Nanoparticle/AMC Contamination Control and Metrology for the EUVL Systems

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Outline

• Background and Motivation
• Protection Schemes for EUVL Masks
  – Carriers at Atmospheric Pressure
  – Scanners at below 100 mTorr
• Nanoparticle Metrology and AMC Issues
  – Standardization of Nanoparticles
  – Mask Deposition and AMC Issues
Background and Motivation

• Pellicles are unavailable for protecting the EUVL masks due to high absorption of EUV beam in most solid materials
• EUVL masks need to be protected against all particles > about 20 nm
Protection Schemes

The Intel project started in 2004. Particle contamination of EUVL photomasks was unknown. It was feared that thousands of particles might deposit on the mask during each operation. We need to investigate a broad range of protection schemes.

- Mask inside a carrier or scanner
- Cover plate to reduce risk volume
- Critical surface upside down to avoid gravitational settling (Cover plate underneath mask during shipping, storage, and pump down)
- Electric field to make use of electrophoresis
- Thermal gradient to make use of thermophoresis
- Particle trap surrounding mask to avoid particle penetration from the side

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Particle Detection Methods

- **Surface particle detection**
  - **Mask Scan**: Lasertec M1350
  - **Wafer Scan**: PMS SAS 3600 XP

- **Airborne particle detection**
  - Laser particle counter (**HS-LAS**) for size distribution
  - Aerosol Time-of Flight Mass Spectrometer (**ATOFMS**) for particle chemical composition
Effect of Secondary Packaging

- **Controlled Vibration**
  - ISTA Procedure 1G at 1.15 G_{rms}
  - Vertical position
  - Particle detection on 4” wafers

- Secondary packaging is helpful in reducing particle generation

**Witness Wafer Scan**
(Deposited Particles)
ATOFMS (Aerosol Time-of-Flight Mass Spectrometers)

D. Gross, Carleton College, Based on TSI, Inc. schematic.
Particle Source Identification

- Complex organic compound or mixture -- possibly polymer

Particles come mostly from contact points between mask surface and pins

Validation of Pozzetta Carrier Design on Particle Generation during Real Shipping

- The pin-support generates considerable particles during shipping.
- The standoff-support generates almost no particles.
Study of Various Protection Schemes inside a Carrier

\[ PF = \frac{\text{Number of injected particles into the chamber}}{\text{Number of deposited particles on the wafer}} \]

- No particle deposition with face-down mounting and a cover plate

Effect of Cover Plate Protection ($d_p = 10$ nm)

- No particle deposition on the critical surface down to $d_p = 10$ nm
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Experimental Setup

\[ \nu_P = \frac{Q}{A} \times \frac{P_1}{P_2} \]

Thermophoresis Test Set Up

No Gradient

-\nabla T = 0 \text{ K/cm}

Quiescent Zone

Gas Flow

With Gradient

-\nabla T = 10 \text{ K/cm}

Quiescent Zone

Gas Flow

Experimental cases:

- \( P \): 100 mTorr, 50 mTorr
- \( \nabla T \): 0 K/cm, -10 K/cm
- \( d_p \): 125 nm, 220 nm (on wafers)
- \( d_p \): 70 nm, 100 nm (on masks)
- \( v_i \): below, at, or above critical speed
- Gap: 1, 2 or 3 cm

Vacuum chamber
Thermophoresis at 100 mTorr, 2 cm Gap

$\nu_p = 31 \text{ m/s for } 125 \text{ nm}$

$\nu_p = 18 \text{ m/s for } 220 \text{ nm}$

- $d_p = 125 \text{ nm}$
- $d_p = 220 \text{ nm}$

- Thermophoresis improves protection.

Simulations at 50 mTorr
125 nm, 1 cm Gap, $v_i = 6.5$ m/s

- $\nabla T = 0$ K/cm

Many particles deposited
(some by diffusion)

- $\nabla T = 10$ K/cm

No particles deposited

- Thermophoresis overcomes diffusion.
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Nanometer Differential Mobility Analyzer (Nano-DMA)
New NIST Nanoparticle Standards: 60 nm and 100 nm SRM

Measurement of 100 nm and 60 nm Particle Standards by Differential Mobility Analysis

The peak particle size and expanded uncertainties (95% confidence interval) for two new particle calibration standards are measured as 101.5 nm ± 1.1 nm and 60.39 nm ± 0.65 nm. The particle samples are polystyrene spheres suspended in filtered, deionized water at a mass fraction of about 0.5%. The size distribution measurements of aerosolized particles are made using a differential mobility analyzer (DMA) system calibrated using SRM# 2663 (100.7 nm polystyrene spheres). An electrospay aerosol generator was used for generating the 60 nm aerosol to almost eliminate the generation of multiply charged dimers and trimers and to minimize the effect of non-volatile contaminants increasing the particle size. The testing for the homogeneity of the samples and for the presence of multimers using dynamic light scattering is described. The use of the transfer function integral in the calibration of the DMA is shown to reduce the uncertainty in the measurement of the peak particle size compared to the approach based on the peak in the concentration vs. voltage distribution. A modified aerosol/sheath inlet, recirculating sheath flow, a high rate of sheath flow to the aerosol flow, and accurate pressure, temperature, and voltage measurements have increased the resolution and accuracy of the measurements. A significant consideration in the uncertainty analysis was the correlation between the clip correction of the calibration particle and the measured particle. Including the correlation reduced the expanded uncertainty from approximately 1.8% of the particle size to about 1.0%. The effect of non-volatile contaminants in the polystyrene suspensions on the peak particle size and the uncertainty in the size is determined. The full size distribution for both the 60 nm and 100 nm spheres are calculated and selected mean sizes including the mean mean diameter and the dynamic light scattering mean diameter are computed. The use of these particles for calibrating DMAs and for making deposition standards to be used with surface scanning inspection systems is discussed.

Key words: differential mobility analysis; dynamic light scattering; electrical mobility; electrospay aerosol generation; particle size calibration standards; transfer function.

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Issues with PSL Particle Standard

- Different light scattering than particles from processes
- Decomposition from exposure to deep ultra-violet (DUV) lights
- Deformation due to adhesion forces

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Standard Particle Deposition for Scanner Calibration

- Calibration of surface inspection tools with particles of different materials
- Development of accurate size standards
- Providing samples for cleaning studies
NIST Traceable Deposition on Photomasks

- Particle Size Range: 20 – 900 nm
- Size Uniformity: > 98%
- Particle Counts: 100-2000 particles/spot
- Materials: PSL, SiO$_2$, TiO$_2$, Au, Al$_2$O$_3$…
- Photomasks: Quartz blank and ML (Ru or CrN Coated)
SiO$_2$ particles down to 30 nm have been deposited on quartz mask blanks.

Results in collaboration with Andy Ma and Ted Liang of Intel.
Haze Observed under Atmospheric and Vacuum Conditions

50nm SiO$_2$. Target deposition area: 1 inch spot size at the center. Testing time: 2 min. (Atmospheric Pressure)

100 nm PSL particle. (Main Chamber p = 50 mTorr). Testing time: 1.5 hours
Airborne Molecular Contaminants (AMCs) Classification of AMCs

Acids
- HF
- H$_2$SO$_4$
- HCl
- HNO$_3$
- H$_3$PO$_4$
- HBr

Bases
- AMINE
- NH$_3$
- NMP
- HMDS

Condensable
- DOP
- DBP
- DEP
- Siloxanes
- BHT

Dopants
- B$_2$H$_6$
- BF$_3$
- AsH$_3$
- TCEP
- TEP
- TPP

No Classes
- H$_2$O
- O$_3$
- IPA
- Acetone

SEMI Standard F21-95, 1996
Acid : SO2/N2, ...
Base : NH3/N2, ...
Carrier gas : Air, N2, N2/O2, ...

Chamber
Soft X-ray
Haze witness plate
UCPC
Temperature Controller
Temp. : 23 ± 0.5 °C
RH% : 45 ± 5%

Wafer surface scanner

Acid : SO2/N2, ...
Base : NH3/N2, ...
Carrier gas : Air, N2, N2/O2, ...
Experimental Setup
Particle Generation during Vacuum Pumpdown

Figure 2. Change of particle counts with time during pump down with various relative humidity.
water vapor and gas phase precursors

*homogeneous nucleation converts water vapor to water droplets*

water droplets and trace gases

*Trace Gases are absorbed into the water droplets once the droplets are formed*

water droplets with dissolved gases

The dissolved trace gases react with each other in the droplets

sulfuric acid droplets

Evaporation of water vapor

residue particles

Figure 8. Hypothesis of Residue particle formation process
Figure 9. Comparison of the numerical and experimental results. Effect of pumping speed on residue particle formation.
Summary

• Experimental methods and models have been developed to evaluate protection schemes for masks in carrier or vacuum tools.
• New carriers with tapered standoff generates almost no particles during shipping.
• Face-down mounting and cover plate are very effective in protection.
• Thermophoresis is most helpful to protect against particles driven by diffusion.
• Method has been developed to deposit standard nanoparticles for inspection tool calibration.
• Method has been developed to avoid haze formation caused by AMC.
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