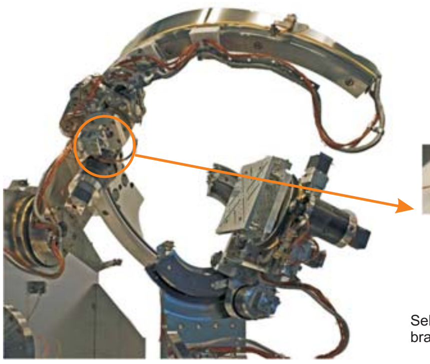
Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Actinic characterization of EUV Photomasks by EUV Scatterometry

C. Laubis[1], F. Scholze[1], V. Soltwisch[1], A. Ullrich[2], V. Philipsen[3] and S. Burger[4]
1: PTB, 2: AMTC, 3: IMEC, 4: JCMwave

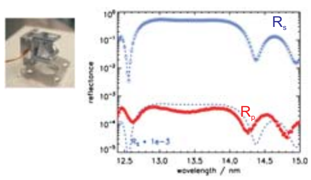
EUV photomasks utilize a multilayer stack to provide high and uniform EUV reflectance and a patterned absorber which defines the features on the mask. Illuminating at an oblique angle as necessary in a stepper gives rise to horizontal-vertical print differences and through-focus pattern placement errors due to shadowing. These 3D mask effects depend on the full 3D mask structure. Characterization by EUV Scatterometry may use zero order specular reflection to assess the multilayer and absorber stack homogeneity. For structured areas the zero order reflectance depends on structure details like CD and can be used to check patterning homogeneity. Intensity measurements of several diffraction orders can be used for the reconstruction of the line shape.
We present data obtained at EUV photomasks featuring large periodic lines & spaces fields suitable for scatterometry with the instruments of PTB which are not specially designed for small measurement spots. We use an FEM-based Maxwell solver for the evaluation of the data with respect to the geometrical parameters linewidth, lineheight, sidewall angle and corner rounding. Using statistical procedures for the inclusion of roughness we could also derive reliable estimates for the line roughness. Results of the EUV measurements were compared to AFM and CD-SEM data.

Instrumentation: Ellipso-Scatterometer



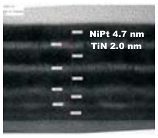
- AOI: 1.5° to 90° (TE and TM orientation)
- Sample capacity: 190 mm sq., max. 5 kg
- Sample goniometer: 6 axes

Bragg-Polarimeter

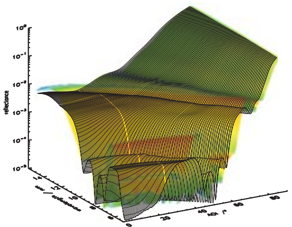


Selectivity > 10^3 at Brewster angle, several braod band mirrors available

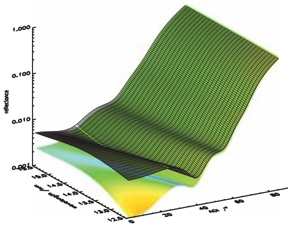
Material characterization



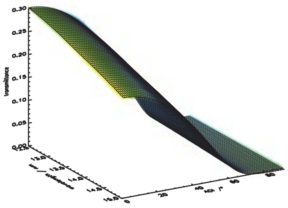
For improved imaging, highly ab-sorbing thin layers are requi-red. TEM image of an advanced layered absorber stack. [1,2]



Measured reflectance of a layered absorber stack (black grid) coated onto a Si wafer. A calculation using the nominal stack parameters is shown as a colored surface. Although not all details are matched (compare the slightly irregular structure in the TEM image) the overall reflectance near normal incidence in the relevant wavelength region around 13.5 nm fits reasonably well.



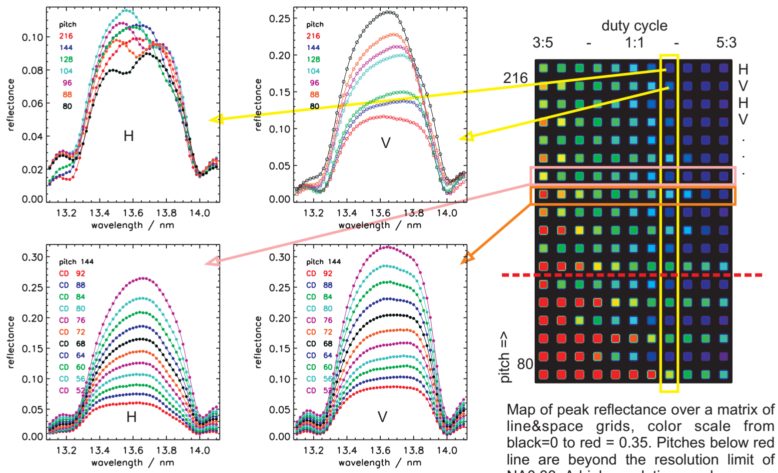
Left: Measured reflectance (black grid) in a reduced wavelength range and a calculation using a single layer model (colored), mimicking the stack by a layer with an effective index of refraction. The data for higher AOI fit well, near normal incidence the calculated reflectance is too low. The calculated transmittance of the layer stack (right), for a single layer model (black grid) and the layered stack (colored surface) show good agreement.



It is possible to derive reasonably good transmittance values for a layered absorber stack using effective optical constants

After patterning characterization

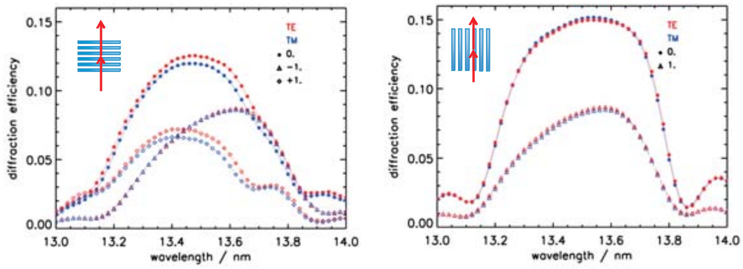
Specular reflectance allows for characterization the full 3D mask response after mask patterning even for mask patterns beyond the resolution limit of today's lithography scanners, to enable exploration of future feature sizes. Significant trends in the specular reflectance versus duty cycle and pitch and also H-V differences are observed which might be used for process control by EUV reflectance measurements.



Zero order specular reflectance measured over a matrix of hor. and vert. line pattern at different pitch and duty cycle.

Map of peak reflectance over a matrix of line&space grids, color scale from black=0 to red = 0.35. Pitches below red line are beyond the resolution limit of NA0.33. A high resolution mask process enabled LS patterning in absorber downto 80 nm mask pitch.

Polarization resolved diffraction efficiency

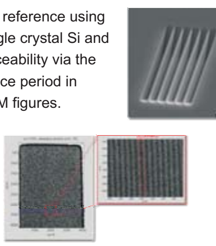


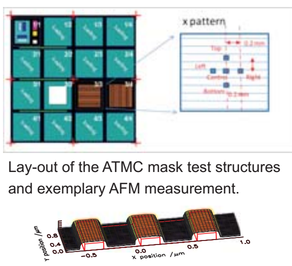
Polarization resolved diffraction efficiency of absorber lines on an EUV test reticle from AMTC, pitch 160 nm and CD 85 nm. [3]

Metrology comparison of CD measurement by EUV scatterometry and AFM

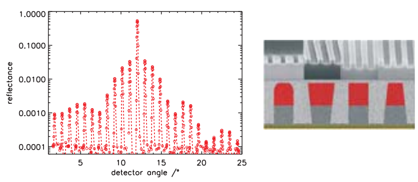
Image of a flared AFM tip for CD metrology.

CD reference using single crystal Si and traceability via the lattice period in TEM figures.

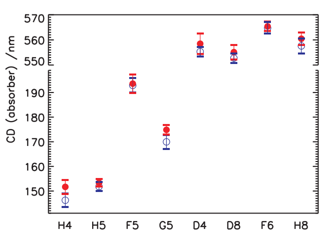




Lay-out of the ATMC mask test structures and exemplary AFM measurement.



Examplary EUV diffraction measuerment and FEM grid for profile reconstruction using JCMsiute program package from JCMwave.[4]



Comparison of measurement data from AFM (red) and EUV scatterometry (blue). Error bars are 2σ-values. [5]

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

Christian Laubis

Abbestr. 2-12
10587 Berlin
phone: + 49 30 3481 7125
fax: + 49 30 3481 7102
email: christian.laubis@ptb.de

References

[1] O. Wood et al., Proc SPIE 9422 9422-17 (2015)
[2] V. Philipsen et al., Proc SPIE 9235, 92350J (2014)
[3] V. Soltwisch et al., Proc. SPIE 9422 9422-38 (2015)
[4] J. Pomplun et al., Proc. SPIE 6349, 63493D (2006)
[5] F. Scholze et al., Proc SPIE 8880 88800O (2013)