Basic 15
Nanometer Scale Measurement And Manipulation by Scanning Probe Microscope

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I. Basics of scanning probe microscope

Scanning Probe Microscope (SPM)

Scanning Probe Microscope:

・Seeing individual atoms

・Manipulation individual atoms

It opens up atomic-scale observation and manipulation.

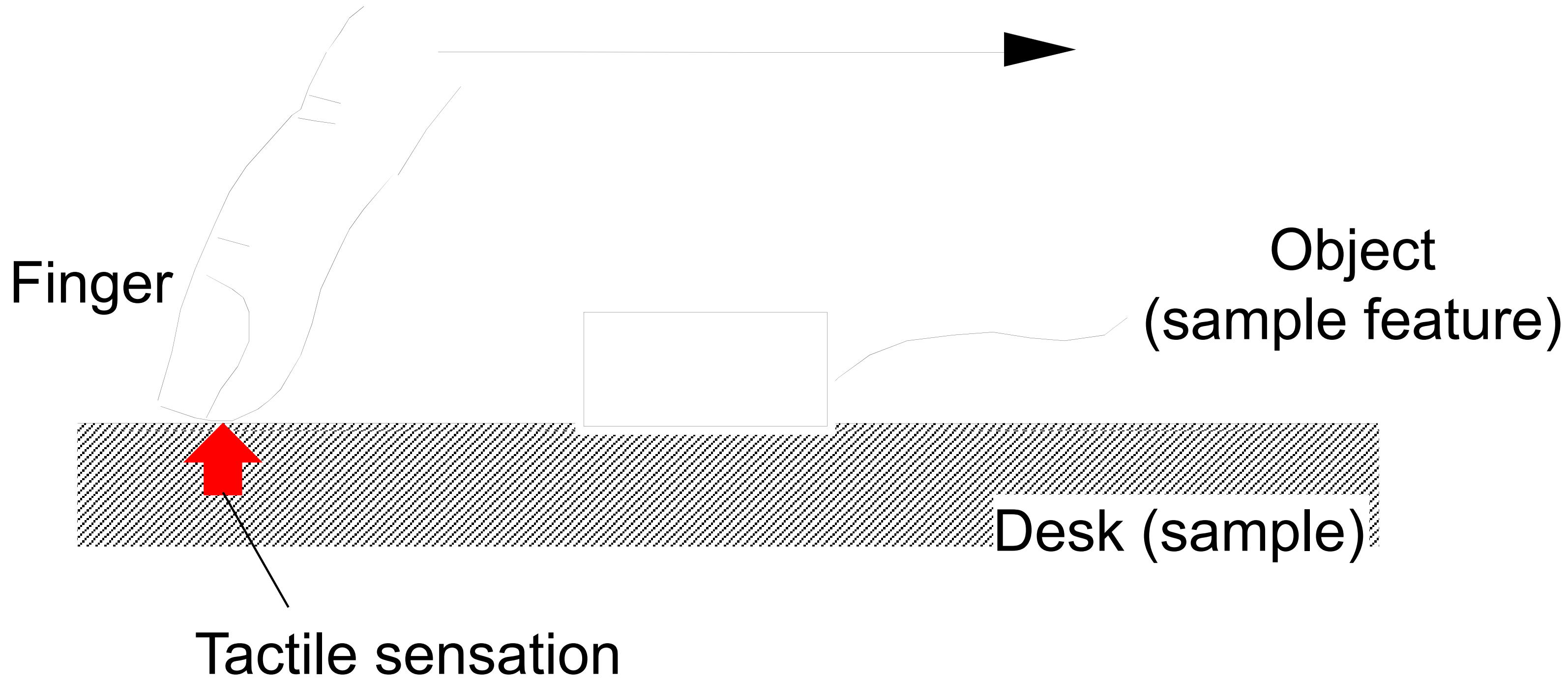
Development of scanning probe microscope

- Gerd Bennig and Heinrich Rohrer were awarded the Nobel Prize (1987), for their invention of the scanning tunneling microscope, only six years after the invention. They demonstrated observation of individual atoms at atomic scale resolution.

- Donald M. Eigler demonstrated manipulation of individual atoms with atomic scale precision by scanning tunneling microscope, 1989.

Principle of scanning probe microscope

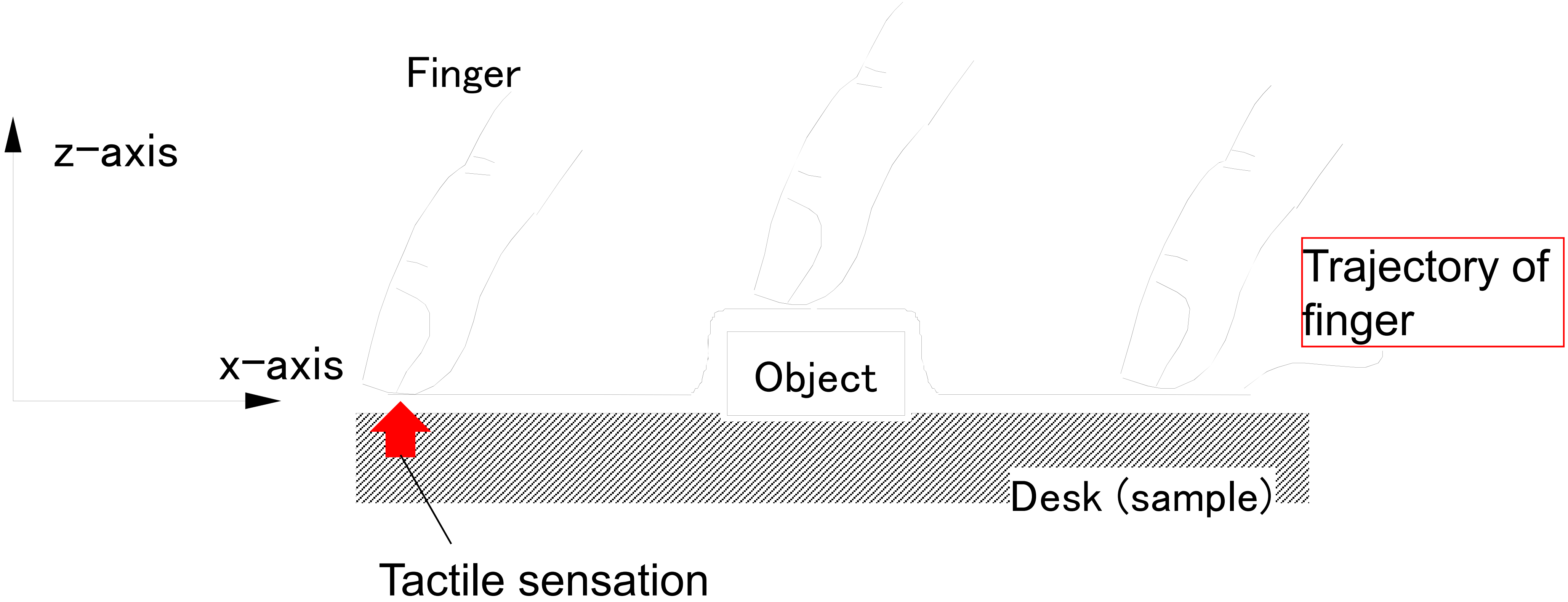
Trace the sample surface with a finger



Trace the sample surface with a finger

How should we do ?

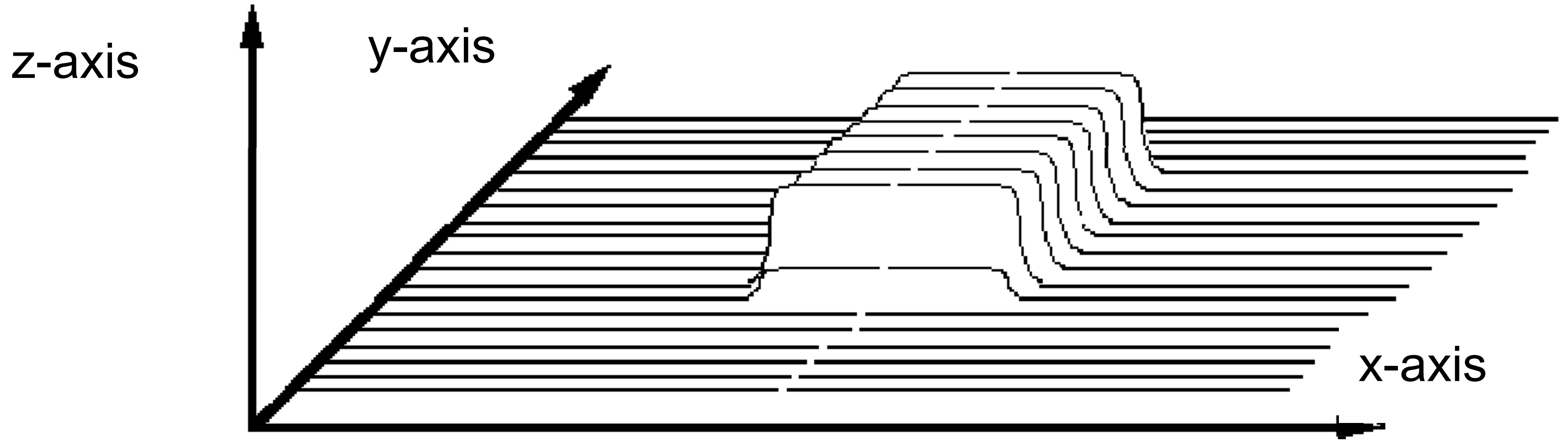
1. Touch the surface
2. Move the finger up or down so that the tactile sensation is equal
3. Memorize the position of the finger
4. Move the finger laterally
5. Go back to 1



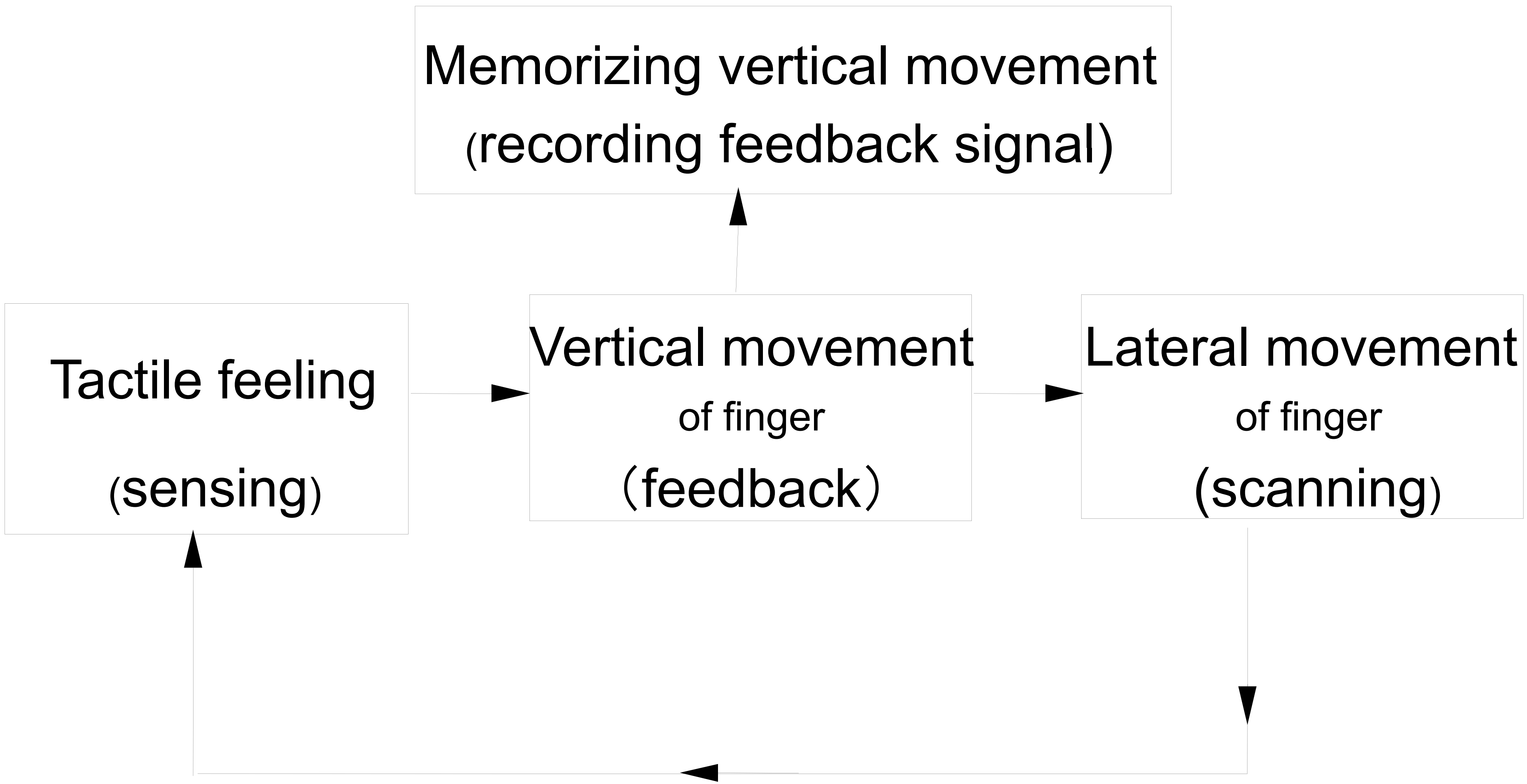
Reconstructing the trajectories of finger

By feeding back the tactile sensation to the movement of the finger (probe) and reconstructing the trajectory, sample surface can be imaged.

Sample image by reconstructing the trajectories



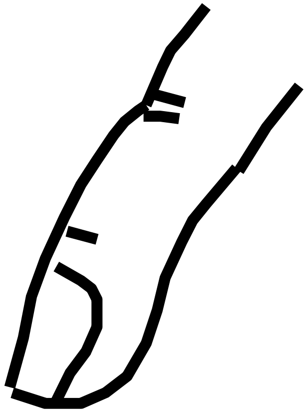
Block diagram of tracing surface with a finger



What happens if you have an extremely sharp finger ?

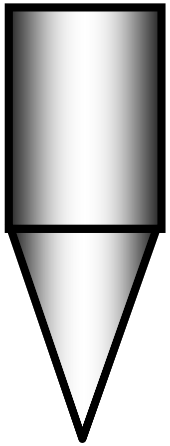
Probe that you use:

Blunt probe (finger)



Apex radius: 10 mm

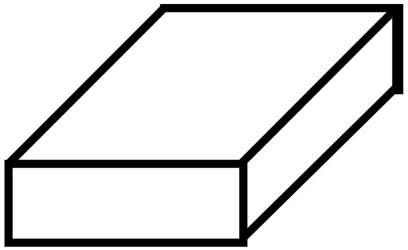
Sharp probe



Apex radius: 0.1 nm

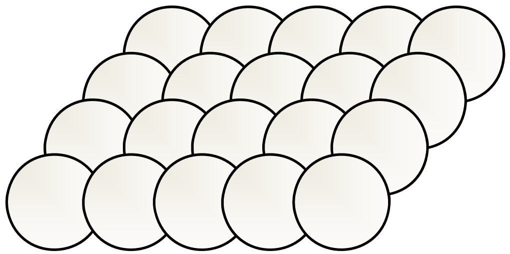
What you can resolve:

Eraser



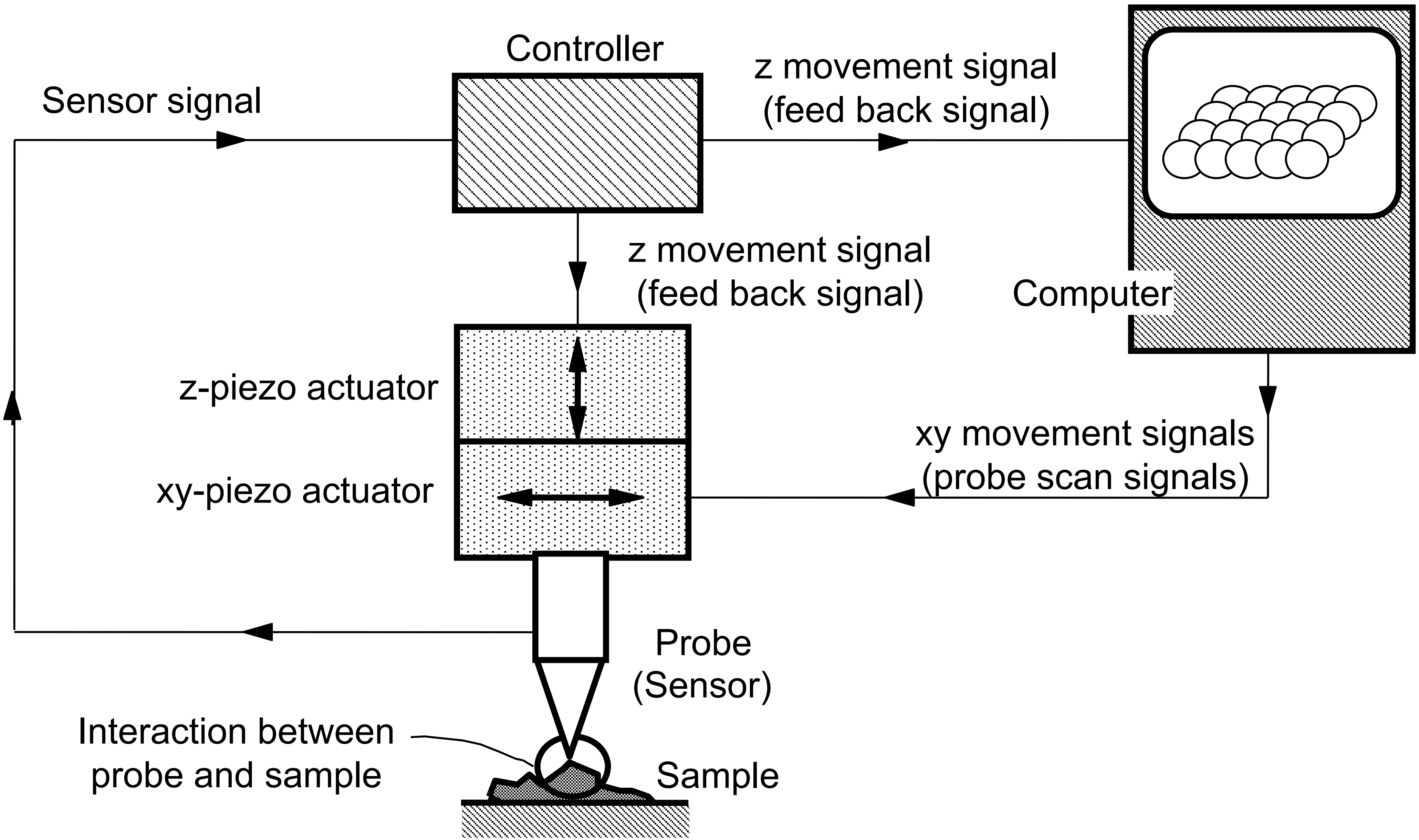
Resolution ~ 10 mm

Atom(radius ~0.1nm)

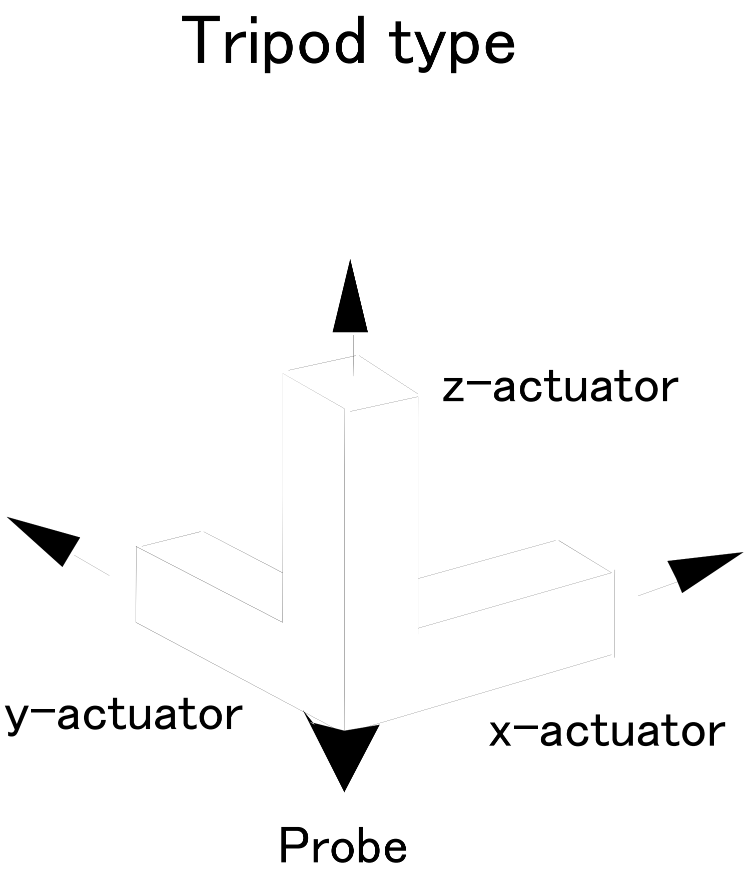


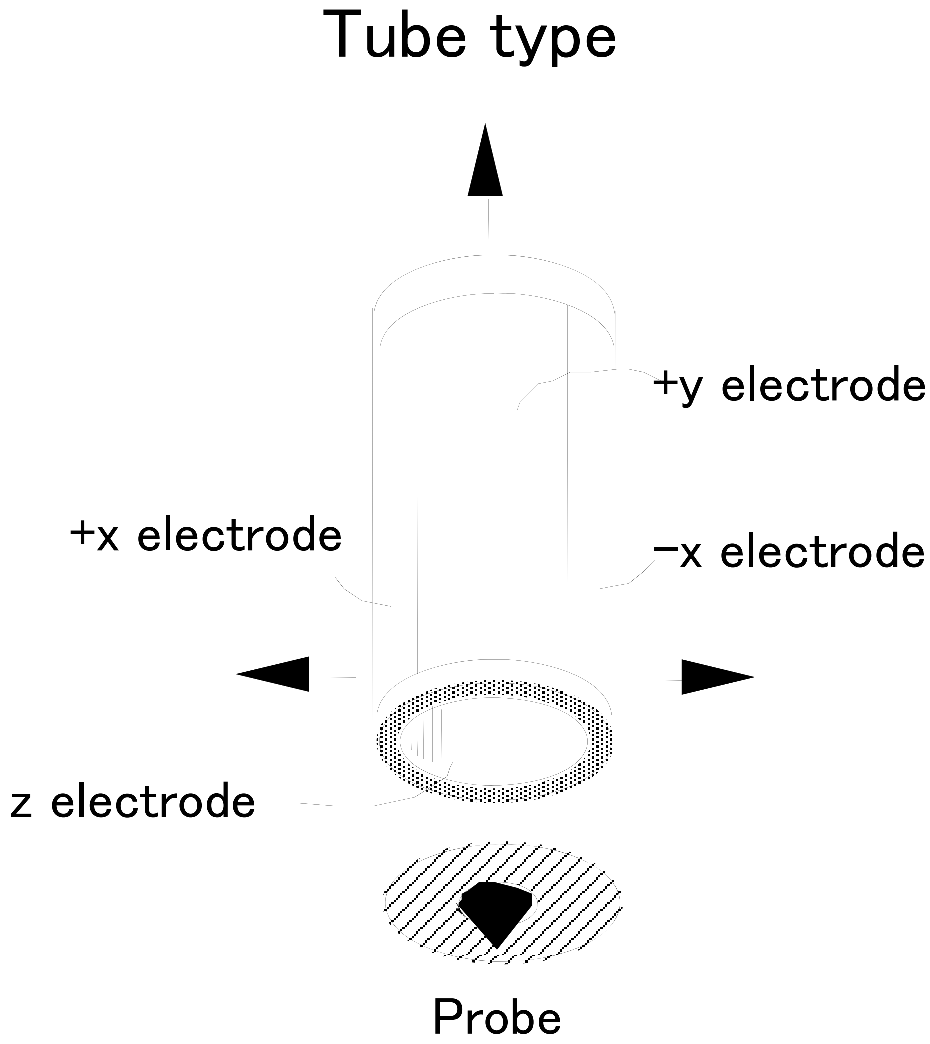
Resolution ~ around 0.1 nm

Basic configuration of scanning probe microscope

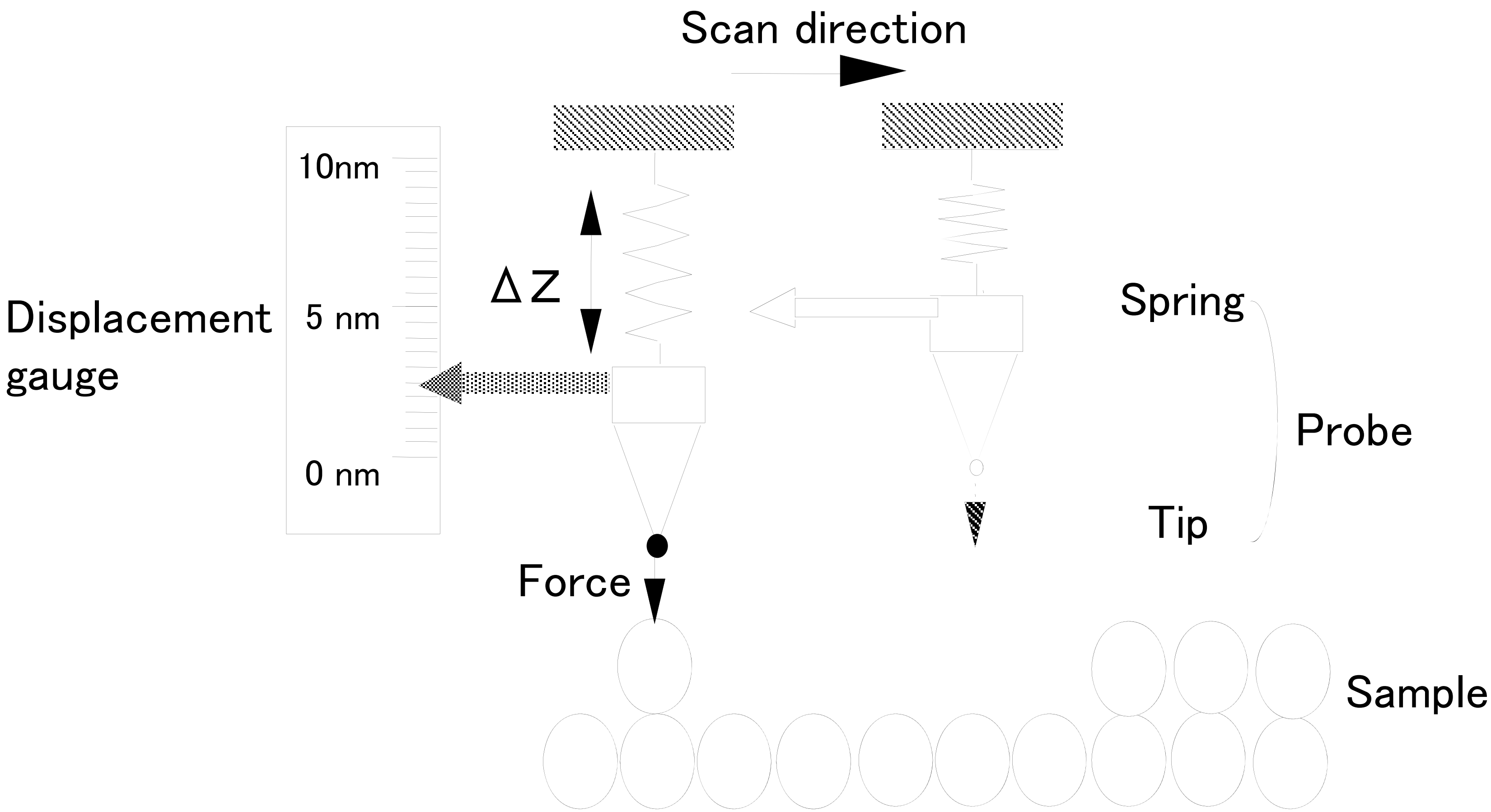


Examples of piezo actuators



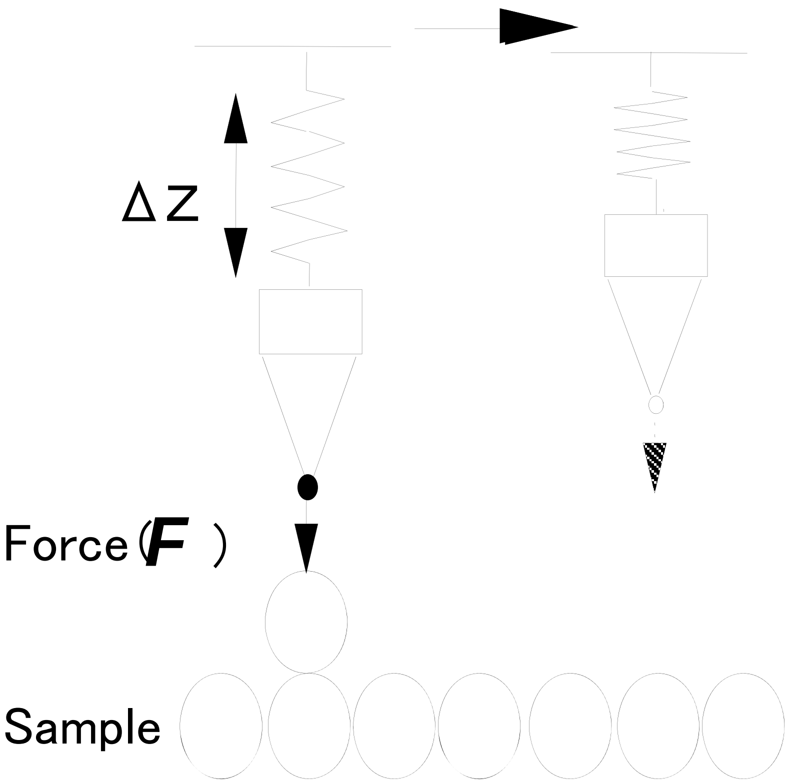


How should you design a probe ?



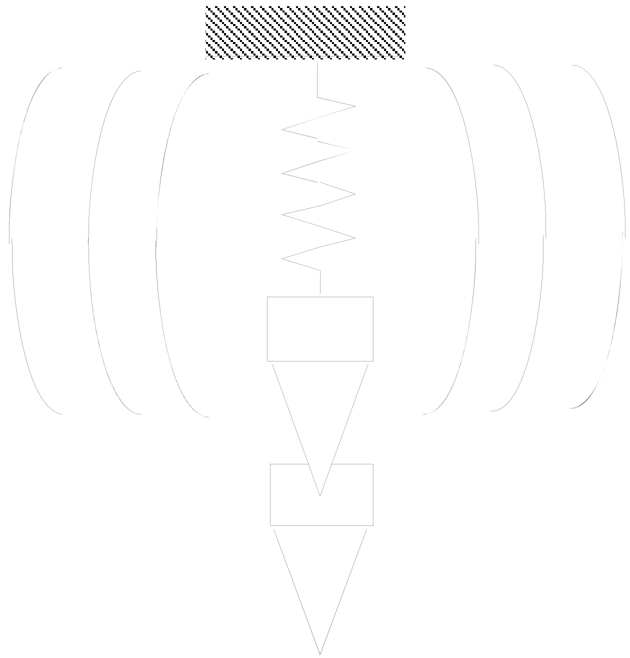
Probe design: requirements for a probe

High force sensitivity
=> soft spring



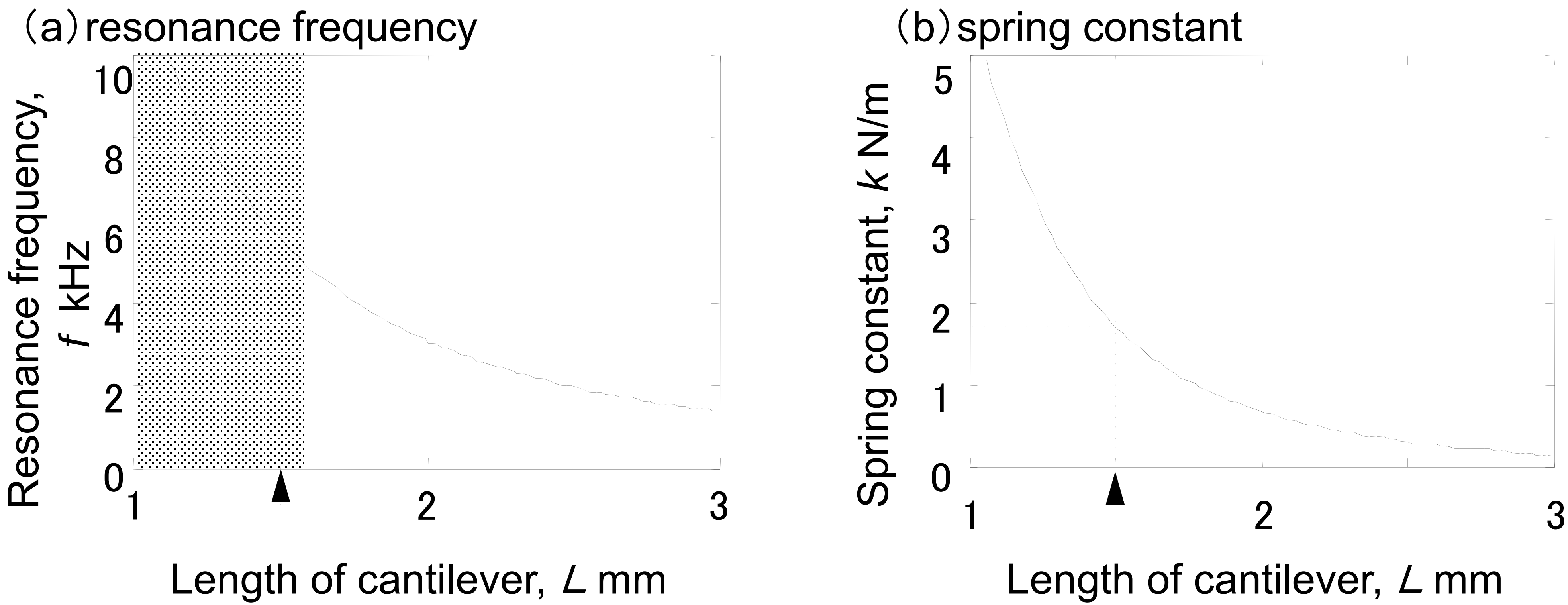
$$\Delta Z = \frac{F}{k}$$

Robustness against environmental noises
=> high resonance frequency



Probe design: an aluminum foil cantilever

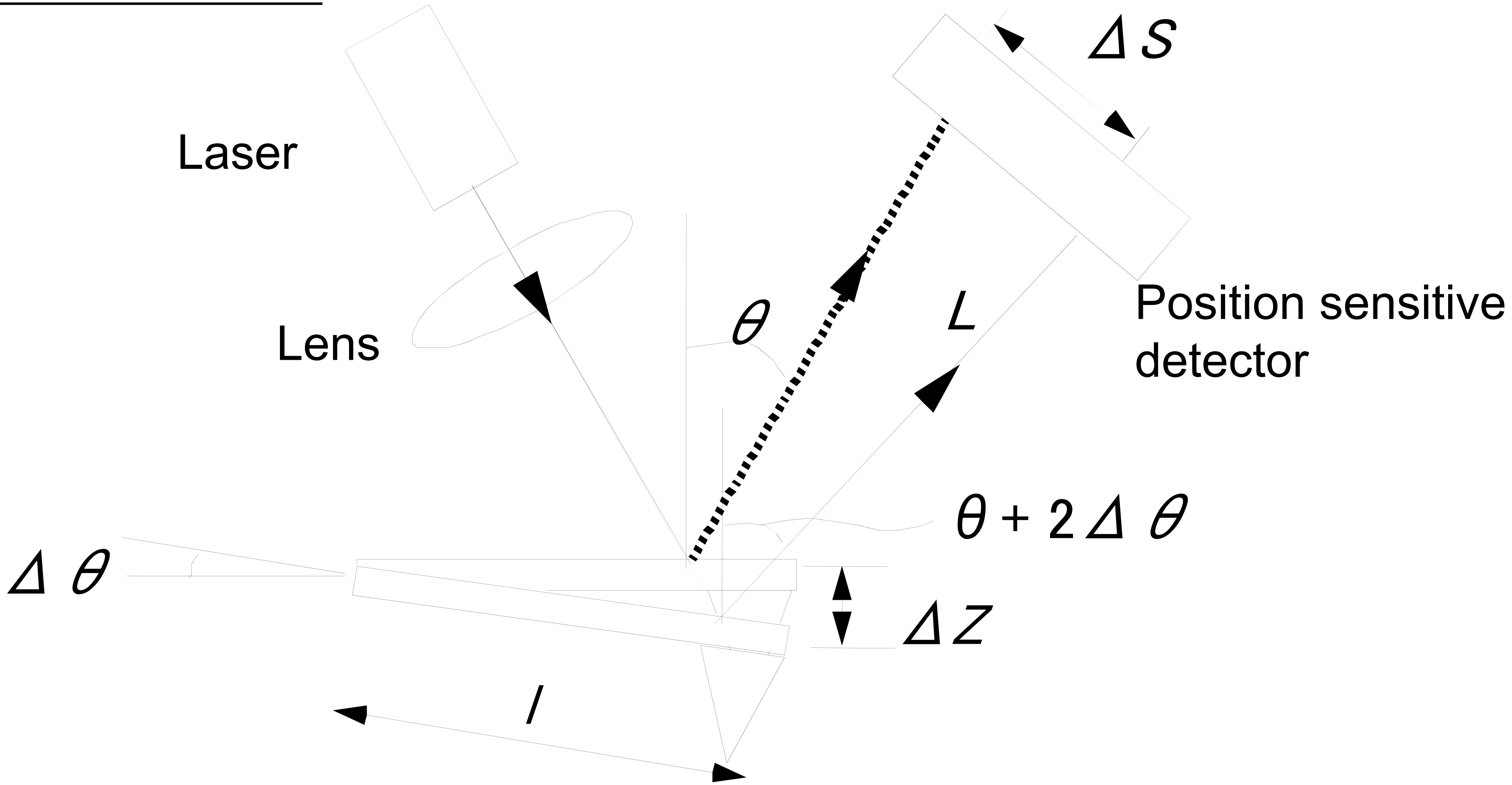
Cantilever probe made of an aluminum foil
Thickness *h* = 15μm, width *b* = 100μm



When L = 1.5 mm *f* = 5 (kHz), *k* = 1. 7(N/m)

Measurement of probe displacement 1

Optical lever method

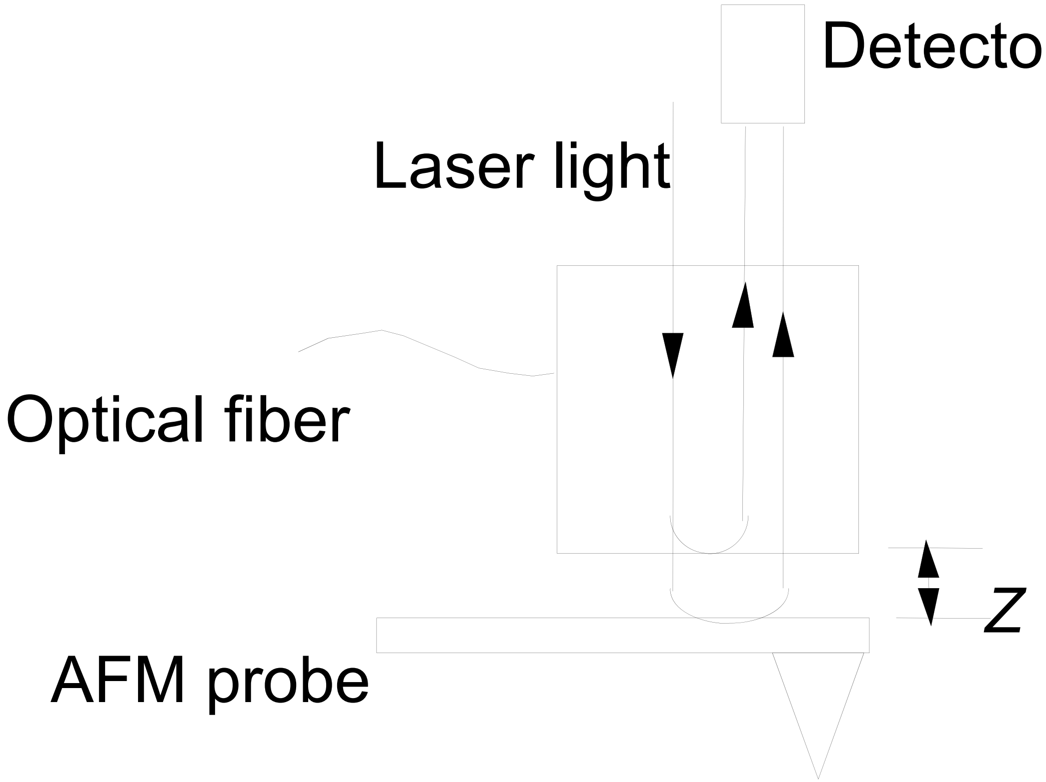


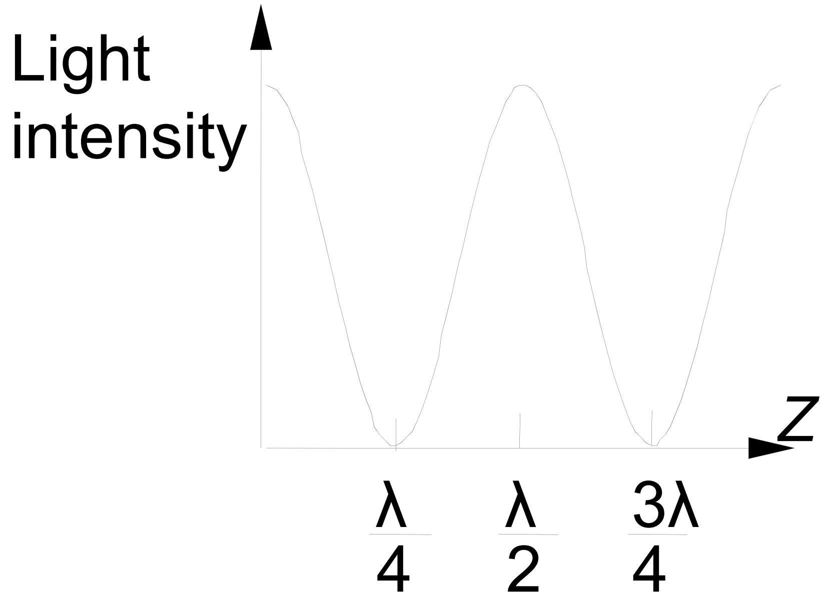
$\Delta Z = l \times \Delta\theta$ $\qquad \Delta S = L \times 2\Delta\theta = 2\dfrac{L}{l}\Delta Z$

When l = 1(mm), L = 1(m), ΔS_{min} = 0.1(μm), ΔZ_{min} = 0.1(nm)

Measurement of probe displacement 2

Optical interference method



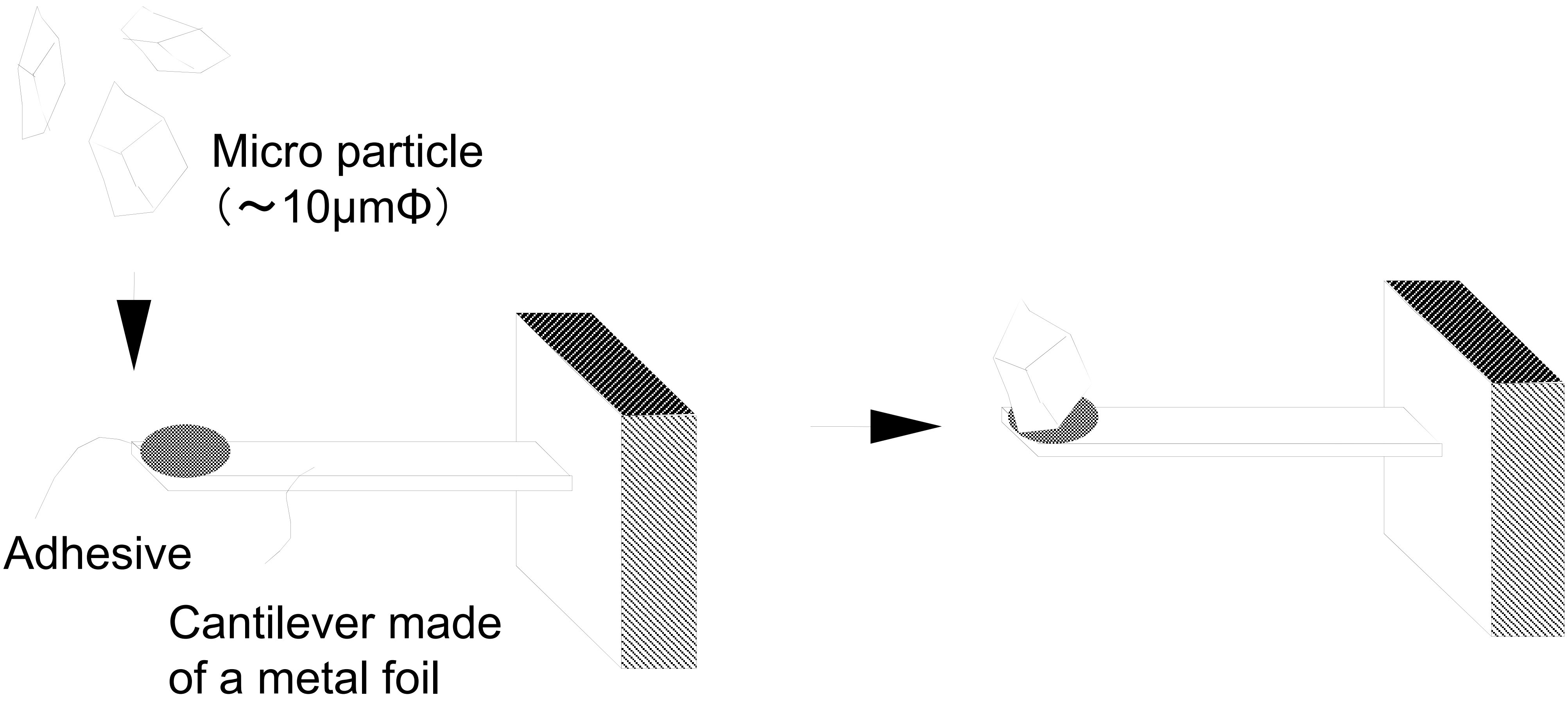


$\frac{\lambda}{4}$ ~150nm

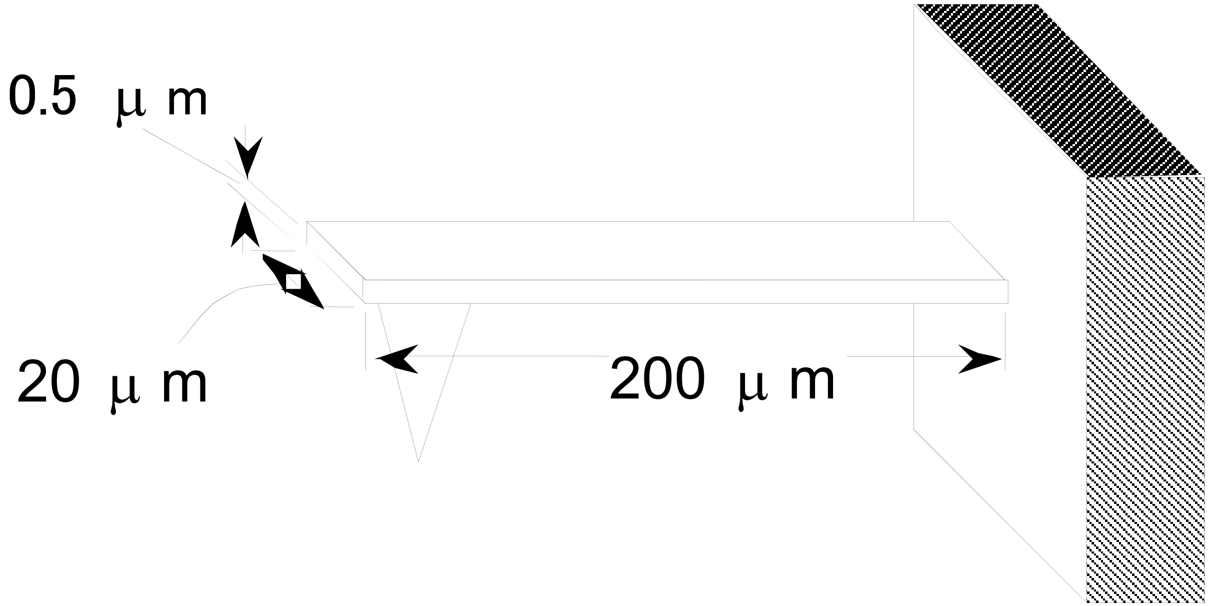
Probe fabrication in the early stages

Do you want to try that ?

Drop micro particles onto a cantilever.
If you have “a little” luck, you can make a probe.



Probe fabrication by micromachining techniques

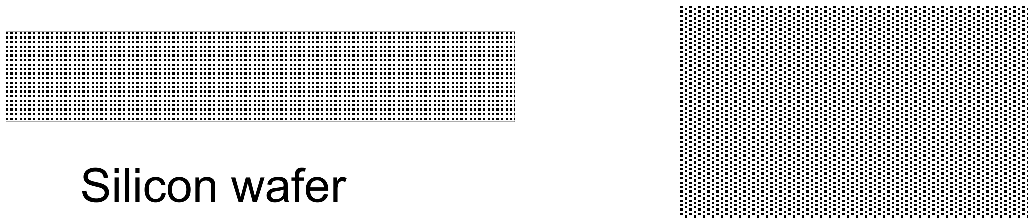


Spring constant 0.1(N/m) → Force sensitivity 0.01 (nN)
Resonance frequency 50 (kHz)
Tip radius several nm

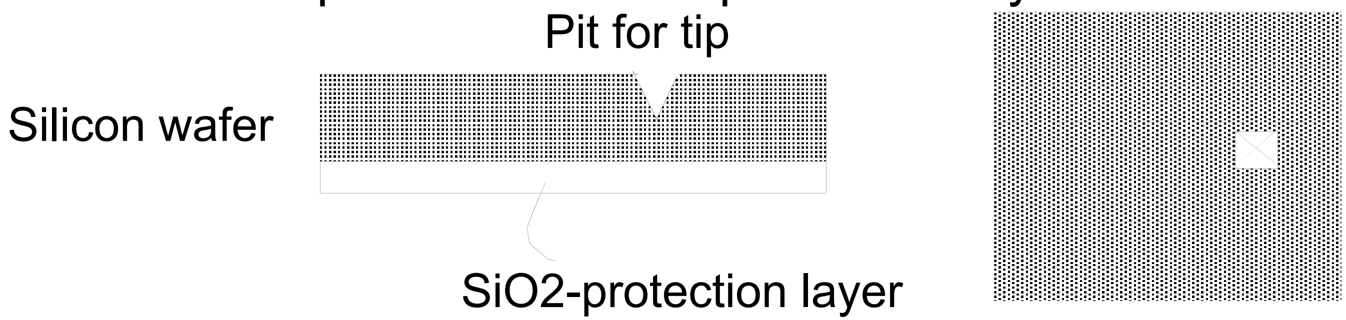
Probe fabrication process 1

Side view   Top view

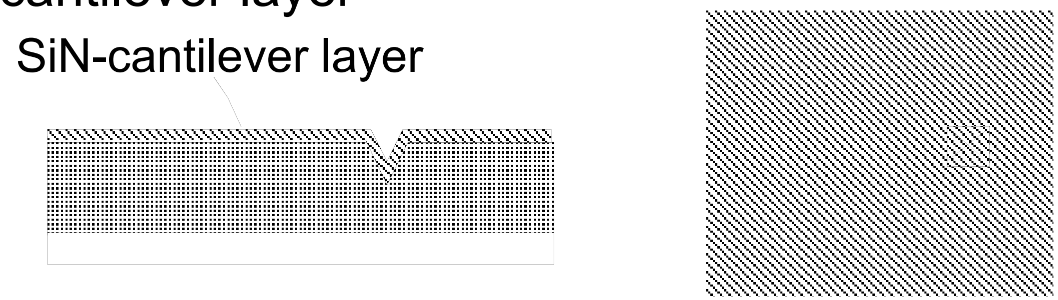
a) Silicon wafer



b) Formation of tip mold and back protection layer



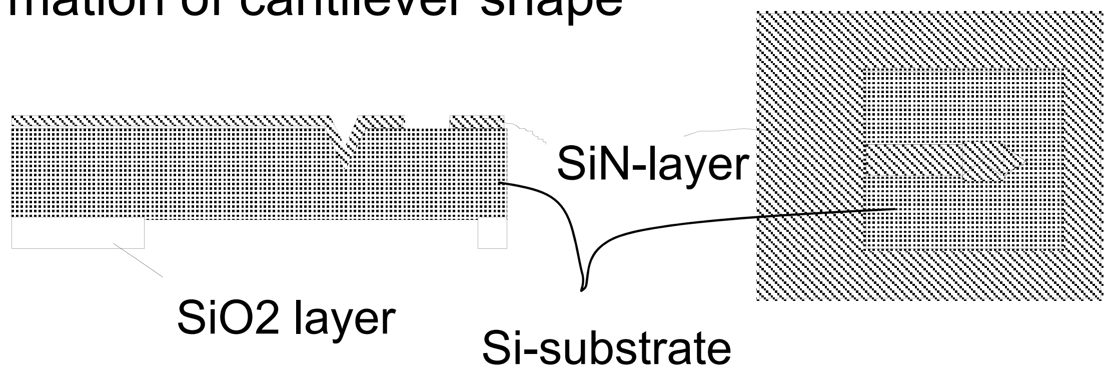
c) Formation of cantilever layer



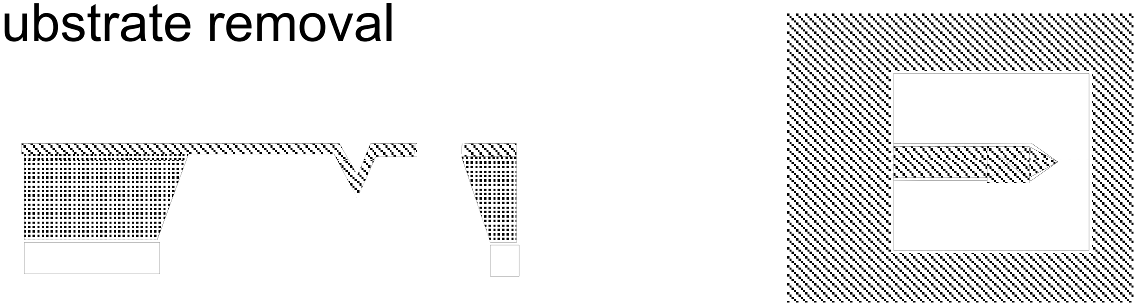
Probe fabrication process 2

Side view | Top view

d) Formation of cantilever shape



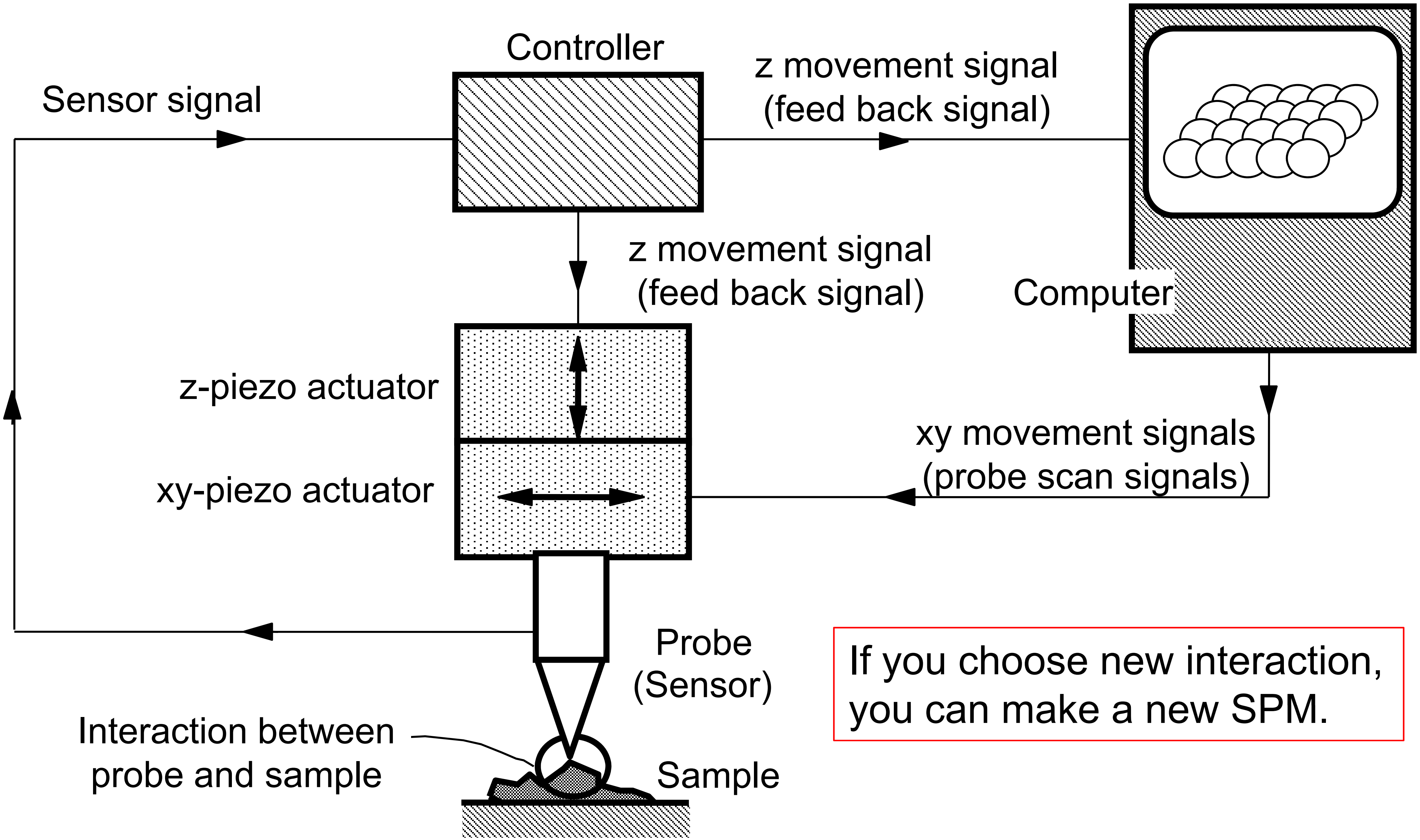
e) Substrate removal



f) Device cutout

II. Various types of scanning probe microscope

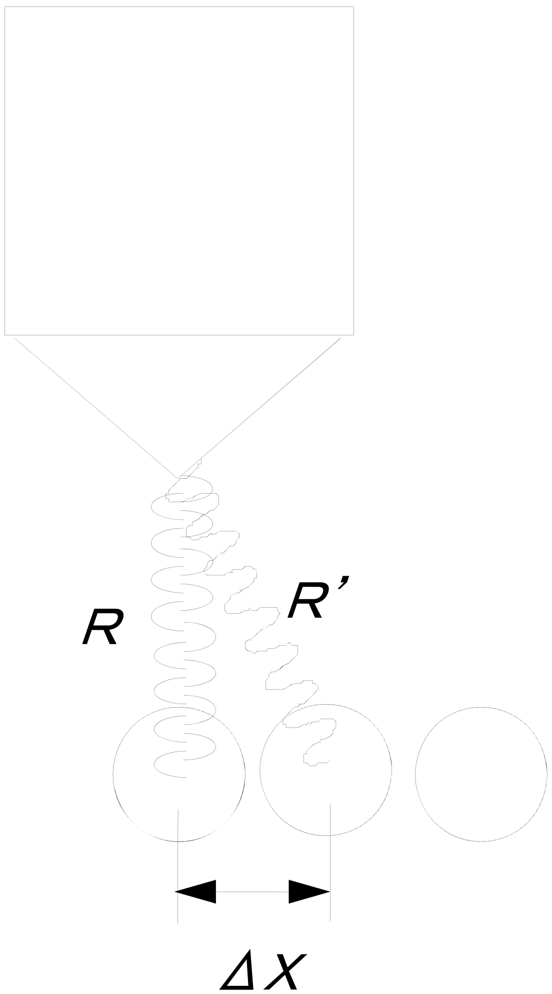
Various types of scanning probe microscope



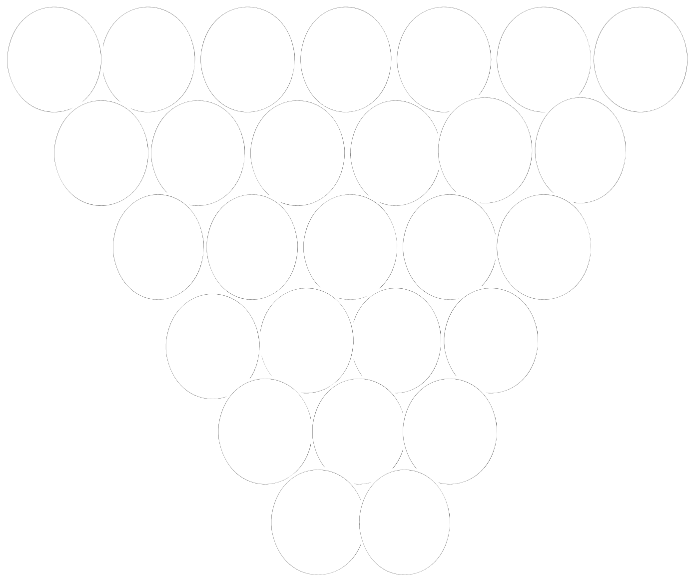
If you choose new interaction, you can make a new SPM.

What determines resolution of SPM ?

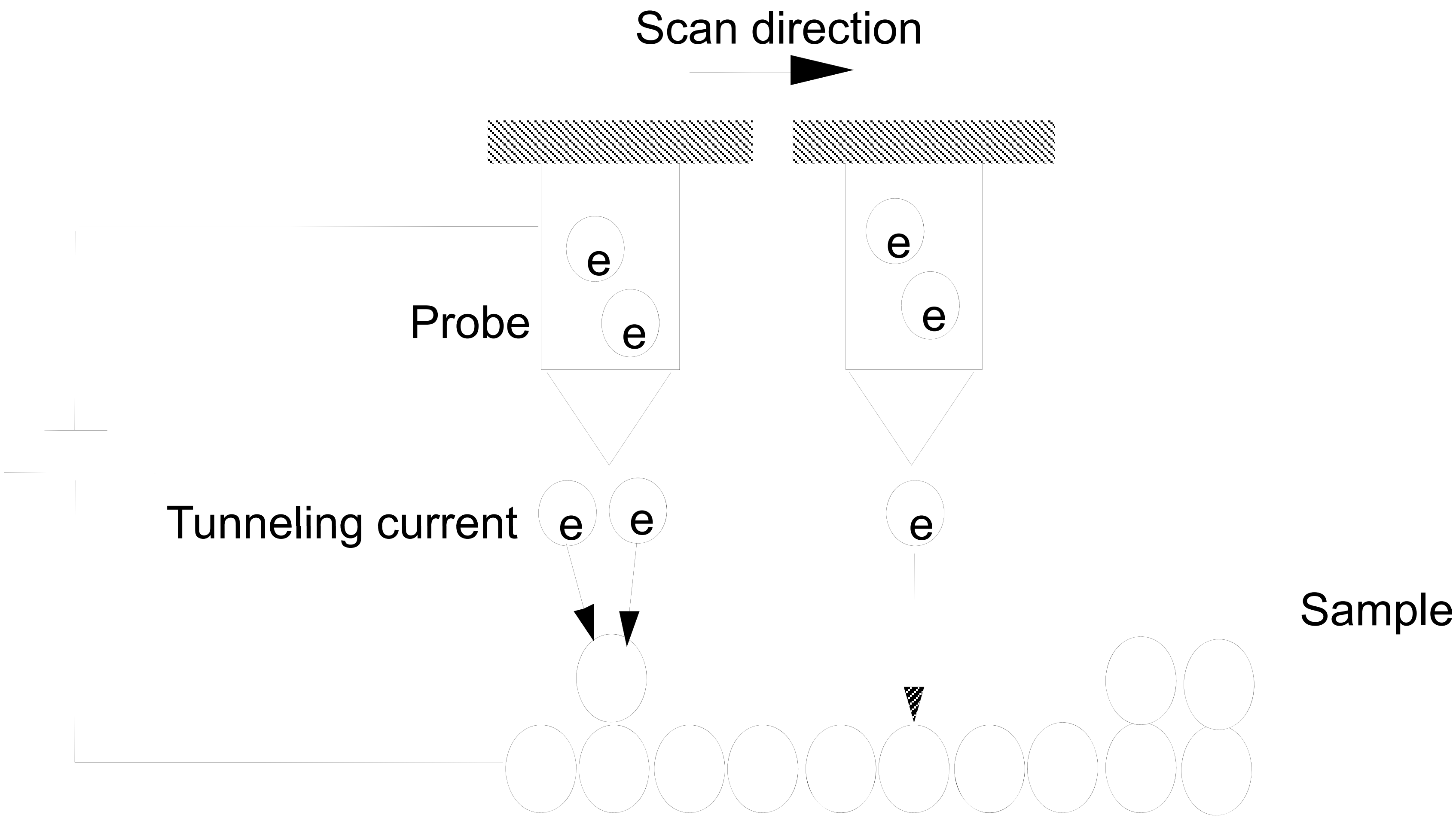
1）distance dependence of interaction



2）tip size



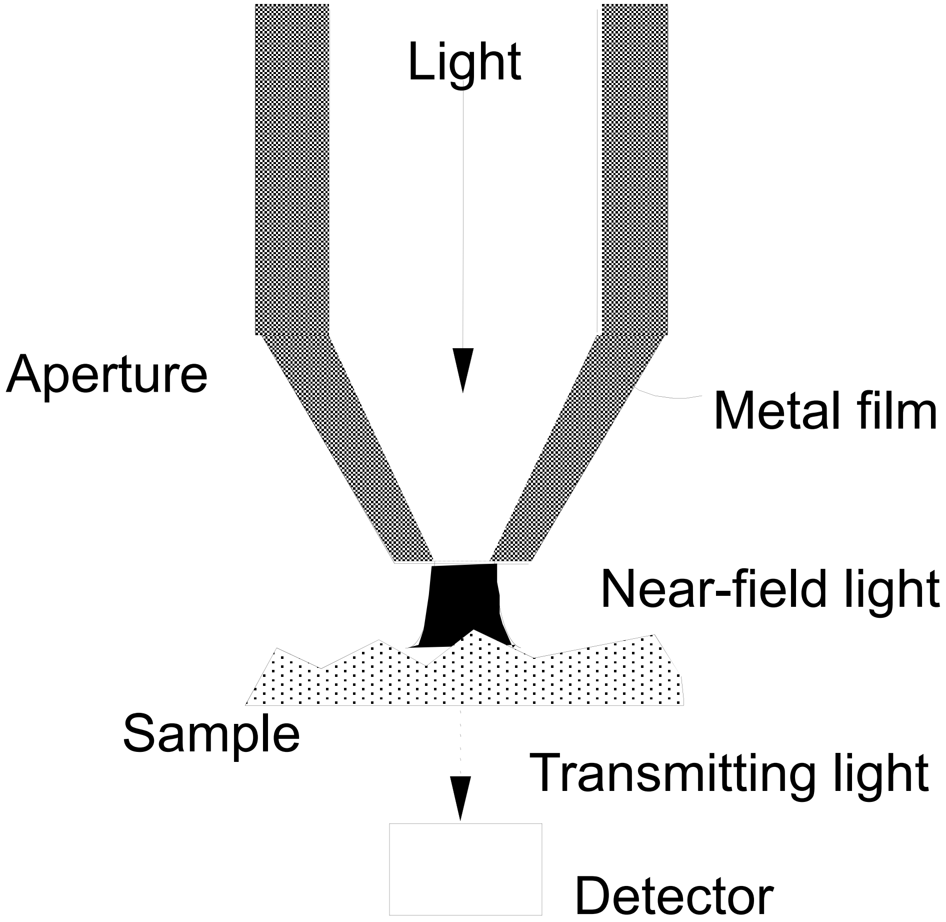
Scanning tunneling microscope (STM)



Tunneling current $I = \mathrm{Exp}\left(-\frac{Z}{D}\right)$ $D = 1$ Å → high resolution

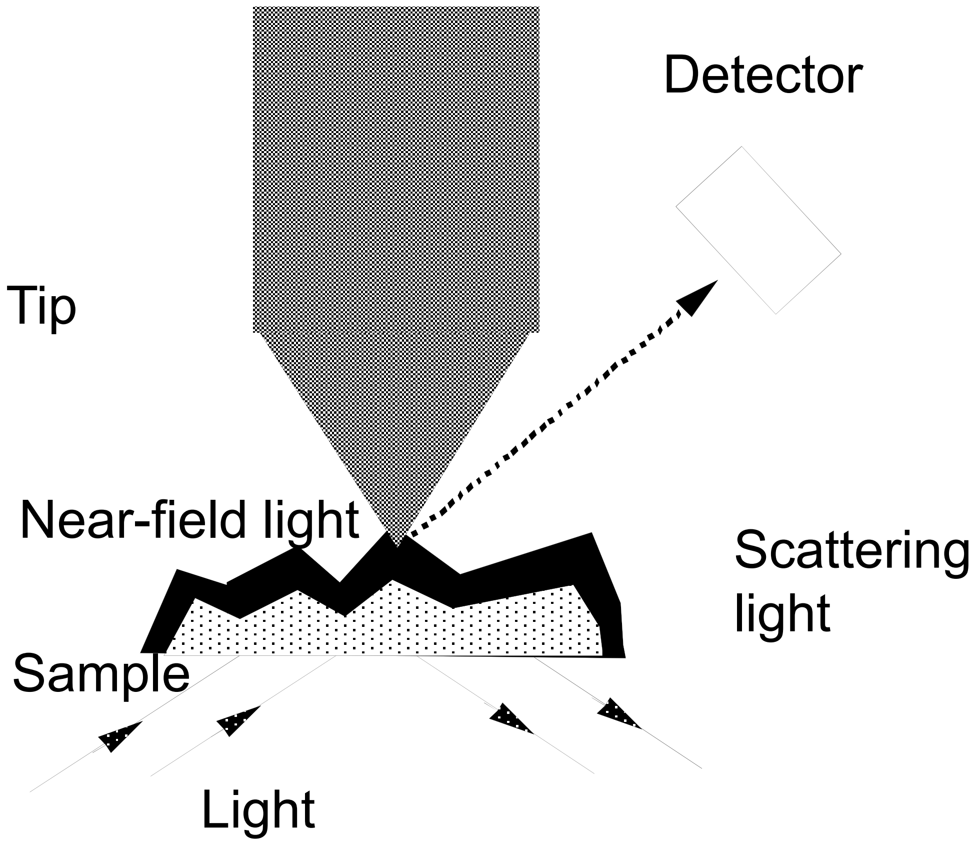
Scanning near-field optical microscope (SNOM)

Aperture type



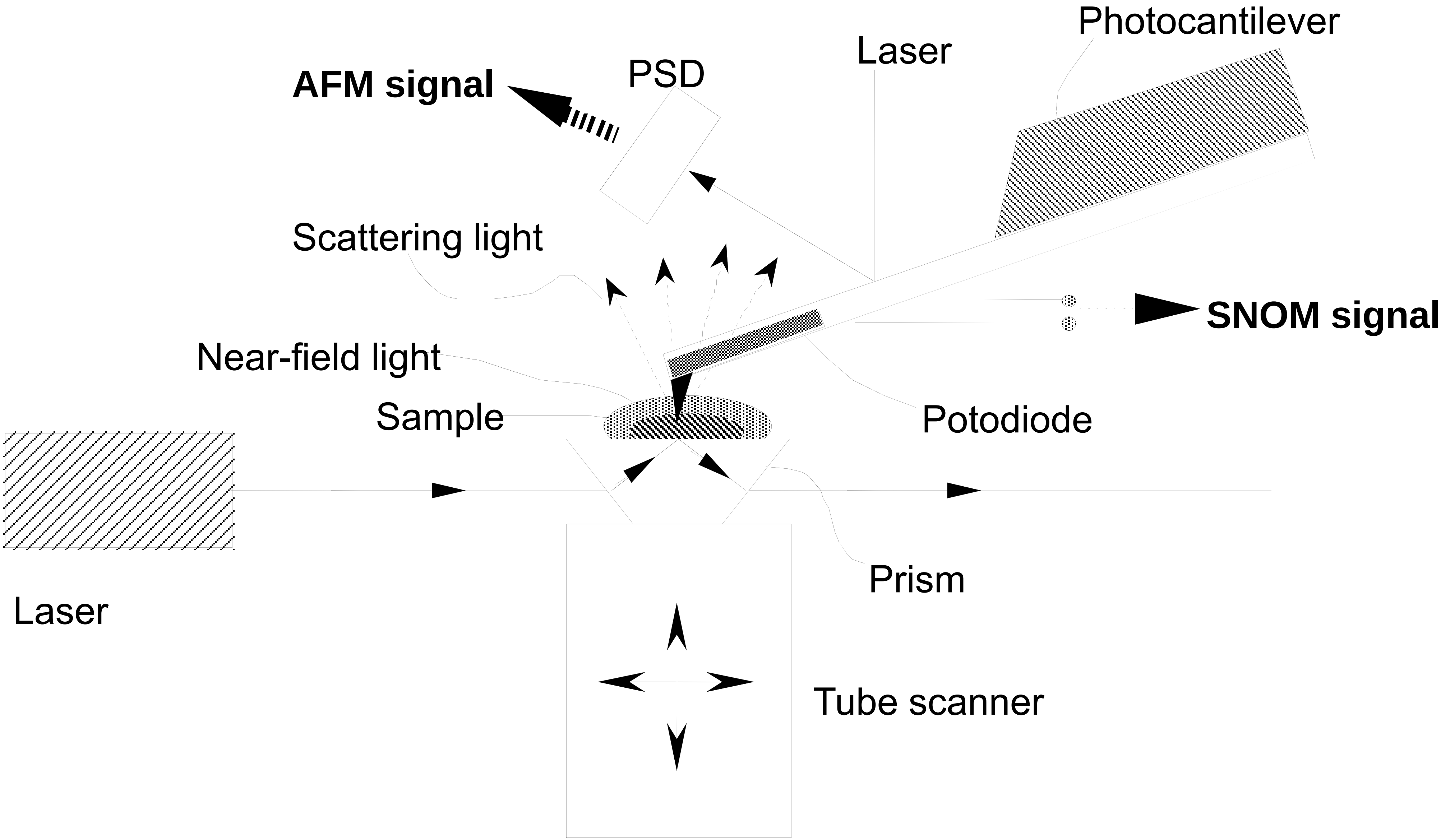
Aperture radius～several tens nm

Tip type

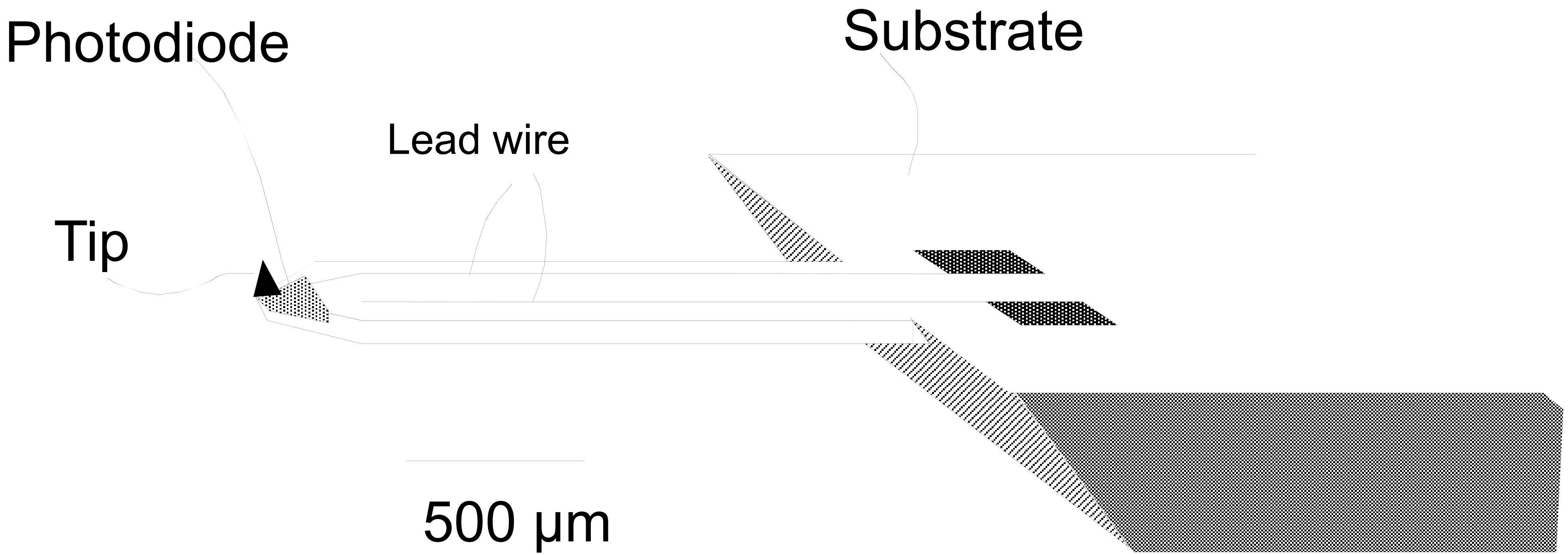


Tip radius ～several nm

SNOM／AFM using a photocantilever

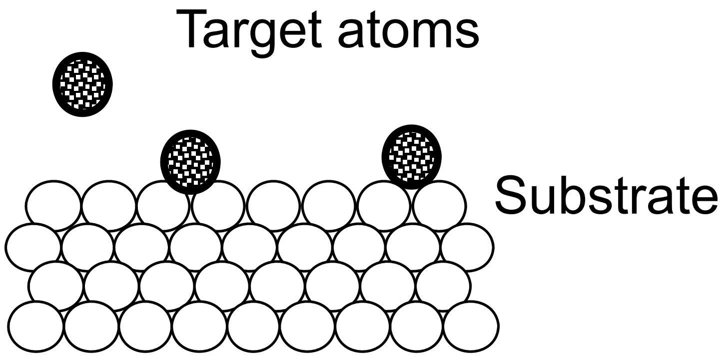


Structure of photocantilever

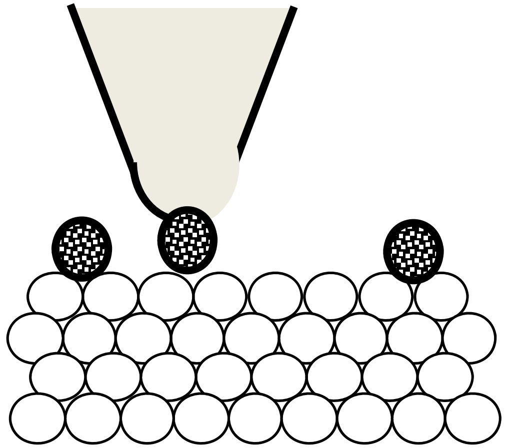


Manipulation of individual atoms 1

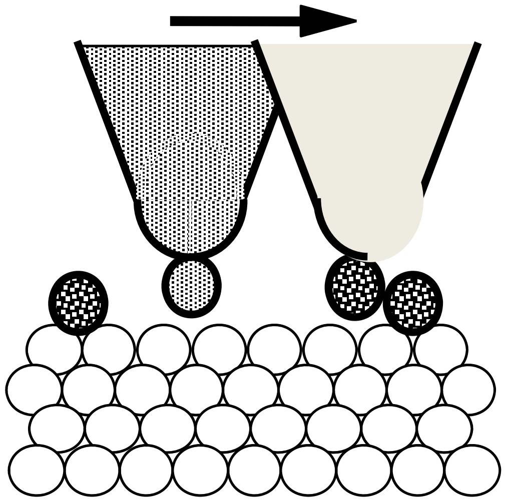
1）Scatter atoms



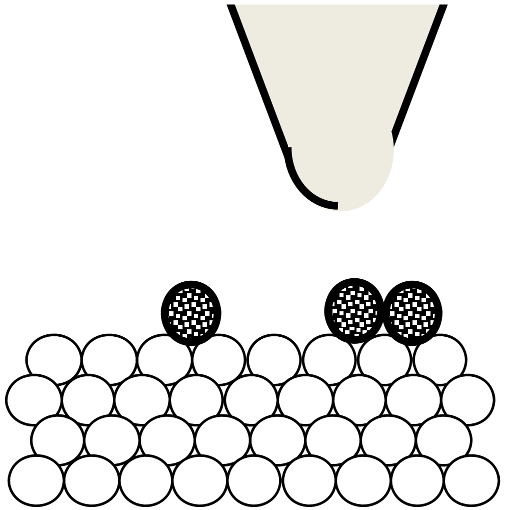
2）Adsorb the target atom to the probe



3）Transfer the atom

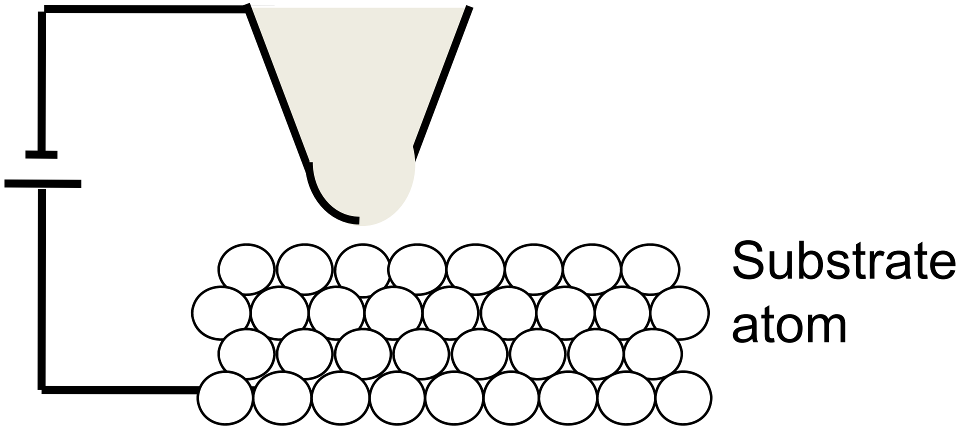


4）Adsorb the atom to the substrate

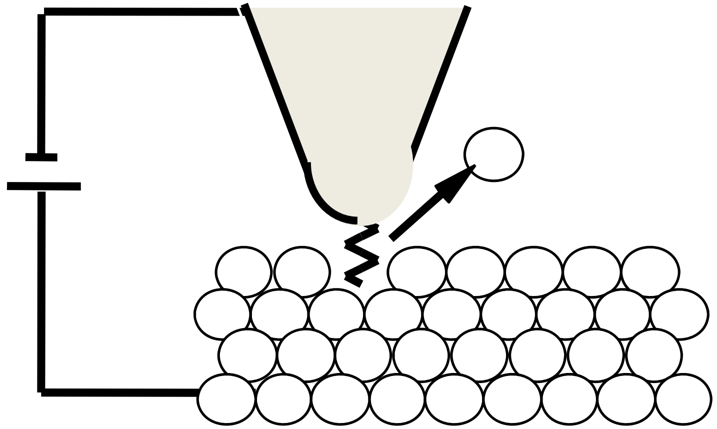


Manipulation of individual atoms 2

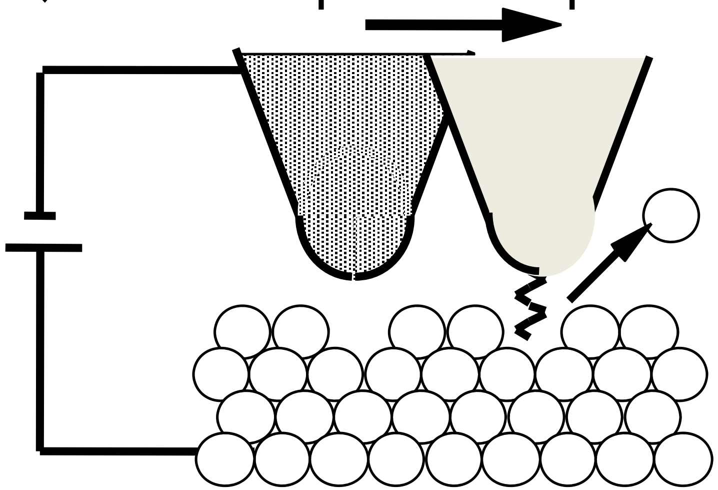
1）Prepare a flat substrate



2）Remove the target atom by electric field

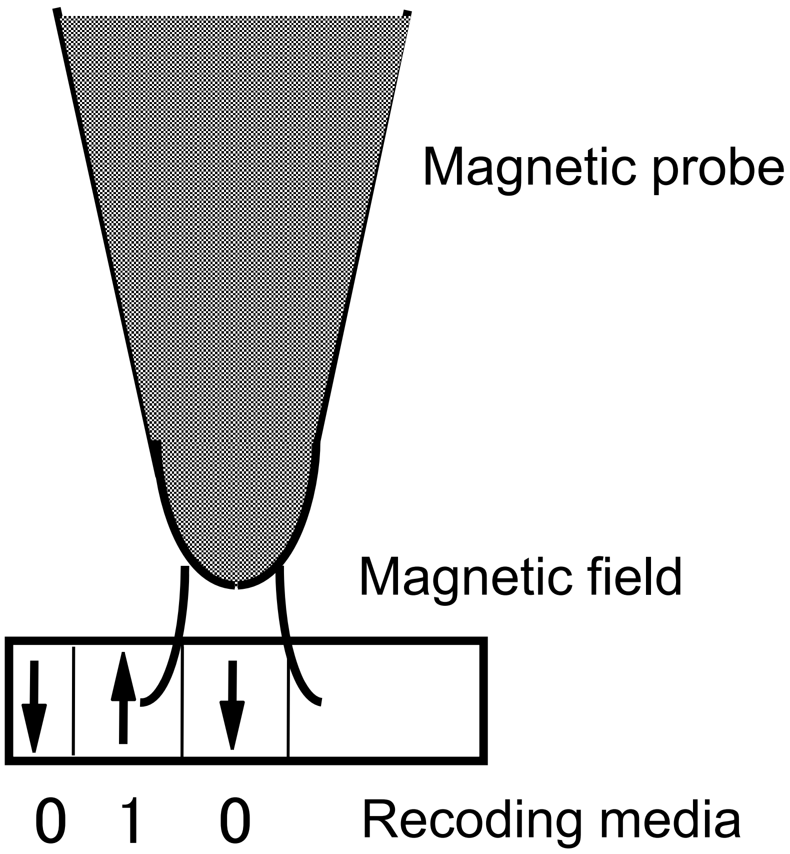


3）Scan the probe for pattern formation

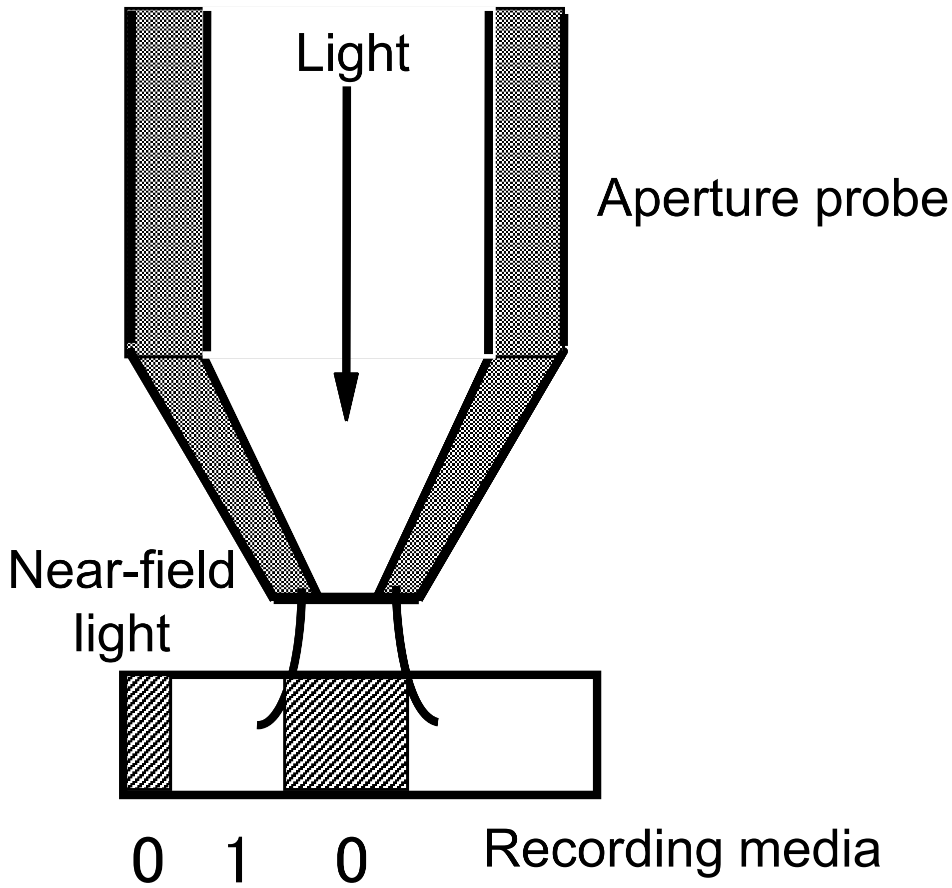


Information storage by using SPM

1）Magnetic recording by MFM



2）Optical recording by SNOM



Summary

Scanning probe microscope:

- Microscope that scan a micro probe mechanically
- Integration of mechatronics and micromachining technologies
- Device that can see and manipulate indicial atoms
- Technology that opens up nanotechnology

Advanced reading

1) R. Wisendanger, Scanning Probe Microscopy and Spectroscopy, Cambridge

2) R. Wisendanger, H. -J. Guntherodt edited, Scanning Tunneling Microscopy I - III, Springer-Verlag