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Comparison measurements for hybrid evaluation approaches in optical nanometrology

Tim Käseberg[1,*], *Bernd* Bodermann[1], *Matthias* Sturm[1], *Matthias* Wurm[1], *Thomas* Siefke[2], *Lauryna* Siaudinyté[3], *Astrid* Tranum Rømer[4], and *Poul-Erik* Hansen[4]

[1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany
[2]Friedrich-Schiller-Universität Jena, Institute of Applied Physics, 07745 Jena, Germany
[3]VSL National Metrology Institute, 2629 JA Delft, Netherlands
[4]Dansk Fundamental Metrologi A/S, 2970 Hørsholm, Denmark

Abstract. In the pursuit of closing the gap between nanometrology and nanofabrication, we investigate the use of advanced optical far field methods for sub-wavelength parameter reconstruction. With the goal of establishing a hybrid evaluation scheme connecting different methods and including different information channels, we performed comparison measurements on a silicon line grating sample with buried as well as not buried surface relief lines. To this end, the results of our measurement are in good agreements with each other, and the collected structure data is feasible to be used for hybrid evaluation.

1 Introduction

In optical nanometrology, several advanced far field methods like scatterometry, reflectometry, or ellipsometry, including methods based on high-NA Fourier optics, are currently available for nanostructure characterization. Each of these methods has on its own been proven to deliver high performance in terms of metrological results in both, research and industrial applications [1]. Critical dimensions (CD) down to a few nm can be retrieved, making these methods valuable in fields like nanoelectronics manufacturing, semiconductor industries, and defect inspection. However, the mentioned optical methods often struggle when they are applied to smallest structures, intermediate layers, or intricate three-dimensional architectures. In these areas, the fast progress in modern nanofabrication still requires nanometrology to keep pace [2]. Despite the developments in metrology in the last years, this metrology gap remains a major hurdle in fulfilling the requirements for advancements in the so-called key enabling technologies defined by the European Commission [3]. Thus, the development of new metrological methods for the assessment of nano-structural information beyond the current state-of-the-art is indispensable. A promising direction for this is the complete exploitation of all accessible degrees of freedom in optical measurements, encompassing spectral, angular, spatial, as well as polarisation diversity.

In pursuit of closing this metrology gap, we investigate in modern optical methods to accurately measure lateral feature sizes below the specifications of currently available techniques with low uncertainty. This contribution presents a measurement comparison on specially designed reference artefacts. They contain periodically structured samples based on common material systems, featuring both surface relief line gratings as well as buried structures as a first assessment of the methods' capabilities in measuring more complex sample architectures with objects located at different depths. The measurement methods discussed and compared in this contribution encompass conventional light microscopy, 3D through-focus microscopy, goniometric scatterometry, coherent Fourier scatterometry, spectral Mueller ellipsometry, as well as imaging Mueller matrix ellipsometry. Apart from comparing the individual optical methods with each other, a hybrid evaluation of the measurement results regarding structural features is endeavoured. Undertaking this task however necessitates a prior comparison of the different methods on the same sample to gain insight about possible deviations in the different setups.

2 Comparison framework

The samples used to compare the different methods are one-dimensional line gratings. They were realized on a silicon wafer by means of character projection electron beam lithography as well as inductive coupled plasma etching. The gratings have a nominal height of 150 nm and pitch sizes between 181 nm and 792 nm. Due to the fabrication, a sidewall angle of around 88° is expected. Grating area size, grating periods, as well as chip sizes were chosen to accommodate all targeted measurement methods. For investigations of more complex sample architectures, half of the samples were then buried under a layer of Al_2O_3 by means of atomic layer deposition. The formation of trenches that naturally occur with this method was counteracted by keeping the burying layer as thick as the pitch size. Figure 1 shows a sketch of the

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[*] Corresponding author: tim.kaeseberg@ptb.de

cross-section of one grating line, with and without burying layer.

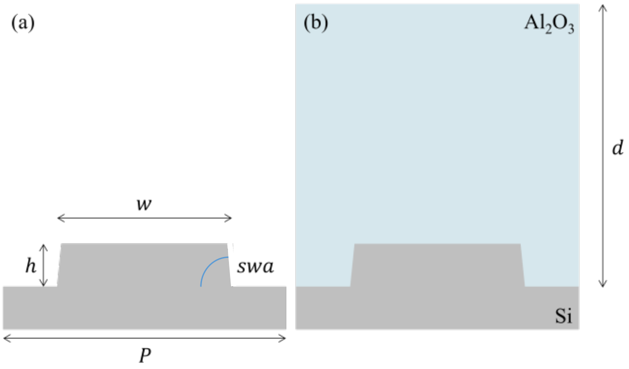

Fig. 1. Cross-section of the line grating used for comparison measurements. The lines have a nominal height of h = 150 nm with an expected side wall angle *swa* ≈ 88°. The burying layer thickness is d = 589 nm.

3 Preliminary results

Measurements from different conventional Mueller matrix ellipsometry setups are in good agreement with each other and reconstruct the sample parameters within a 1σ interval of around 3 nm [4].

As an example, Fig 2 shows the full Mueller matrix of a grating with nominal pitch of 792 nm, measured with the spectroscopic Mueller ellipsometry setup at DFM at wavelengths from 250 nm to 850 nm. While the reconstructed height is found to be within 5 nm of the design value of 150 nm, the measured widths of 451,4 nm deviates considerably from the nominal width of 396 nm.

In general, the retrieved parameters show a comparably large deviation from the designed values, especially concerning the structure width (CD). However, this is not unusual for e-beam lithography.

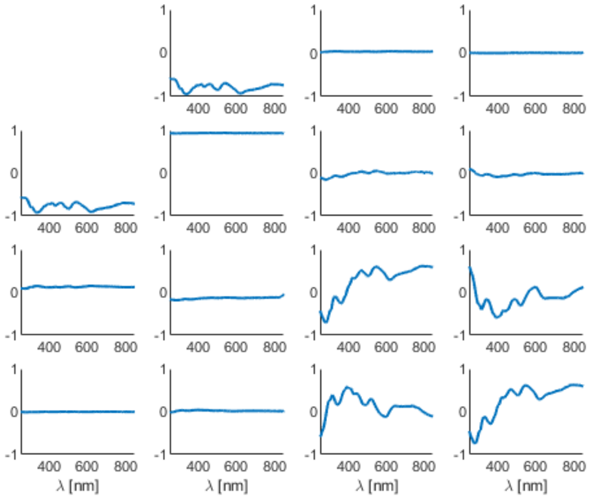

Fig. 2. Mueller matrix elements for spectral ellipsometry obtained at the ellipsometer at DFM for a grating of nominal pitch size of P = 792 nm and a nominal width w of 396 nm.

Figure 3 shows an example of the uncertainty estimation from Bayes analysis for Mueller ellipsometry measurements performed at PTB. This analysis allows to derive the expectation value and uncertainty as well as parameter correlations of the measurement.

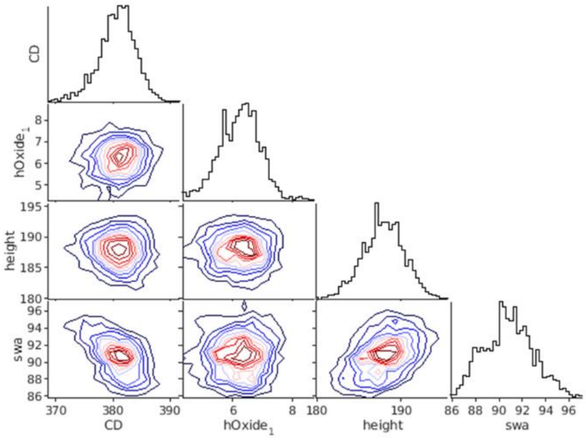

Fig. 3. Example of uncertainty estimation from Bayes analysis obtained for Mueller ellipsometry measurements of the same a grating structure as fig. 2 obtained at PTB

The test structures have additionally measured by other sophisticated optical methods, such as coherent Fourier scatterometry. In this method the diffraction pattern which is formed in the back focal plane of the microscope objective after the light and matter interaction is captured on a image sensor. Then the library of multiple parameter combinations is numerically simulated and after finding the best match for the measured data, the geometrical parameters of the sample are retrieved. Additionally, 3D through focus microscopy has been applied, which captures a stack of images at different focus positions [5]. This set of images are compared to a stack of modelled images. Data processing and analysis of these measurement are currently performed and the results and comparison with the ellipsometric measurement will be presented.

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References

1. P.E. Hansen et al., *Introductory Guide to Nano-metrology*. (European Commission and the participating consortium partners, 2010)
2. B. Bunday, A.F. Bello, E. Solecky, A. Vaid, Proc. SPIE **10585**, 105850I (2018)
3. https://www.europarl.europa.eu/RegData/etudes/STUD/2021/697184/EPRS_STU(2021)697184_EN.pdf
4. M. Wurm, T. Grunewald, S. Teichert, B. Bodermann, J. Reck, U. Richter, Optics Express **28**, 6 (2020)
5. 5. J. Xu, A.Refino, A. Delvallee, S. Seibert, Ch. Schwalb, P.- E. Hansen, M. Foldyna, L. Siaudinyte, G. Hamdana, H. Wasisto, J Kottmeier, A. Dietzel, T. Weimann, J. Prussing, H. Bracht and E. Peiner. Deep-reactive ion etching of silicon nanowire arrays at cryogenic temperatures. Appl. Phys. Rev. 11, 021411 (2024); doi: 10.1063/5.0166284