Influence of Particle Contamination on EUVL Reticle Distortion During Exposure Chucking

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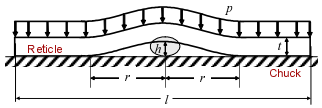
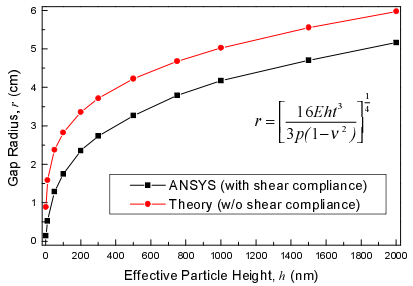
Significance of the Particle Entrapment Problem

- Successful imaging of circuit patterns with critical dimensions less than 45 nm in extreme ultraviolet lithography (EUVL) requires stringent controls on sources of errors.
- Particle contamination poses a serious threat to meeting EUVL error budgets. Trapped particulates as small as 1.0 μm in diameter can distort the patterned mask enough to affect printing accuracy.
- Experimental assessment of the effects of particle-induced reticle distortion is extremely difficult, thus requiring computational studies.
- Finite element (FE) simulations using ANSYS® and LS-DYNA® have been conducted to investigate the response of chucked reticles to the presence of trapped particulates.

Modeling the "Macro" Response

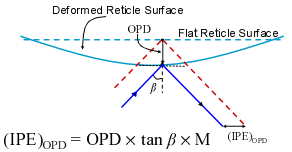


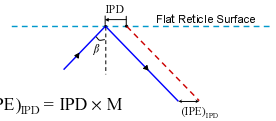
r : gap radius
t : reticle thickness = 6.35 mm
p : chucking pressure = 15 kPa
l : reticle length = 152 mm
h : effective particle height

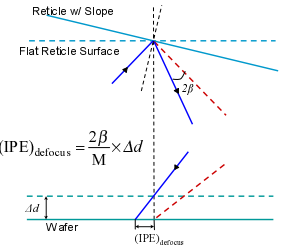


- The reticle is assumed to be chucked to a perfectly flat and rigid chuck by a uniform pressure of 15 kPa.
- The maximum out-of-plane distortion (OPD) of the reticle will occur directly above the particle and will be equal to the "effective particle height" i.e., the residual height of the particle after it has been crushed and/or has been embedded into the reticle.
- The particle causes a gap between the reticle and chuck of some finite radius (or gap radius) as shown above and is a measure of the extent of particle-induced reticle deformation. A particulate having an effective height of 1.0 μm can cause a gap radius of about 40 mm.

Sources of IP Errors







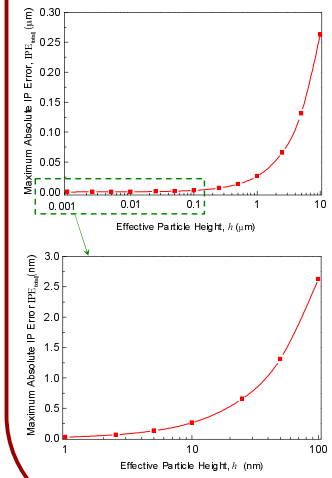
Ref: E. Gullickson, STEP: EUVL Masks, 13 July, 2004.

β : incident angle of illumination
M : magnification factor
Δd : wafer defocus

IPE : image placement error
IPD : in-plane distortion
OPD : out-of-plane distortion

Modeling the "Macro" Response

Component	Material	Elastic Modulus (GPa)	Poisson's Ratio	Material Behavior
Reticle	ULE®	66.3	0.17	Elastic
Chuck	ULE®	66.3	0.17	Rigid



Total IP error

$(IPE)_{total} = (IPE)_{IPD} + (IPE)_{OPD}$

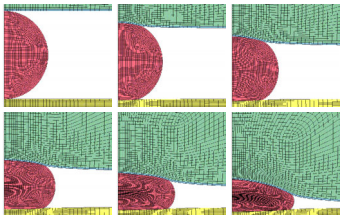
or,

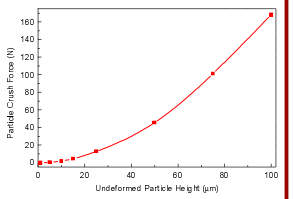
$(IPE)_{total} = (IPD \times M) - (OPD \times \tan\beta \times M)$

- Wafer defocus and reticle slope effects are not included.
- Maximum absolute errors were obtained by combining the IPD and OPD contributions.
- Image placement (IP) errors are primarily driven by OPD of the reticle.

Modeling the "Micro" Response

Component	Material	Elastic Modulus (GPa)	Poisson's Ratio	Yield Stress (GPa)	Material Behavior
Reticle	ULE®	66.3	0.17	8.5	Elastic-plastic
Backside Layer	Chrome	248.0	0.30	-	Elastic
Particle	ULE®	66.3	0.17	8.5	Elastic-plastic
Dielectric Film	Alumina	370.0	0.22	-	Elastic
Chuck	ULE®	66.3	0.17	8.5	Elastic-plastic





- FE simulations can accommodate different materials for the reticle, chuck, and particle. The above simulation uses a 1.0 μm spherical ULE® particle. The reticle, and chuck are made of ULE® as well.

Summary and Conclusions

- IP errors are driven by the residual height of particles after they have been crushed and / or embedded into the reticle.
- To limit IP error to less than about 1 nm, the effective particle height should be no more than approximately 40 nm (for a typical chucking pressure of 15 kPa).
- Material behavior at the micro/nano scale differs from the macro scale.
- Macro-scale FE models predict the gap radius, OPD, and IPD of reticles while the micro-scale model predicts the crushing/embedding response of particles.

Future Work

- To obtain material property data, perform nanoindentation studies on the mask, chuck, and backside layer materials, as well as the types of materials that are expected to appear as contaminants or particulates.
- For each material type, measure the shape of the indented surface and simulate the actual nanoindentation test to identify the elastic-plastic properties to be used in the FE models.
- Using parametric studies, characterize the effects of backside material properties and thicknesses to minimize the consequences of entrapped particles.

Acknowledgments

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