Nanotweezers for removing nanoparticles on EUVL masks

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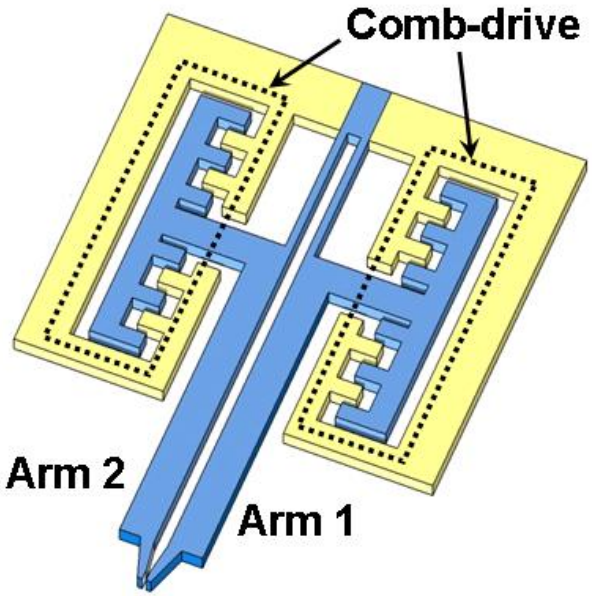
Introduction

In recent years, the process of cleaning high-end masks has been mild in exchange for haze prevention. Since the current process can not remove a part of particles, a reliable tool to remove particles on EUVL masks is expected.

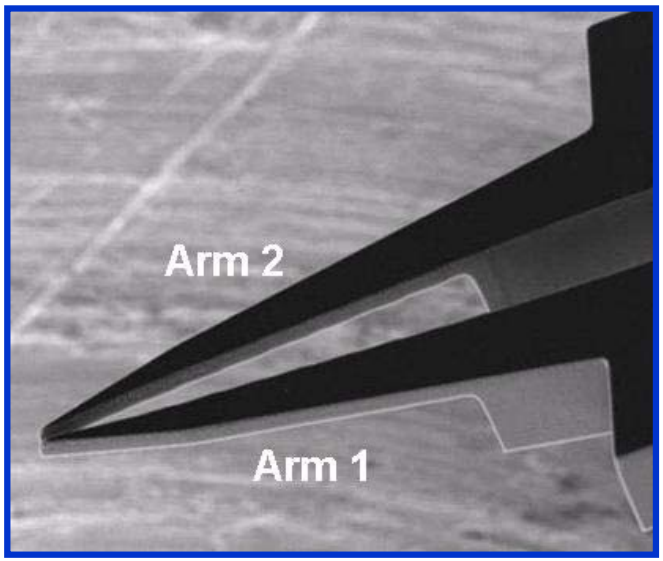
We have been reported an unique particle removal tool which is called Nanotweezers. Nanotweezers are literally a pair of minute tweezers and a kind of Micro Electro Mechanical System (MEMS). One arm of the past Nonotweezers can be opened and closed, but the other is fixed. Now we developed new Nanotweezers with dual active arms.

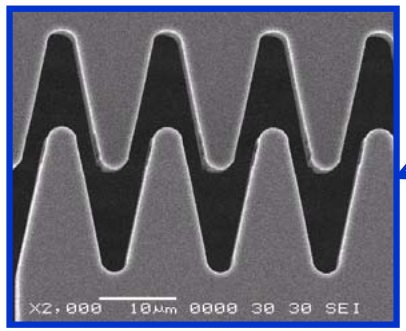
This paper has two main objectives. One is to investigate whether new Nanotweezers are feasible to remove particles on EUVL masks. The other is to confirm the advantage of Nanotweezers over AFM as a particle removal tool.

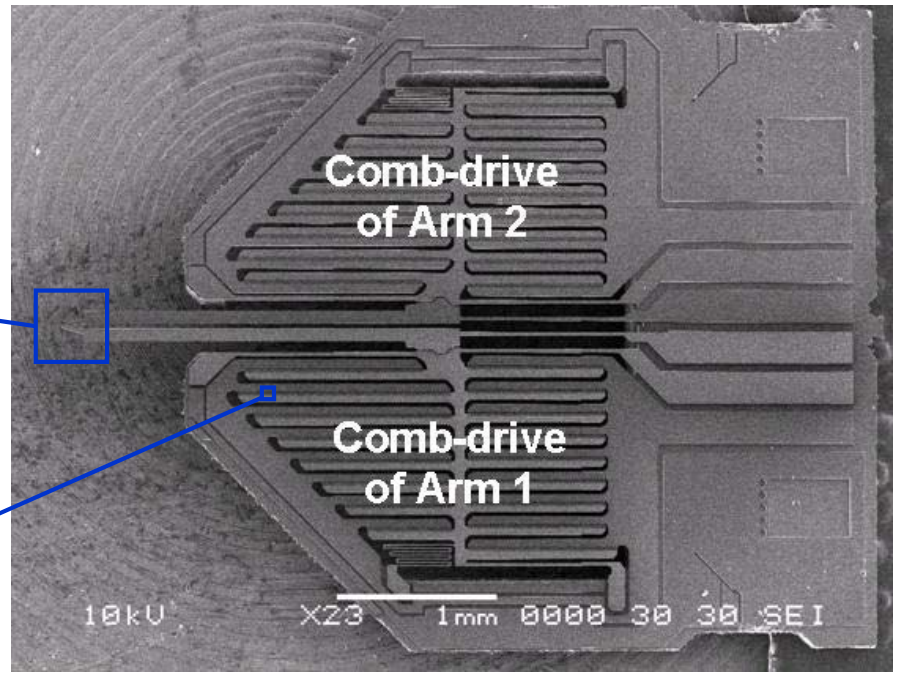
Core device of Nanotweezers



- Nanotweezers are a kind of Micro Electro Mechanical System (MEMS).
- Nanotweezers have two arms which are opened and closed by electrostatic comb-drive actuators.
- Those actuators detect the force exerted on each arm.

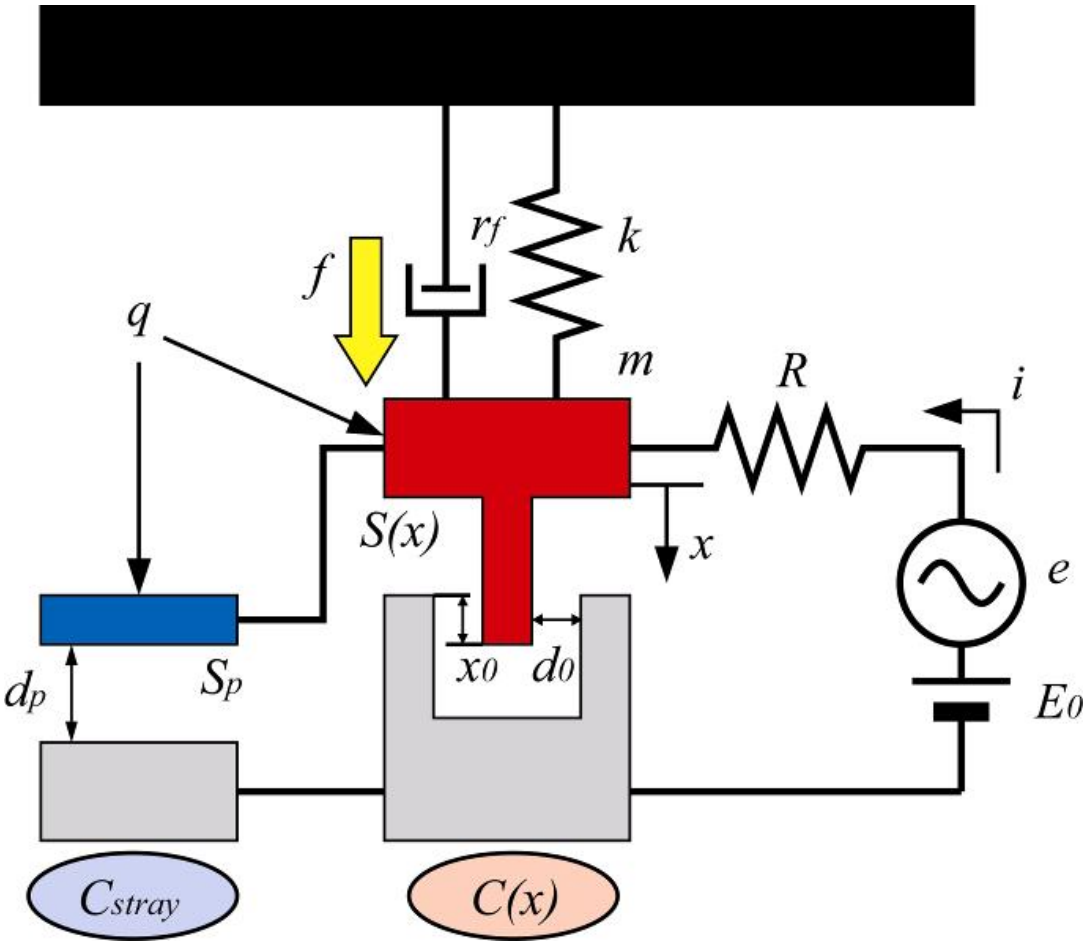






Equivalent model of Nonotweezers

The electromechanical system of Nanotweezers including comb-drive actuator can be modeled as an equivalent circuit, and the electrical characteristics can be evaluated analytically using Lagrange's equation.



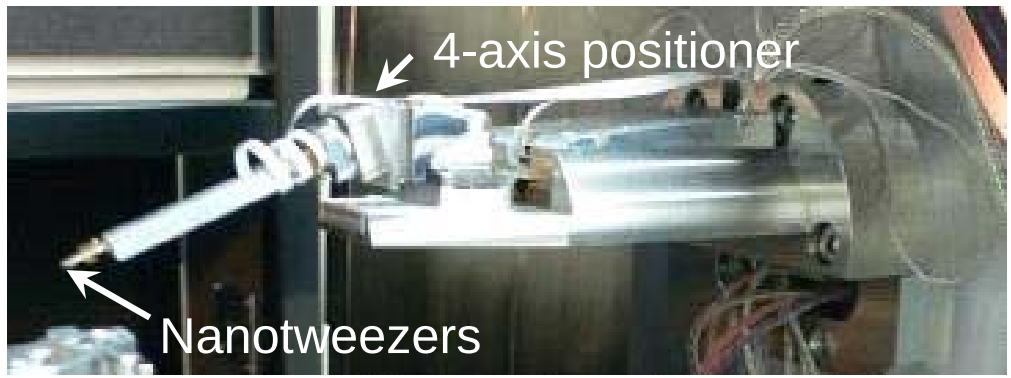
C(x)	: capacitance of comb-drive
Cstray	: stray capacitance
d0	: gap between comb fingers
E0	: DC voltage
e	: AC voltage
f	: applied force
k	: spring constant
m	: mass of moving part
q	: charge
rf	: frictional resistance
S(x)	: area of combs
x	: displacement
x0	: initial overlap

Experimental system

- Nanotweezers are built in a scanning microscope with focused ion beam (FIB) and electron beam (EB).
- Nanotweezers are mounted on 4-axis (XYZR) positioner in the process chamber of the above microscope.

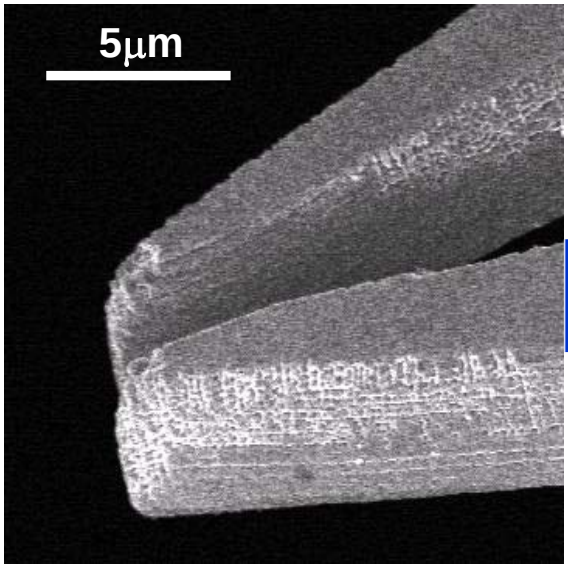
Scanning Microscope with FIB & EB

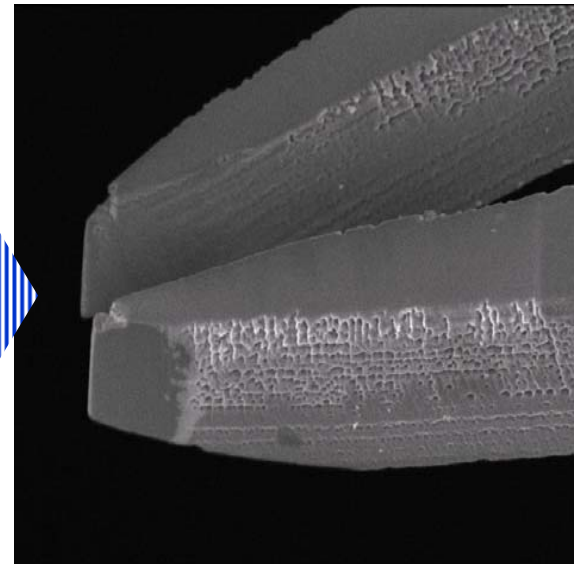
- EB enables to observe the motion of Nanotweezers.
- FIB enables to sharpen and clean the tips of Nanotweezers.



Nanotweezers in the left microscope

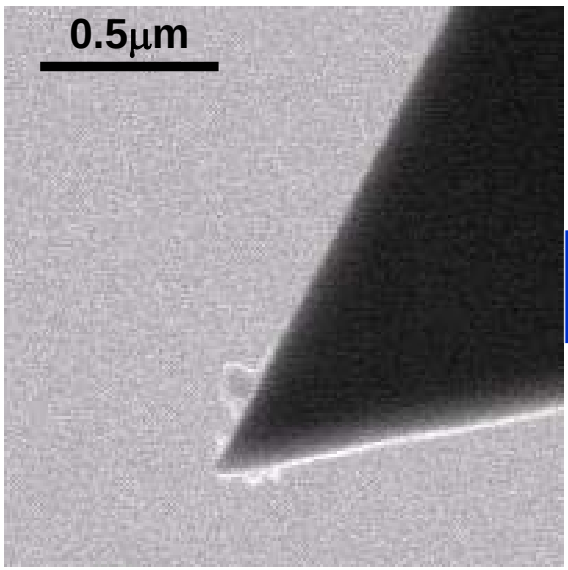
Tip sharpening and cleaning with FIB

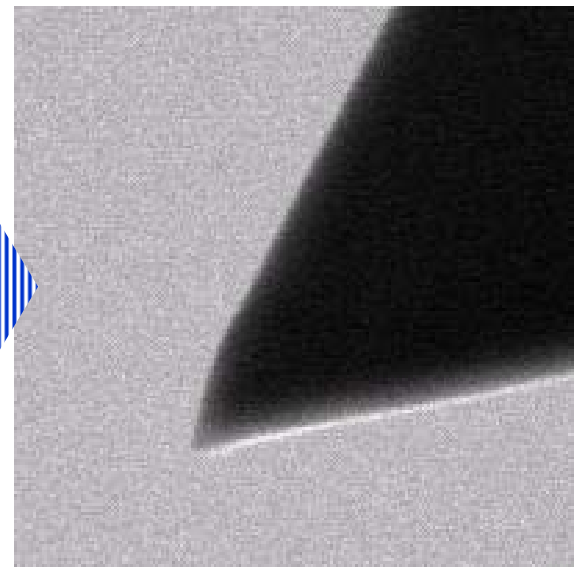




FIB can sharpen the tips of the arms for the following purposes.

- To enable the tips to pick up minute particles
- To enable the tips to enter a narrow groove.





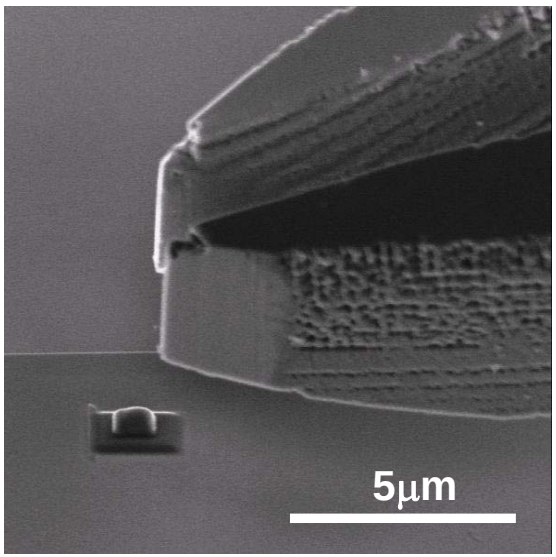
Nanotweezers can be used without tip exchange, by using FIB for the following works.

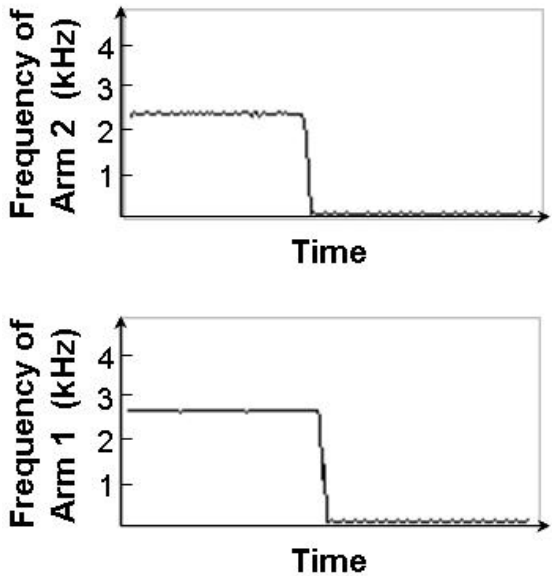
- To remove stuck particles and contamination on the tips
- To repair chipped or abraded tips

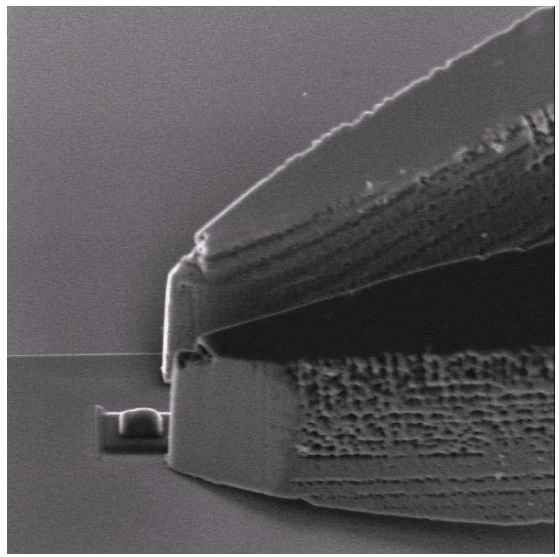
Function to detect tips contacting a mask

Nanotweezers have a function to detect their tips contacting mask surfaces. By using the following method, Nanotweezers approached a mask surface without crashing.

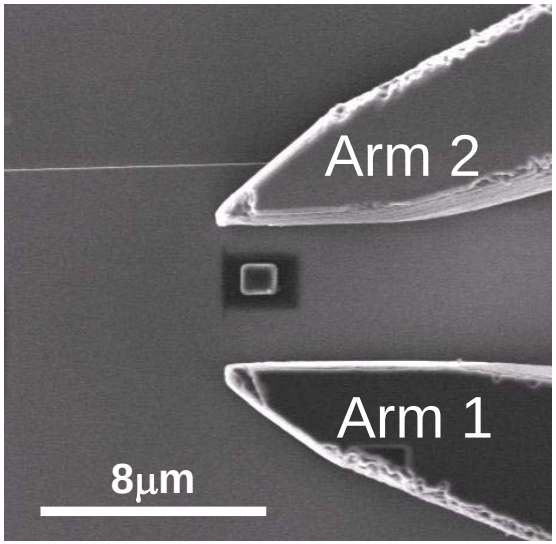
1. The arms are vibrated, while approaching a mask surface.
2. The approaching is automatically stopped when the frequency of arm's vibration changes.
3. The arms are retracted a few nanometers away from the mask surface.

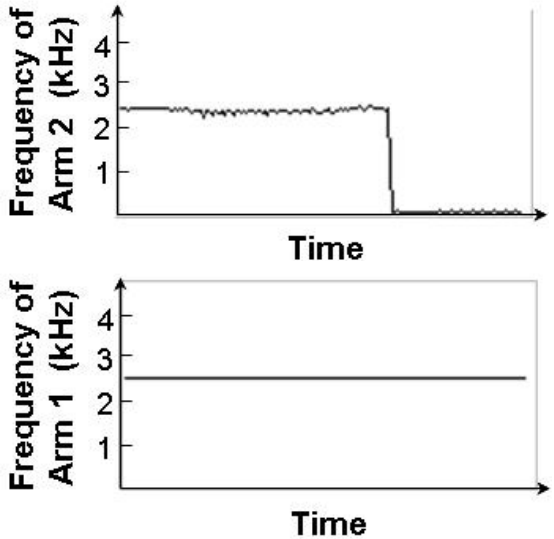


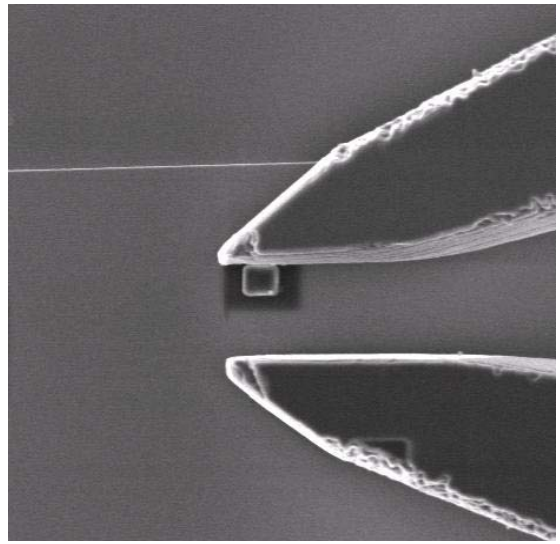


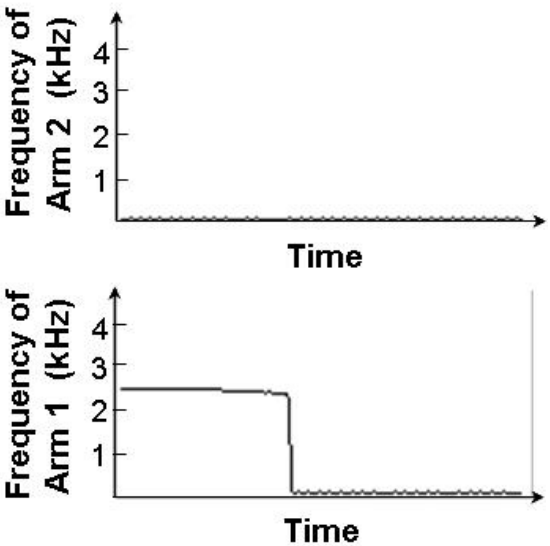


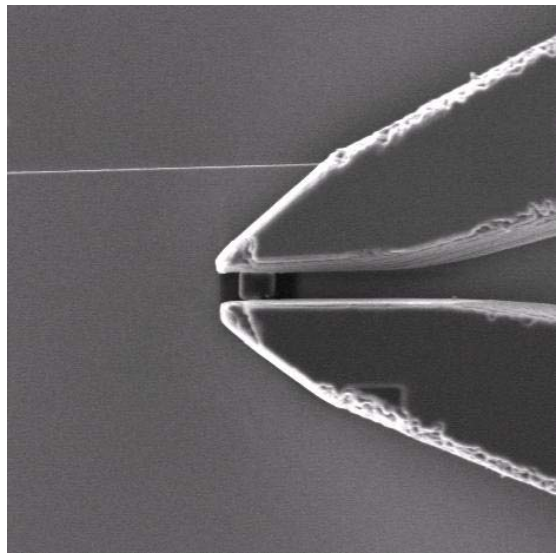
Function to detect tips gripping an object







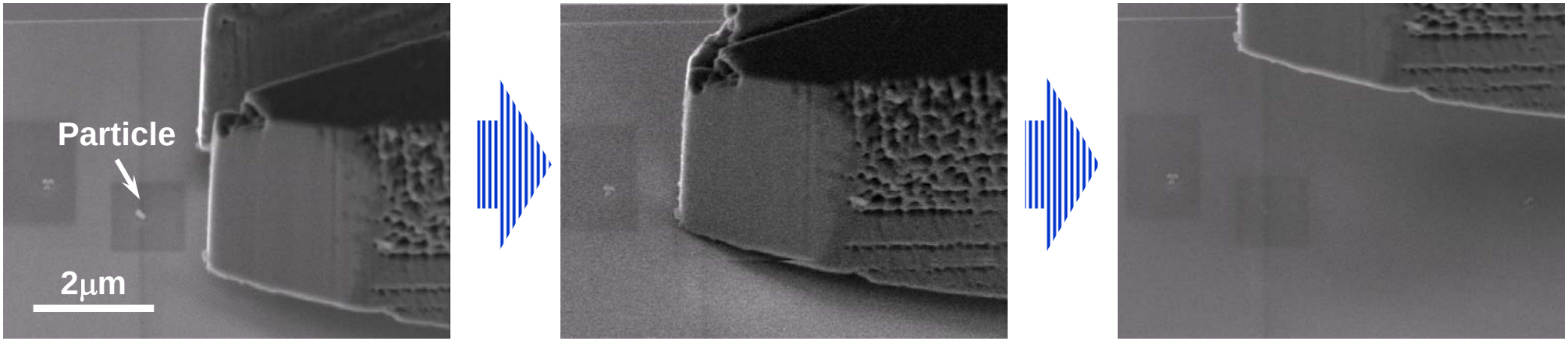




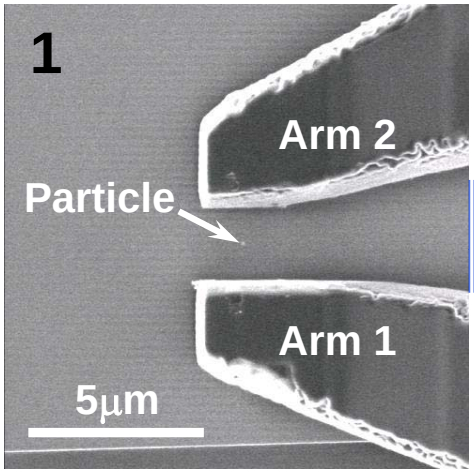
Nanotweezers have a function also to detect their tips contacting an object. Thus Nanotweezers gripped an object without dropping nor mashing.

Removal of a particle

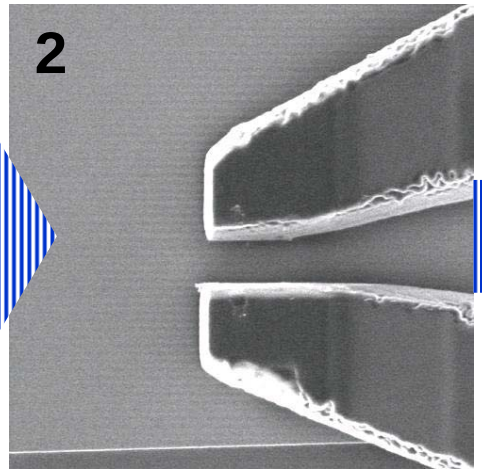
Nanotweezers picked up a polystyrene particle of about 50nm diameter and about 100nm length on an EUVL mask surface without scratching the mask.



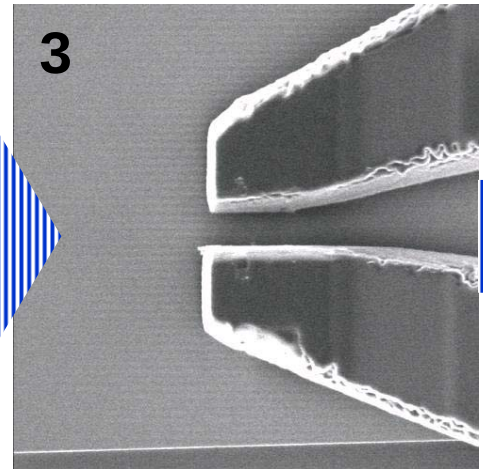
Removal of a non-adhesive particle



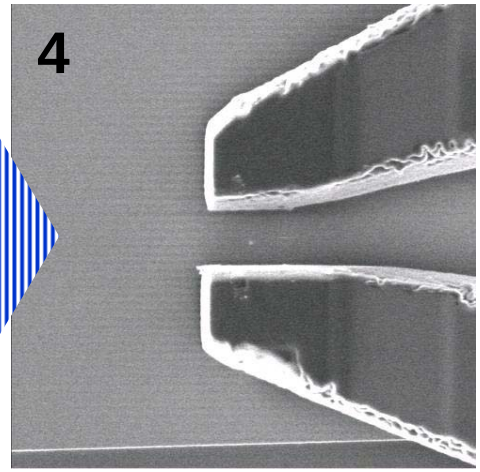
100nm dia. polystyrene particle is put on a mask.



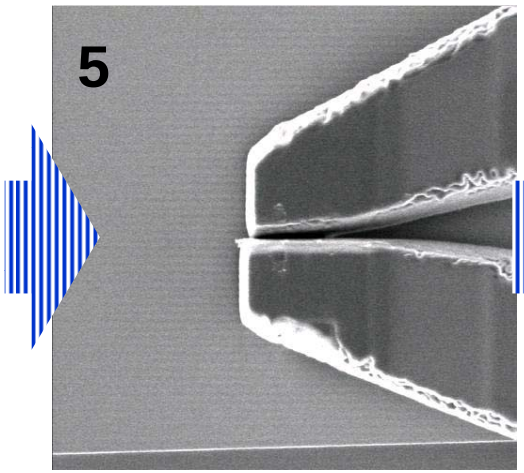
Arm 2 contacted the particle.



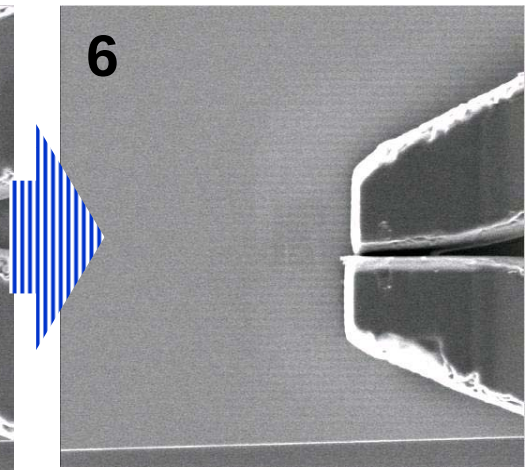
Arm 1 contacted the particle.



The particle does not adhere to the arms.



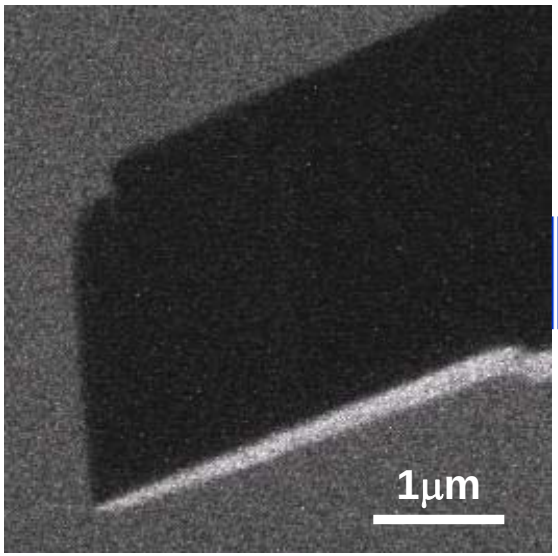
Both arms gripped the particle.

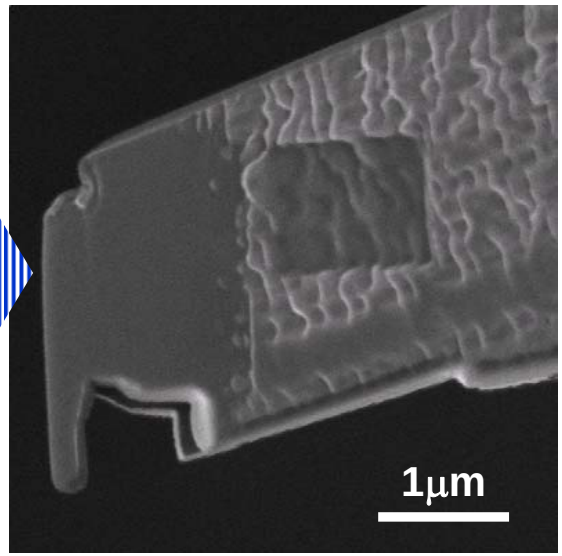


Both arms picked up the particle.

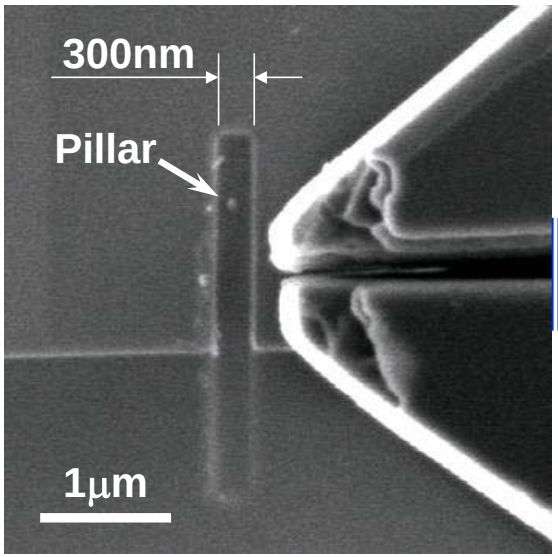
It is difficult for AFM to remove particles that do not adhere to its tip, but Nanotweezers removed the particle that had not adhered to their tips.

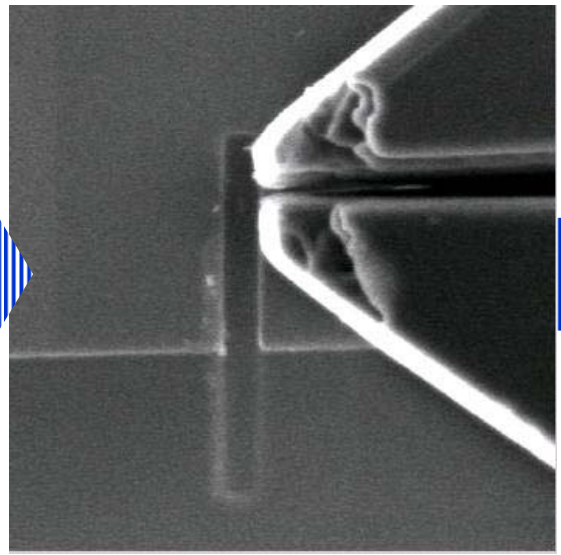
Removal of an object in a groove

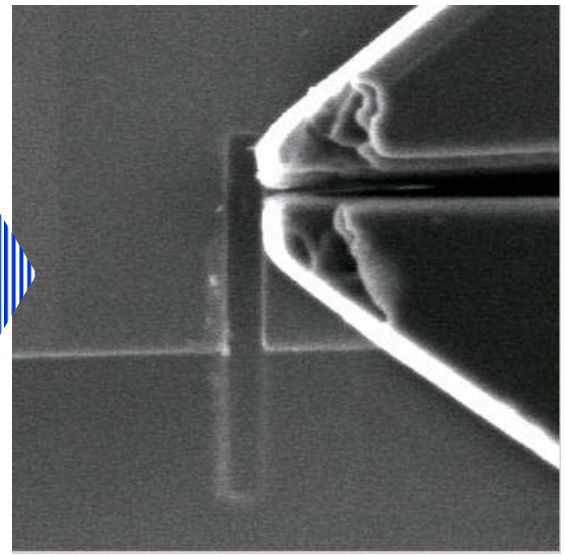




1. FIB sharpened the tips to enable those to enter narrow grooves.
2. FIB dug a groove of 300nm width and 70nm depth on a mask.
3. EB deposited about 80nm diameter carbon pillar at the bottom of the groove.
4. Nanotweezers picked up the pillar from the bottom.







Conclusion

- **Nanotweezers removed the particle of about 50nm diameter and about 100nm length without scratching the mask surface.**
- **Nanotweezers removed the particle that had not adhered to their tips.**
- **By using the tips that FIB sharpened, Nanotweezers removed the about 80nm diameter object from the bottom of a groove of 300nm width and 70nm depth.**

Acknowledgements:

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References:

[1] T.Takekawa, et al., “The AFM Tweezers:Integration of a tweezers function with an AFM probe”, Int’l Conf. on Solid-State Sensors, Actuators and Microsystems (2005).

[2] T.Umemoto, et al., “Nanotweezers with Proximity Sensing and Gripping Force Control System”, Japanese J. of Appl. Phys. 48 (2009).