Imaging Mueller matrix ellipsometry measurements on measuring fields in the micrometre range

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Abstract. An imaging Mueller matrix ellipsometer is used to measure structures in measuring fields in the micrometre range, which are too small for conventional ellipsometry. Line and grid structures are measured and evaluated with the help of numerical simulations using the finite element method to characterize the structure parameters.

1 Introduction

In semiconductor technology, the production of nanoscale structures is of great importance for many different applications. Quality control is necessary to ensure precise production of these structures. Various high-resolution microscopic methods can be used for this, such as atomic force microscopy (AFM), scanning electron microscopy (SEM) or transmission electron microscopy (TEM). However, optical methods are also used and have the advantage that they measure non-destructively and can therefore also be used in-line. An important parameter for the characterization of small structures is the polarization information. For this reason, polarization-based methods for quality control, such as Mueller matrix ellipsometry (MME), are being used more and more frequently [1].

The structures manufactured in industry have ever smaller dimensions down to a few nanometre, with sizes of the measuring field in the micrometre range. In conventional ellipsometry, the Mueller matrix is integrated over the whole illumination spot, which has a diameter in the range of 1 mm. This poses a challenge for conventional ellipsometry to measure these small measurement fields, avoiding impact of the surrounding area and the measurement field size and shape. In order to meet these increasing requirements, conventional ellipsometry requires an extension. One promising solution is imaging Mueller matrix ellipsometry (IMME). A conventional ellipsometer is extended by the components of a microscope. In this way, it is possible to measure the Mueller matrix for each pixel of the camera, which makes it possible to measure measuring fields in the micrometre range.

Since ellipsometry is an indirect measurement method, numerical simulations using the finite element method are needed to reconstruct the structural parameters and to solve the inverse diffraction problem.

2 Imaging Mueller matrix ellipsometer

For the Mueller matrix image measurements, the imaging Mueller matrix ellipsometer EP4 (Park Systems GmbH, Accurion Division, Göttingen, Germany) is used. The Mueller matrix can be measured in a wavelength range from 400 nm to 1000 nm, the interchangeable objectives have a magnification of 10, 20 and 50 and the angle of incidence can vary between 38° and 90°. The detector is a CCD camera with 1392 × 1040 pixel and a pixel size of 6,45 μm × 6,45 μm, allowing lateral resolution of up to 1 μm. A second compensator has been added to the commercial device to be able to measure the whole 4 × 4 Mueller matrix [2]. This extension is useful for metrological purposes, to be able to determine measurement uncertainty and to draw conclusions about the depolarization of the investigated structure [3].

3 Sample

A sample from Supracon [4] is used for the measurements. The sample consists of a quartz substrate with a nanocrystalline silicon film in which the different structures are etched. There are line structures, gratings and circular gratings with different line widths from 80 nm to 2000 nm and pitches from 160 nm to 4000 nm. The measurement area of each structure is 10 μm × 10 μm with the exception of the larger structures with a pitch of 4 μm. An isolated single line is on one side of the line structures available, so that it is possible to measure both a single line and periodic lines. The structures on the sample can be seen in figure 1.

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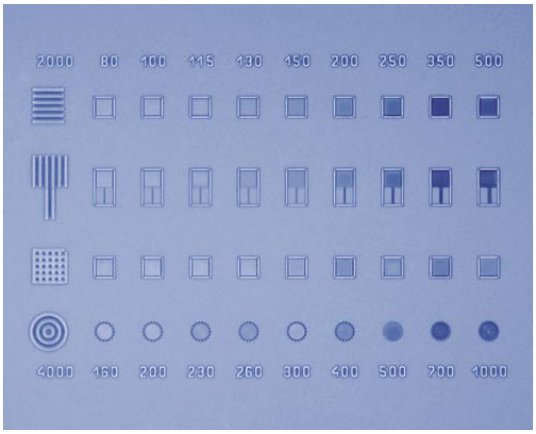

Figure 1: Line structures, gratings and circular gratings on the Supracon sample.

4 Measurements and simulations

Measurements are carried out on various structures in the spectral range from 400 nm to 1000 nm at different angles of incidence. Associated simulations are performed using the commercial FEM Maxwell solver *JCMwave* [5] to evaluate these measurements. Figure 2 illustrates the grid of a single line with a width of 100 nm and of a circular grating with 100 nm pitch, as representative examples.

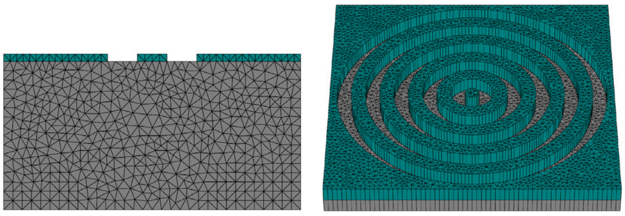

Figure 2: Simulation grid of a single line with 100 nm width (left) and of a circular grating with 100 nm pitch (right); gray: quartz, turquoise: silicon.

Figures 3 and 4 show what the Mueller matrix images of such structures look like. An optimization process, as described in detail in [3], is then carried out to draw conclusions about the real structure parameters. Measurement and simulation results are fitted to each other and the simulation parameters are varied until the best fit result is found.

On the one hand, these small measuring fields can be measured with the imaging ellipsometer and, on the other hand, they can be used to determine the physical limits of the measuring method.

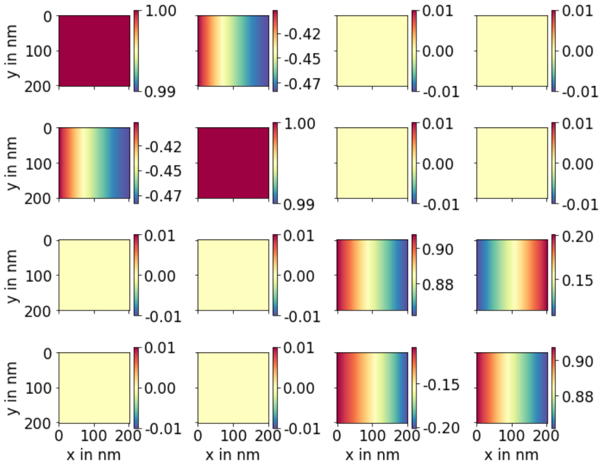

Figure 3: Simulated Mueller matrix image of a single line with 100 nm width at a wavelength of 500 nm and an angle of incidence of 50°.

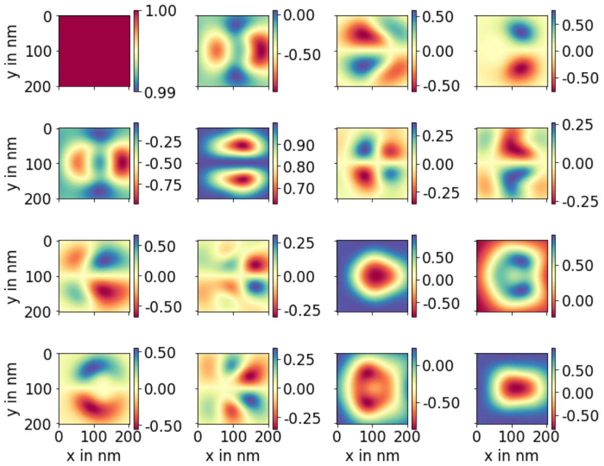

Figure 4: Simulated Mueller matrix image of a circular grating with 100 nm pitch at a wavelength of 500 nm and an angle of incidence of 50°.

References

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[4] http://www.supracon.com/en/nanoscale_linewidth_pitch_standard.html

[5] https://jcmwave.com/