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Advanced Error Modelling of a Fourier Scatterometer

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Summary:
Several error sources of a Coherent Fourier Scatterometer have been modelled to improve the accuracy and uncertainty evaluation of the measurement of geometrical dimensions of gratings, such as the critical dimension, height and pitch. Using the error model, the sensitivities of the geometrical dimensions of a grating to the error sources have been evaluated. In combination with the uncertainties of these error sources, these sensitivities can provide insight into how to improve measurements of gratings with nano dimensions, which can be of great benefit to the semiconductor industry.

Keywords: error model, virtual model, uncertainty evaluation, scatterometry, nano measurements

Coherent Fourier Scatterometry

Coherent Fourier Scatterometry (CFS) is a technique that has shown promising results in measuring nano dimensions in gratings, as shown in [1] for example. In CFS, an object is illuminated by a focused coherent light source. The scattered light is measured by means of a camera, and the geometrical parameters of the grating (such as critical dimension (CD), pitch, and height) are reconstructed from that image. A schematic sketch of the measurement set-up and the relevant geometrical parameters of the periodic sample are visualized in figure 1.

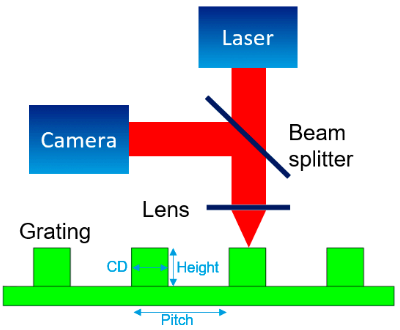

Fig. 1. Measurement set-up of CFS and relevant geometrical parameters.

The reconstruction of the parameters characterizing the sample geometry is done by inversion of the so-called forward model, in which the measurement is replicated by a virtual experiment. The aim of the model inversion is to find the set of geometrical parameters that minimizes the difference between the measured image and the simulated image.

By using a specific measurement scheme, CFS is reported to yield an enhanced sensitivity, as discussed in [2]. This is desirable in for example the semiconductor industry, given the shrinking dimensions in microchips.

The virtual experiment is a crucial ingredient in CFS. It is not only part of the measurement procedure, it also provides a means to evaluate the uncertainty associated with the estimates of the geometrical parameters. It is therefore essential for the virtual experiment to be as realistic as possible. This means that the error sources that can contribute to (a distortion in) the measurement result, should also be addressed in the virtual experiment. Although research has been performed in modelling error sources in scatterometry [3, 4], so far, relatively little research has focused on CFS.

In our research, we have focused on modelling several error sources that can occur during the CFS measurement. This enables more accurate estimates of the geometrical parameters of the grating, as well as more realistic estimates of the uncertainties associated with these estimates. We distinguish two different main sources of error: errors coming from the measurement set-up and errors coming from undesired artefacts in the grating.

Errors in measurement set-up

Errors in the measurement can come from, for example, errors in the properties of the measurement equipment or from the positioning of the grating that has to be measured.

There are several error sources that can come from the properties of the measurement equipment. For example, the numerical aperture of the lens determines the angles of the incident light. Different incident angles lead to different scattering patterns. In addition, the wavelength of the laser is a component in determining how the light scatters from the grating. It is therefore important to consider all uncertainties in the numerical aperture of the lens as well as in the wavelength of the laser. The properties of the measurement equipment should therefore be accurately measured. This is out-of-scope for this paper.

Errors can also be introduced by the positioning of the grating. For example, it is possible that the light is not properly focused on the sample or that the sample is rotated or slightly tilted (either parallel to the grating, perpendicular to the grating, or a combination of the two). A defocused sample will, for example, alter the point at which the incident planewaves refract on the grating. This leads to a phase shift that can be incorporated into the virtual experiment.

Errors in grating

It is possible that there are artefacts in the grating that influence the scattered light. If not accounted for, these artefacts can cause a mismatch between the measurement and the virtual counterpart. This can lead to errors in the estimates of the geometrical parameters. We have modelled the following sample artefacts: rounded corners, oxide layer, bulged walls, and roughness, as shown in figure 2.

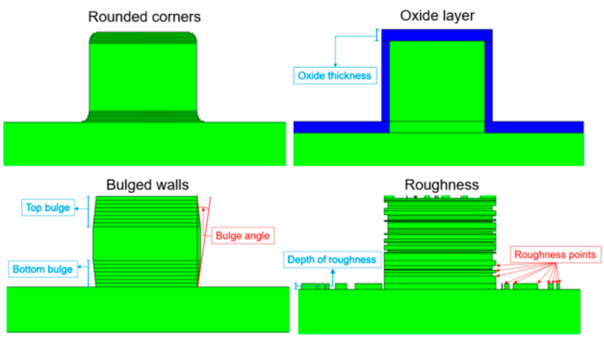

Fig. 2. Sample artefacts that have been modelled in the virtual experiment.

Sensitivities

Having included these errors in the virtual experiment, we are able to determine the sensitivity of the measurement with respect to the different error sources. Once the magnitudes of the individual errors sources have been measured of the real scatterometer, this will provide insight into which error sources have the most impact on the estimates of the geometrical parameters. Knowing the most dominant error sources, one can more effectively perform the measurement which reduces the overall uncertainty of the geometrical parameters. The sensitivities of the error sources for a particular grating and measurement set-up can be found in table 1. To ease the presentation, a nominal error with value 1 has been used, and its effect on the measured critical dimension, pitch and height has been evaluated.

Tab. 1: Sensitivities of the critical dimension (CD), pitch, and height with respect to the error sources.

Error source	**Nom. Error**	**CD [nm]**	**Pitch [nm]**	**Height [nm]**
Numerical Aperture	0.01	0.61	0.55	0.69
Laser wavelength	1 nm	0.65	1.37	0.32
Parallel tilt	1°	0.00	0.00	0.00
Perpendicular tilt	1°	0.00	0.00	0.00
Rotation	1°	0.00	0.00	0.00
Defocus	1 nm	0.09	0.25	0.53
Rounded corners	1 nm	0.00	0.00	0.00
Oxide layer	1 nm	0.98	0.36	0.44
Roughness	1 nm	1.22	0.11	0.19
Bulged walls	1°	0.94	0.44	0.92

The sensitivity coefficients can be used for determining the measurement uncertainty, e.g. an uncertainty of 0.1 nm in laser wavelength would result in an uncertainty of 0.065 nm in the CD. Note that this is not an exhaustive list of all errors and more error sources will be included at a later stage.

When the uncertainties of all the error sources have been established experimentally, the combined measurement uncertainty can be calculated. At the same time it will become clear what the dominant sources of uncertainty are. These insights can help in subsequently reducing the overall uncertainty of measurements based on CFS.

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