Length Scale
 $\sim \frac{1}{10,000}$ th human
Hair

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 IIT Kharagpur

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Microscopes → Optical Microscope.

5 nm

3-5 Å

1-2 Å

SEM → Scanning Electron Microscope.
 TEM → Transmission Electron Microscope
 Resolution ⇒

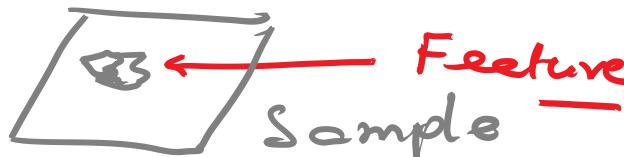
FESEM = ✓

TEM = ✗

Transmission.
 TEM → uniqueness of TEM?

Mostly, microscopes allow to see/observe

"Surface Features"



Internal Structure.



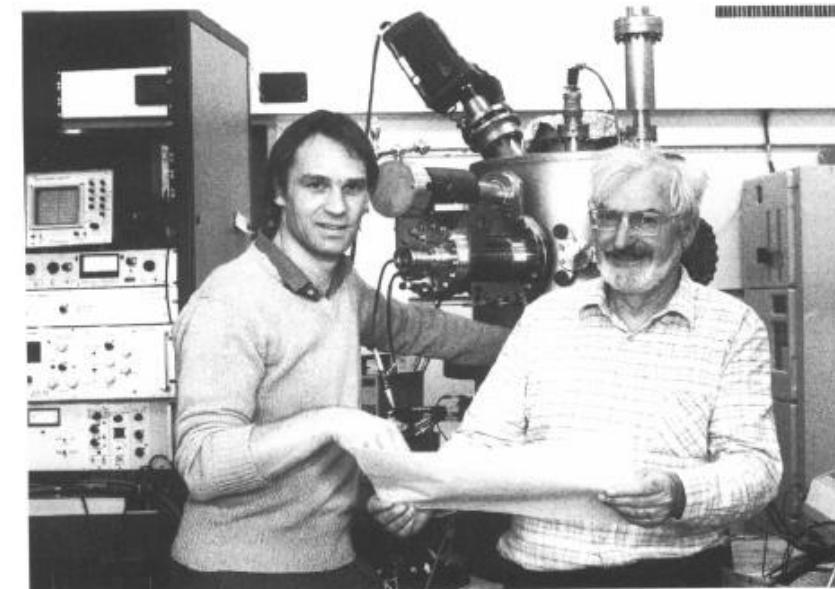
AFM was discovered in 1986.

**Gerhard Binning and Co - workers IBM Corporation
Physical Review Letters, 56,930 (1986).
(An extension cum derivative of the STM)**

**Gerd Binnig and Heinrich Rohrer were awarded
Nobel Prize in 1986 for their Discovery of STM in
1982.**

Why AFM?

STM = ? **1982**



Gerd Binnig (left) and Heinrich Rohrer (right) who were awarded the Nobel Prize for their invention of the scanning tunneling microscope.

SCANNING TUNNELING MICROSCOPY - FROM BIRTH TO ADOLESCENCE

Nobel lecture, December 8, 1986

by

GERD BINNIG AND HEINRICH ROHRER

IBM Research Division, Zurich Research Laboratory, 8803 Rüschlikon,
Switzerland



⇒ What is so special about the nano scale / or Nano sized objects?

① Finite Size effect → Band Structure of the materials starts to change as the size becomes too small → becomes size dependent.

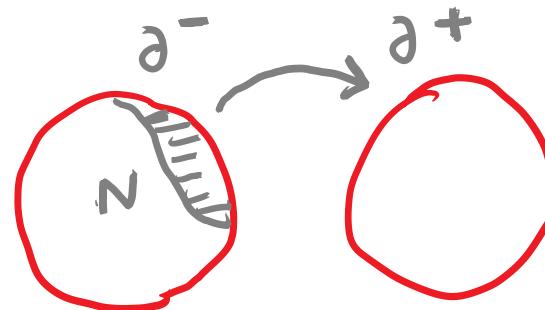
Consequently

Many properties starts to change with respect to their bulk properties.

⇒ Properties that are intensive → become extensive (size dependent)

② van der waal's Interaction

2 → van der waal's Interaction
 (or more generically intermolecular Interaction).



Most Generic

I.D - I.D

Second most

important aspect of Nano Science / Nano scale → It is a
 Length Scale that's dominated by intermolecular Interaction.

London Forces

(1) Induced dipole - Induced Dipole

(2) Permanent dipole - Permanent dipole

(3) P. D - I. D interactions,
 ↳ Debye Interaction

Keesom Force

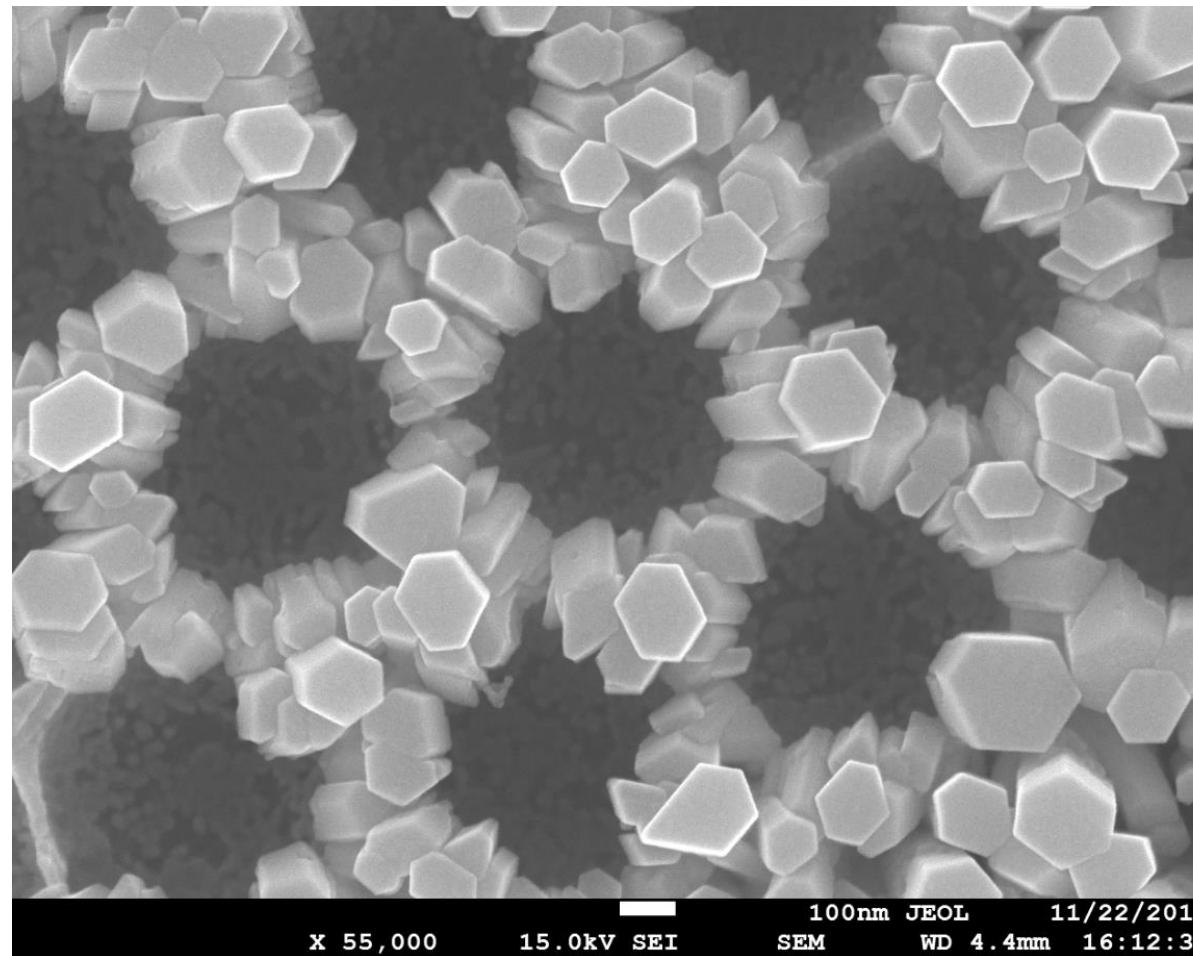
Hydrogen Bond.

$$\Phi \approx -\frac{A}{\sqrt{r}}$$

Mgh ↓

Why AFM?

We all use a microscope to visualize small things! Here is an FESEM image.



Can you think of any limitation of this image?

Any information that is missing?



What information is missing in this photograph?



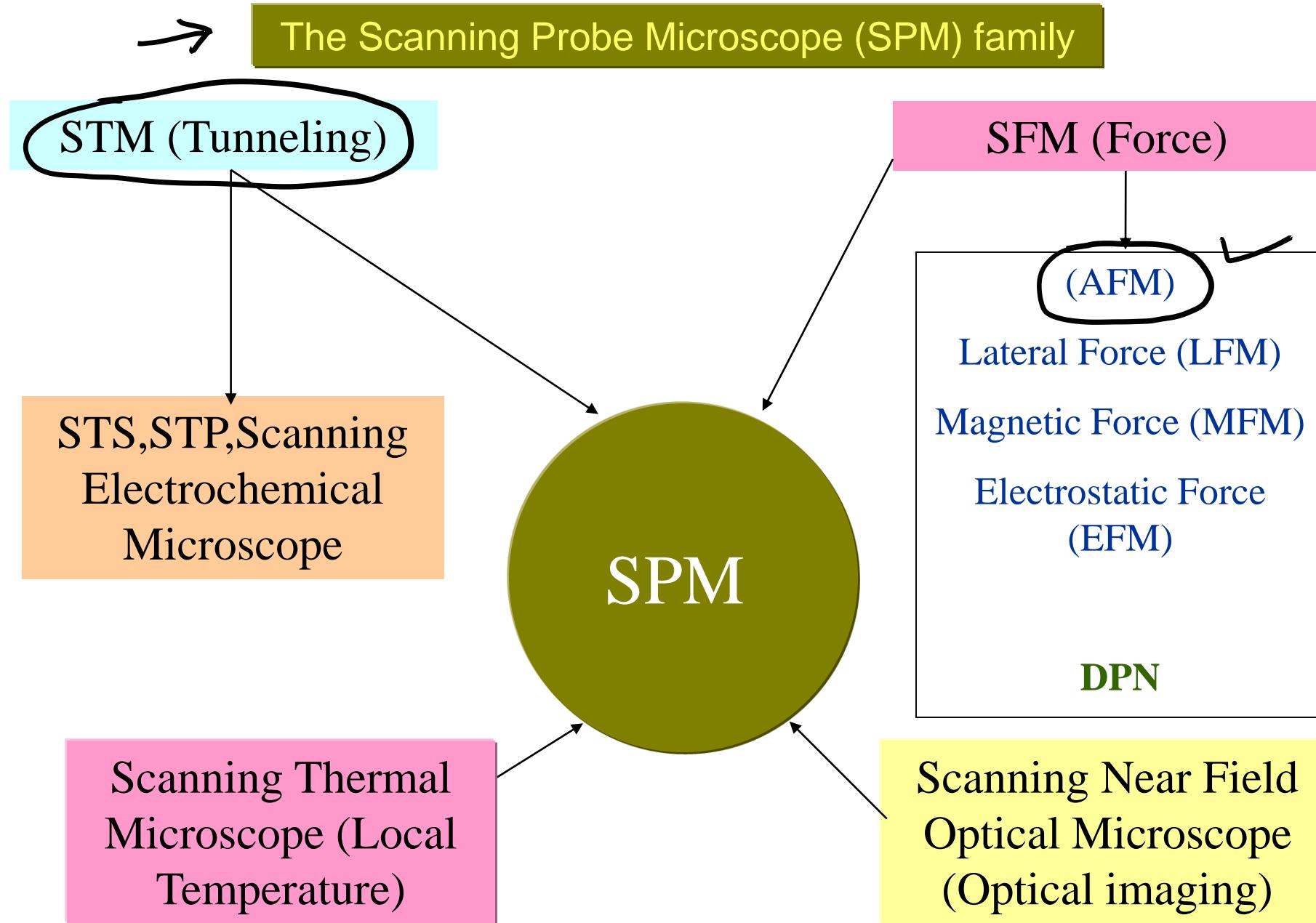


An AFM is Fundamentally totally different from ALL other Microscopes

Microscopes Generate an Enlarged IMAGE.

An AFM DOES NOT capture an Image.

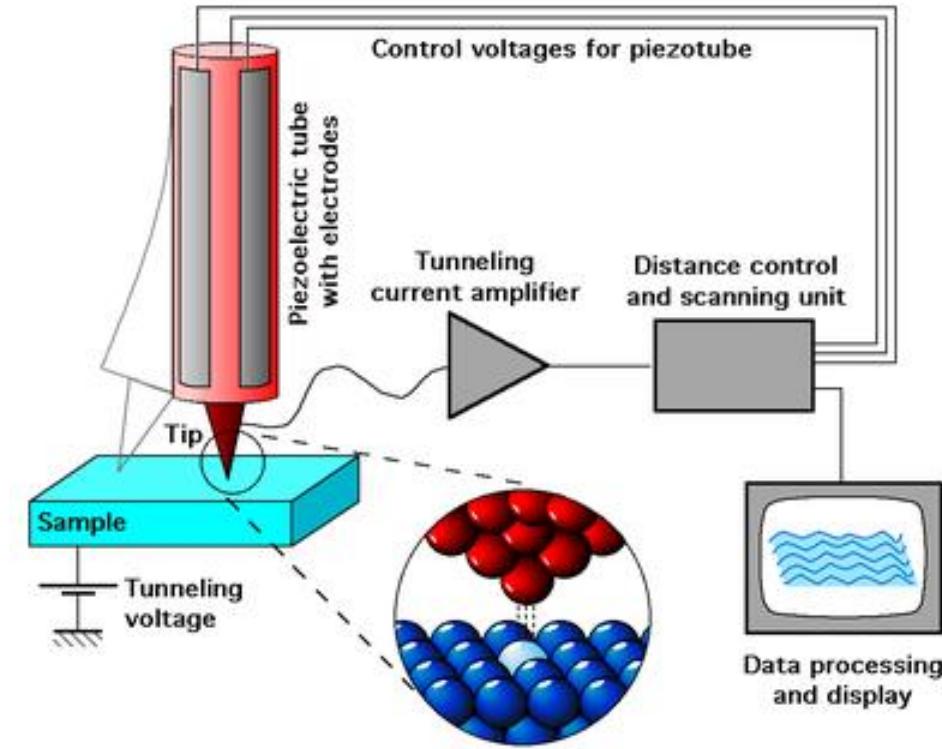




STM (Tunneling)

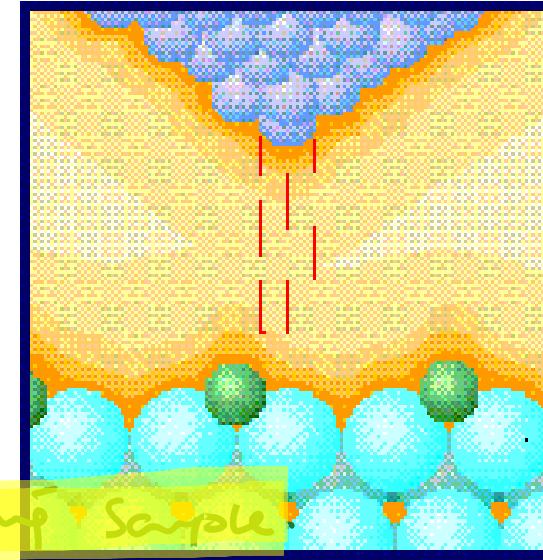
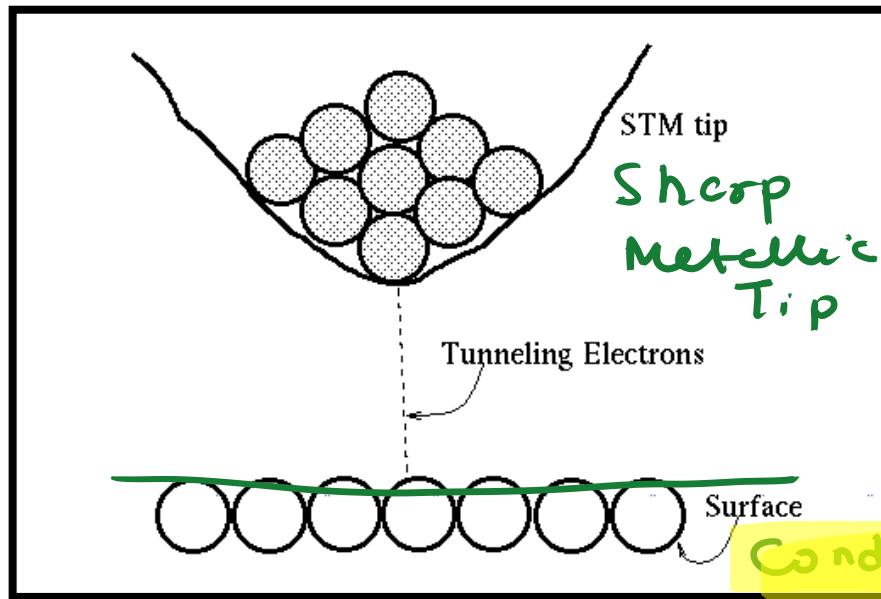
The STM is based on the concept of quantum tunneling.

When a conducting tip is brought very near to the surface to be examined, a bias (voltage difference) applied between the two can allow electrons to tunnel through the vacuum between them.

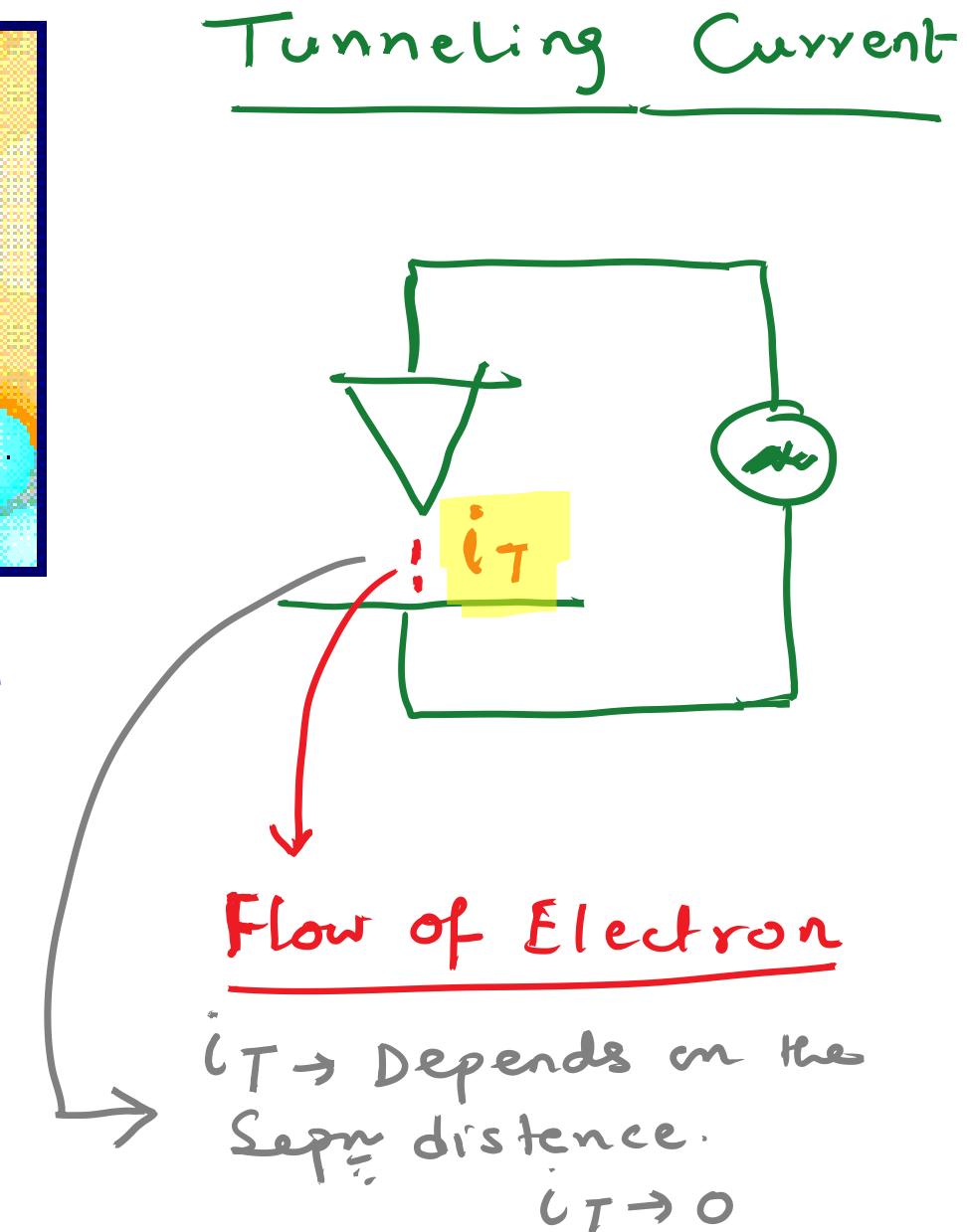


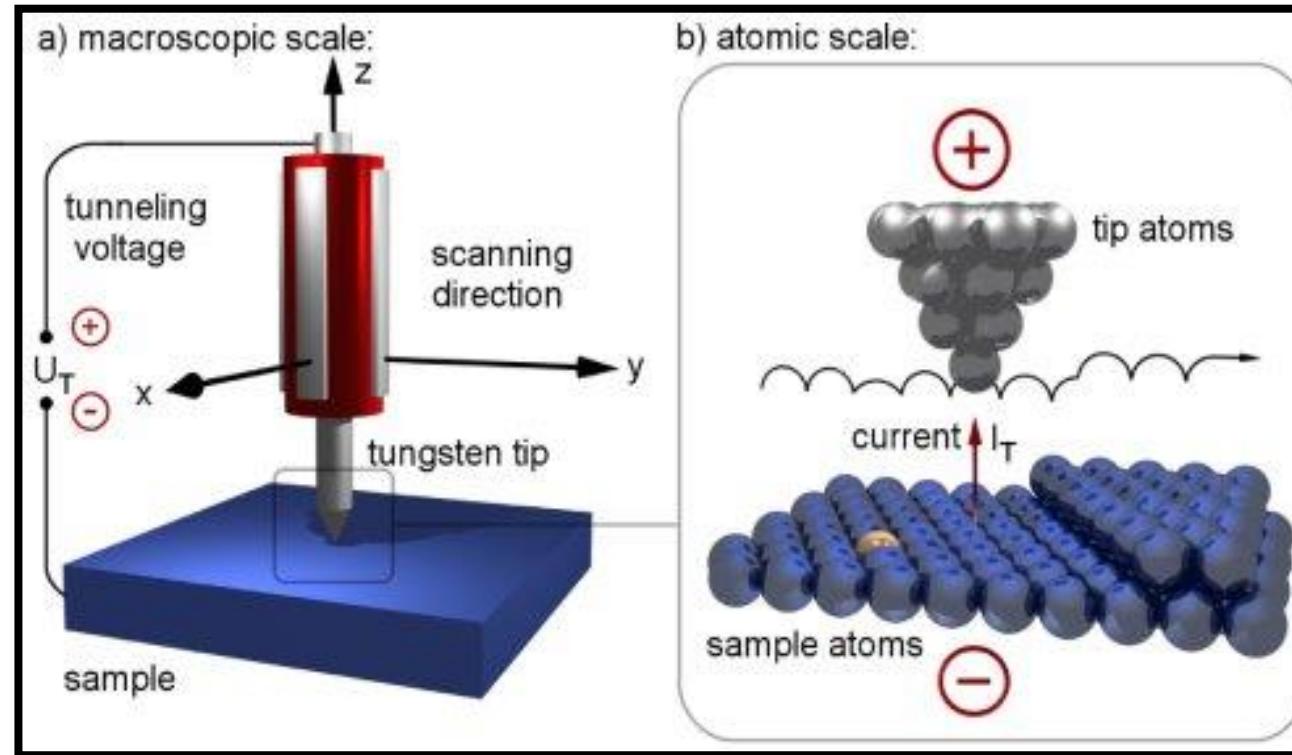
The resulting *tunneling current* is a function of tip position, applied voltage, and the local density of states (LDOS) of the sample. Information is acquired by monitoring the current as the tip's position scans across the surface, and is usually displayed in image form.

STM can be a challenging technique, as it can require extremely clean and stable surfaces, sharp tips, excellent vibration control, and sophisticated electronics.



When a sharp conducting tip is sufficiently close to the surface of another conducting sample ($\sim 1\text{nm}$), and a bias is applied, a tunneling current gets established

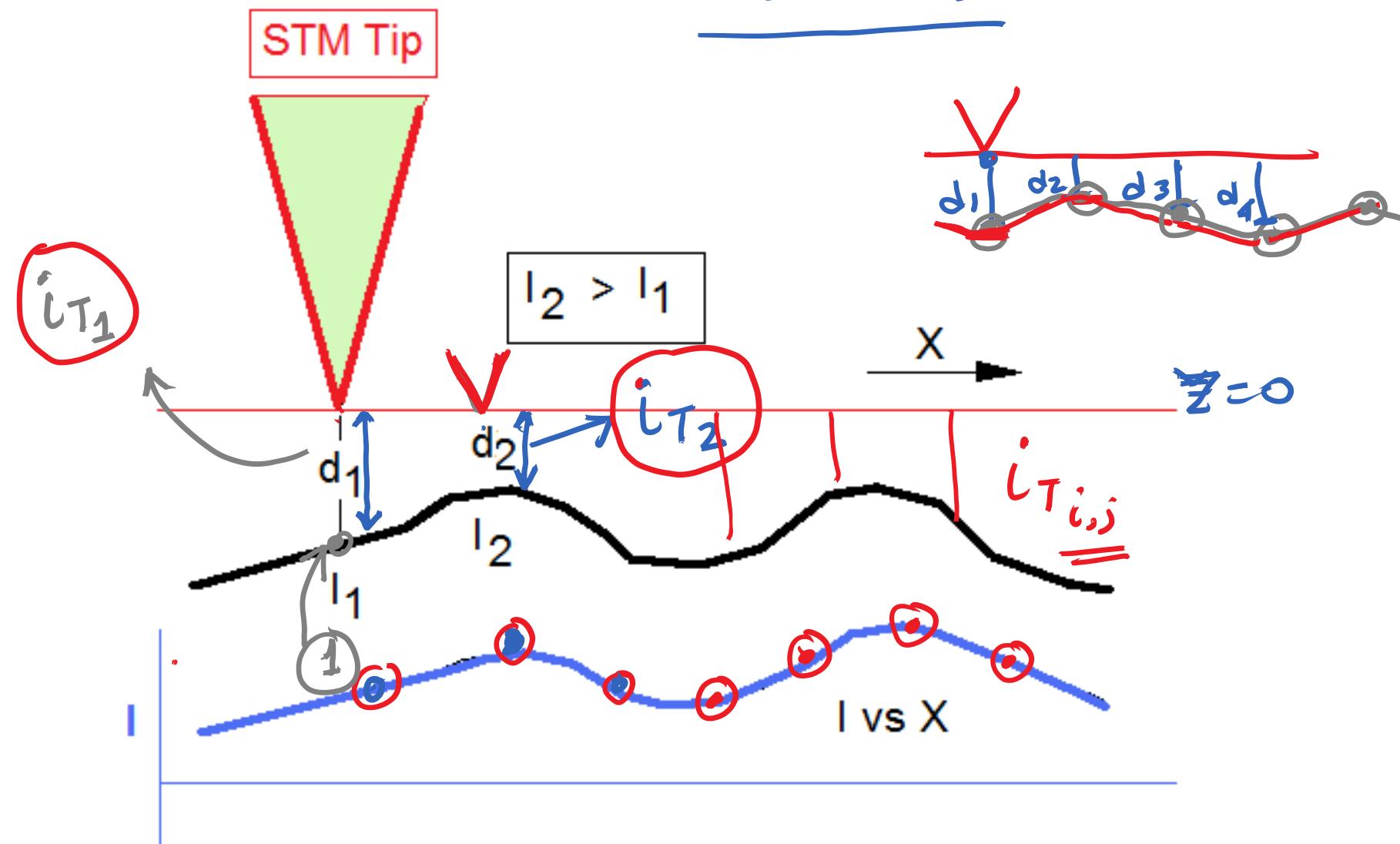




The tunneling current is exponentially proportional to the distance and thus via a feedback loop the tip can be maintained at a constant distance from the surface by maintaining a constant tunneling current.



Constant Height Mode STM

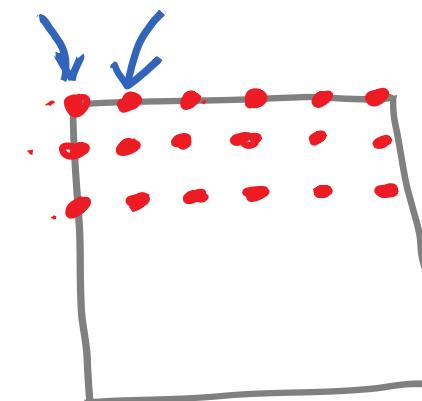


$$i_{T2} > i_{T1} \quad ??$$

height or

tunneling current varies

lata set, the



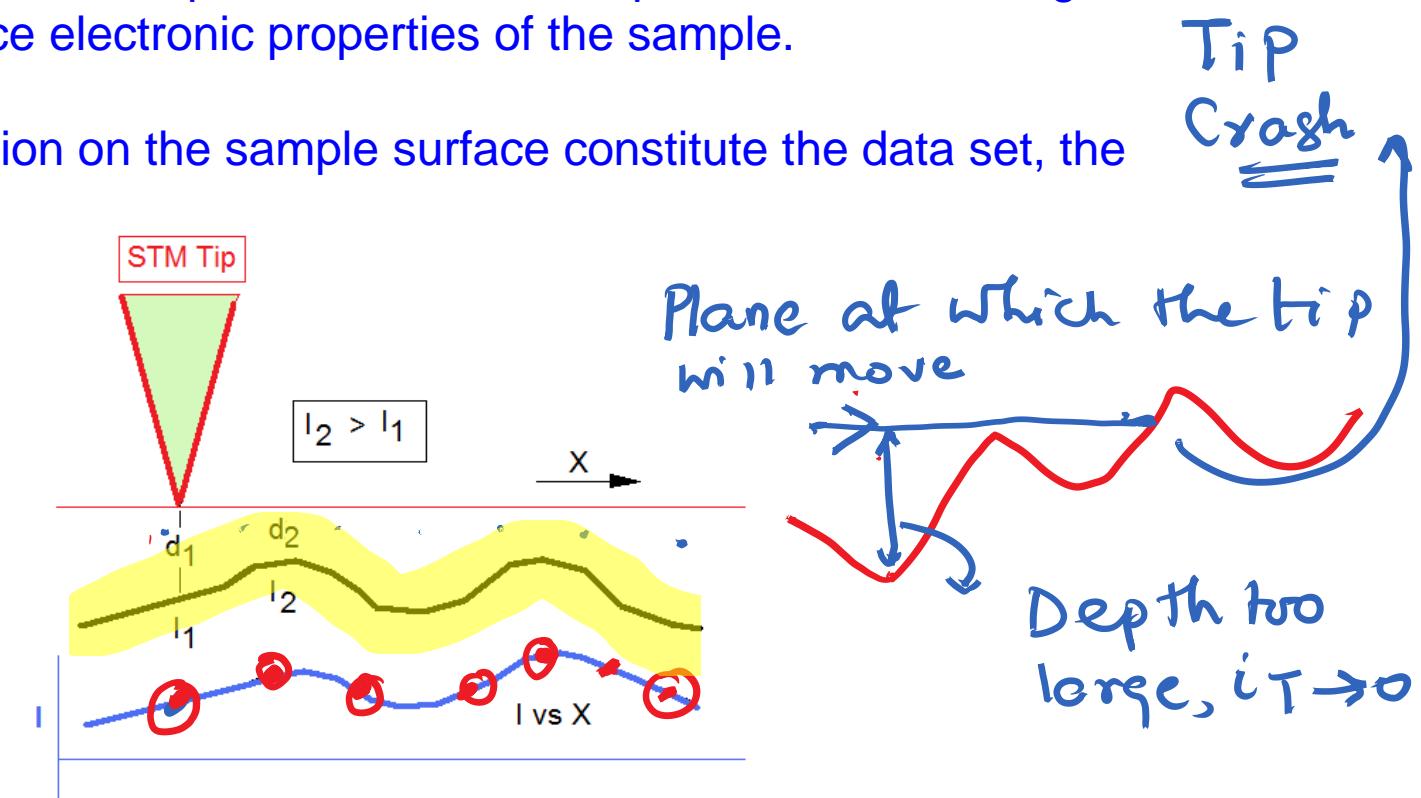
Rastering

Constant Height Mode STM

STMs can be designed to scan a sample in either of two modes: ***constant-height*** or ***constant-current*** mode.

In constant-height mode, the tip travels in a horizontal plane above the sample and the tunneling current varies depending on topography and the local surface electronic properties of the sample.

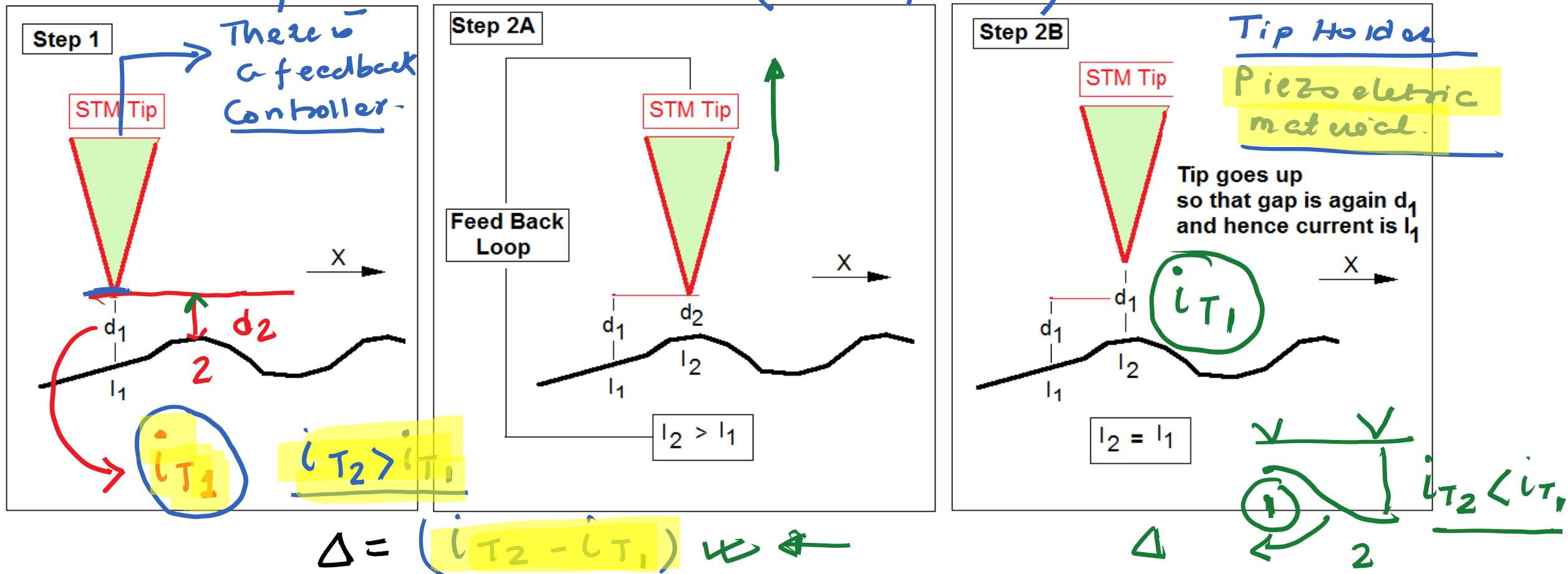
The tunneling current measured at each location on the sample surface constitute the data set, the topographic image.



Constant Current Mode STM

In constant-current mode, STM uses feedback to keep the tunneling current constant by adjusting the height of the scanner at each measurement point.

→ That can adjust the vertical movement of the tip.
(Set point)

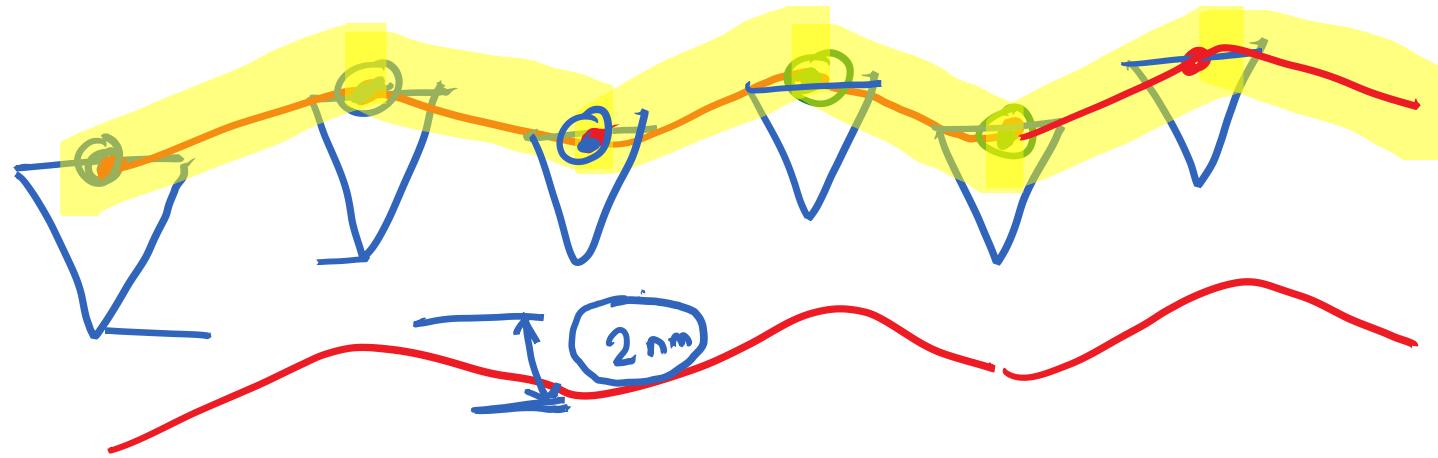


Limitation? = ?

PZT

Constant Current Mode

PICRO: If we apply mech stress, electric field gets generated.
or apply electric field \rightarrow Size/shape changes.



Mathematically rendered.

Actual Surface

Tunneling \rightarrow STM Tip.

Constant Height Mode \rightarrow Limitations.

\rightarrow Constant Current Mode \rightarrow

Integration of a Feed back controller to the Tip.

① $(i_{T_2} - i_{T_1}) \leftarrow$ Which is very small. ② Vertical movement of the Tip

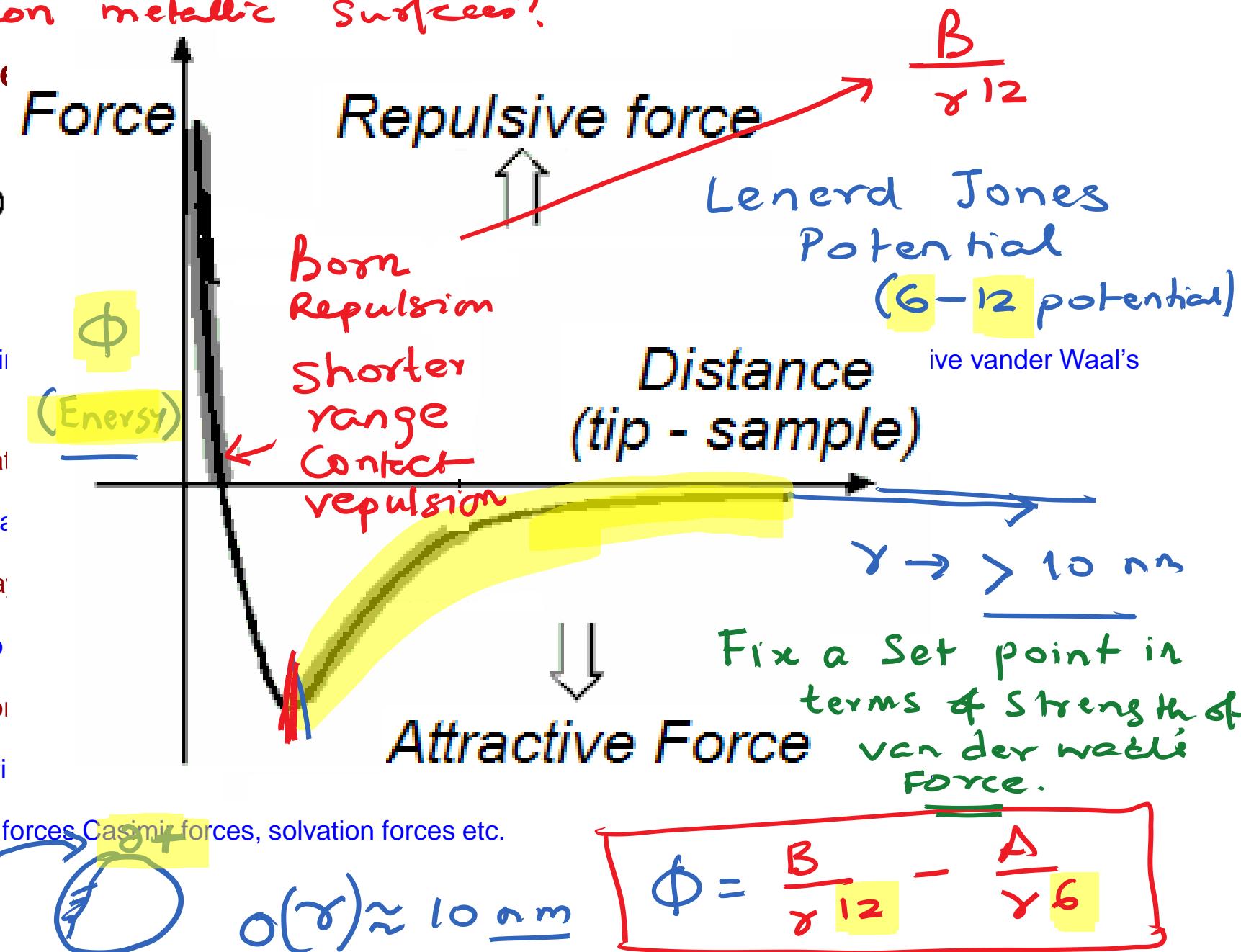
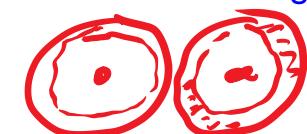
How to extend for non metallic surfaces?

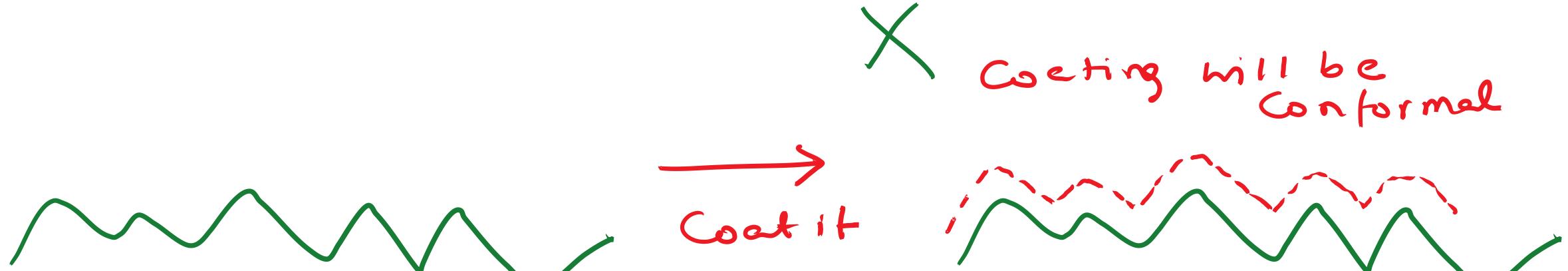
Replace
Tunneling?
Current

Origin of intermolecular

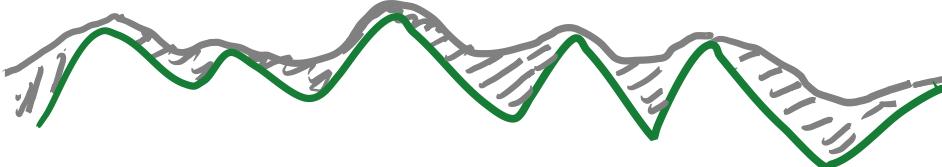


- For a charge neutral sample scanned in air interaction.
- Between two molecules (or atoms), the nat
- The signature of non retarded van der Wa
- Between two surfaces, the scaling or dec
- The signature of the interaction extends to
- This force is in the range of inter-atomic fo
- There can be host of other type of interacti
- cal bonding, electrostatic forces, magnetic forces Casimir forces, solvation forces etc.





Practical Conditions

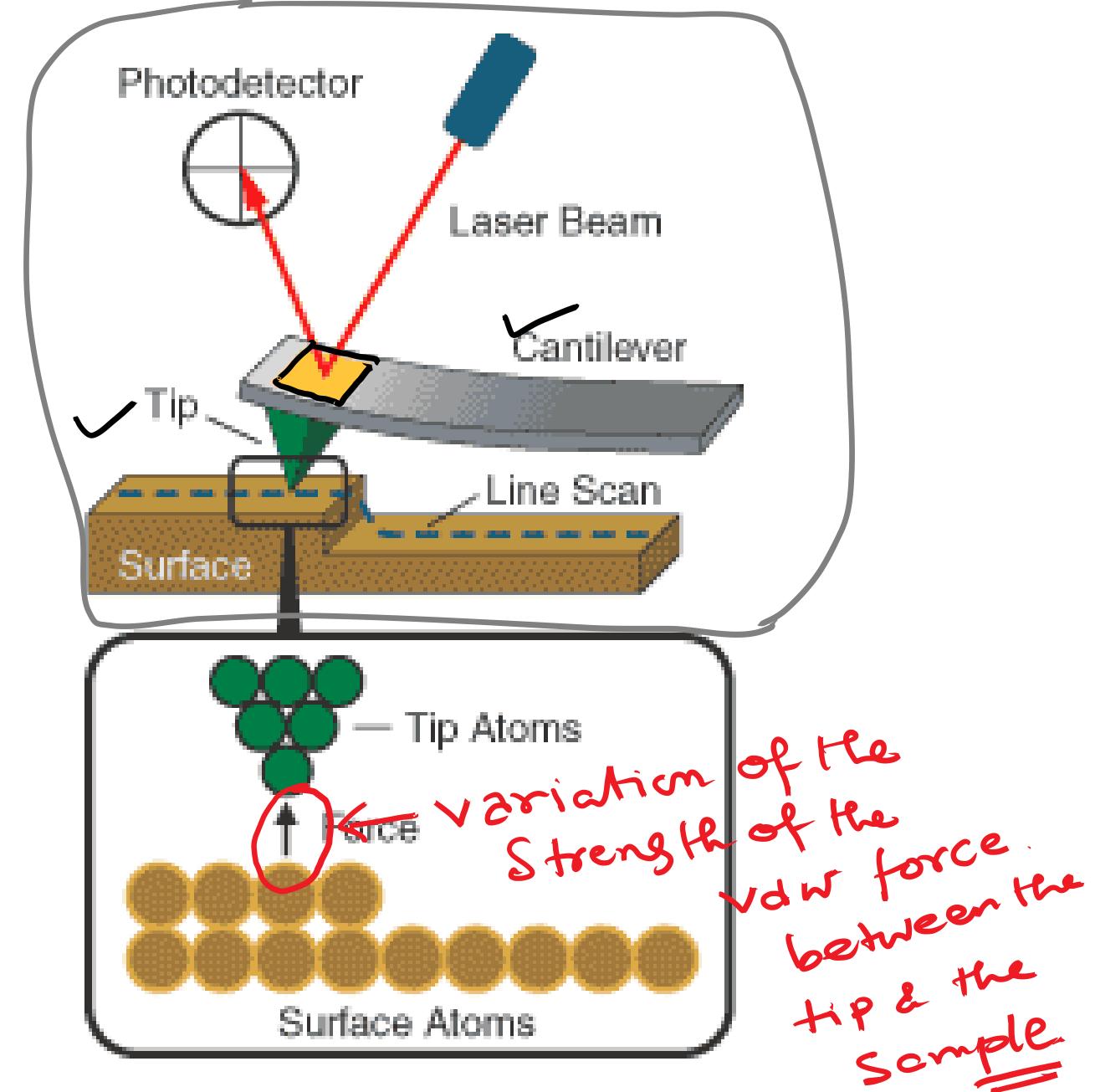


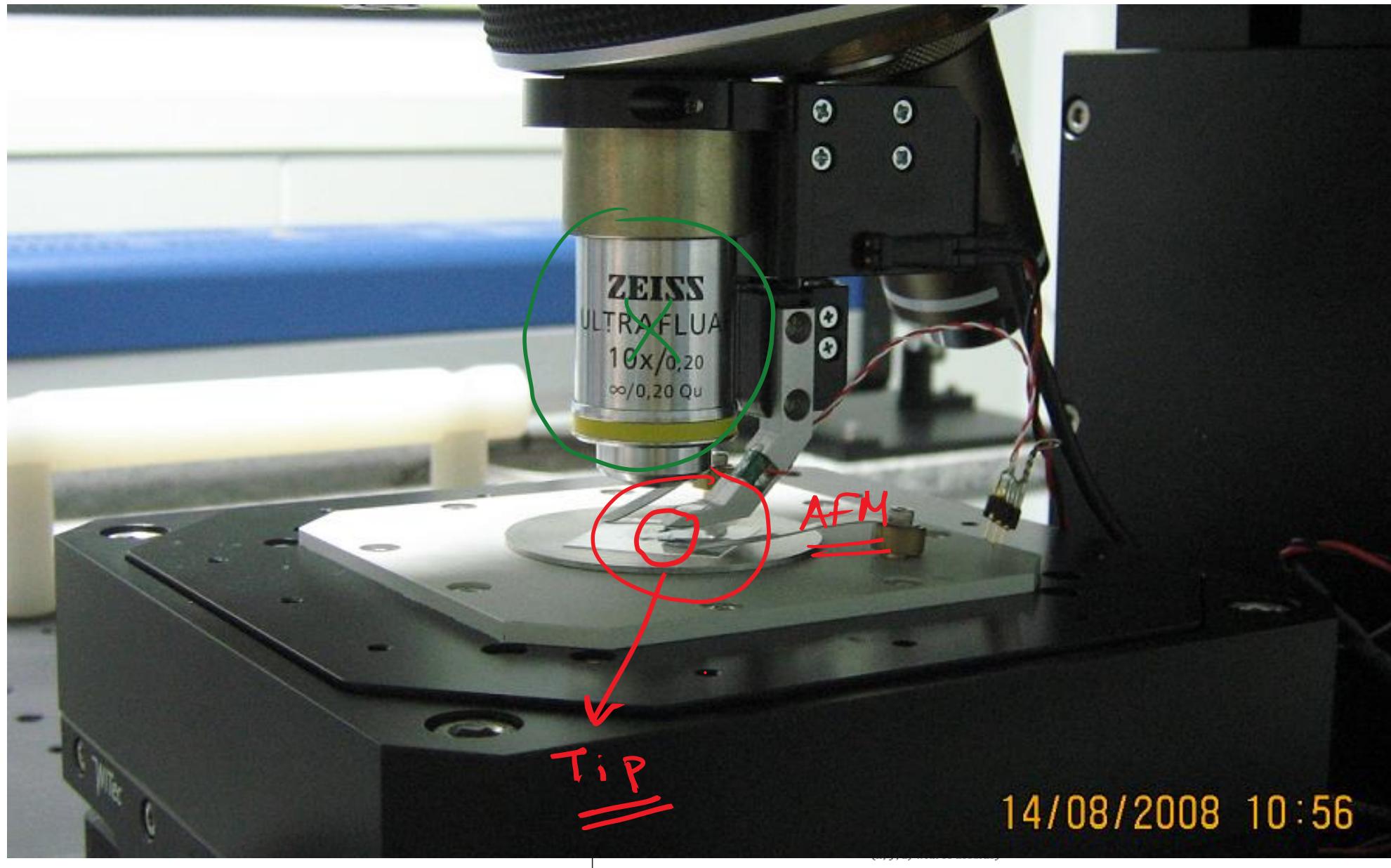
- ① Tunneling Current is going to be replaced by van der waal's forces.

Any Problem: → How to measure the variation in the strength of vdw force.

What is an AFM

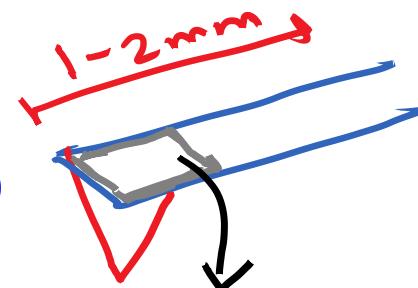
- In an Atomic Force Microscope the imaging (or more accurately, the information about the topography) of a surface is done based on the modulation of interaction forces between two atoms (or molecules).
- In reality, the instrument operates based on the interaction between two surfaces, the sample and a sharp tip.
- The probing tip is attached to a cantilever and the force acting on the tip causes a small deflection of the cantilever.
- This deflection is detected and mapped as the tip scans the surface to obtain the image of the surface.





- Probes or Tips and Cantilever for mounting the tips
- Photo detector (with laser Source)
- Stepper motors for coarse movement
- Sample stage and Ruster Scanning
- Data Renderina

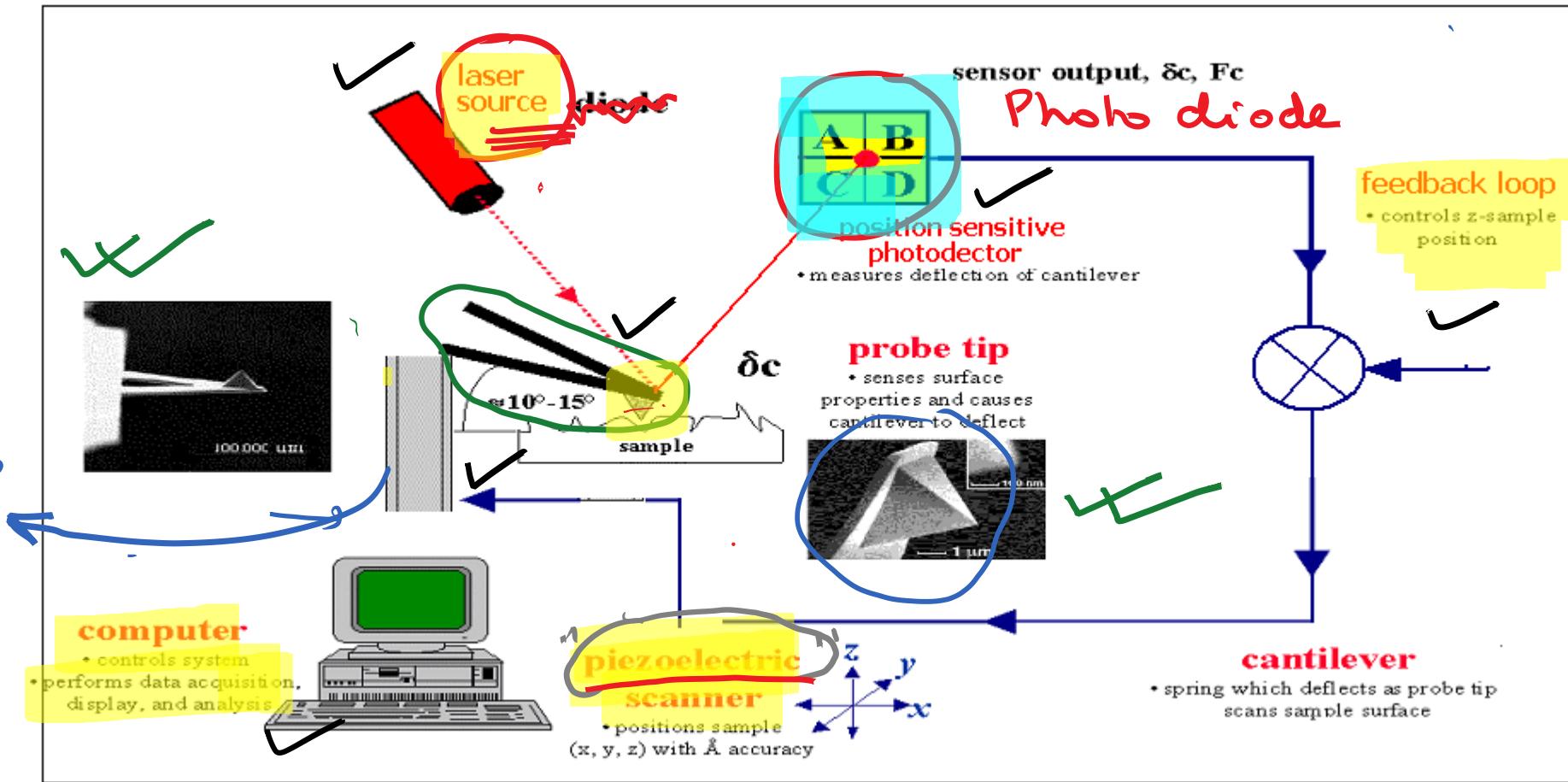
Alignment (Operational Aspect)
Feed back control module
Scanning Modes (Opt. Aspect)



Microv

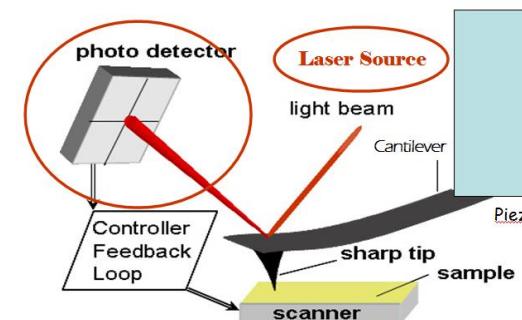
$\gamma \approx 10-12$
nm

You
need
electric
signal to
change
it's size



AFM Probes or Tips

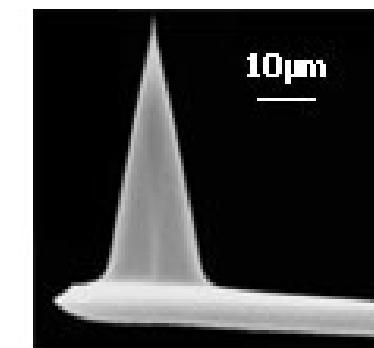
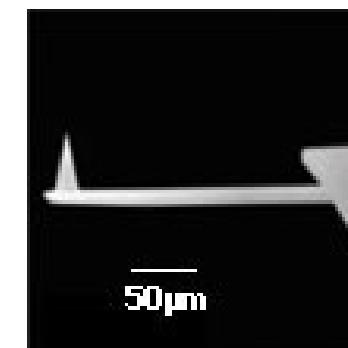
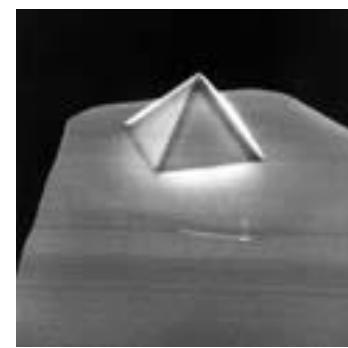
- Tips are some sort of a sharp probe that is used to “Scan” the surface.
- This is the closest approximation of a single molecule probing the surface.
- Tip diameters are typically ~ 15 – 25 nm (Hundreds of molecules)
- Resolution is a major function of tip Size and Geometry



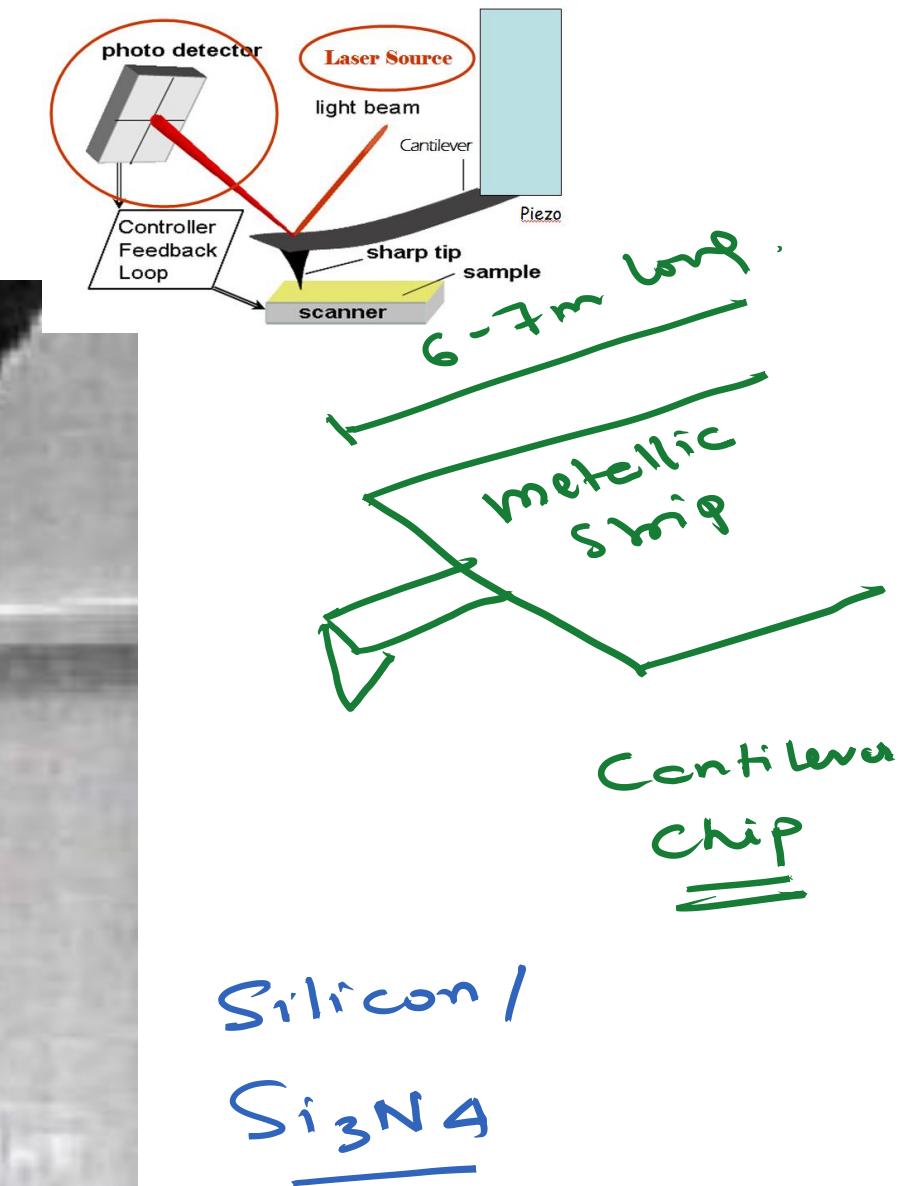
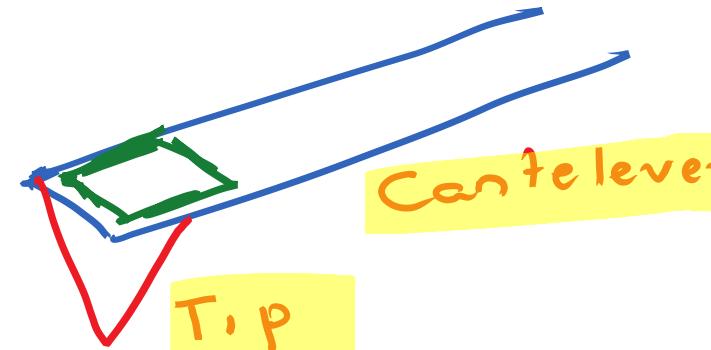
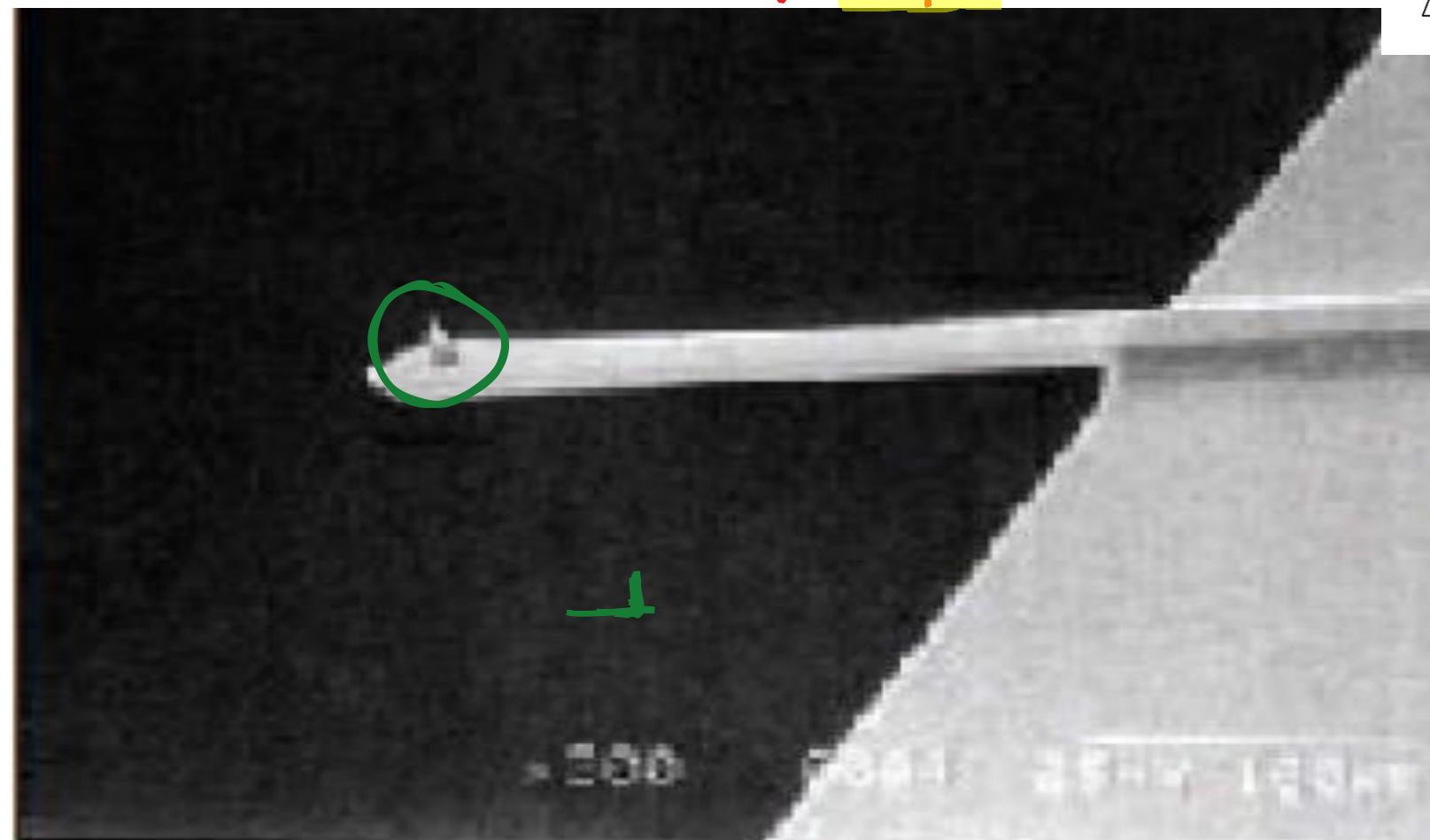
The cantilever behaves like a spring

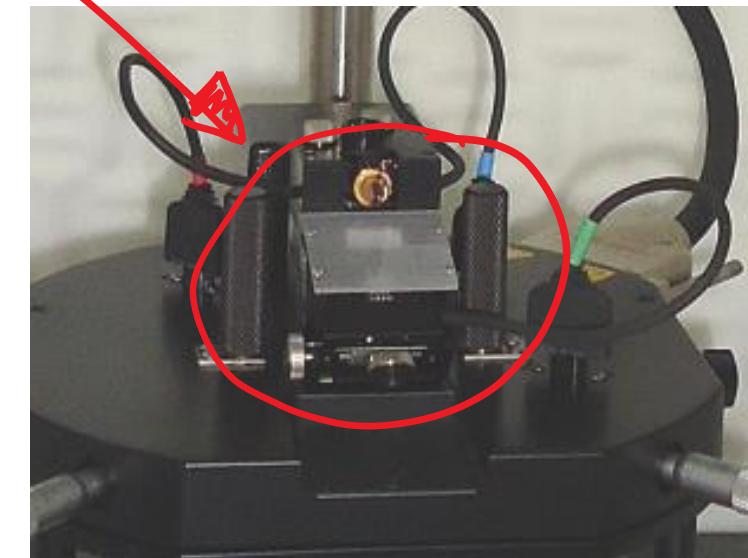
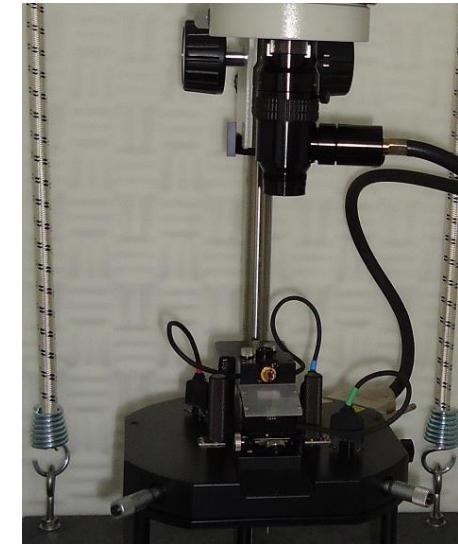
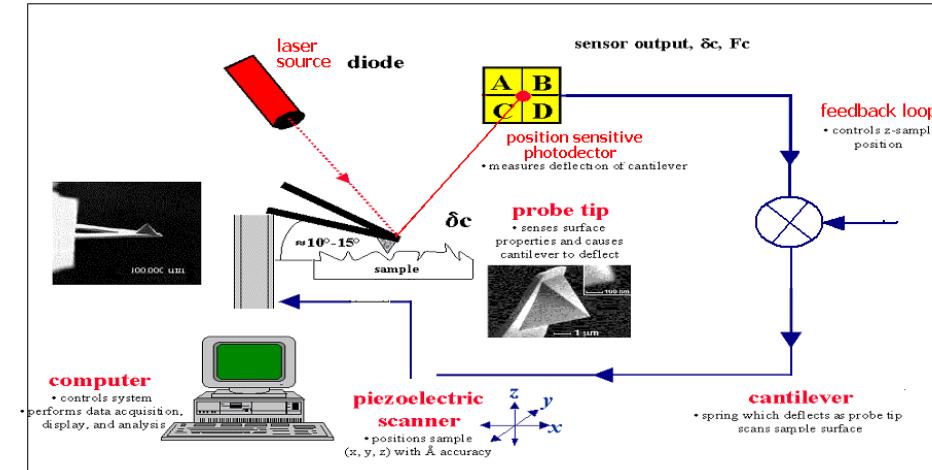
Its stiffness is critical

Stiffness determines the spring constant

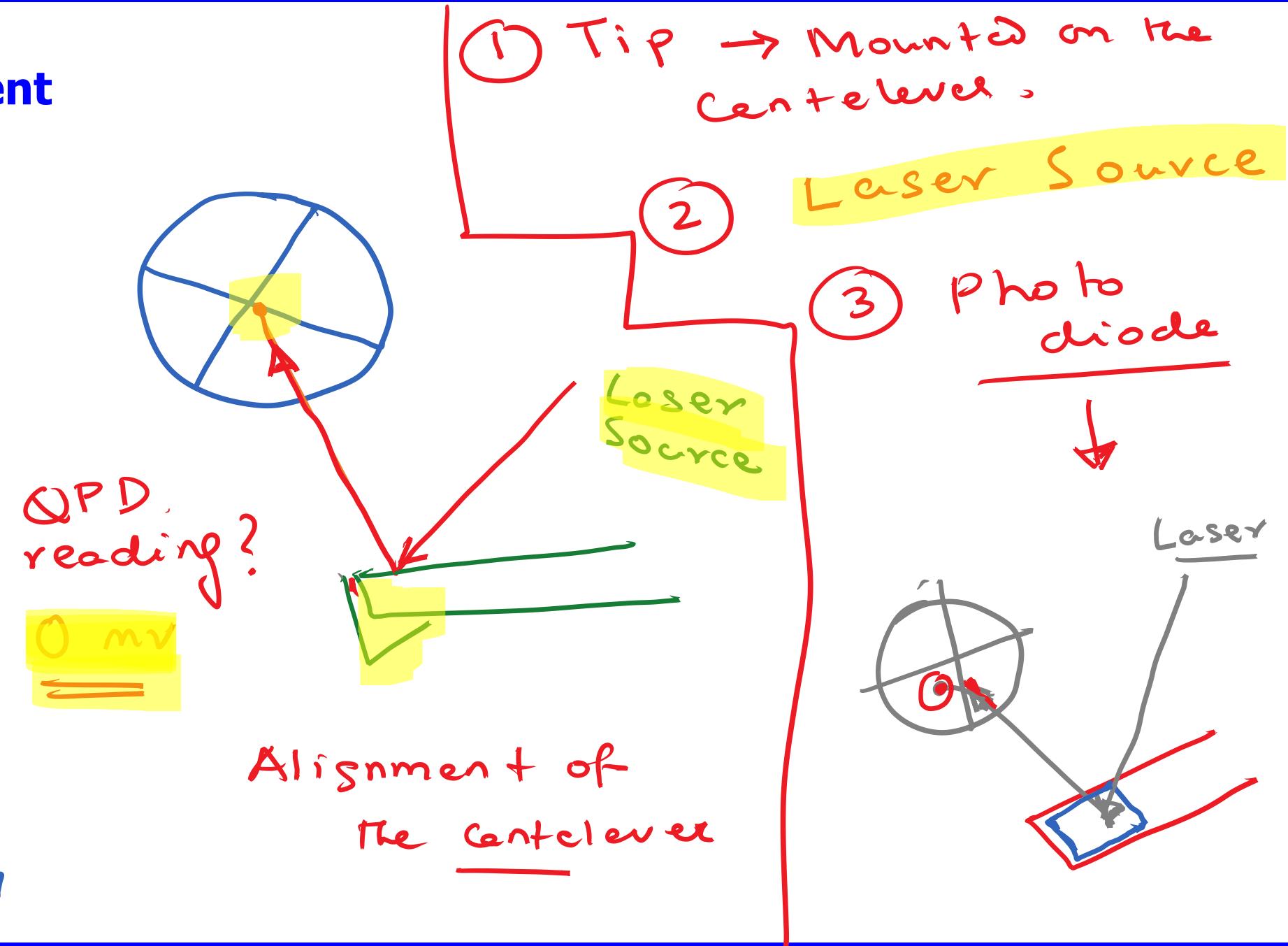
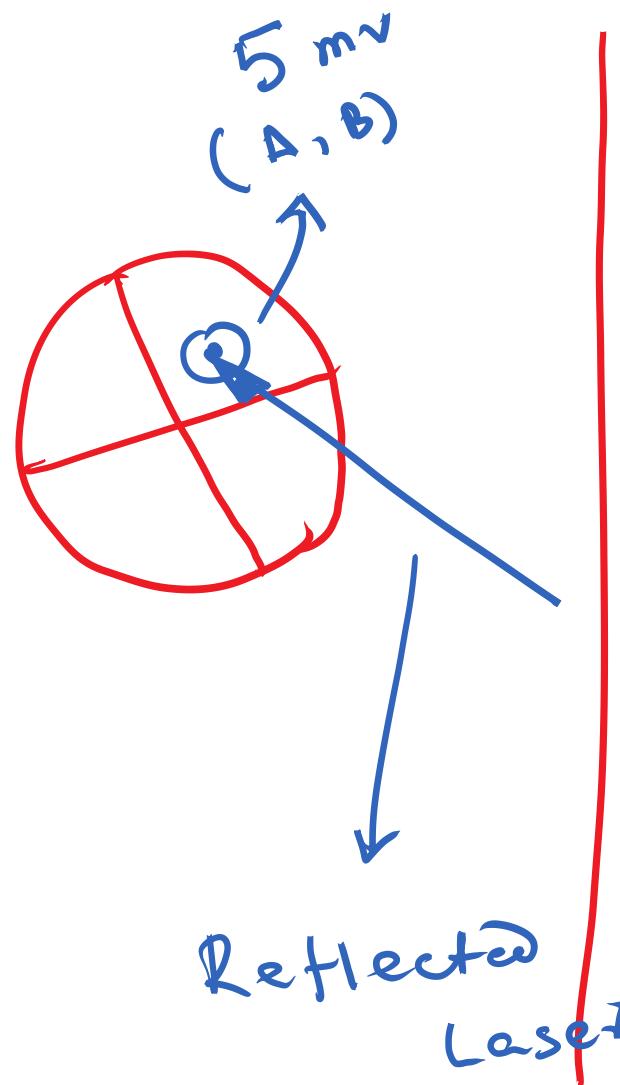


AFM Probes or Tips





Allignment



When a Reverse Biased P – N junction diode is illuminated with light, the reverse diode current varies linearly with the light flux. Such a P – N junction diode is called as photo diode.

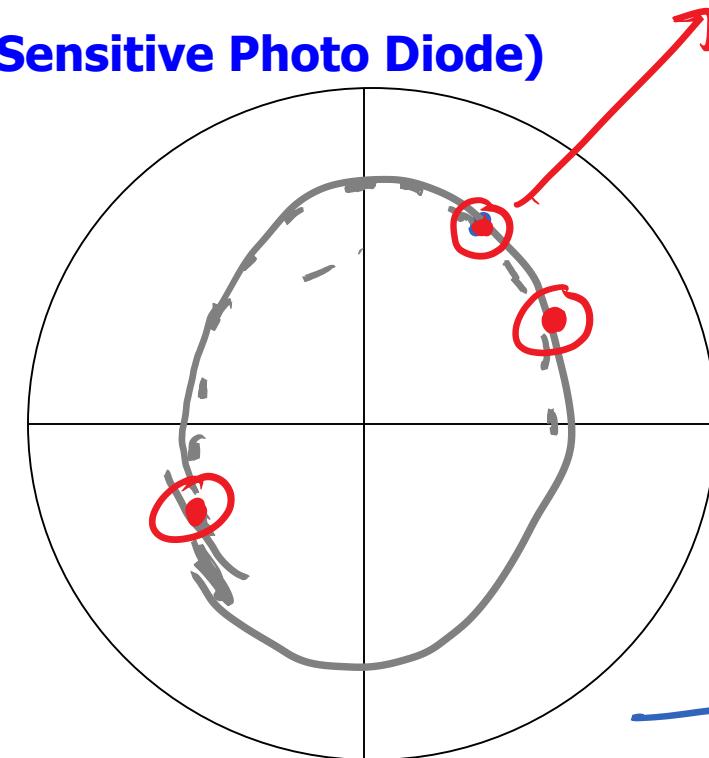
QPD (Quadrant Photo Diode)

SPD (Split Photo Diode)

PSD (Position Sensitive Photo Diode)

C1 → Lower voltage

C2 → Higher voltage



*measure
(A, B) for
every point*

Photo Diode:

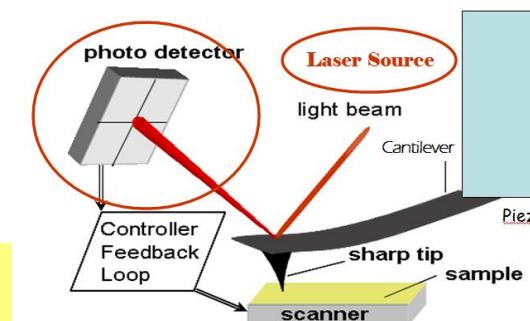
When light (of a certain wavelength) falls on it, a voltage is generated.

Here, the voltage generated is a function of the position at which the light falls.

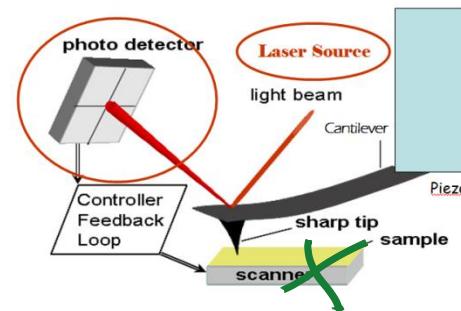
Best way to understand is to consider it as a graph paper

— Light falls at the center = 0 mV

For most commercial AFMs, the range of the voltage is 0 - 10 mV with centre being 0 mV.



Alignment



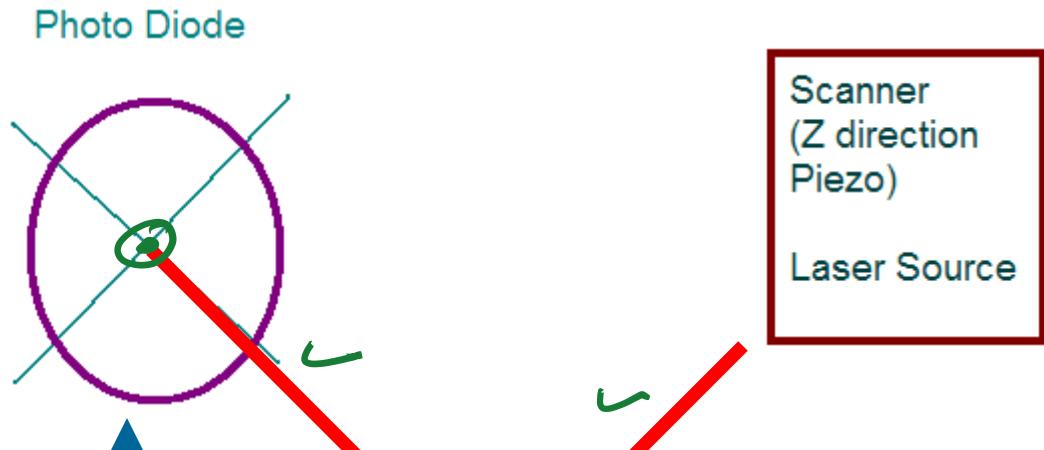
Reading 0 Volts!

3 Different Components

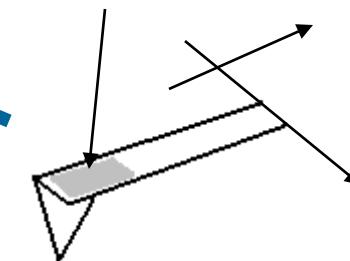
(1) Laser Source.

(2) Tip and Cantilever

(3) QPD



Reflective
Coating



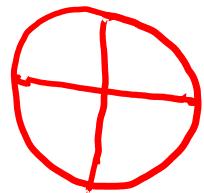
Cantilever

You optically couple these 3. !!

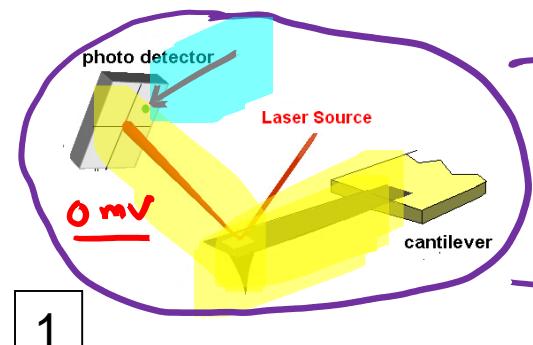
- Tip is far away (few microns to ~ mm) from sample surface.



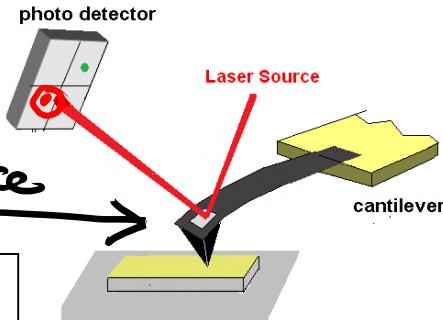
Approach



The tip has started to experience attraction due to the presence of the Surface !!



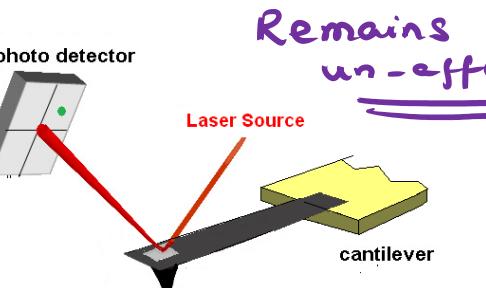
Sample
(Far away from the tip)



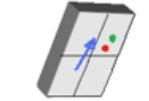
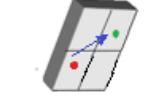
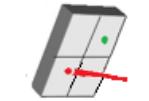
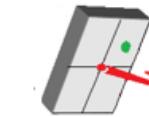
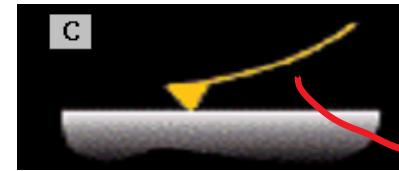
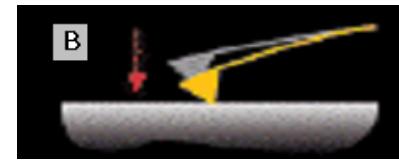
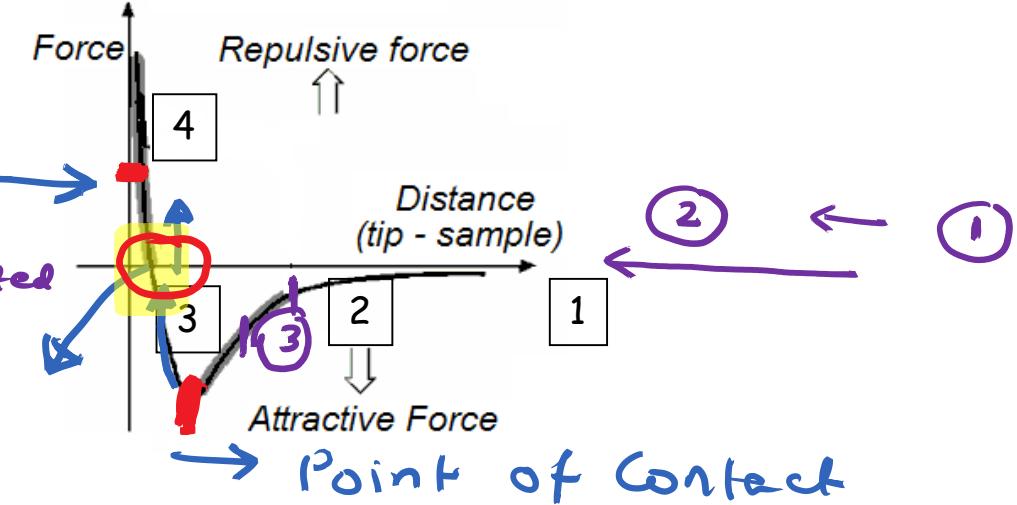
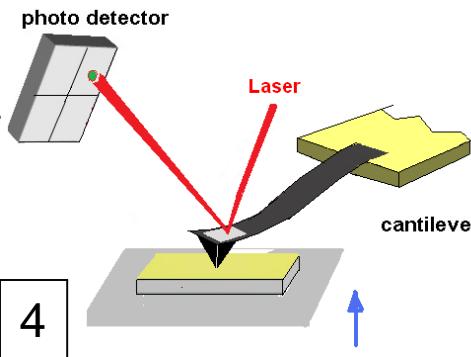
Once approach is complete the Piezo elements get activated
There are typically 3 piezos, 1 each for X and Y and 1 for Z.

Set a Set Point

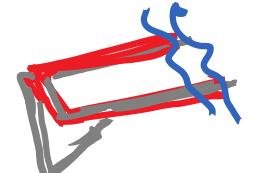
Where you want your Stepper motor to stop

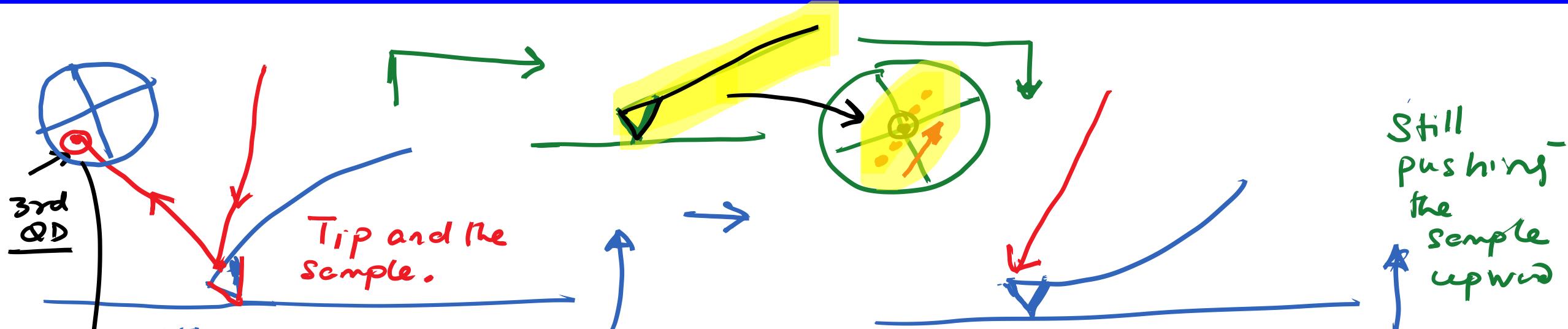


The Sample moving up → Still far away from the tip →



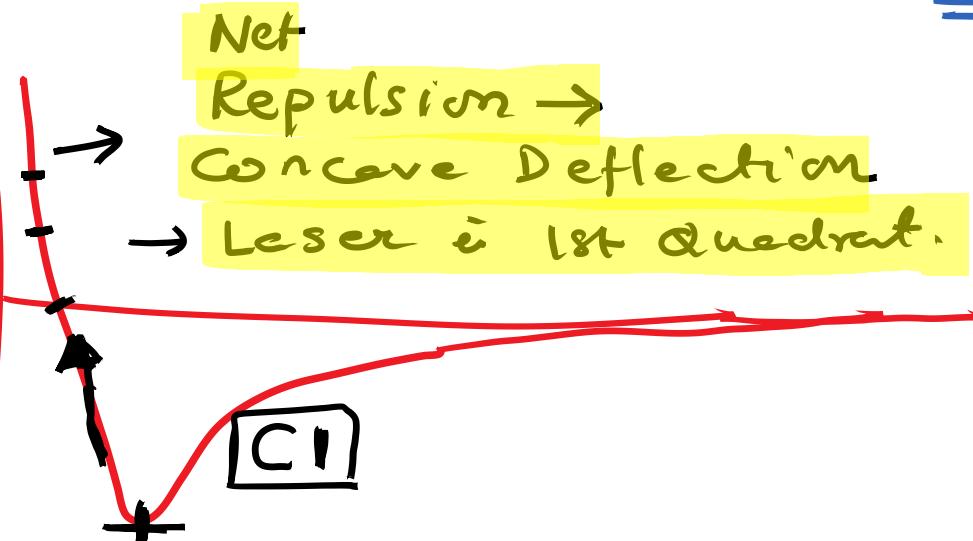
Corresponding to Frame 3.





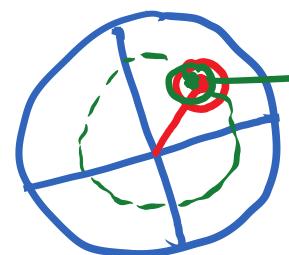
Nature of the deflection changes from
Convex to Concave!

Max deviation from (0,0)



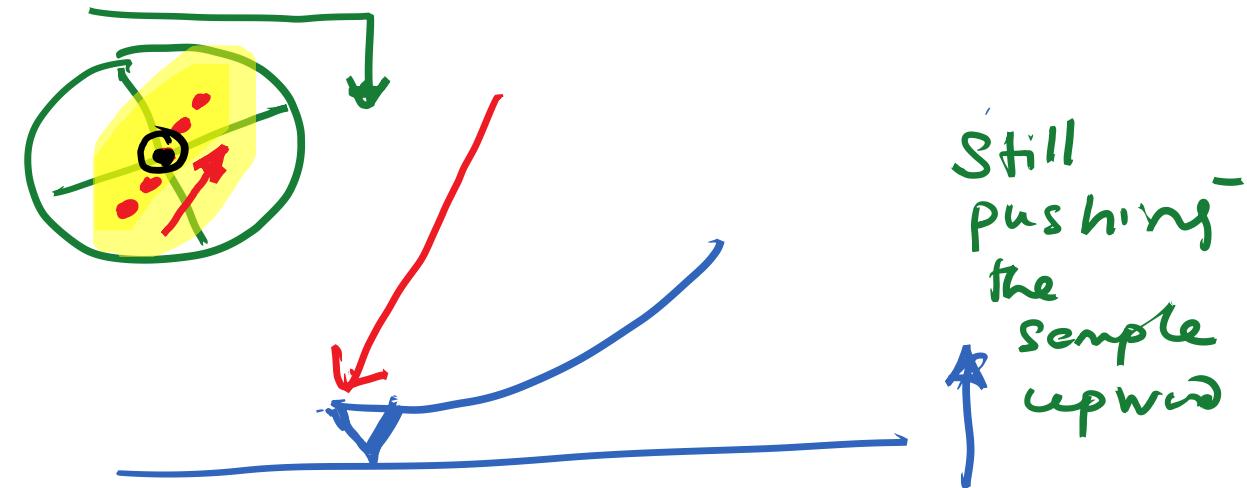
Tip-Sample Interaction:
There are three simultaneous signatures:-
(1) Deflection of the Cantilever
(2) Position of the reflector lens
(3) On the Force Curve

When does the upward movement of the sample stop?

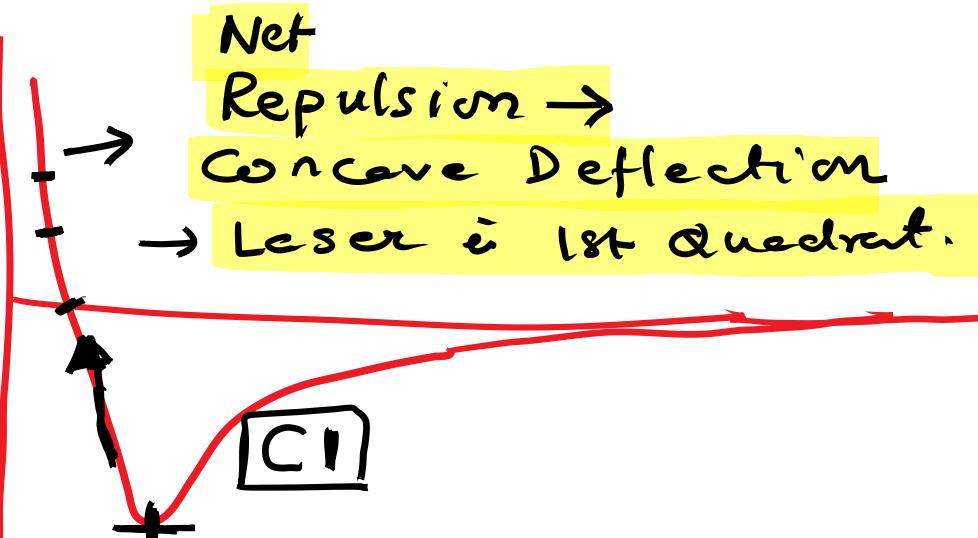


Set point (3 mV)

\hookrightarrow 3 mV or 5 mV



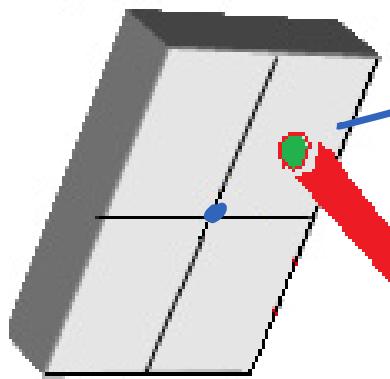
\Rightarrow Operator's prerogative
softer sample \rightarrow Lower set point



Tip-Sample Interaction:
There are three simultaneous signatures:-

- (1) Deflection of the cantilever
- (2) Position of the reflector lens
- (3) On the Force Curve

photo detector



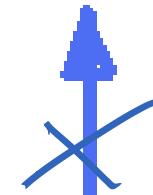
set point

Laser

Approach
of an AFM

Tip has
approached the
sample

Sample is
also coupled.



~~movement has~~
stopped

