Contamination control in EUV exposure tools

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Contamination control in EUV exposure tools

- EUV-induced contamination
  - Carbon contamination
  - Surface oxidation

- Particles in vacuum
EUV-induced contamination

- Carbon contamination
  - EUV + O\(_2\) mitigation
  - On-body UV dry cleaning
- Surface oxidation

Particles in vacuum
Contamination study using a synchrotron facility

Neutral density filter
Branch chamber
Folding mirror
Gate valve with Zr filter
Neutral density filter
Rotational photo diode
Sample stage
Exposure chamber

BL 18 at SAGA LS SR facility

Contamination growth with perfluorohexane (C_{6}F_{14})

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EUV + O₂ mitigation of carbon contamination

Contamination growth rate and O₂ cleaning rate

O₂ cleaning rate exceeds carbon contamination growth rate in appropriate condition. Degradation of IU (Illumination Unit) transmittance of EUV1 was stopped after optimization of O₂ flow rate.

EUV + O₂ mitigation is very effective to carbon contamination.
UV dry cleaning of carbon contamination

Before cleaning

After cleaning

Carbon contamination on an illumination optics of EUV1 can be removed with UV dry cleaning. Initial reflectivity was recovered.
UV dry cleaning in depressurized atmosphere

Cleaning rate of carbon contamination with UV dry cleaning increases with reduced pressure.

**UV dry cleaning was applied to an on-body cleaning method in EUV1.**
Low pressure mercury lamps placed near each mirror enabled on-body cleaning of illumination optics.
Contamination control in EUV exposure tools

- EUV-induced contamination
  - Carbon contamination
    - EUV + O₂ mitigation
    - On-body UV dry cleaning
  - Surface oxidation
    - Metal-oxide capping layer

- Particles in vacuum
Reflectivity change of Mo/Si multilayers with several different capping layer materials during EUV exposure in water vapor was measured.

Metal oxide capping layers have much higher oxidation durability compared with conventional Ru capping layer.
Contamination control in EUV exposure tools

- **EUV-induced contamination**
  - Carbon contamination
    - EUV + O₂ mitigation
    - On-body UV dry cleaning
  - Surface oxidation
    - Metal-oxide capping layer

- **Particles in vacuum**
  - Particle capture using silica aerogel
Particles in vacuum: Materials

• Potential particle generating events
  – Physical contact
    • Collisions: wafer/reticle transfer, pod open/close, valve o/c, grounding pin contact, …
    • Rubbing: bearings, ultrasonic motors, …
  – Physical reaction
    • Sputtering: corona ionizers, EUV sources, …
    • Evaporation and condensation: pumping down in load lock
  – Electrical discharge/spark
    • EUV sources
    • Discharge between reticle and pod during a transitional region in load lock
    • Micro-discharge between wafer/reticle backsides and e-chucks.

• Potential materials
  – Metal/metalloid: Na, Al, Si, K, Ca, Ti, Cr, Fe, Ni, Mo, Ru, Sn, Ta, …
  – Inorganic: SiO$_2$, …
  – Organic: C$_x$H$_y$O$_z$

HEAVY! > 7 g/cm$^3$

cf. PSL~1 g/cm$^3$
Interaction with surfaces “bounce or stick” depends on the relationship between the particle impact velocity $V_i$ and the critical velocity $V_c$.

- $V_i < V_c$: stick
- $V_i > V_c$: bounce
- $V_i >> V_c$: split and stick/bounce

$V_c$ is determined by the surface material, the particle material, the particle size, etc.

Particles that have lower velocities than the critical velocity cannot continue to fly.

**FAST!** Typical $V_c$:
- 100 m/s for 100-nm particles
- 2,000 m/s for 10-nm particles
• Forces acting on particles in vacuum
  – **Gravity**: \( \propto r^{-3} \), dominant force but not decelerating force
  – **Drag force**: \( \propto r^{-2} \), weak, depends on the gas pressure
  – Coulomb force: weak, depends on \( E \) and amount of electric charge
  – Thermophoretic force: very weak, depends on the thermal gradient

**Flying range vs. Initial velocity**

![Graph showing flying range vs. initial velocity](image)

- Mo particles in 0.01-Pa O\(_2\) gas
- Below \( V_c \)
- LONG! > 100 m
Particle reduction system

Particle shield

Particle source at the top. Shield between the particle source and the mask.

→ Performance of shield is insufficient.

Particle source at the top. Particle catcher on the shield.

→ Particle catcher can drastically reduce the number of flying particles.

To simplify the models, gravity is neglected and the same coefficient of restitution (COR) is used for both the vertical component and the parallel component to the wall.
Silica aerogel as particle catcher

**STARDUST**: NASA’s comet sample return mission, 1999 - 2011

**Comet particles**
- Velocity: ~ 6.5 km/s
- Diameter: 40 - 300 µm

**Vacuum tool particles**
- Velocity: 10 m/s - 1 km/s
- Diameter: 1 µm - 10 nm

**Thinner sheet is enough for EUV tools.**

Photos from jpl.nasa.gov

Aerogel In Hand

Dust Collector with aerogel

February 7, 1999 Stardust Launch

Comet Ejecta in Aerogel

*Thinner sheet is enough for EUV tools.*
Structure of silica aerogels

**Pore network**

*Apparent density: 0.003–0.35 g/cm³*

Density of air: 0.0012 g/cm³ at 20 °C

- **Silica particle diameter**: 2–5 nm
- **Pore size**
  - **micro pores**: < 2 nm
  - **mesopores**: 2–50 nm
  - **macro pores**: > 50 nm

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Experimental setup of particle catcher

MPE Tool

Particle generator installed in ESC chamber

High voltage feedthroughs

Induction coil

Lead wire: –V

Lead wire: +V

Particles were generated by discharging (Air pressure ~5E-3 Pa)

Photos of aerogel tested: bare (left) and covered by a foil (right)

Size: 100 mm (W), 100 mm (D), 15 mm (H)
Density: 0.012 g/cm³

Aerogel in ESC chamber

10-20% of particles can go out through the gap

Metal Plate having a through hole

Cover plate

Aerogel holding plate

A quartz substrate for particle adhesion evaluation (not shown in the photo)
#1: **Aerogel sheet covered with a foil**

- An aerogel sheet covered by a foil on the holding plate was put between the quarts substrate and the particle generator.
- Discharging was continuously and the total time was about 8 seconds.

Particles are not captured.

#2: **Bare aerogel sheet**

- The foil was removed.
- Discharging was continuously and the total time was about 8 seconds.

Particles are captured.
Experimental results #1: Covered with foil

Particle density: 1,331 particles/cm²

Particle density: 1,368 particles/cm²

Almost the same density

Total = 291,645

Total = 283,622

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Experimental results #2: Bare aerogel

Particle density: 68 particles/cm²

Particle density: 111 particles/cm²

The aerogel sheet caught almost all particles that impacted it!!
Oxygen introduction during EUV exposure effectively mitigates carbon contamination growth on optical elements in EUV exposure tools.

Carbon contamination on optical elements can be removed by UV dry cleaning. It can be applied to an on-body cleaning method in EUV exposure tools.

Surface oxidation of multilayer mirrors during EUV exposure can be prevented by using metal-oxide capping layer.

Particles in a vacuum chamber fly very long distance. Silica aerogel is suitable material to capture such flying particles in EUV exposure tools.
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