Quantitative measurements of pattern damage and particle removal forces for below 45 nm wafer cleaning

Jin-Goo Park

Department of Materials Engineering, Hanyang University, Ansan, 426-791, Korea
* IMEC, Kapeldreef 75, B-3001 Leuven, Belgium
** Northeastern University, Boston, MA, 02115, USA
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
- Environmental Friendly Cleaning
  (Ozone and Surfactant)
- Nanocontamination Control and
  Particle/Metallic Removal and Adhesion
- Laser Shock Cleaning (LSC)
- EUVL cleaning
KOTEF Lab of Excellence in Cleaning
Nano-level Defect Free Wafer Cleaning

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

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

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

- KOTEF Lab of Excellence in Cleaning
- Micro Biochip Center

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

- Students (23)
  Ph.Ds: 4
  Masters: 15
  Undergrads: 3
  Secretary: 1

- Korea Cleaning UGM
- Korea CMPUGM

5th Surface Cleaning Workshop, Boston, MA, Nov. 13, 2007
**New Cleanroom**

- **Total Construction Space 1,800 sq ft**

Classroom (Class 10, ~700 sq ft)

- Wet Bench
- Wafer Brush Scrubber
- Wet Station
- Ozone
- Wet Station
- Optical microscope
- Fluorescence microscope
- Laser Shock Cleaning System
- Laminar Flow Hood & Surface Scan
- EUV Cleaning System
- EUV Controller
- AFM
- Smock Room
- E.P.S.

New Cleanroom

- Total Construction Space 1,800 sq ft

5th Surface Cleaning Workshop, Boston, MA, Nov. 13, 2007
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 can happen in various wafer process steps with different root causes.

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<td>Hard mask stack, Gate stack, etc</td>
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**Resist Pattern Collapse**

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

Pattern Collapse in Cleaning Process

Physical Force-Induced Cleaning

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

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
• 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 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

- 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.
Normal and lateral spring constant was calculated by following equations.

\[ k_N = \frac{G \rho w t^3}{4l^3} \]
\[ k_{lat} = \frac{Gw l^3}{3l(h + t/2)^2} \]

\( \rho \): Design of silicon  
\( f_0 \): Resonance frequency of cantilever  
\( l \): Cantilever length  
\( E \): Young’s Modulus of silicon, 1.69\times10^{11} \text{ N/m}^2
\( G \): Shear modulus of silicon, 0.5\times10^{11} \text{ 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.

\[ t = \frac{2\sqrt{12\pi}}{1.875^2} \sqrt{\frac{\rho}{E}} f_0 l^2 = 7.27 \times 10^{-4} f_0 l^2 \text{ (s/m)} \]

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 quite small.

\[ F_{\text{lat}} = k_{\text{lat}} \times \Delta x \]
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.
Shapes of Collapsed Patterns

SiON/poly-Si/SiO₂
- One end broken → Bending

SiO₂/poly-Si
- Two end broken

DUV Photoresist
- Torn and deformation

- 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

• 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.
SiON/poly-Si/SiO₂ Hard Mask Gate Stack

- 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 $\mu$N 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

1. Adhesion failure
2. One end breaks off.
3. Second end breaks off.


Damage Pattern Behavior by AFM

Pattern damage behavior by AFM was similar to damaging by the high velocity aerosol cleaning.
• 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 ($k_{\text{lat}}=1.56$ N/m)
• 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.

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Summary of Results

![Graph showing frequency against applied force (\(\mu N\)). The graph includes bars for PSL on Si, Photoresist, and SiON and SiO\(_2\). The y-axis represents frequency, and the x-axis represents applied force in \(\mu N\).]
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)
• 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.
Acknowledgements

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Thank You for Your Attention