LEVITRONIX
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Wafer Cleaning Conference 2008
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Quantitative measurements of pattern damage and particle removal forces for below 45 nm wafer cleaning

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Areas of Research

- Nano-imprint by Hot Embossing
- Surface Modification
- Plastic MEMS
- Microfluidics(Bio-MEMS)
- (Nano) Metal Molds

CMP

- Metal CMP Process (Cu, Ru, Noble metals and low-k)
- CMP Consumables (Slurries, Pad and Conditioner)
- Post CMP Cleaning (Scrubber and Megasonic)

Nanoimprint

EMPL

Cleaning

- Environmental Friendly Cleaning (Ozone and Surfactant)
- Nanocontamination Control and Particle/Metallic Removal and Adhesion
- Laser Shock Cleaning (LSC)
- EUVL cleaning

EMPL Infra-Structure

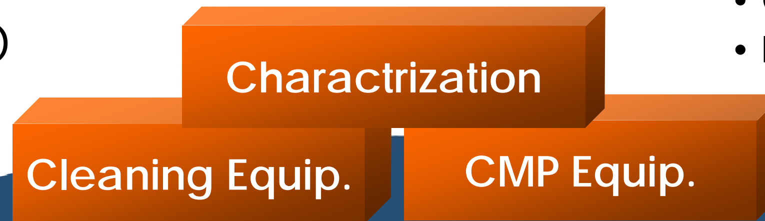
EMPL Hanyang University

- KLA-Tencor Particle Scanner, 6200
- Nanometer Particle Scanner
- Atomic Force Microscopy
- Zeta-potential Analyzer
- 273 EG&G Potentiostat …

Micro Biochip Center

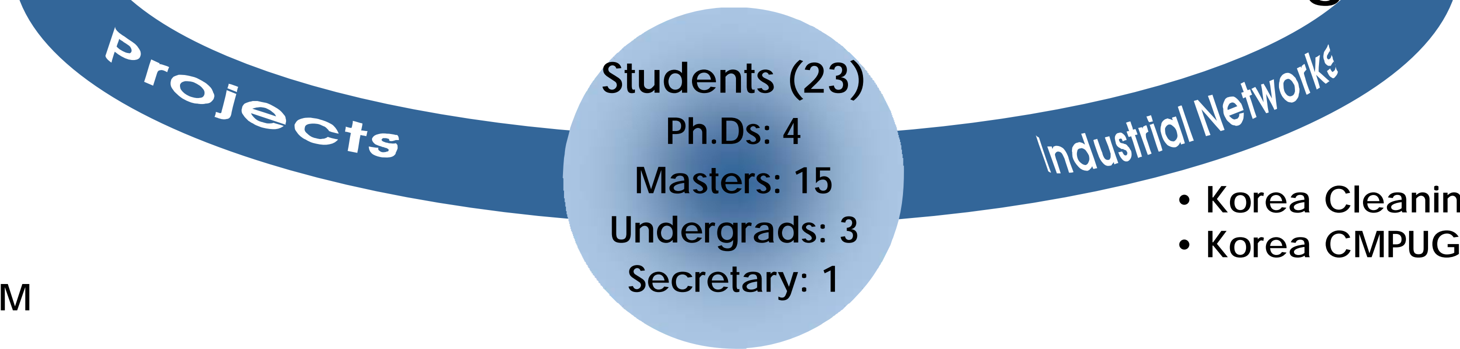
- Cleanroom (Class 10, 100 and 1000)
- Wet station @ 2
- DI water Generator (500 lpm)
- IPA Dryer
- Brush Scrubber
- Megasonic Cleaner …

- E-CMP Polisher (4″)
- CMP Polisher (6″)
- Friction Polisher (4″, 6″ and 8″)



KOTEF Lab of Excellence in Cleaning

Nano-level Defect Free Wafer Cleaning

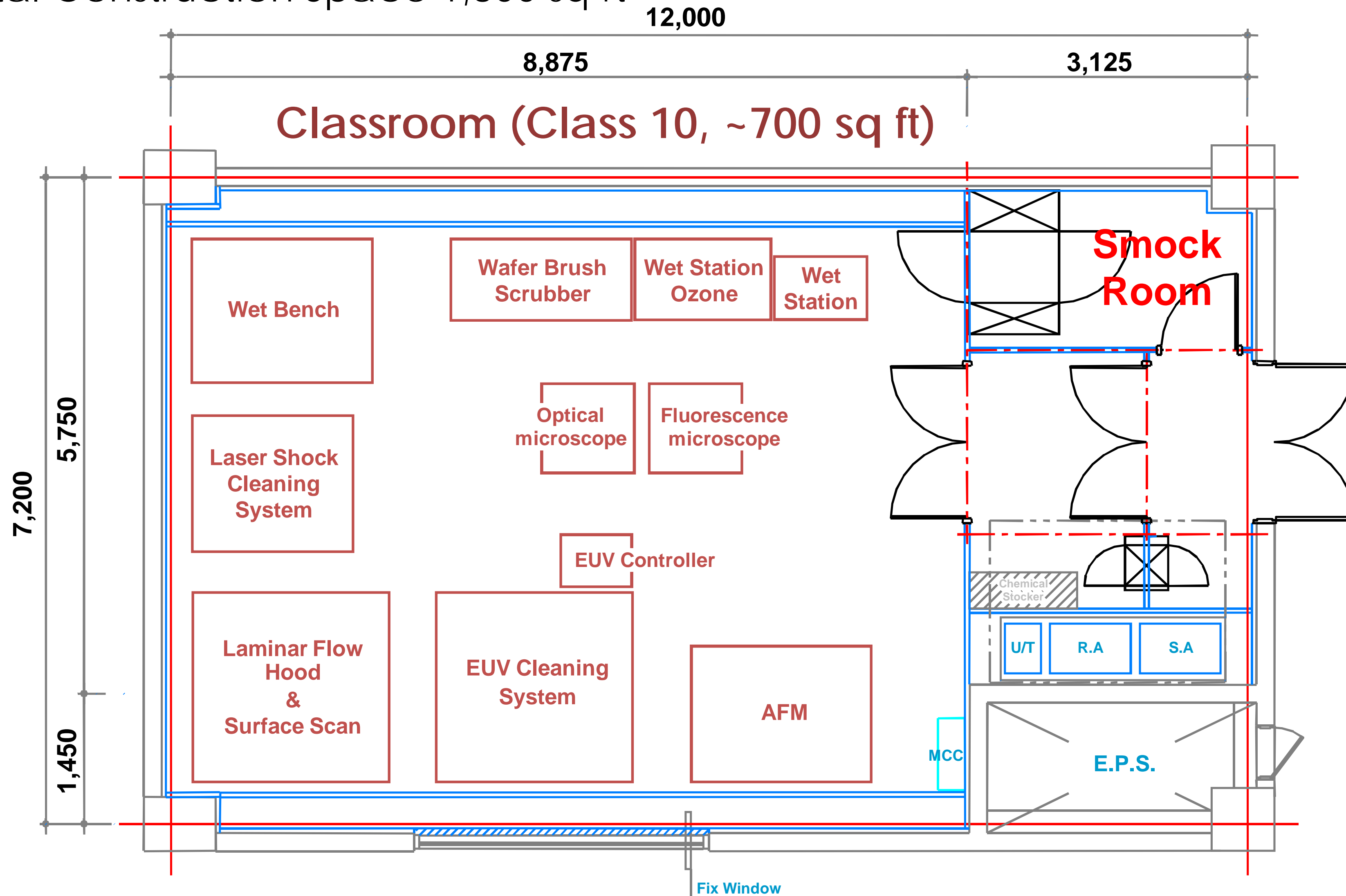


- Samsung
- Hynix
- Intel
- Dongwoo
- MOICE
- KOSEF
- Doosan
- Siltron, LGM
- IMT …

- Korea Cleaning UGM
- Korea CMPUGM

New Cleanroom

- Total Construction Space 1,800 sq ft



Outline

Introduction

- Pattern Collapse
- Physical Force Induced Cleaning Process

Motivation and Goal

Background on AFM

Experiments

Results and Discussion

- Collapsed Pattern Shapes
- Pattern Collapse Force and Particle Removal Force

Conclusions

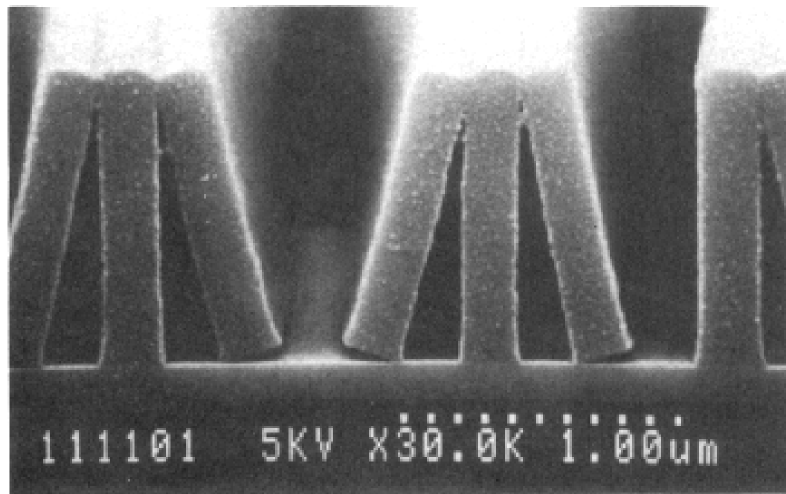
Pattern Collapse

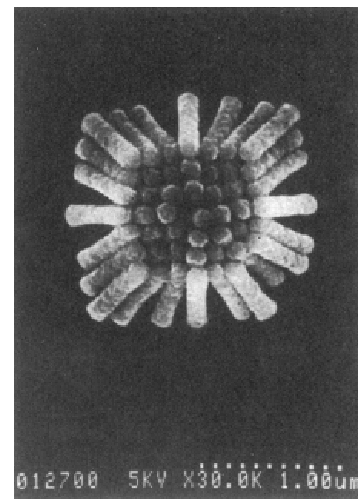
Pattern collapse can happen in various wafer process steps with different root causes.

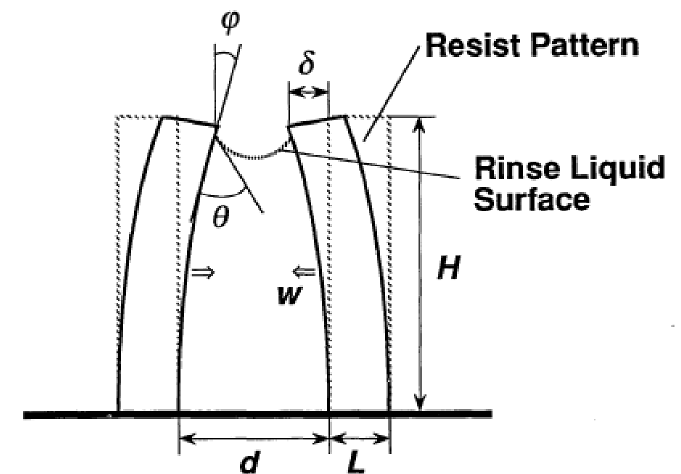
Processing Step	Materials	Causes
Development Process	Photoresist	Capillary Force
Cleaning Process	Hard mask stack, Gate stack, etc	Physical Force (Cavitation, Shock wave etc.)

Resist Pattern Collapse

Dense and fine structure collapse depends on the **aspect ratio**, **line-and-space** , and the **surface tension of a rinse liquid**.







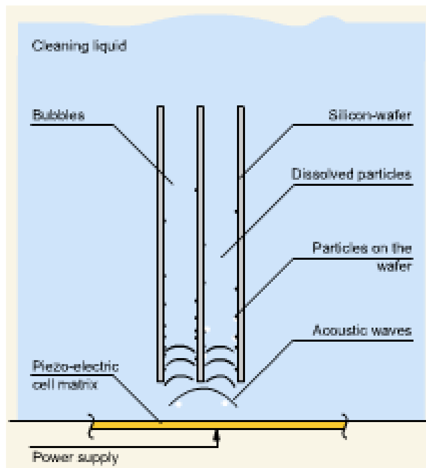
T. Tanaka, *Jpn. J. Appl. Phys.*, 32 6059 (1993)

Pattern Collapse in Cleaning Process

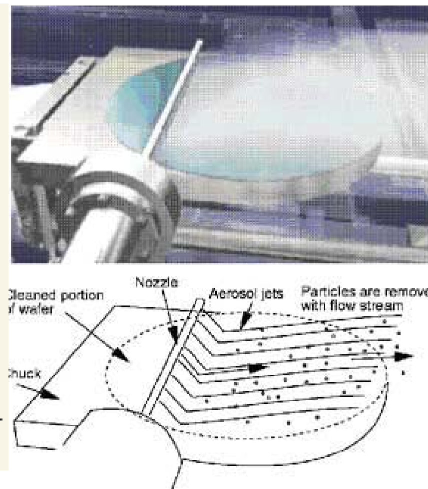
Physical Force-Induced Cleaning

- Megasonic
- Aerosol Jet Spray
- Laser Induced Plasma Shockwave
- …

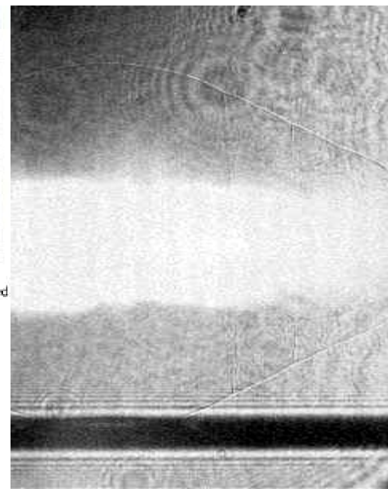
Megasonic Cleaning



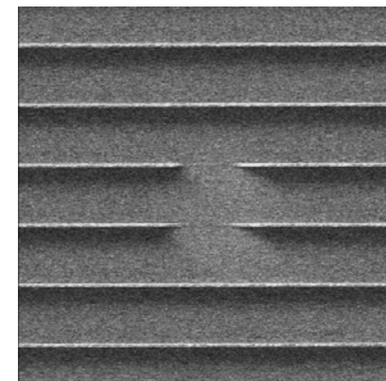
Jet Spray Cleaning



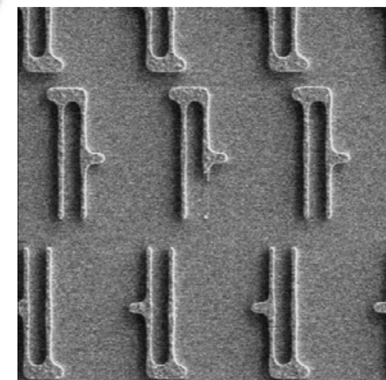
Laser Shock Wave



Damage Problems



65nm poly Si lines



120nm Poly Gate lines

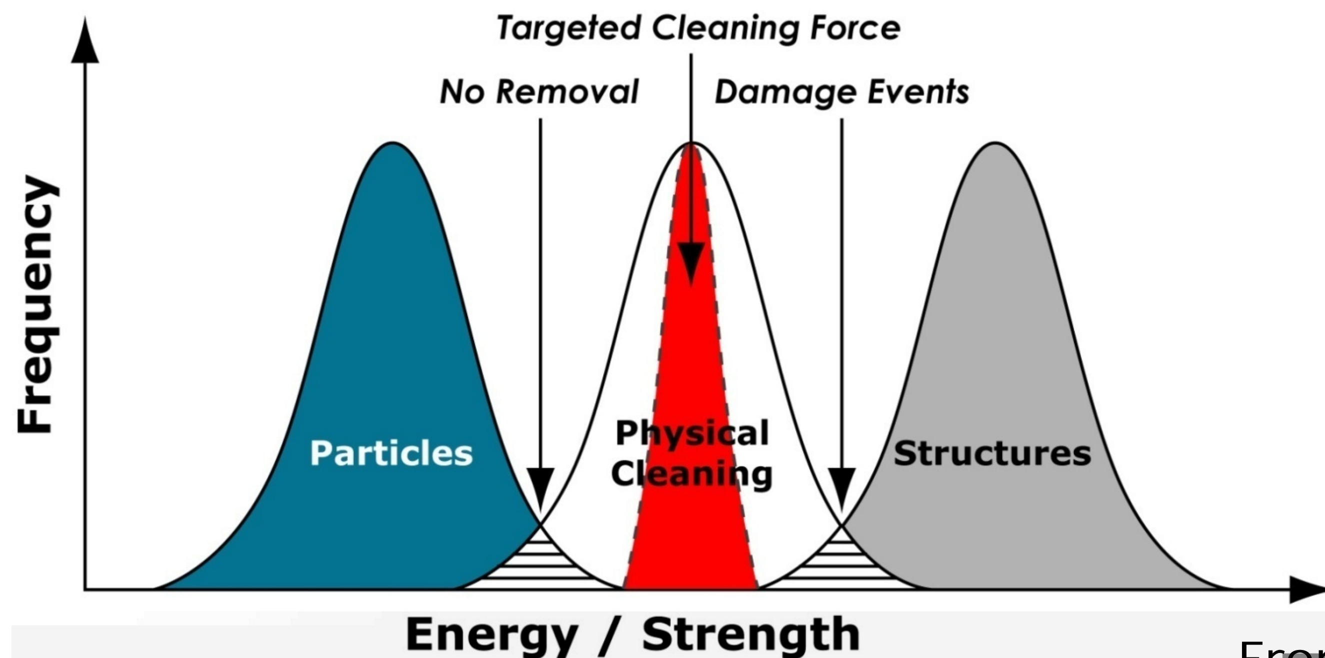
Physical force-induced cleanings are very effective in particle removal, but **pattern damages** can be occurred.

Motivation and Goal

- Process development for effective physical cleaning without damaging patterns
- Need to measure particle removal force versus pattern damaging force.

In this study,

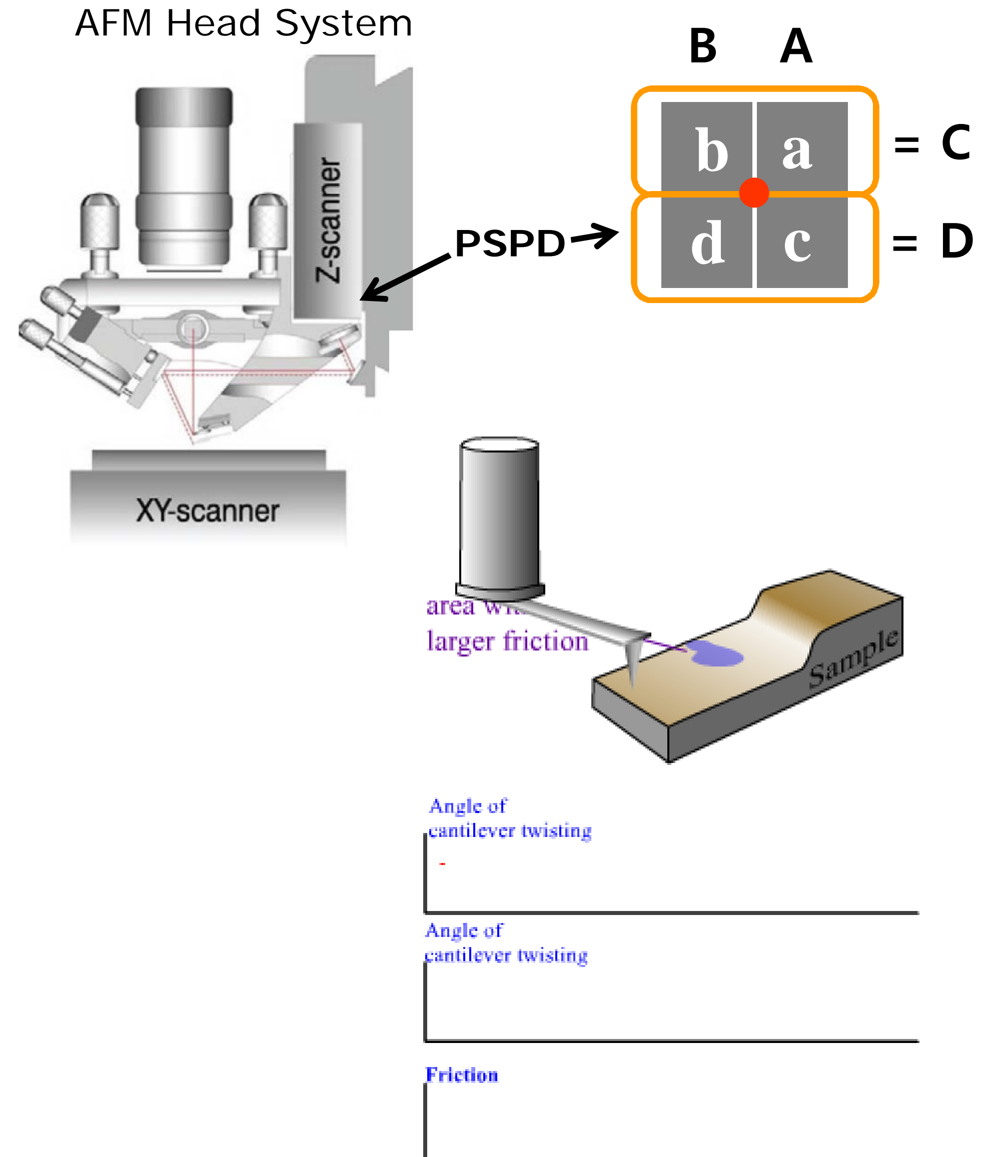
Quantification and comparison of pattern collapse force and particle removal force by AFM



From IMEC

Background on AFM

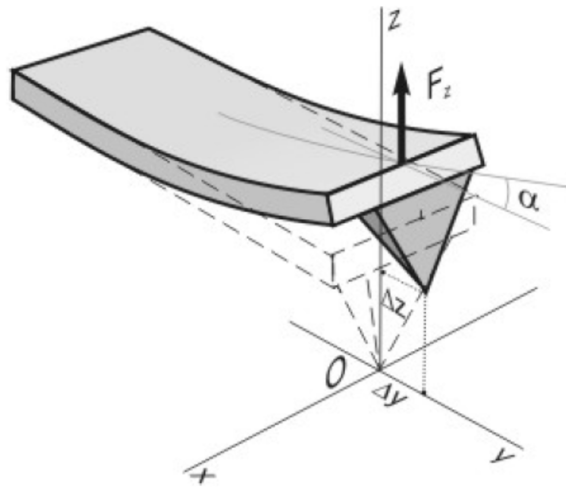
- AFM consists of scanner, laser, and position sensitive photo detector (PSPD).
- AFM measures the signal changes from the PSPD which are caused by the change of cantilever deflection.
- In PSPD, a+c=A, b+d=B, a+b=C, c+d=D.
- The Z scanner moves up and down when a cantilever bends up and down during measurement at constant contact force mode.
- Cantilever twists due to the friction force between tip and surface.
- Sample surface may get the damages during measurement in contact mode.
- Therefore, non-contact mode is used for reducing the surface damage.

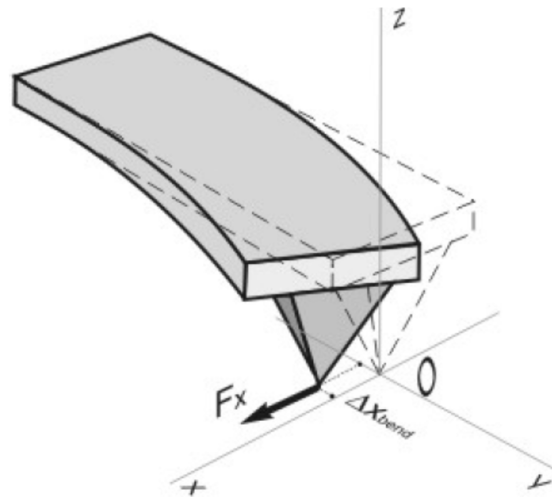


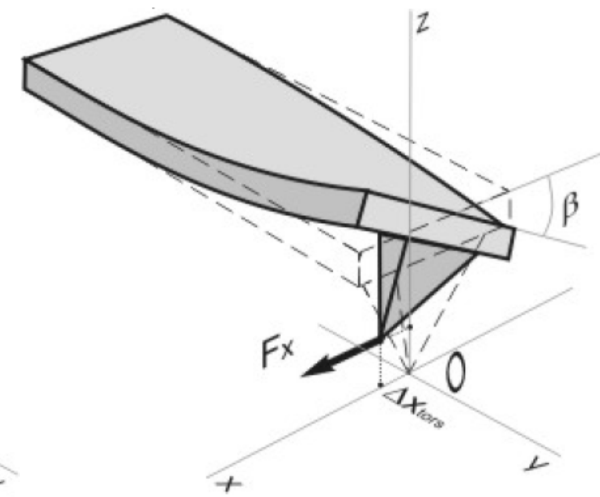
Introduction to Motion of Cantilever

Cantilever has three shape changes during scan

Vertical Bending **Lateral Bending** **Torsion**





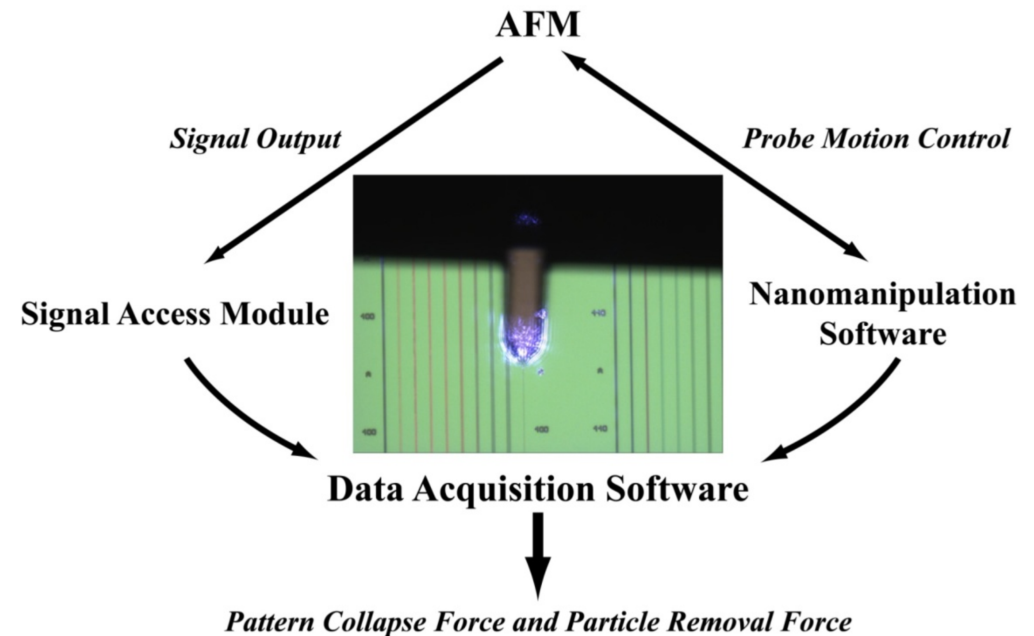


- Vertical bending can be determined by measuring A-B signals
- Lateral Bending can be determined by measuring A+B signal
- Torsional behavior can be determined by measuring C-D signal

Experimental Setup

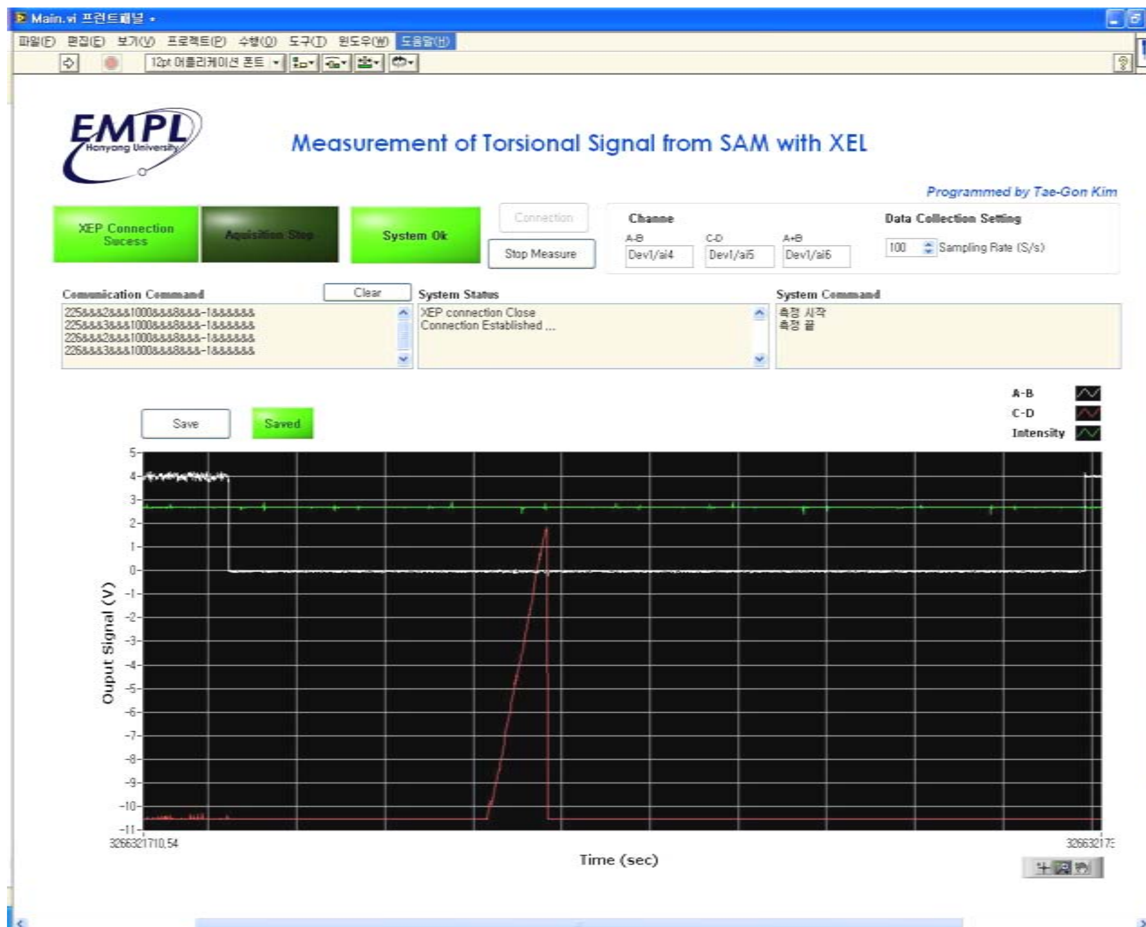
AFM System at EMPL

System Configuration



- AFM (Park Systems, XE-100)
- Signal Access Module (Park Systems)
- Nanomanipulation (Nanolithography) software (Park Systems, XEL)
- Data Acquisition System (National Instrument)
- Data Processing Software (National Instrument, LabVIEW)
- All experiments were conducted in Cleanroom (100 Class)

Signal Acquisition Software



- Used Program: LabVIEW
- Automatic measurements
- Three signals are acquired:

  A+B, A-B, C-D.

Quantification of Spring Constants

Normal and lateral spring constant was calculated by following equations.

$$k_N = \frac{G \cdot w \cdot t^3}{4l^3}$$

$$k_{lat} = \frac{Gwt^3}{3l(h + t/2)^2}$$

ρ : Design of silicon
f_0 : Resonance frequency of cantilever
l : Cantilever length
E : Young's Modulus of silicon, 1.69×10^{11} N/m^2
G : Shear modulus of silicon, 0.5×10^{11} N/m^2
h : Tip height
t : Cantilever thickness
w : Cantilever width

To characterized the cantilever thickness,
the first resonance frequency in normal direction was used.

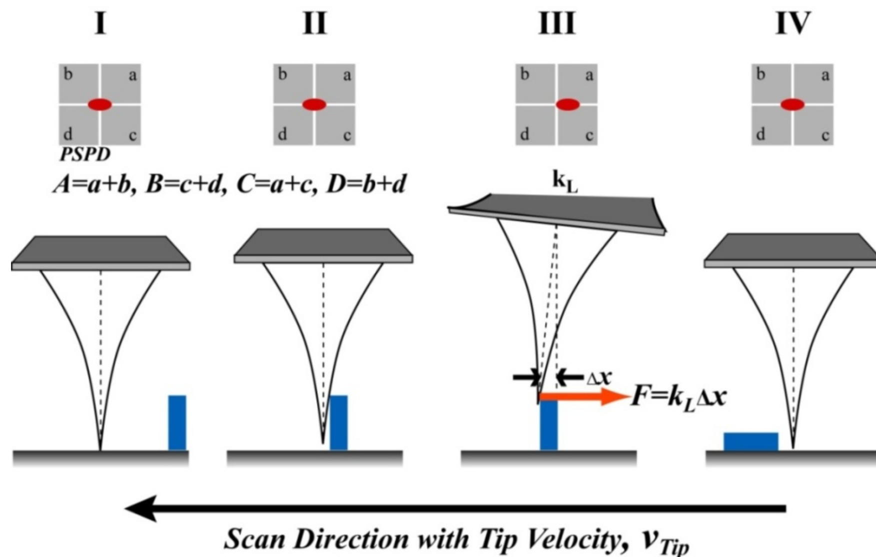
$$t = \frac{2\sqrt{12}\pi}{1.875^2}\sqrt{\frac{\rho}{E}} f_0 l^2 = 7.27\times10^{-4} f_0 l^2 \, (s/m)$$

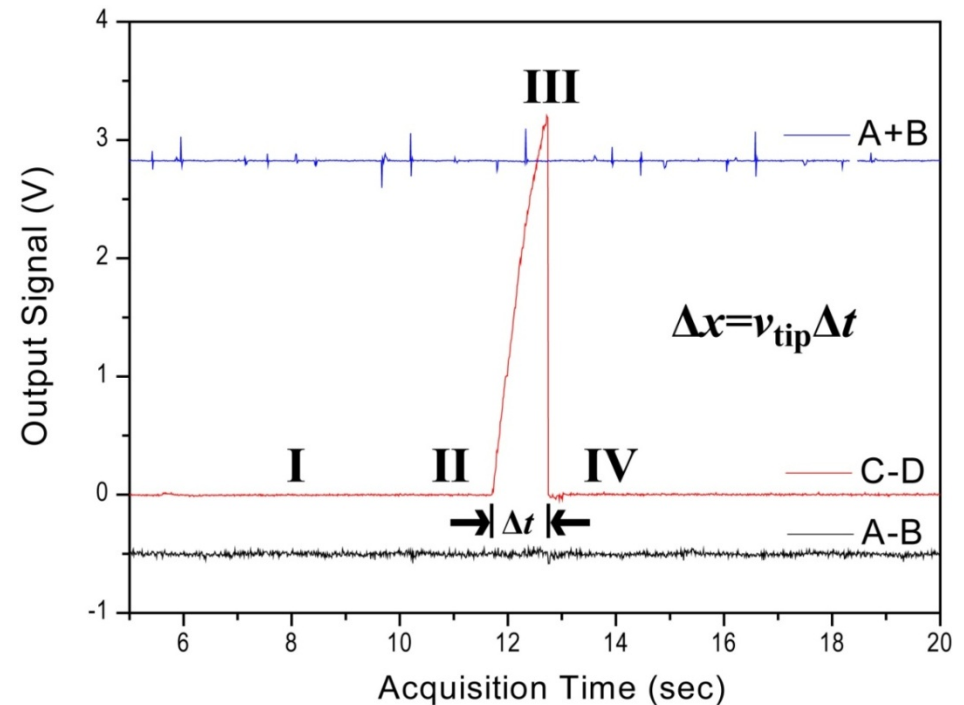
M. Nonnenmacher, et al., *J. Vac. Sci. Technol. B*, **9**, 1358 (1991)

Quantification of Torsional Signal

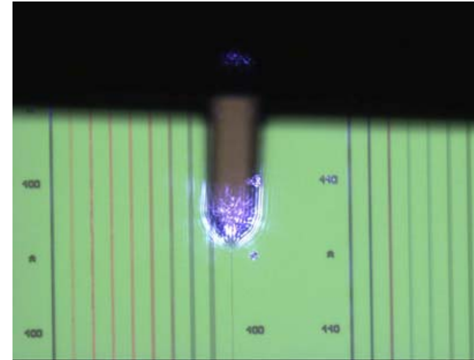
- **Tip velocity** and **Direction** were controlled by the nanomanipulation software.
- Tip travel distance can be calculated from deflection time of cantilever.
- Actually, tip travel distance is not exactly same as distance of torsional deflection
- However, tip travel distance is similar to distance of torsional deflection because torsional angle of cantilever is quit small.

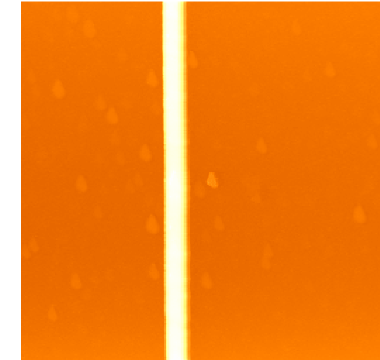
$$F_{lat}=k_{lat} \times \Delta x$$





Experimental Procedure





1. Positioning AFM probe on the pattern

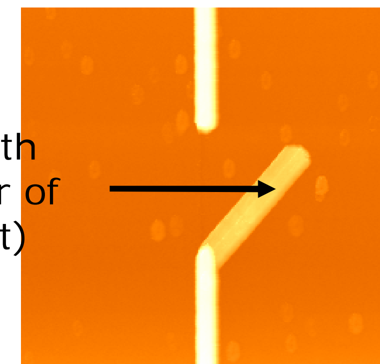
2. Imaging the pattern in noncontact mode
: To eliminate pattern damaging during imaging

3. Aligning the pattern or the probe
: Adjust the moving direction of AFM probe perpendicular to the pattern

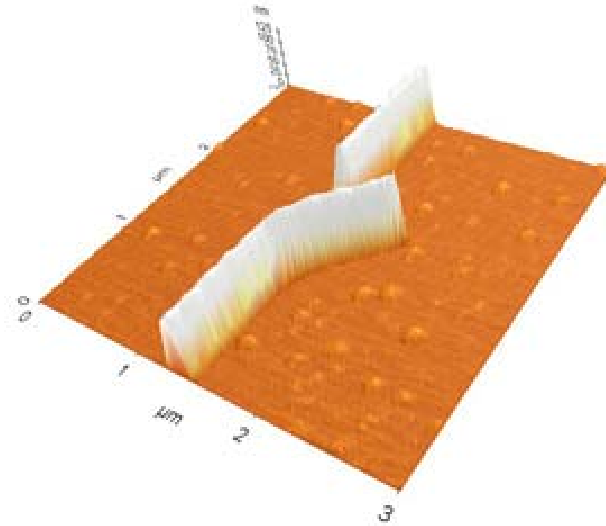
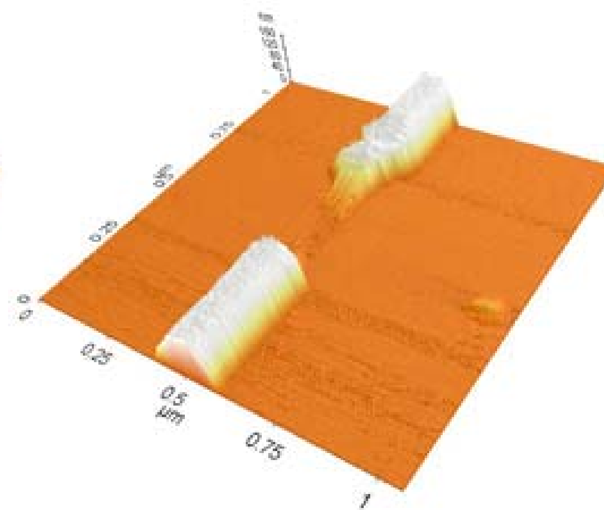
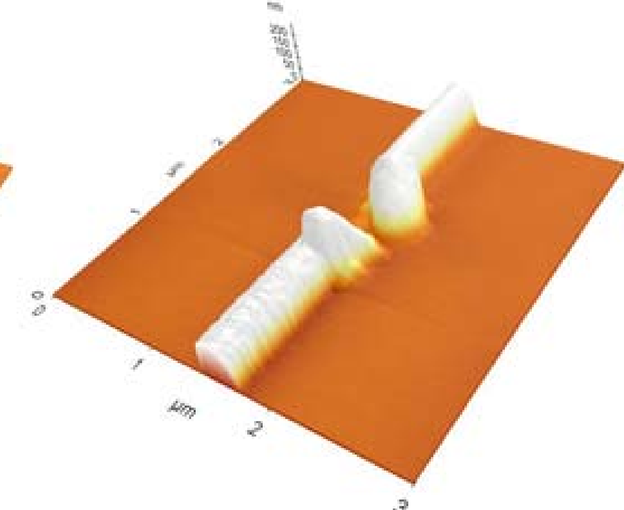
4. Measurement of the pattern collapse force in constant force mode
: Control the probe speed and normal force

5. Imaging the pattern in noncontact mode.
: Check the pattern damage or not.

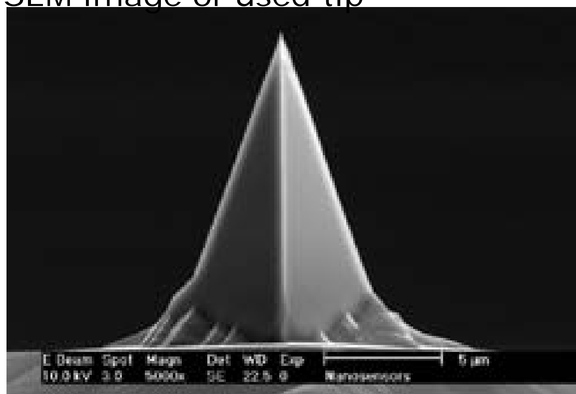
Tip moving path
(Always center of
collapsed point)



Shapes of Collapsed Patterns

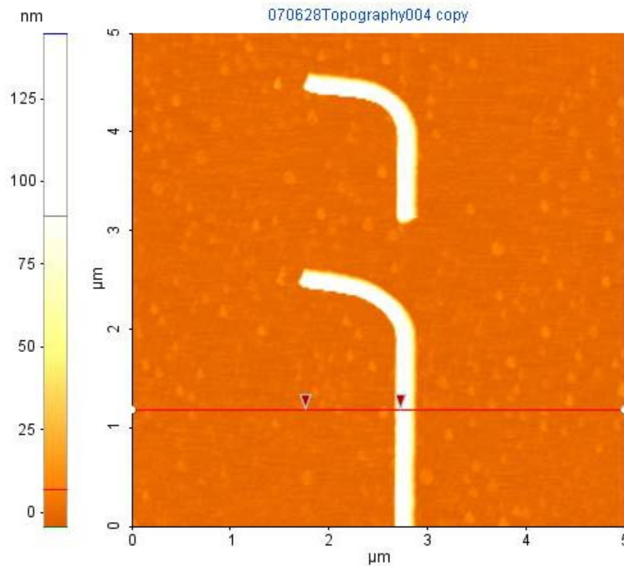
SiON/poly-Si/SiO_2	**SiO_2/poly-Si**	**DUV Photoresist**
		
One end broken → Bending	Two end broken	Torn and deformation

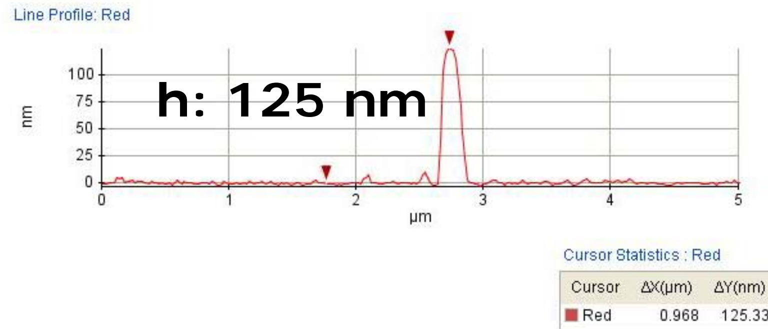
SEM image of used tip

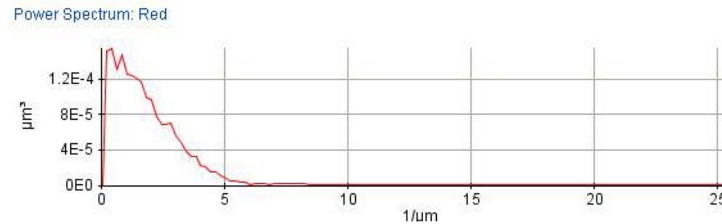


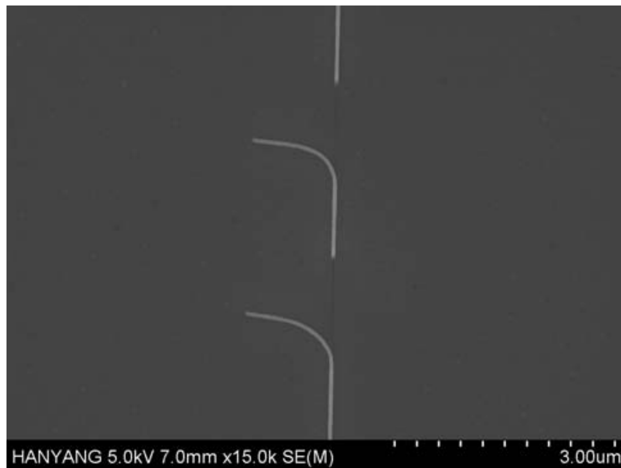
- The shape of tip on cantilever look like a pinnacle and the end of tip acts pattern collapse.
- If the adhesion force between pattern and surface was larger than the yield strength of pattern, the tip would cut the pattern and followed by its deformation such as photoresist pattern.

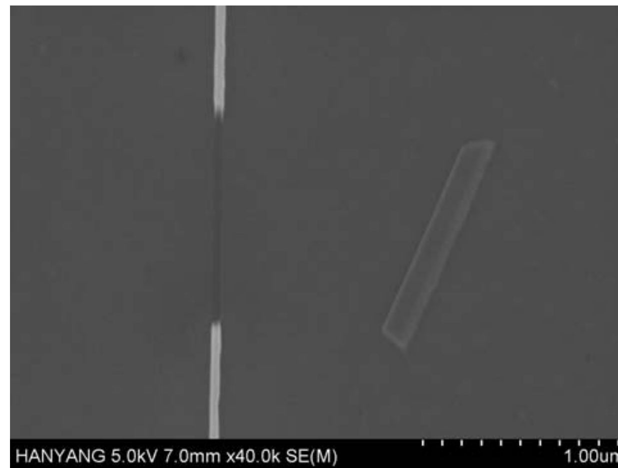
SiON/poly-Si/SiO_2 Hard Mask Gate Stack











Images of FESEM

- Bending, delamination, and breaking were observed after collapse.
- Especially, bending of line was easily observed as shown in left picture of SEM images in most case.

Observation of Collapsed Area

$SiON/poly-Si/SiO_2$ Hard Mask Gate Stack

Line width: 60 nm

Cursor Statistics : Red

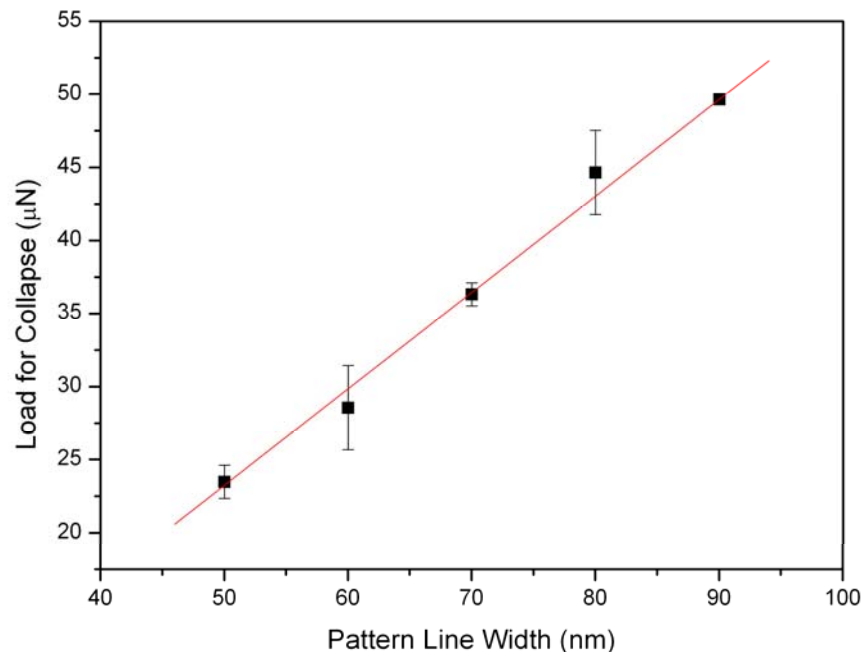
Cursor	ΔX(nm)	ΔY(nm)	Angle(deg)
Red	91.734	-2.490	-1.555

- The trench was observed underneath after collapsing.
- Depth of trench was 2.5 nm.

Results of Pattern Collapse Forces

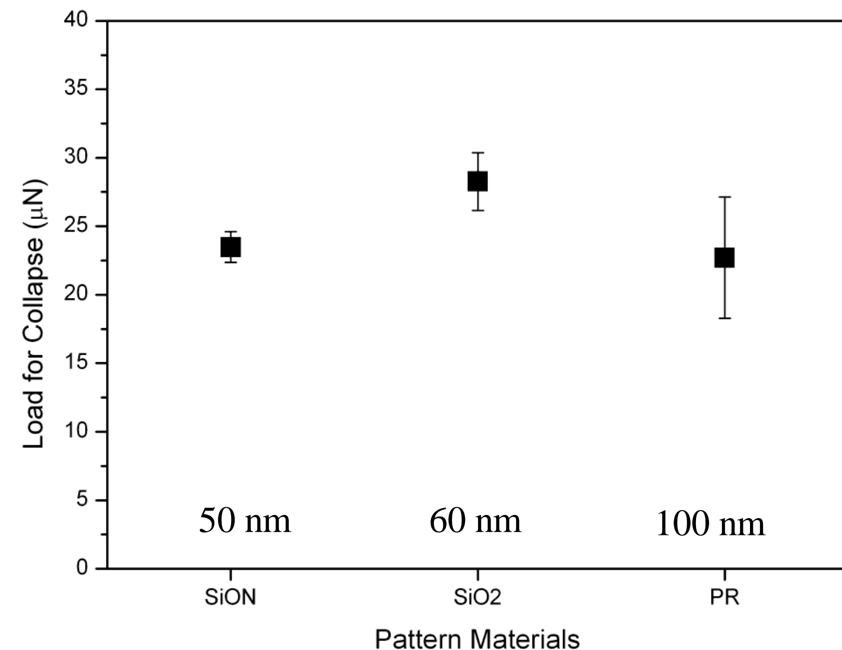
Used Cantilever: NCHR (Nanosensros, k_{lat}=362 N/m)
Method: Measuring deflection time

As a function of line width of SiON/poly-Si/SiO_2 gate stack



The pattern collapse force of 50 nm of line width was 23 µN and it was linearly increased as a function of the line width of patterns.

Different Pattern Materials

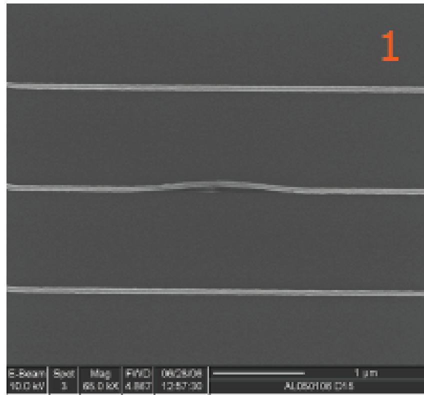


If those patterns were compared at the same line width, PR would be the smallest among them.

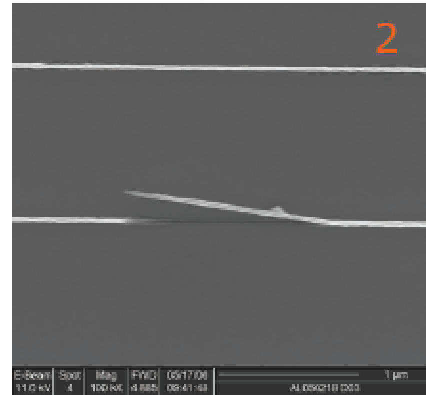
Comparison of Damage Pattern Behaviors by High Velocity Aerosol Cleaning and AFM

Damage Pattern Behavior by High Velocity Aerosol Cleaning

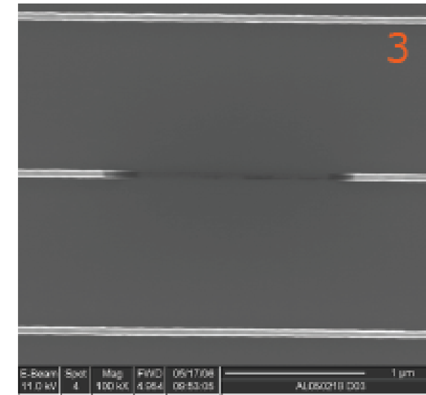
Adhesion failure



One end breaks off.

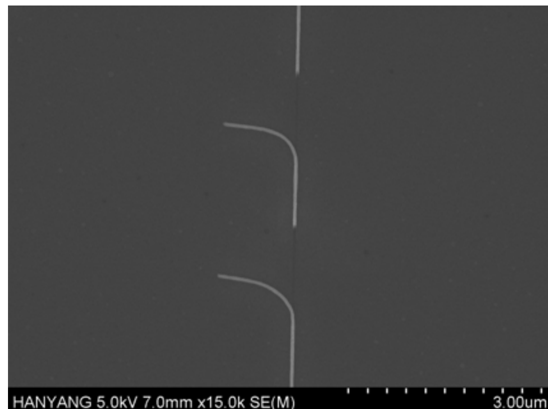


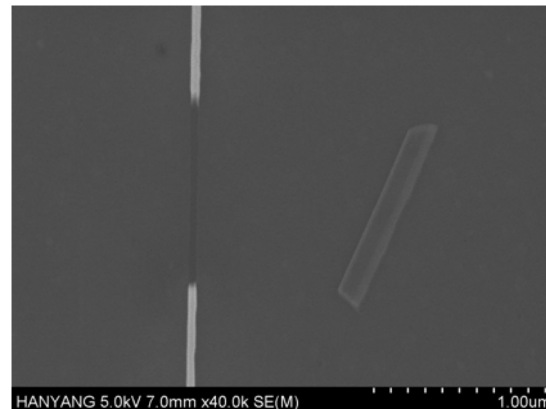
Second end breaks off.



Reference: K. Wostyn *et al*, *Sematech Surface Preparation and Cleaning Conference*, Austin, Texas, Apr. 25-26 2007.

Damage Pattern Behavior by AFM



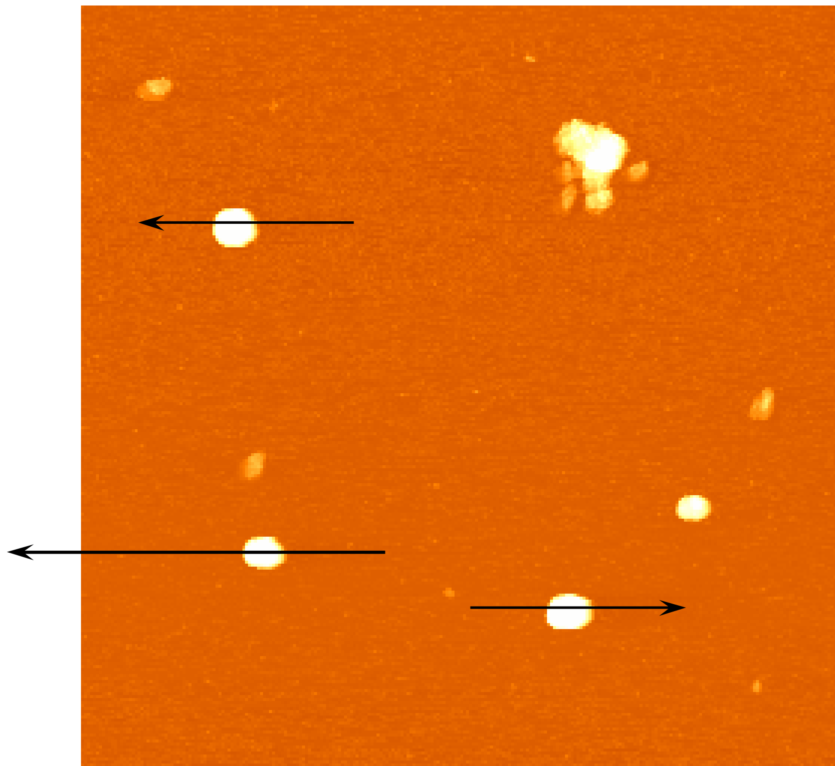


Pattern Damage behavior by AFM was similar to damaging by the high velocity aerosol cleaning.

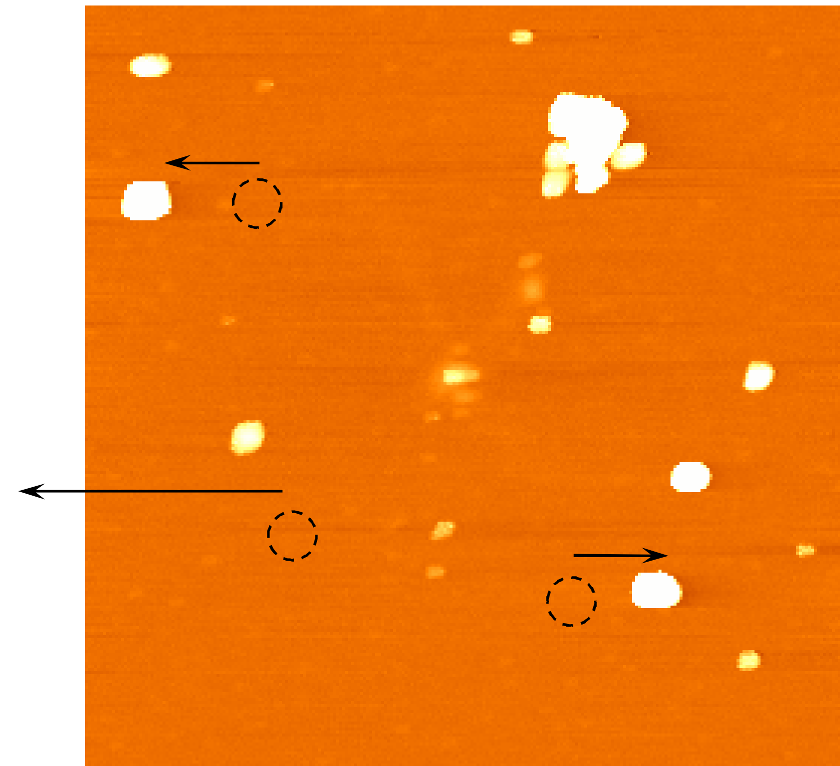
Particle Removal

- Sample Preparation: Hydrophilic Si which was pre-cleaned by SPM
- Particles: Dip into IPA and 100 nm PSL mixture
- Aging Time: 2 days
- Used Cantilever: NSC36 B type (k_{lat}=1.56 N/m)

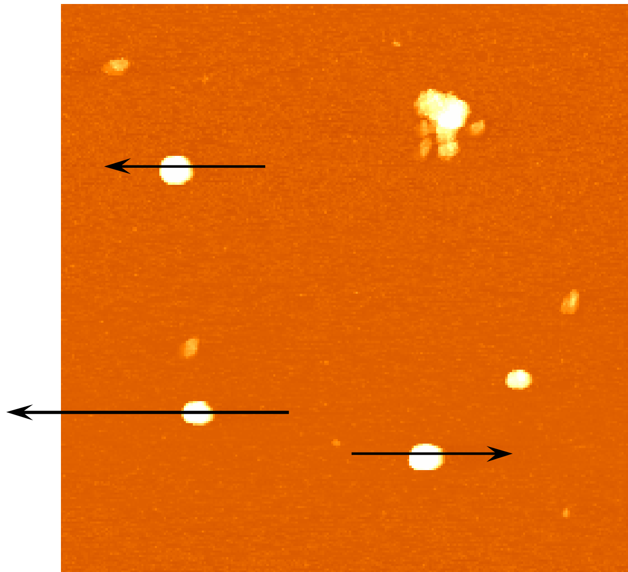
Before Particle Manipulation

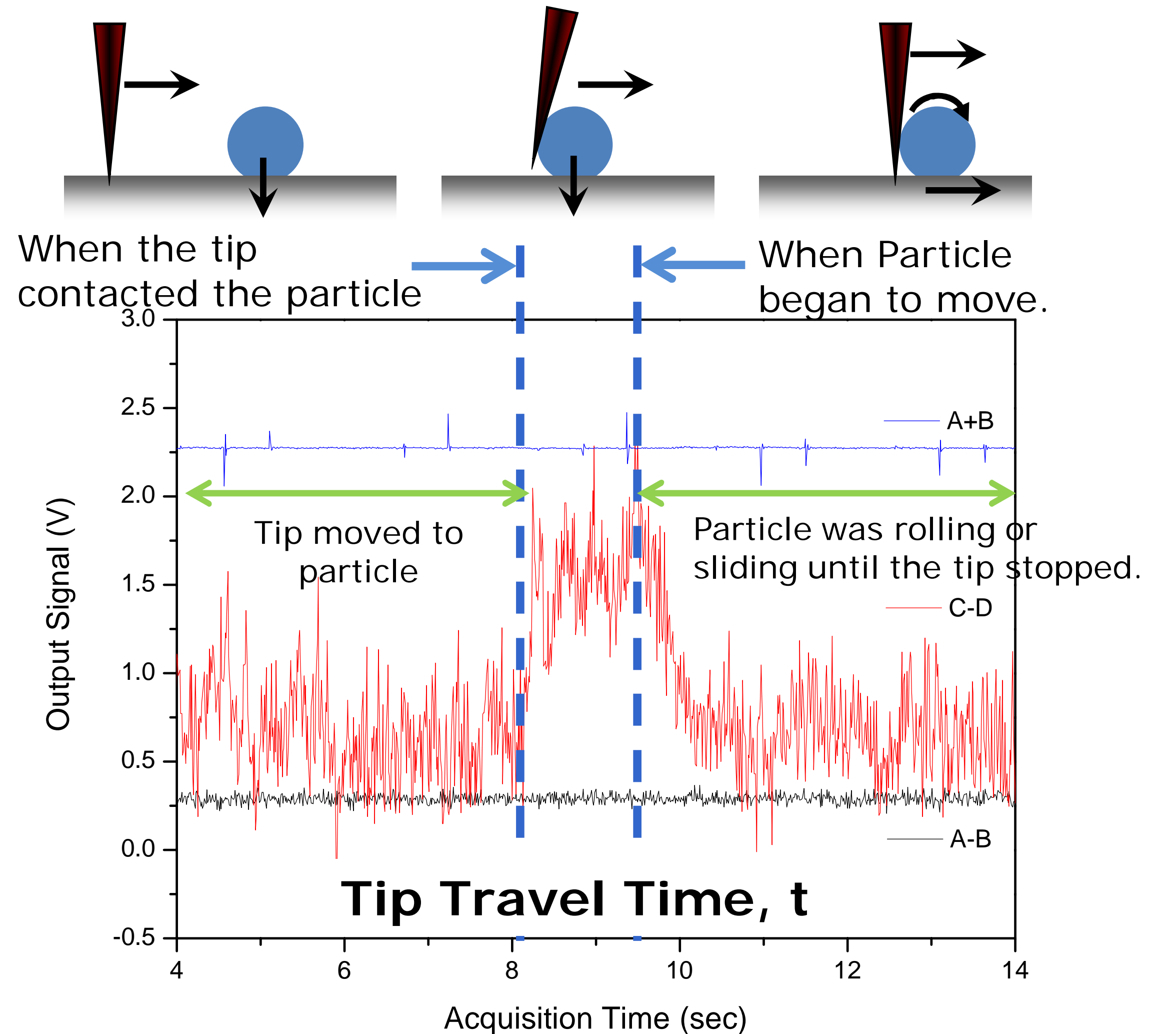


After Particle Manipulation



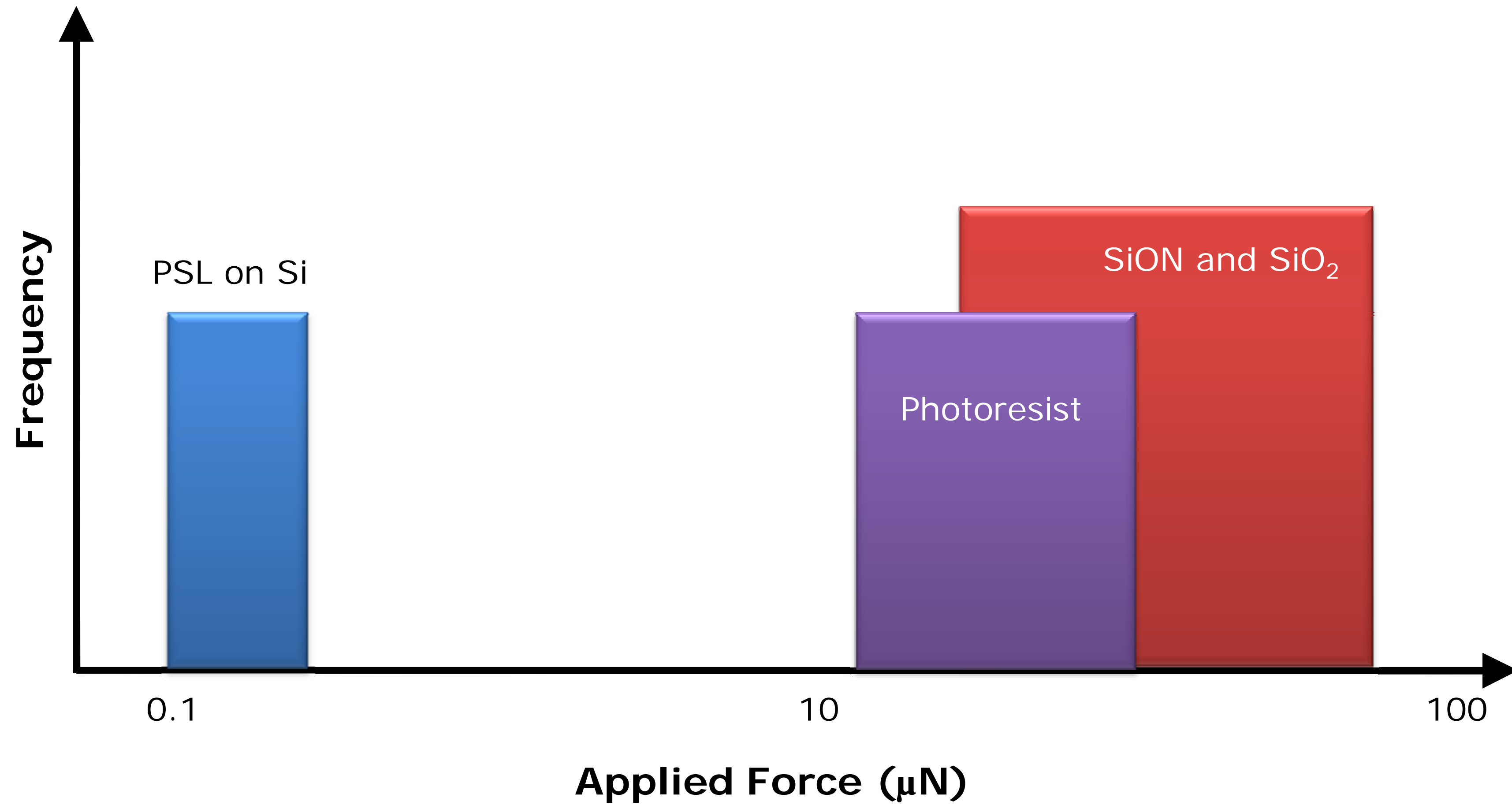
Signal for Particle Removal





- Removal force of 2-day aged particle was measured to be about 180 nN.
- It is two orders of magnitude lower than the pattern collapse force.

Summary of Results



Application

Possible applications are

- Optimization of Physical Force Induced Cleaning Process
- Understanding Damage Mechanism
- Nano Pattern Adhesion Test
- Optimization of Patterning Process (adhesion force vs yield strength of patterns)

Conclusions

EMPL Hanyang University

- Pattern collapse and removal forces were successfully measured by AFM.
- Damage shape and mechanism can be studied by AFM.
- Pattern damage shapes of
  - SiON/poly-Si/SiO_2 hard mask gate stack: One end break and bending
  - SiO_2/poly-Si: Two end breaks
  - Photoresist: Torn and deformed
- Trench was observed the structure underneath when the structure was collapsed.
- The collapse force of SiON pattern which was a 50 nm of line width was 23 μN and it was linearly increased as a function of the line width of patterns.
- Photoresist can be collapsed more easily than SiON/poly-Si/SiO_2 hard mask gate stack or SiO_2/poly-Si stack.
- Damage behaviors by high velocity aerosol cleaning and by AFM were similar.
- Removal force of 2-day aged PSL particle on hydrophilic Si was 180 nN and it was two orders of magnitude lower than pattern collapse force.
- This technique can apply to optimize cleaning and patterning process.

EMPL Hanyang University

Acknowledgements

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- The EUV R&D Program of Ministry of Commerce, Industry and Energy (MOCIE)
- The fostering project of the Lab of Excellency and post BK21 program.
- This study was supported by IMEC through international internship program.

Thank You for Your Attention