Masks Induced Imaging Artifacts in Extreme Ultraviolet Lithography

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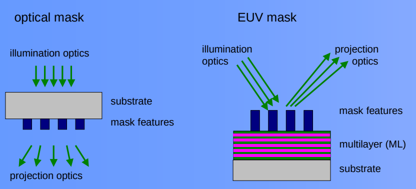
Abstract

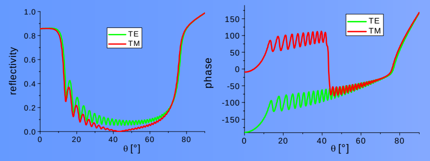
Since the late 90-ties, extensive simulations were performed to explore the imaging characteristics of EUV-masks. Several important imaging artifacts such as orientation dependent placement errors, telecentricity errors, and asymmetric Bossung curves were observed. It is important to note that these imaging artifacts result from the specific geometry of EUV-masks. They occur even for aberration free-projection systems.
This contribution presents specific simulations for real and idealized mask geometries that reveal the physical origin of the observed effects. Possible strategies to reduce the magnitude of the unwanted artifacts will be discussed.

Light Diffraction from Optical and EUV Masks



Peculiarities of EUV Masks

- off-axis illumination: 4-6°
- absorber thickness large compared to the wavelength: 6-8 λ
- multilayer reflectivity



Amplitude and phase of reflected light depend on angle of incidence θ

EUV-Masks Induced Imaging Artifacts - Observations

Bollepalli 1998:
- imaging bias between features on dark and bright field masks
- orientation dependence of pattern placement, line-widths ...

Otaki 2000:
- focus dependent placement errors (telecentricity errors)

Krautschik 2001:
- focus shifts, asymmetric Bossung curves

- What is the reason for these artifacts ?
- How do off-axis illumination, “thick” absorber, and multilayer reflectivity contribute to these artifacts?
- How to reduce the artifacts ?

Literature

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- Krautschik C., Ito M., Nishiyama I., and Otaki K., ”The impact of EUV mask phase response on the asymmetry of Bossung curves as predicted by rigorous EUV mask simulations”, Proc. SPIE **4343** (2001) 392.
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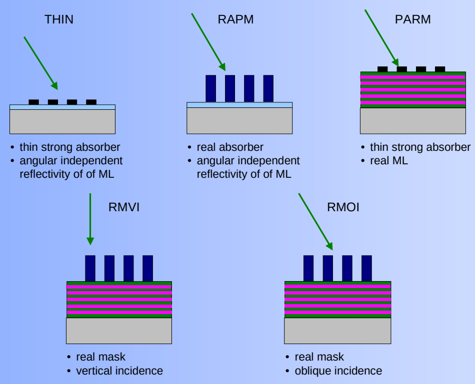
Simulation Study for Idealized Mask Properties

Mask/Illumination Geometries



THIN
- thin strong absorber
- angular independent reflectivity of of ML

RAPM
- real absorber
- angular independent reflectivity of of ML

PARM
- thin strong absorber
- real ML

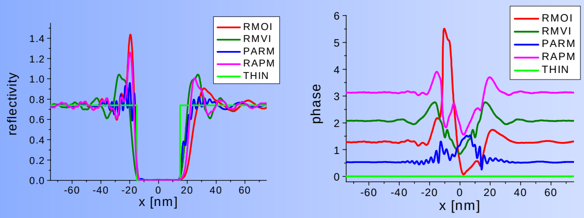
RMVI
- real mask
- vertical incidence

RMOI
- real mask
- oblique incidence

Default Simulation Parameters

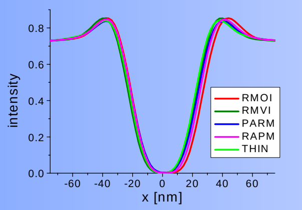
mask	30nm isolated lines, absorber: 80nm chromium, multilayer: 40 bilayers of MoSi
optics:	λ=13.4nm, NA=0.3, σ=0.5, TE-polarization
resist:	simplified DUV-CAR model

Near Fields

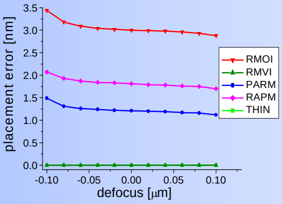


- off-axis illumination and absorber cause”intensity imbalancing”
- multilayer and absorber modify phase

Aerial Images

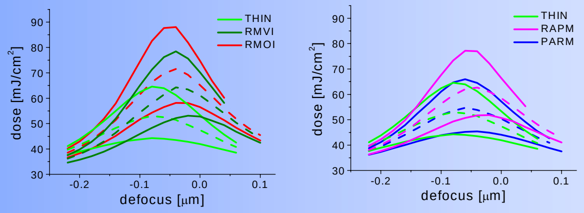


Placement Error versus Focus



- both absorber and ML contribute to placement error
- absorber causes larger contribution to placement and telecentricity errors

Process Windows



- small impact of ML reflectivity on shape of process window
- “thick” absorber is main contributor to deformation of process windows

Simulation Study for different Absorber Materials

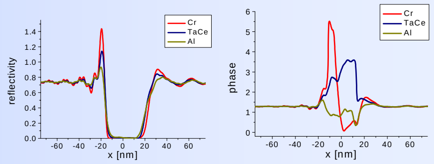
Some of the observed imaging artifacts seem to be dominated by phase deformation inside the “thick” absorber

What about the imaging performance for alternative absorber material with real part of the refractive index closer to 1.0

Possible Alternatives (from simulation point of view only)

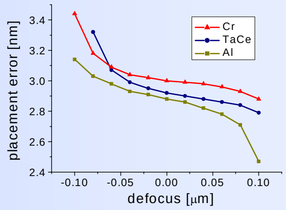
- Cr: n=0.9333, k=-0.0388
- TaCe: n=0.9741, k=-0.0298
- Al: n=1.0030, k=-0.0297

Near Fields



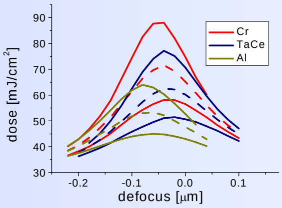
Al absorber shows less “intensity imbalancing” and phase deformation

Placement Error versus Focus



weak dependence of placement and telecentricity error from absorber material

Process Windows



Al absorbers show less deformed process windows

Summary and Conclusions

- **off-axis illumination (OAI), “thick” absorbers (TA), and real multilayer reflectivities (ML) contribute to imaging artifacts in EUV lithography**
- **the placement error depends strongly on OAI.**
- **TA and ML contribute to the placement error. TA contribution to placement and telecentricity error is dominating**
- **deformation of process windows (tilt, shift) is mainly due to TA, absorber with real parts of refractive indices closer to 1 show reduced imaging artifacts**
- **similar observation were made for dense lines and contact holes**

Acknowledgements

The authors would like to thank for the funding of a part of this work by the ”Bayerische Forschungsstiftung” and by Infineon Technologies.