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 Source Identification

- Complex organic compound or mixture -- possibly polymer
- Contact points between the mask surface and pins

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

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

- Absolute Protection: \(PF = \infty\)
- No Protection

- 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

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)

70 nm, 100 nm (on masks)

\[v_r:\] below, at, or above critical speed

Gap: 1, 2 or 3 cm

Vacuum chamber
Thermophoresis at 100 mTorr, 2 cm Gap

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

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

- 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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New NIST Nanoparticle Standards: 60 nm and 100 nm SRM

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

The peak particle size and expanded uncertainty (95% confidence interval) for two new particle calibration standards are measured as 60.8 nm ± 1.1 nm and 93.7 nm ± 0.5 nm. The polydisperse suspensions are filtered, deionized water at a mass fraction of about 0.5%. The size distribution measurements of monodisperse particles are made using a differential mobility analyzer (DMA) system calibrated using SRM 1963 (100 nm polyacrylmae particles). An electrophoresis aerosol generator was used for generating the 60 nm aerosol to almost eliminate the generation of multiply charged species; and earned to minimize the effect of non-volatile components introduced in the particle size. The testing for the homogeneity of the samples and the presence of multiple scattering dynamic light scattering measurements were performed 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 cumulative vs. residence distribution. A modified aerosol stream, circulating aerosol flow at a high rate of aerosol flow to the second, and aerosol pressure, temperature, and voltage measurements have increased the resolution and accuracy of the measurements. A significant reduction in the uncertainty analysis was the correlation between the slip correction of the calibration particle and the measured particle. Including the correlation reduced the expanded uncertainty at asymptotically 1.8% of the particle size to about 1.0%. The effect of non-volatile components in the polyacrylmae suspensions on the peak particle size and the uncertainty in the size is determined. The full size distributions for both the 60 nm and 100 nm spheres are collected and selected mean sizes including the superimposed diameters are compared. The use of these particles for calibrating DMA's and for making deposition standards in which with surface scanning laser imaging is discussed.

Keywords: differential mobility analysis; dynamic light scattering; electrical mobility; electrophoresis aerosol generation; particle size calibration standards; transfer function.

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Available online: http://www.nist.gov/JRST
Nanometer Differential Mobility Analyzer (Nano-DMA)
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
Haze Observed under Atmospheric and Vacuum Conditions

50nm SiO$_2$. Target deposition area: 1inch 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
- Condensable
  - DOP
  - DBP
  - DEP
  - Siloxanes
  - BHT
- Bases
  - AMINE
  - NH$_3$
  - NMP
  - HMDS
- Dopants
  - B$_2$H$_6$
  - BF$_3$
  - AsH$_3$
  - TCEP
  - TEP
  - TPP

No Classes

H$_2$O$_2$
O$_3$
IPA
Acetone

SEMI Standard F21-95, 1996
Controlled Particle Deposition on Mask Blanks

Deposition Plan
(~ 2000 particles)

Detection of Particles on a Quartz Mask

- Known material
- Known number of particles
- NIST-traceable particle size
- Controlled deposition spot size
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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