Dimensional optical metrology on deep sub-wavelength nanostructures

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We have investigated the limits of AGID-microscopy at islotated structures as well as goniometric scatterometry at grating structures for measuring linewidths down to the sub-wavelength regime. Numerical simulations show, that DUV-AGID microscopy is capable of measuring linewidths down to a few 10 nm while for scatterometry no fundamental limit has been observed.

1 Introduction

Novel applications in nanotechnologies covering the range from highest performance nanoelectronics, nanoscale sensing devices, to artificial materials and devices require accurate, reliable and efficient dimensional metrology to characterise the size and shape of the nanostructures. Although sophisticated ultra-high resolution techniques such as scanning electron microscopy (SEM) and atomic force microscopy (AFM) are available, optical methods such as microscopy and scatterometry are important and in many cases mandatory because of unique advantages and features.

At PTB two different and to a certain degree complementary methods for dimensional optical characterisation of nanostructures have been developed and investigated: Alternating Grazing Incidence Dark field microscopy using UV illumination (UV-AGID) allows measuring individual isolated structures. On the other hand polarisation sensitive DUV scatterometry is suitable to measure average dimensional parameters of periodic structures. Both methods have proven the ability to characterise accurately even sub-wavelength structures.

By numerical simulations we have investigated the performance of both methods for linewidths measurement of deep sub-wavelength line structures.

2 AGID microscopy

At PTB we have developed recently Alternating Gracing Incidence Dark-field microscopy (AGID), which enables accurate quantitative structure width (Critical Dimension, CD) measurements on isolated line structures even in the sub-diffraction regime [1]. AGID microscopy separates the dark-field signals of opposing edges in time, so that the edge positions can be analysed separately and without any mutual interaction. With a UV AGID microscope operated at an illumination wavelength of 375 nm, we demonstrated both numerically and experimentally accurate CD measurement down to 100 nm [1].

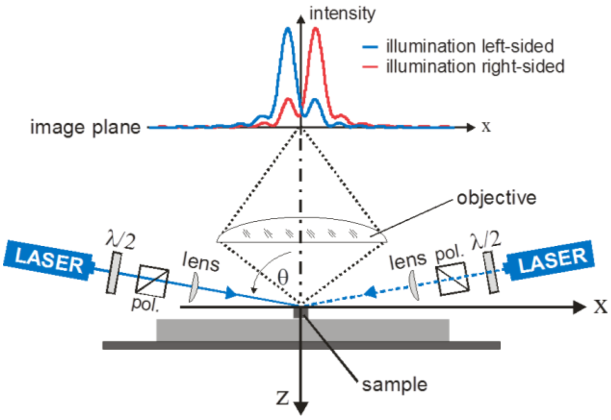

Fig. 1 *Schematic diagram of AGID microscopy.*

3 Goniometric DUV Scatterometry

For CD measurements and dimensional nanometrology on periodic structures at PTB we have designed and set up a goniometric DUV scatterometer system [2, 3]. Figure 2 shows a schematic diagram of the measurement configuration (top) and a photo of the measurement system (bottom).

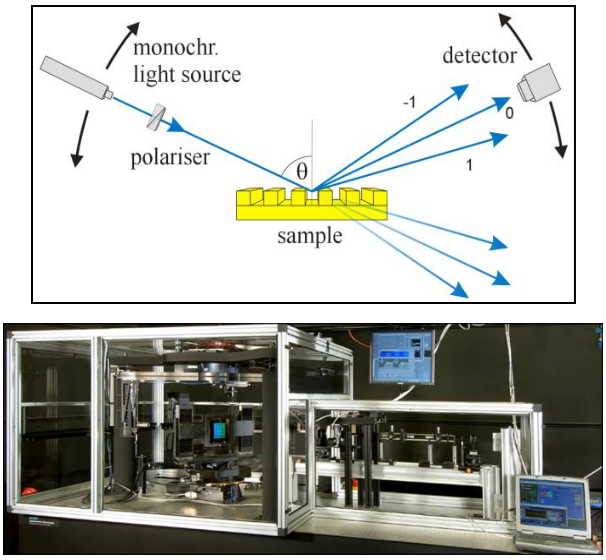

Fig. 2 *Scheme of scatterometry (top) and experimental set-up (bottom) of PTB's DUV scatterometer.*

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Recently, we have demonstrated the performance of DUV goniometric scatterometry for the measurements of deep sub-wavelength silicon line structures for grating periods down to 50 nm and CDs down to about 25 nm. For these measurements we applied a set of different polarisations and measurement geometries to enhance the degree of structure information in the measured scatterograms.

4 Subwavelength capability of UV-AGID

We have simulated AGID images both for silicon and chrome line structures with varying linewidths between 10 nm and 600 nm for three different wavelengths: 193 nm, 266 nm and 374 nm. The simulation results are presented in figure 3 for the silicon structures. The corresponding distances of the AGID peaks for left-sided and right-sided illumination versus the nominal width of the structure show a good CD linearity for structure widths down to about 30 nm.

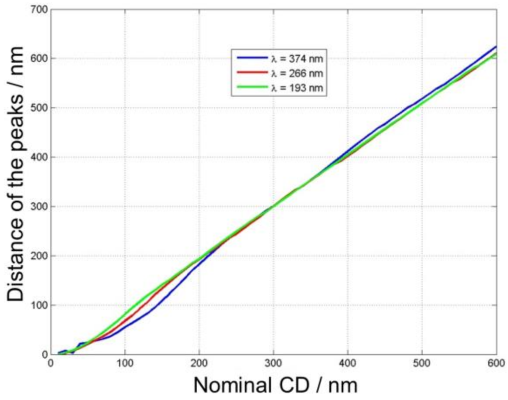

Fig. 3 *UV-AGID: CD linearity for isolated Si line structures, different wavelengths; angle of incidence of 85°*

5 Subwavelength capability of scatterometry

The four different polarisation and measurement geometries used for sub-wavelength scatterometry are depicted in figure 4a. We modelled the corresponding reflectance curves obtained for silicon gratings with scaling down the grating structure sizes in different ways. Figure 4b shows simulation results for gratings with a constant CD-to-period ratio of 1/2 and a constant structure-height-to-CD ratio of two and a proportional downscaling of the structure CD values from 25 nm to 0 nm. A significant and characteristic modification of the four reflectance curves is obtained, even for CD values below 5 nm. For all investigated numerical test series no fundamental lower limit for measurable CDs or grating periods has been observed.

6 Conclusions

We have investigated by means of numerical simulations the potential of two optical metrology approaches, AGID microscopy and polarisation sensitive scatterometry, for dimensional nanometrology in the deep sub-diffraction regime.

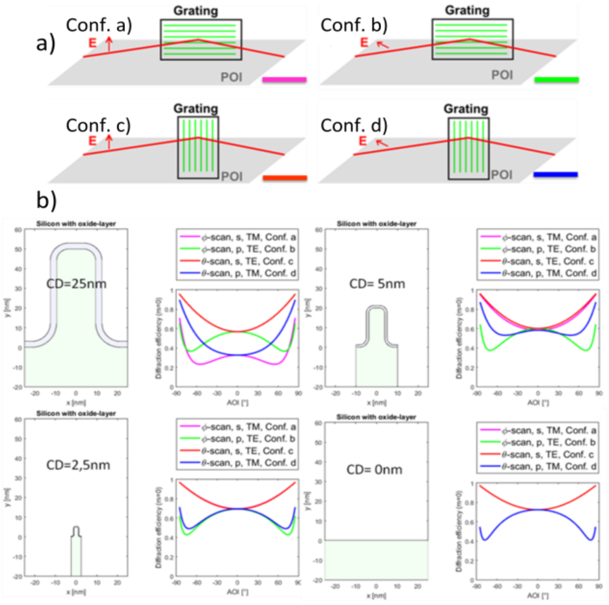

Fig. 4 *a) The four measurement configurations used, b) simulated reflectance versus the angle of incidence (AOI) for different structure dimensions proportionally scaled down from CD=25 nm to CD=0 nm.*

It has been shown that UV-AGID microscopy in the DUV spectral range is in principle capable to measure isolated line structures down to about 30 nm, depending on the structure material. For scatterometry on periodic grating structures no fundamental limit has been observed. In practise technical issues such as the signal-to-noise ratio will ultimately limit the performance.

In the future we are going to confirm these numerical results experimentally by conducting measurements on suitable sub-wavelength structures and comparisons with SEM measurement results, and to investigate the practical limits of these methods

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