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High precision optical step detection

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For a high precision positioning and measurement system high accuracy detection of surface specific profiles such as steps or edges is required. The interaction of light with microscopic structures results in typical diffraction pattern which contain information about the 3D-profile. In this work we investigate these diffraction images in view of wavelength and position dependence.

1 Introduction

Due to the ongoing trend in miniaturization the demands for a precise determination of the relative position between a surface profile or structure and the measurement tool increase. An electromagnetic wave incident on a surface profile generates a characteristic diffraction pattern. This pattern depends on the properties of the radiation and the surface profile. Our aim is to increase the measurement accuracy of a position and height detection system by analyzing the resulting diffraction patterns using several wavelengths. In our work we focus on structures like steps with dimension in the sub-micrometer range. By use of a tunable laser source [1] we investigate the case if the step height is comparable to the wavelength. In order to compare the experimental results to the theory we use Fourier optical simulations.

2 Methods

Theory:

For the simulation of the interaction of a Gaussian beam with an edge or step we use a Fourier optical approach with a thin element approximation. That way the structure and the incident radiation are described within the framework of complex amplitude with amplitude and phase term. By multiplying the complex amplitudes of the element and the source and performing a Fourier transform we obtain the diffraction pattern in the far field.

Experimental setup:

The laser source we use provides a super continuum in the wavelength range of 420 to 2300 nm. By use of an additional active filter we select the wavelength of choice. Connecting an optical fiber with integrated collimator optics to the filter box a collimated output beam with an $M^2 < 1.1$ is achieved. [1]

In order to precisely realize the relative positioning between the optical system and the sample a 3-axis-piezo-stage is used. For coarse adjustment the piezo-stage is combined with manually driven translation stages.

The collimated beam of the laser source is focused by a 40x objective. The reflected light is collected by the same objective and coupled out with a beam splitter, as shown in figure 1. Finally the diffraction pattern is recorded with an 8bit 1MPixel CMOS array.

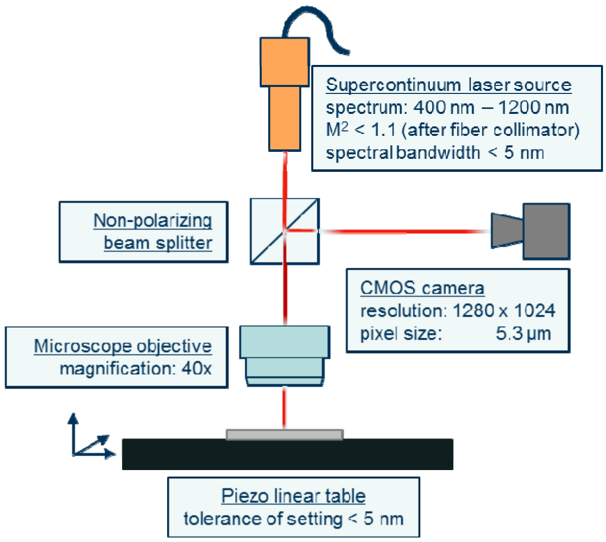

***Fig. 1** Measurement setup for optical step detection.*

The objects of study are fused silica glass wafers with step structures manufactured lithographically. To ensure that the laser spot only hits one step the lateral structures are in the order of several microns whereas the step heights are 540 ± 4.09 nm and 255 ± 4.59 nm.

3 Results and discussion

After adjusting and characterizing the whole measurement system we focus on experiments concerning the relationship of the step height and the wavelength of the laser beam. Thereby we

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choose a position of the laser spot relative to the center of the step.

Simulation and experimental results for 3 wavelengths, which yield specific phase shifts concerning the step height (540 nm) are shown in figure 2.

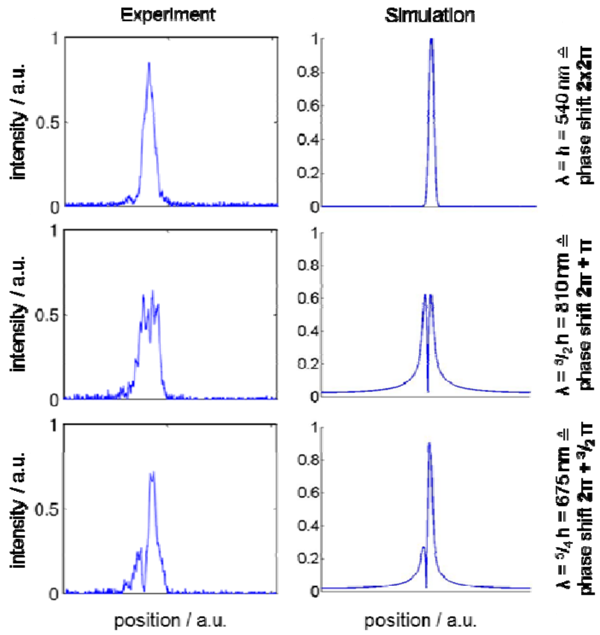

Fig. 2 *Diffraction patterns depending on special phase shifts of 4π, 3π and* $3^{1}/_{2}\pi$.

If the step height *h* is an even multiple of the chosen wavelength *λ* the pattern looks similar to the one obtained by a plane surface. A phase shift of π results in a double peak with half the intensity. Phase shifts with non-integer multiples of half the wavelength lead to variations of the two cases described above. Based on this behavior it is possible to expand the resolvable step height beyond several multiples of the wavelength.

Considering that the correct step height is known the determination of the step position is next.

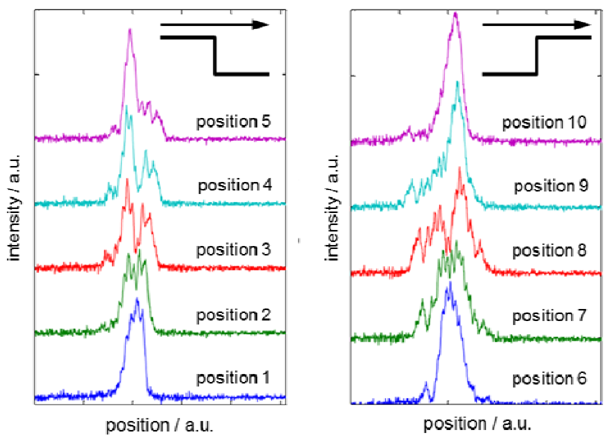

Fig. 3 *Diffraction patterns depending on the relative position (1 µm shift each position) between laser (λ = 810 nm) spot and step (height = 540 nm).*

Depending on the position of the step relative to the laser spot the diffraction patterns show a similar behavior to the curve shapes caused by the phase shift (compare figure 2 and 3). Figure 3 shows a path starting on the upper left position of the downwards step to the upper right position of the upwards step which both form a gap like structure. The increment of each position shift is 1 µm which represents a first value of the lateral position resolution and leaves leeway for optimization.

The wavelength dependent change of the diffraction pattern with respect to the movement of the laser spot relative to the step is used in current project work to significantly increase the lateral and height resolution.

4 Outlook

Up to now, we have demonstrated the proof of principle of a multiple wavelength improved position and height determination measurement system. Based on these results we trace 2 ways in the current project. The system has to be optimized in terms of integration and in view of enhancing the resolution.

In order to achieve better lateral and height resolution we have to decrease the spectral bandwidth of the wavelengths. Furthermore the dynamic range of the CMOS chip is a limiting factor of the current measurement setup.

Beside the improvement of the performance the system and its components have to be minimized and adapted to the application. A broadband laser source can be replaced by 3 to 4 LEDs or LDs. That way the system becomes cheaper and the spectral bandwidth is decreased. The detector can be replaced by a line sensor or a diode. Both steps reduce the system cost and increase the dynamic range of the measurement. Finally the process has to be automatized by use of a special adapted software routine.

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6 References

[1] NKT Photonics GmbH, *www.nktphotonics.com/*