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# Characterisation of nanowire structures with scatterometric and ellipsometric measurements

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**Abstract.** Nanowire structures arranged in a hexagonal lattice are to be characterized in terms of their diameter, height and pitch. A scatterometer and an imaging Mueller matrix ellipsometer, which is a combination of a commercial Mueller matrix ellipsometer and a microscope, have been used as measurement tools. These measurements are supported by numerical simulations using the finite element method to characterize the structure parameters.

## 1 Introduction

Within a European research project, the suitability of nanowire structures for energy harvesters of renewable sources, like solar, heat and movement, are investigated. These energy harvesters have great potential to address our global energy problem. Thus, nanowire based energy harvesters are particularly interesting due to their small physical size and high surface to volume ratio. For example, nanowire energy harvesters as solar cells have been shown to increase their efficiency from currently 17,8% up to 46,7% [1].

To achieve this, it is important to characterise dimensional parameters such as diameter, height and pitch of the nanowires to gain a better understanding of the performance of individual nanowires and an overall device, and to enable reliable and cost-effective device production. For this purpose, efficient and principally in-line capable measurement methods are required. Fast optical methods such as scatterometry and ellipsometry are very promising for this purpose. However, classical scatterometers and ellipsometers as integrating methods only provide global information about a nanowire array due to the spot size of typically 1 mm$^2$. An imaging ellipsometer in contrast is combining classical ellipsometry with microscopy. The data is no longer integrated over the entire illumination spot size, but evaluated for each pixel of the camera, which corresponds typically to about 1 µm$^2$ in the object space. Thus, areas much smaller than the illumination spot size and even non-periodic structures can be measured. In this way, data about the homogeneity of the nanowires over a large area as well as about the local polarization properties of individual nanowires can be obtained. Furthermore, full Mueller matrix ellipsometry providing the complete polarisation encoded information about the nanostructures has been shown to provide the best option to enable nanoscale dimensional metrology [2]. Thus, combining imaging and non-imaging methods add both fast integral as well as local information about the samples and therefore both are investigated here to develop the required nano-dimensional metrology. Both methods require numerical simulations to solve Maxwells equations and the inverse diffraction problem [3]. We use a finite-element-based Maxwell-solver for this purpose. In the following we present the experimental setups, the models used for the data analysis and first measurement examples for both investigated methods.

## 2 Experimental setup

In the first approach, measurements are performed with a goniometric DUV scatterometer. Thereby it can be checked if the distribution of the nanowires on the sample is stochastic or deterministic. In case of stochastically distributed nanowires, the surface is too inhomogeneous to perform measurements. For the second approach, an imaging Mueller matrix ellipsometer is used for the measurements to measure individual nanowires or local features in periodic nanowire gratings. In both cases, simulations are performed using JCMwave's finite element method to support the evaluation of the measured data with respect to the structure parameters.

### 2.1. Scatterometer

The used measurement device is a DUV scatterometer of own construction. The device has a high degree of automation, the detector is locating on a nearly 360° rotating arm, so that measurements in transmission and reflection are possible. The working wavelength is 266 nm and the illumination spot has a diameter of about 1 mm.

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### 2.2 Imaging Mueller matrix ellipsometer

For the Mueller matrix image measurements, an imaging Mueller matrix ellipsometer EP4 from Accurion is used (see figure 1). The Mueller matrix can be measured in a wavelength range from 400 nm to 1000 nm, the 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. A second compensator has been added to the commercial device in order to be able to measure the whole 4 × 4 Mueller matrix.

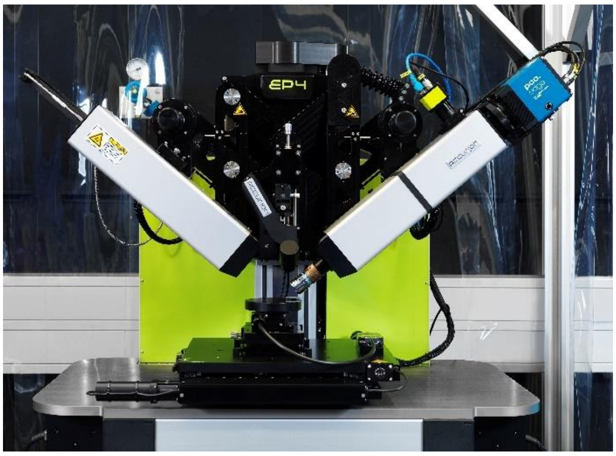


**Fig. 1.** Imaging Mueller matrix ellipsometer from Accurion.

### 2.3 Model structure

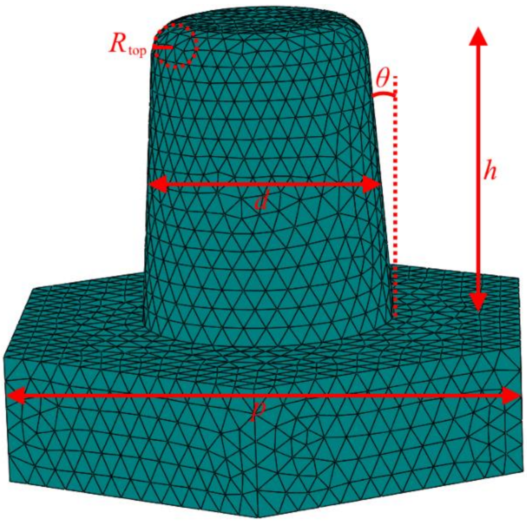


**Fig. 2.** Schematic layout of the used model with structure parameters: height $h$, pitch $p$, diameter at half maximum $d$, sidewall angle $\theta$, top edge rounding $R_{top}$.

A sample from Eulitha AG in Switzerland is used for the measurements. The sample consists of a silicon substrate with silicon nanowires arranged as pillars on hexagonal lattice. For the model of the simulations in JCMwave the dimensions of the manufacturer are used:

- height $h$: 600 nm ± 15%
- pitch $p$: 1000 nm
- diameter $d$: 460 nm ± 10%
- sidewall angle $\theta$: 2° - 6°

In addition, an edge rounding $R_{top}$ with a radius of 50 nm is assumed. The final model with periodic boundaries can be seen in figure 2.

## 3 Measurements and simulations

Previous work [3, 4] has used 1D nanowire structures to demonstrate that measurements with a scatterometer provide reproducible results and that best fit results from simulations can be used to reconstruct the structure parameters. This procedure is extended for the scatterometric measurements on the sample presented here.

First simulations of the Mueller matrix images were performed (see figure 3). The images already provide meaningful results. When varying the structure parameters height, pitch, diameter, sidewall angle and top edge rounding, the individual matrix elements change, especially the off-diagonal elements. In this way, by comparing the measurements with the simulations in a non-linear optimisation the inverse problem can be solved to derive the searched structure parameters.

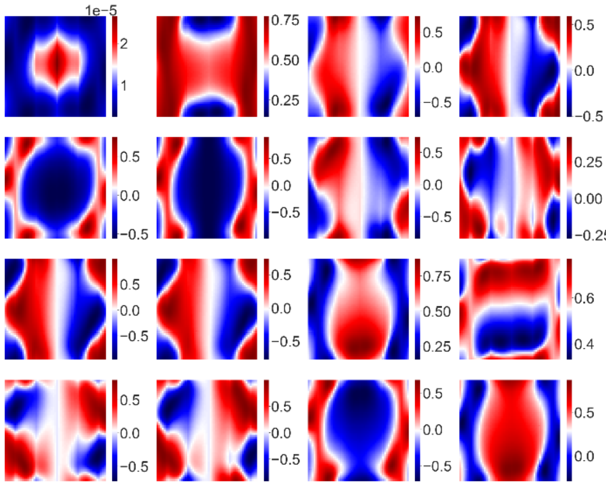


**Fig. 3.** Simulation of the Mueller matrix images at a wavelength of 500 nm with the structure parameters: $h$ = 600 nm, $p$ = 1000 nm, $d$ = 460 nm, $\theta$ = 4°.

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