Investigation of thermophoretic protection with speed-controlled particles at 100 mTorr, 50 mTorr, and 25 mTorr

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Motivation

Particle contamination control is crucial for protecting Extreme Ultraviolet Lithography (EUVL) masks in manufacturing tools. Due to the small feature sizes, particles with diameters down to 30 nm can deteriorate the mask performance. Therefore control schemes are required to protect the mask from particle deposition during applications in EUVL exposure tools at reduced pressure. A non-contact method for protection of EUVL mask, like thermophoresis, is most desirable.

Vacuum Chamber and Particle Injection System

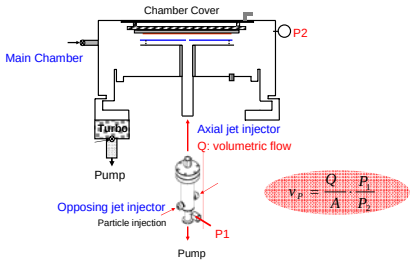

Figure 1: Schematic of the vacuum chamber system for experimental investigations and dual-stage particle injection system. Desired particle injection speed can be achieved by controlling volumetric flow rate and pressure ratio between the opposing jet injector and the main chamber. [1,2]

Thermophoresis Test Zone

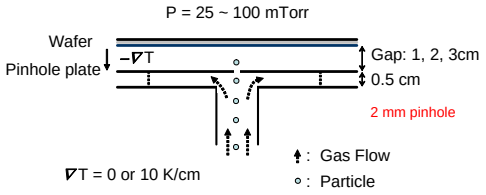

Figure 2: Schematic of the thermophoresis test zone. Injection tube diameter is 35 mm. Gap distance between the critical surface and the pinhole plate is variable from 1 cm to 3 cm. [1]

Thermophoretic Protection

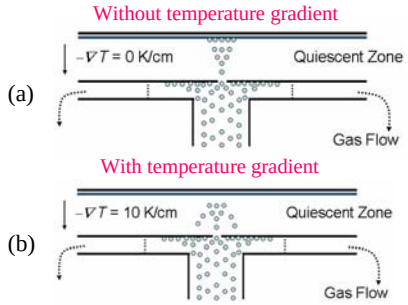

Figure 3: Schematic of particle motion in the quiescent zone without temperature gradient (a) and with 10 K/cm temperature gradient (b).

References

[1] J.H. Kim, H. Fissan, C. Asbach, S.J. Yook, K.J. Orvek, A. Ramamoorthy, D.Y.H. Pui (2005): Investigation of thermophoretic protection with speed-controlled particles at 100 mTorr, 50 mTorr, and 25 mTorr, *Journal of Vacuum Science & Technology B (submitted).*

[2] J.H. Kim, H. Fissan, C. Asbach, S.J. Yook, and D.Y.H. Pui (2005): Speed-controlled particle injection into a low pressure system, *Journal of Vacuum Science & Technology A (submitted).*

[3] C. Asbach, J.H. Kim, S.J. Yook, D.Y.H. Pui, H. Fissan (2005): Analytical modeling of particle stopping distance at low pressure to evaluate protection schemes for EUVL masks, *Applied Physics Letters (in press).*

Particle Speed Calculation

Table 1: Initial particle speed required to reach the critical surface for three gap distances after exiting the pinhole plate, based on an analytical model. [3] See companion poster.

Pressure (mTorr)	Particle size (nm)	∇T (K/cm)	Initial particle speed (m/s)		
			Gap = 1 cm	Gap = 2 cm	Gap = 3 cm
100	125	0	14.9	29.7	44.6
		10	15.8	30.8	45.7
	220	0	8.5	16.9	25.4
		10	9.3	17.9	26.4
50	125	0	7.5	14.9	22.4
		10	8.8	16.5	24.1
25	125	0	3.8	7.6	11.3
		10	5.8	9.6	13.7

Thermophoresis Test at 100 mTorr

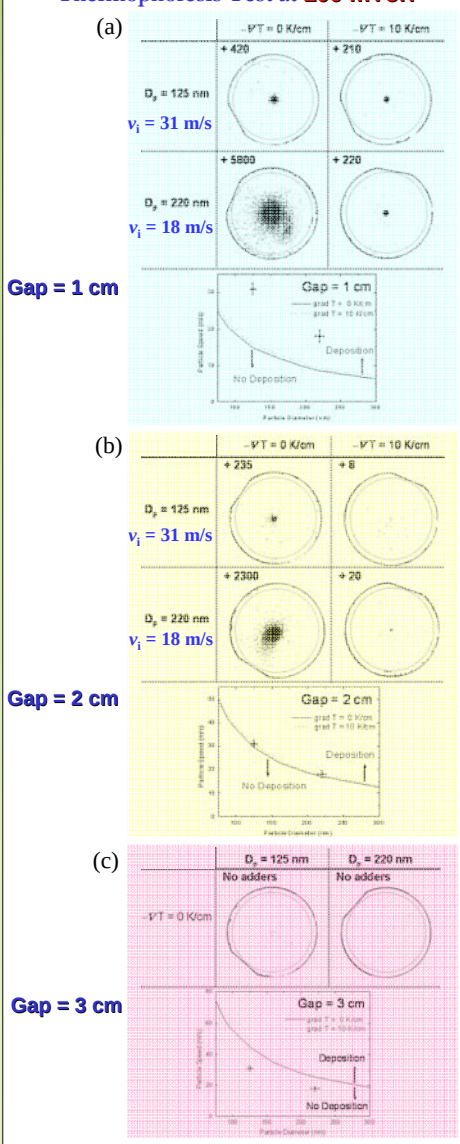

Figure 4: Deposition results of 125 nm and 220 nm PSL particles at 100 mTorr for the gap distance 1 cm (a), 2 cm (b), and 3 cm (c). [2]

Thermophoresis for 1 cm Gap

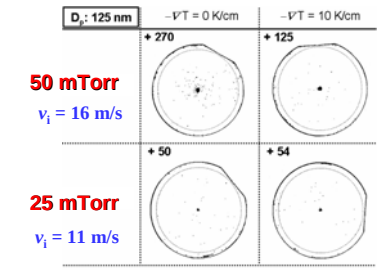

Figure 5: Deposition results of 125 nm PSL particles at 50 mTorr and 25 mTorr with particle injection speeds of 16 m/s and 11 m/s for the 1cm gap distance under no temperature gradient and with 10 K/cm temperature gradient. The number of particles added for each case is shown to the wafer maps. [1]

Thermophoresis for 2 cm Gap

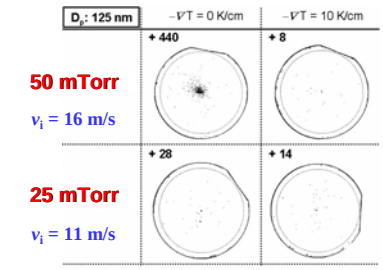

Figure 6: Deposition results of 125 nm PSL particles at 50 mTorr and 25 mTorr with particle injection speeds of 16 m/s and 11 m/s for the 2 cm gap distance under no temperature gradient and with 10 K/cm temperature gradient.

Conclusions

- A vacuum chamber in conjunction with a dual-stage particle injection system was constructed to examine the effect of thermophoresis on the protection of critical surfaces from particle contamination
- A pin-hole plate was used to create a quiescent zone to establish a constant thermal gradient for the thermophoresis study
- The particle injection speed could be controlled by the volumetric flow of the carrier gas, the injection tube cross sectional area, and pressure ratio between the main chamber and the opposing jet injector
- Particle speed, gap distance, and temperature gradient were varied as control parameters
- Thermophoresis showed excellent protection efficiency against deposition from diffusion driven particles at pressures down to 50 mTorr
- Experimental results validated the use of the analytical model [3] for low pressure systems

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