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Measuring multiple nano-textured areas simultaneously with imaging scatterometry

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Abstract

Periodic nano-textured surfaces have been characterised using the new optical imaging scatterometry technique. A major benefit of imaging scatterometry compared to traditional scatterometry is that an area much smaller than the illuminated area can be analysed. That is, instead of averaging over the full illumination spot, scatterometry analysis can be made pixel by pixel. An area of interest much smaller than the spot size can therefore be characterized and the user first has to select the area of interest in the post-processing. Furthermore, a specific area on the sample can easily be found and areas with defects can be avoided. These advantages make imaging scatterometry a very effective and user-friendly characterization method and allow us to determine the homogeneity of a nano-textured surface by performing pixel-wise analyses. In the analysis an inverse modelling approach is used, where measured diffraction efficiencies are compared to simulated diffraction efficiencies using a least-square fitting approach. We demonstrate an imaging scatterometry setup built into an optical microscope. The setup is capable of measuring multiple 2D gratings with pitches of 200 nm simultaneously. It is demonstrated that the imaging scatterometer can measure 2D nano-textured surfaces with an accuracy of a few nm for the depth and width of the structures on areas down to 3 x 3 µm^2.

Keywords: Scatterometry, Instrumentation, Nanostructures, Nanometrology

1. Introduction

Products can get new or additional functionalities, such as iridescence or hydrophobicity, by having nano-textured surfaces [1]. Structural colours is a phenomenon also evident in nature, where diffracted light from nanostructures generates vivid colours [2]. Conventional techniques like atomic force microscopy (AFM) and scanning electron microscopy (SEM) give high resolution but are time consuming [3].To keep up with an increasing production rate, new faster measurement systems are desired. In addition AFM is hindered by a small field of view and SEM requires a low ambient pressure, which limits the sample size [4]. Scatterometry is a fast, non destructive, measurement technique with high resolution and it is used for in-line characterisation in the semiconductor industry [4]. It is based on the reconstruction of a grating profile from its optical diffraction responses. Conventional scatterometry analyses the entire area covered by the spot size. In this paper we use an imaging scatterometer [4], to perform a pixel-wise analysis of a nano-patterned area.

2. Method

The diffraction efficiency, η, is measured as the ratio of the diffracted light with respect to the incoming light [4]. The background is accounted for with a dark measurement. Hence three measurements, with the same settings, are required for each wavelength, λ, a sample measurement, I_{Sample}, a reference measurement, I_{Ref}, and a dark measurement, I_{Dark}. Each measurement including positioning the sample takes less than a minute, much faster than SEM, where the chamber needs to be evacuated, and AFM, which is a slow scanning technique. Figure 1(A) shows a sample measurement and labels the gratings.

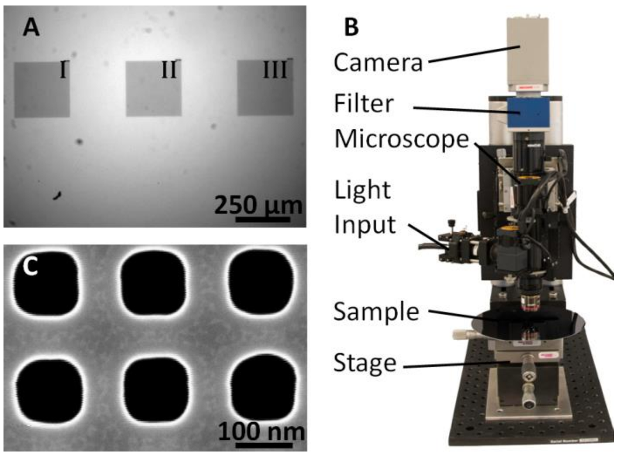

Figure 1. Imaging scatterometer setup. (A) Image from the sample measurement using a wavelength of 670 nm. The 3 gratings are referred to according to this image. The structures have a period, Γ, of 200 nm. (B) Photo of the setup. The light from the LED is modified by optical components and interacts with the sample placed on a translational stage. The diffracted light is filtered by a band pass filter and collected by a CCD camera. (C) SEM image of grating I.

In the post-processing an area of interest is selected, and the diffraction efficiency is calculated as described in [4],

$$\eta(\lambda) = \frac{I'_{\text{Sample}}(\lambda) - I'_{\text{Dark}}(\lambda)}{I'_{\text{Ref}}(\lambda) - I'_{\text{Dark}}(\lambda)} R(\lambda), \qquad (1)$$

where I'_{Sample}, I'_{Ref} and I'_{Dark} are the sample, reference and dark measurement, for the selected area, respectively. $R(\lambda)$ are the reflectance coefficients of the reference material. An inverse modelling approach is used where a set of parameters, describing the sample and the measuring conditions, are used to simulate the diffraction efficiencies for various structures. The simulations are based on rigorous coupled wave analysis [3]. Each simulated structure is compared to the experimental data using chi-square (χ^2) minimization as described in [4]. The simulated structure with the lowest χ^2–value is selected as the best description of the grating structure. The confidence limits for the fitting parameters are found using constant chi-square boundaries [3,4].

3. Experimental setup

The experimental setup is shown in figure 1(B). The setup is built into a conventional microscope (Navitar, 12x zoom), using a 4x infinite focus objective (Olympus, RMS4X-PF, NA = 0.13) with a field of view of approximately 2 mm^2. A cold white LED light source (Qioptiq, CLS-LED USB) is used to illuminate the sample. The incoming light is modified by a diffuser and a Glan-Laser polarizing crystal before it enters the microscope. The sample is placed on an XYZ-stage and brought into focus by adjusting the height of the stage. The light collected by the microscope is filtered by a tunable band pass filter (Varispec VIS-07-20, Perkin Elmer). The filter has a bandwidth of around 10 nm in the range from 400 nm to 700 nm. A charge coupled device (CCD) camera (Pixelink, PL-B957), is placed after the tunable band pass filter. Data have been obtained in the wavelength range from 440 nm to 670 nm in steps of 5 nm. The resolution is limited by the numerical aperture of the objective to around 3 x 3 μm^2. However, for reconstruction of a 1D grating with a step height of around 190 nm, the confidence interval is found to increase from 2 nm to 6 nm when switching from a spectrometer based scatterometer [5] to an imaging scatterometry setup [4].

4. Results and discussion

Holes etched in Si(100) with a pitch of 200 nm, see an SEM image in figure 1(C) have been studied. The holes can be described by depth, d, width, w, and rounding of the holes, r.. The rounding varies from $1/\sqrt{2}$, a perfect circle, to 1, a perfect square. Each grating span an area of 250 x 250 μm^2 and are thus challenging to characterize using conventional spectroscopic scatterometry. A plot of the measured diffraction efficiencies, with λ = 550 nm, is shown on figure 2(A) and the analysis of a single pixel is shown on figure 2(B). The 95 % confidence limits of a single fit is around 10 nm, 6 nm and 0.04 for the depth, width and radius, respectively. Better fits can be obtained by extending the wavelength range to the UV-region. The structural parameters estimated using the imaging scatterometer and reference instruments are shown in table 1.

Table 1. Estimated structural parameters using imaging scatterometry and reference measurements obtained from SEM and AFM of grating I. The values are an average over the grating and the ± denotes the standard deviation of the measurements. The standard deviation of grating II is found in the reduced area marked in figure 2(C), to avoid the observed defects. Around 40 000 pixels are analysed for each grating.

	Depth /nm	Width/nm	Rounding/1
Im. Scat. I	127 ± 3	122 ± 6	0.78 ± 0.06
Im. Scat. II	128 ± 3	122 ± 4	0.80 ± 0.04
Im. Scat. III	127 ± 3	122 ± 6	0.78 ± 0.06
SEM	N/A	118 ± 4	0.87 ± 0.03
AFM	139 ± 1	N/A	N/A

For reference measurements of the depth of the holes we used a metrology AFM (Park Systems, NX20) equipped with tilt-corrected tips (Nanosensors, AdvancedTEC) to ensure that we reached the bottom. The SEM images were analyzed using ImageJ with an algorithm for measuring the width and corner rounding. The expanded uncertainties (k=2) for the AFM and SEM measurements are estimated to 3 nm and 10 nm, respectively.

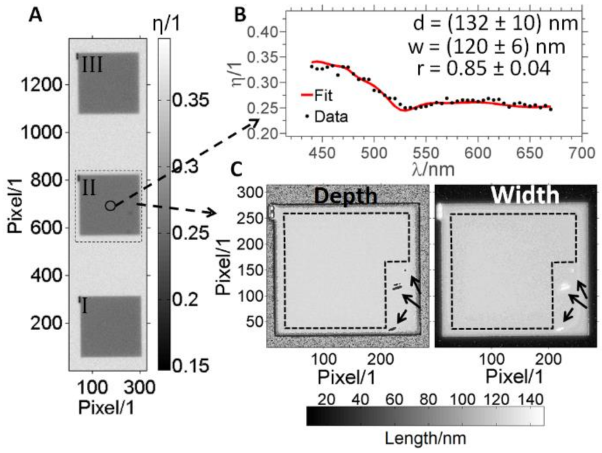

Figure 2. Imaging scatterometry analysis. (A) Measured diffraction efficiencies for a single wavelength (λ = 550 nm) in an area covering three gratings. (B) The calculated diffraction efficiencies, the best fitting model and the fitted parameters from a single pixel. The ± denotes the 95 % confidence limits of the fitted parameters. (C) Depths and widths for each pixel in an area covering grating II. The plots share the same y-axis and colour bar. The pixels have an area of approximately 1 x 1 μm^2. Defects on the grating can be observed and are highlighted by arrows. When performing standard deviation measurements the marked area is used, to avoid defects.

Pixel-wise scatterometry analysis of homogeneity for a grating area is shown in figure 2(C). The ability to make multiple local scatterometry analyses can be utilized to determine the homogeneity of a grating area by calculating the standard deviation of the scatterometry reconstructions for the three grating areas, as shown in table 1. The lower standard deviation measured on grating II is caused by a higher light intensity on this area, as can be seen in figure 1(A). The multiple local measurements are useful for defect detection in large grating areas.

5. Conclusion

We have used an imaging scatterometer to determine the structural parameters of multiple nanostructures simultaneously using multiple local scatterometry analyses. The imaging scatterometer offers a new method to identify defects and analyse areas smaller than the spot size. With imaging scatterometry we have analyzed a grating section of 3 x 3 μm^2, and studied the homogeneity of 250 x 250 μm^2 grating areas.

Acknowledgments

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