Towards traceability in scatterometric-optical dimensional metrology for optical lithography

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To achieve absolute measuring and traceable scatterometry the measurement process and impact of many input parameters have to be analysed thoroughly. Exemplarily we evaluated the impact of line edge roughness, and how to compensate for. To transfer traceability in industrial applications we develop a scatterometry reference standard. First design considerations are shown.

1 Introduction

Currently, the application of scatterometry for dimensional metrology for optical lithography is limited to relative measurements for process control and development. Reasons are the complexity of the measurement and the fact, that many different tool, modelling and sample related approximations are applied leading to systematic measurement offsets of generally not well specified amount.

To establish scatterometry for traceable and absolute dimensional metrology an estimation of the measurement uncertainty is required. This is especially for the indirect measuring scatterometry a time consuming issue, since it is influenced by many parameters, which have to be investigated and the influences evaluated.

2 Traceability in scatterometry

In scatterometry, the geometry of the object is deduced from measured light properties after interaction with the object under test. This indirect method requires the solution of an inverse diffraction problem e. g. by nonlinear optimisation. Different aspects have to be considered: Algorithms are required to propagate the uncertainties of the input parameters, the directly measured optical properties, to the output using covariance or Monte-Carlo methods. The model representation of the object geometry and inherent model assumptions of the mathematical methods are essentially imperfect.

Figure 1 shows the scheme of the scatterometric measurement process: Optical signatures (scatterograms) are measured and modelled by rigorous solution of Maxwells equations. The modelling requires a-priori information like optical material parameters and a geometrical model for the structures to be measured. Measured and modelled scatterograms are compared and the geometrical model is systematically modified by nonlinear optimisation until a good matching is achieved. Measurement and modelling require many different input parameters, each with a systematic and/or stochastic error. For a complete measurement uncertainty analysis the impact and error propagation for each input parameter has to be evaluated. Additionally both the tool, the structure model as well as the applied Maxwell-solver suffer from some limitations and require specific approximations, which have to be evaluated thoroughly, either. As an example, the structures are typically regarded as ideal 1-dimensional perfect gratings without line edge roughness. As an example, in section 3 we show investigations of the impact of edge roughness on measurement results and also, how consider it in the data analysis.

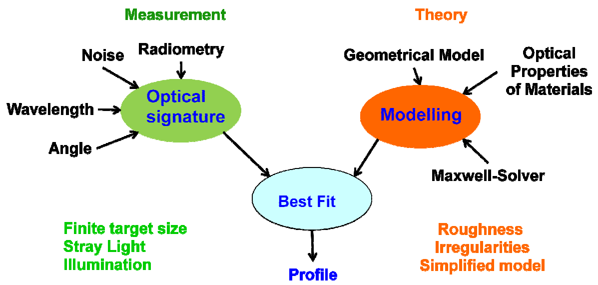

***Fig. 1** Scheme of the scatterometric measurement process. Both the measurement and the numerical modelling rely on many input parameters, only some of the most important are shown*

3 Line edge and line width roughness

Recent investigations [1, 2] have shown, that even small feature details like line edge (LER) or line widths roughness (LWR) do significantly affect the analysis of scatterometric measurements. To quantify this effect we performed numerical investigations based on finite element (FEM) based rigorous modelling [3]. We modelled a set of gratings stochastically perturbed by edge roughness (Fig. 2) for different amounts of roughness and investigated both the effect on the diffractions efficiencies (Fig 3) as well as on the construction results, i. e. the results of the nonlinear optimisation.

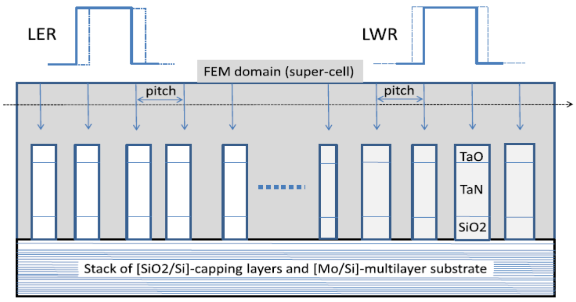

Fig. 2 *Applied geometrical model for LER and LWR modelling*

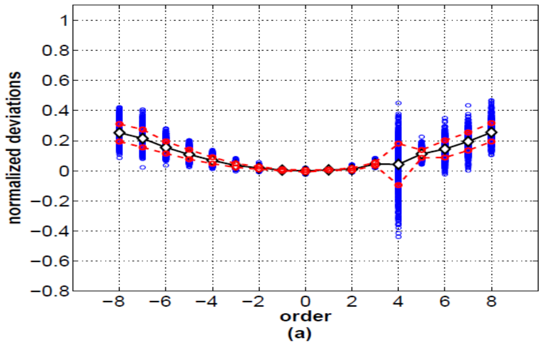

Fig. 3 *Normalized deviations of the calculated diffraction efficiencies for gratings with and without roughness*

The perturbed diffraction efficiencies are damped increasingly with increasing diffraction order. Equations 1 and 2 show the mathematical description of the unperturbed and perturbed efficiencies. The reconstruction result for the side wall angle SWA using these simulated data sets with shows, that a roughness of about σ = 3 nm leads to a systematic measurement error for e. g. the SWA of as large as 5°, if not taken into account in the data analysis.

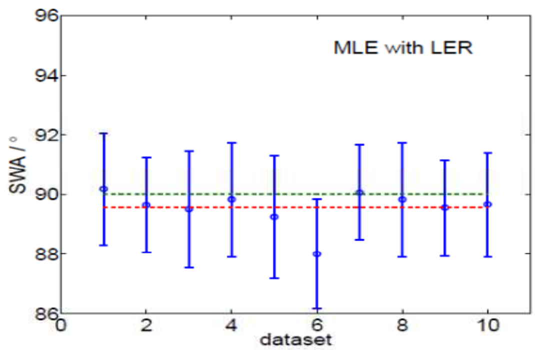

Fig. 4 *Reconstruction results for the SWA for different datasets for gratings with roughness. The result is in good agreement with the input SWA of 90°*

However, if correctly taken into account, the reconstructed SWA agrees with the exact value well within the statistical contribution to the measurement uncertainty (Fig 4).

$$\eta_i = f_i\,(p) + \varepsilon_i \qquad (1)$$

$$\eta_i = \exp\,(-\sigma_r^2 \cdot k_i^2) \cdot f_i\,(p) + \varepsilon_i \qquad (2)$$

4 Development of a scatterometry reference standard

To enable traceable scatterometry also in semiconductor industry, a wafer based scatterometry standard is required, but not available. Therefore we started to develop such a scatterometry reference standard with an aimed measurement uncertainty of $U_{CD} \approx 1$ nm for linewidths measurements. The standard shall meet the following requirements and specifications:

- the design takes into account different requirements of scatterometers, SEMs and AFMs
- set of targets are representative for current and future lithography technologies
- good knowledge of optical (as well as electrical and mechanical) parameters of the materials and of structure geometry details
- two materials: Silicon, resist mimicking material

A thorough characterisation of materials by Mueller Polarimetry, Ellipsometry, Reflectometry as well as of detailed structure geometries including roughness using specially developed AFMs, SEM, EUV scatterometry and GISAXS are performed. The standard samples will be tested and validated by comparison measurements by different type of scatterometry like Mueller Polarimetry, goniometric and spectroscopic Scatterometry, short wavelength scatterometry down to X-Ray and by Fourier Scatterometry.

5 Conclusion

To reach traceability in scatterometry we currently evaluated all significant effects both theoretically and experimentally. Additionally we started with the development of a scatterometry standard for dissemination of traceability.

6 Support

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References

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