Effect of Differential Pressure on Particle Contamination on EUVL Photomasks

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Abstract

Particle contamination on EUVL photomasks is a very critical issue. While active protection of masks against particle contamination by thermophoresis requires a certain minimum pressure (≥50 mTorr), the optics zone of an EUVL scanner has to be maintained at a pressure as low as possible (5 mTorr or below) to avoid excessive absorption of the EUV beam. It was thus proposed that EUVL scanners can be separated into two zones: 1) mask zone at higher pressure and 2) optics zone at lower pressure. To avoid losses of the EUV beam intensity, the interface between the two zones must be open, resulting in a compensation flow from the mask to the optics region. The effect of this reverse flow on particle contamination on a mask has been studied and is presented here.

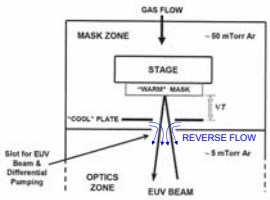

Fig 1: Original concept for differential pressure scanner [1]

- Pressure in optics zone needs to be as low as possible to avoid absorption of EUV beam
- Pressure in mask zone must be above approx. 50 mTorr to enable thermophoresis as active protection [2,3]
- Particles with high initial speed are mainly stopped by drag force [2]
- Deposition of particles with low initial speed, e.g. diffusional particles, can be effectively overcome by thermophoresis [2-4]

→ What is the effect of reverse flow in interface on particle penetration from optics to mask zone?

→ What is the effect of flow near the photomask on particle deposition on the mask?

Experiments

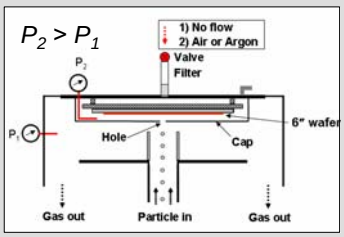

Fig. 2: Experimental set up [3]

- Witness wafers used as substitute for masks
- Cap around the mask with adjustable pressure
- Pressure inside main chamber maintained at lower level than in cap → Reverse flow through hole
- Particles injected towards hole with known speed
- Pressure level limited to $P_1 \geq 50$ mTorr (insufficient pumps)

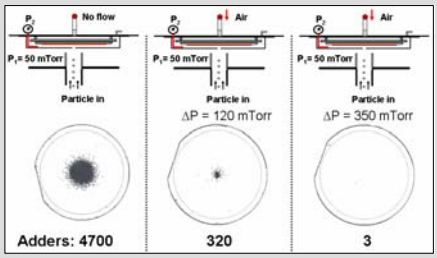

Fig. 3: Example for experimental results with P_1 = 50 mTorr; 125 nm PSL particles injected with 180 m/s [3]

Table 1: Number of deposited 125 nm PSL particles on witness wafers at P_1 = 50 mTorr and different pressure differences and injection speed [3,5]

Speed [m/s]	Gas	Differential Pressure ΔP [mTorr]						
		0	65	120	170	200	350	500
25	Air	970	3					
100	Air	2850	3*					
180	Air	4700	1920	320	40		3	
	Argon		1600	270	17			
270	Air	21400		15200		4940	1380	1120
	Argon			11000		3300	1200	1050

* Numerical case

Simulations

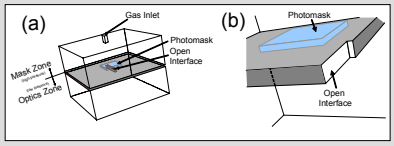

Fig. 4: Calculation domain for simulations; (a) full geometry, (b) magnified view of cut through mask and interface

- Model validated against experimental results
- Model used to study lower pressure levels
- Model used to study effect of flow near the mask on deposition

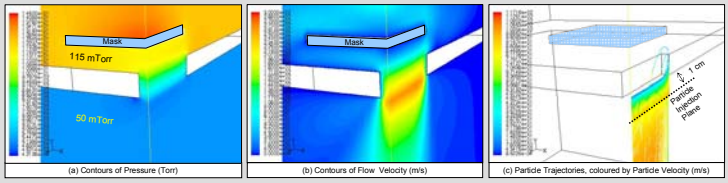

Fig. 5: Pressure in optics zone: 50 mTorr, ΔP = 65 mTorr; (a) pressure distribution, (b) flow velocity distribution, and (c) particle trajectories of 125 nm PSL particles, injected with 100 m/s; no particles deposited (compare with experimental results)

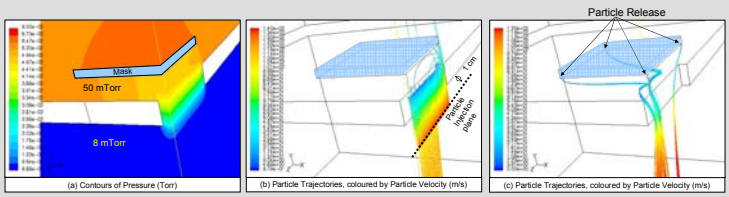

Fig. 6: Pressure in optics zone: 8 mTorr, underneath mask 50 mTorr; (a) pressure distribution, (b) particle trajectories of 125 nm PSL particles, injected from below with 140 m/s, and (c) particle trajectories of 125 nm PSL particles released from mask corners

Conclusions

- Effect of reverse flow, caused by differential pressure, was studied experimentally and numerically
- Experiments show increased protection against particle penetration with increasing pressure difference
- Argon shows slightly higher protection than air due to higher molecular mass
- Simulations were extended to lower pressure levels (8 mTorr in optics zone)
- Reverse flow can protect against 125 nm particles with up to ≈140 m/s (even higher for smaller particles); such high speeds are very unlikely in real systems
- Flow carries particles away from the mask if released in mask zone

→ Reverse flow is promising in preventing particle contamination

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