Evaluation of Scatterometry Tools for Critical Dimension Metrology

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Scatterometry as a non-imaging metrology method offers access to the geometrical parameters of photolithography masks and provides independently achieved additional information that can be used for cross-calibration with AFM, SEM, and optical microscopy results. Here sensitivity studies towards geometrical parameter changes as well as first experimental results are presented.

1 Introduction

Today's standard methods for measuring critical dimensions (CDs) on lithographic photomasks, atomic force microscopy (AFM), scanning electron microscopy (SEM), and optical microscopy, provide significantly different results with decreasing CDs. The reasons for this are not understood in all details. But one reason for example is that the methods are sensitive to lateral CDs on different heights of the structures under test. For example an AFM measures the top CD values while optical microscopy usually measures the optically efficacious linewidth which corresponds to a CD value at approximately 50% height.

Non-imaging methods provide an additional and independent access to geometrical parameters of photomasks. This becomes even more important in spectral regions where quantitative optical microscopy fails due to a lack of high NA (numerical aperture) imaging elements. Here the sensitivity of standard and ellipsometric scatterometry setups is demonstrated by solving the forward problem for various input geometries.

2 Scatterometric measuring setups

With a standard scatterometer (Fig. 1) the normalised intensity I/I_0 of the single diffraction orders and the angular position of the detector as a quantity that is related to the propagation vector of the diffracted order are measured. The measurement can be performed in reflection and/or transmission (if accessible). The angle of incidence is a parameter of the experiment and is kept constant during the measurement.

In ellipsometric scatterometry (Fig. 1) the sample's influence to the polarisation state of the 0^{th} diffraction order is measured with respect to the angle of incidence and at a fixed wavelength.

The ellipsometric measurands Ψ and Δ are related to the (complex) reflection coefficients by the fundamental equation of ellipsometry:

$$\tan \Psi e^{i\Delta} = \frac{r_p}{r_s} \qquad (1)$$

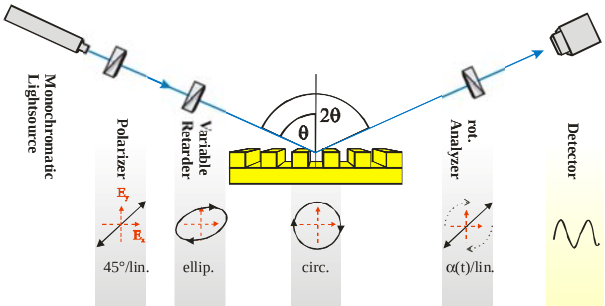

Fig. 1 *Ellipsometric Scatterometer for measuring Ψ and Δ of the 0th diffraction order. Here the PCSA configuration (Polariser, Compensator, Sample, and Analyser) with rotating analyser is sketched. At a standard scatterometer the polarising elements are lacking and the detector scans the diffraction pattern.*

Ψ corresponds to the ratio of the amplitudes and Δ represents the phase difference between both polarisations.

3 The test samples

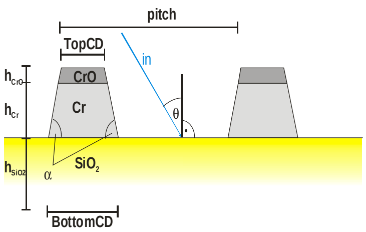

Fig. 2 *Scheme of the periodically structured CoG masks as they are used here for simulations and measurements, respectively.*

Mask	Pitch [nm]	TopCD [nm]	α [°]	CrO [nm]	Cr [nm]	SiO_2 [mm]
CoG1	1120	580	73	23	50	6.35
CoG2	100	50	90	23	50	6.35

Tab. 1 *Nominal geometrical parameters of the two types of lithography masks. For optical parameters see [2] (@ λ=193, 633nm), [3] (@ λ=13.55nm).*

4 Sensitivity studies

Fig. 3 and Fig. 4 show several simulation results for the CoG1 and CoG2 masks performed with Microsim [1] which is based on the rigorous coupled wave analysis (RCWA). Microsim provides access to the amplitudes and phases of the reflected (and transmitted) diffraction orders. With this information the ellipsometric values Ψ and Δ can be obtained. They are shown versus the angle of incidence in the first row of Fig. 3 (CoG1) and Fig. 4 (CoG2) for wavelengths of 13.55 nm, 193 nm, and 633 nm.

The sensitivity to a geometrical parameter of the structures can be estimated from the second and third row of the figures. In Fig. 3 a variation of the sidewall angle of ± 5° and in Fig. 4 of the line/space ratio of ± 1% (which corresponds to a linewidth change of 0.5 nm) is presented. Here in each case the differences to the origin curve are shown. One can recognise a very strong sensitivity (especially at the Brewster angle) to the parameter variations as long as the wavelength is not significantly smaller than the lateral structures. This is not the case for λ=13.55 nm.

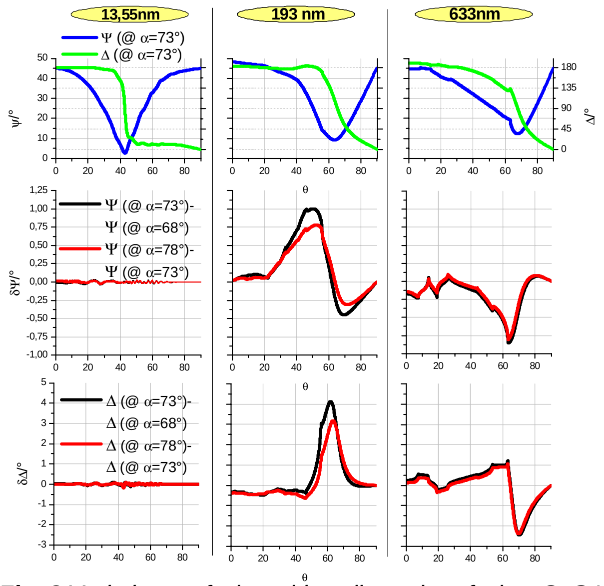

Fig. 3 *Variations of the sidewall angle of the CoG1 mask. For details see text.*

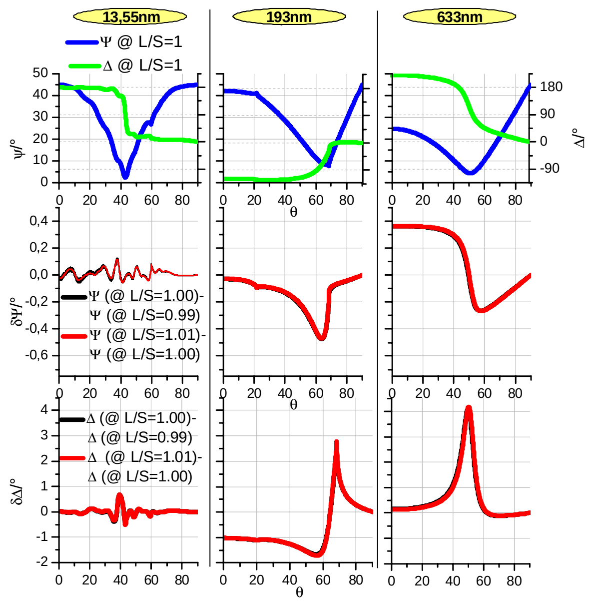

Fig. 4 *Variations of the line/space ratio of the CoG2 mask. For details see text.*

5 Experimental Results

Due to the promising results in the previous section PTB is planning to build up an ellipsometric scatterometer (for λ=193…840nm). Up to now there are two scatterometric facilities at the PTB available. One at 633 nm and one in the EUV range [4], located in Berlin at Bessy II. With the latter first measurements at the mask CoG1 were done, Fig. 5. Though there are deviations between the calculated and measured data, one - in general – can state a good agreement.

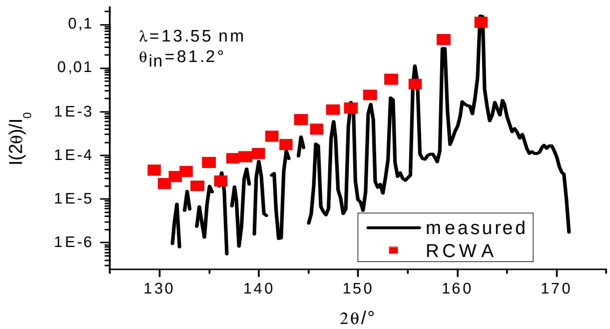

Fig. 5 *Measurements on the CoG1 mask @ λ=13.55 nm. The simulated data has been scaled by a factor of 0.6.*

6 Conclusions

The ability of ellipsometric scatterometers to measure structure parameters with dimensions much smaller than the inspection wavelength has been proofed. Even variations of less than λ/1000 of structures smaller than λ/10 give strong signal changes in the range of some degree for Ψ and Δ.

As the simulations show, the sensitivity of an ellipsometric scatterometer - regarding geometrical parameters of a test sample - even increases with increasing wavelength.

First scatterometric measurements show a good agreement with simulations done with Microsim.

References

[1] M. Totzeck, *Numerical Simulation of high-NA quantitative polarisation microscopy and corresponding near-fields*, Optik 112(9), pp.399-406, 2001.

[2] J. Guhr (MBW&A, Lebus) and Dr. J. Bauer (ihp-microelectronics, Frankfurt/O. (private communication)

[3] Center for X-Ray Optics (CXRO), online database for X-Ray Interactions With Matter, http://www-cxro.lbl.gov/optical_constants/

[4] J. Tümmler, G. Brandt, J. Eden, H. Scherr, F. Scholze, G. Ulm, *Characterization of the PTB EUV reflectometry facility for large EUVL optical components*, Proc. SPIE **5037**, 265-273 (2003)