Imaging and Applied Optics 2018, The Optical Society of America, Paper AW3A.1, Orlando, Florida, USA
25–28 June 2018, https://doi.org/10.1364/AIO.2018.AW3A.1

Nanoscale 3D Shape Process Monitoring Using TSOM

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Abstract: Through-focus scanning optical microscopy (TSOM) is sensitive to three-dimensional shape changes of nanoscale to microscale targets. Here we demonstrate process monitoring method of 3D targets using TSOM down to sub-nanometer.

OCIS codes: (120.3930) Metrological instrumentation; (170.0110) Imaging systems; (110.0180) Microscopy

1. Introduction

Through-focus scanning optical microscopy (TSOM) is a novel method [1-5] that allows conventional optical microscopes to collect dimensional information down to the nanometer level by combining 2D optical images captured at several through-focus positions, transforming conventional optical microscopes into truly 3D metrology tools for nanoscale to microscale dimensional analysis with nanometer scale sensitivity. TSOM identifies the 3D profile dimensional changes at the nanoscale for small perturbations in sidewall angle, width and height of isolated lines with little or no ambiguity. This work will present TSOM results to demonstrate the metrology application to features below 50 nm, showing the ability to measure changes in line width (LW) line height (LH), and sidewall angle (SWA) variations.

2. Results

Here we present experimental TSOM results using isolated Si lines on a Si substrate. The designed line widths varying between 30 nm and 40 nm were fabricated using standard fabrication methods. The line widths were carefully measured using a critical dimension atomic force microscope (CD-AFM). The smallest and the largest measured linewidths were 44.2 nm and 55.3 nm, respectively, with a fairly uniform height of 71.4 nm. Standard deviation values for line width and height are 1.6 nm, and 0.4 nm, respectively. A typical TSOM image of the 44.2 nm wide line is shown Fig. 1(a) (using 546 nm illumination wavelength, 0.8 numerical aperture (NA) and 0.27 illumination NA). Intensity profiles at several focus positions shown on the right-side help visualize the color scheme in the TSOM image and also demonstrate the way profile changes occur with focus position.

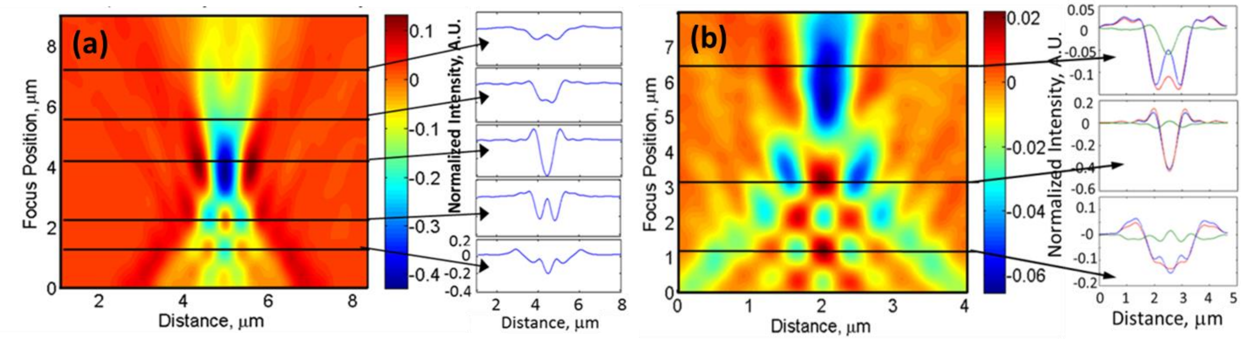
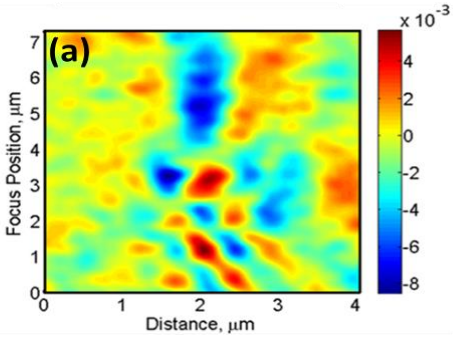


Fig. 1 Intensity of (a) normalized TSOM image of a 44.2 nm wide line (left) with intensity profiles at the selected focus positions on the right side, (b) a normalized differential TSOM image obtained using 44.2 nm and 55.3 nm wide lines (left) with intensity profiles at the selected focus positions and the corresponding differential profiles on the right side. The blue profile is for the 44.2 nm line, the red profile is for the 55.3 nm line, and the green profile is the differential.

A differential TSOM (D-TSOM) image is a pixel-by-pixel difference between two TSOM images. A D-TSOM image highlights nanoscale 3D shape differences. A D-TSOM image for 11.1 nm difference in the line width is shown in Fig. 1(b), which has an optical intensity range (OIR) of 8.5. OIR indicates the optical signal strength. On the right side, the optical intensity profiles and the differential profile from the two TSOM images are shown for the three selected focus positions. The maximum difference occurs in the upper region of the D-TSOM image, away from the best focus position (highest image contrast position) which is at about a 4 µm focus position.

The TSOM method was able to detect a linewidth difference as small as 0.8 nm as shown in Fig. 2(a), which has an OIR of 1.5. This is still above the noise threshold of about one, demonstrating the experimental feasibility of detecting sub-nanometer differences in linewidths using the TSOM method.



(b)

Nom.	λ	Minimum Sensitivity		
LW		LW	SWA	LH
nm	nm	nm	Degree	nm
22	546	0.04	0.06	0.08
22	248	0.21	0.38	0.15
22	193	0.08	0.1	0.04
16	546	0.07	0.26	0.24
16	258	0.12	0.45	0.2
16	193	0.13	0.27	0.15

Fig. 2 (a) Intensity of a D-TSOM image for 0.8 nm difference in the LW (47.9 nm and 48.7 nm). (b) Minimum detectable dimensional differences using the TSOM method for the three illumination wavelengths (λ).

Optical simulations were used to predict how TSOM would perform for measuring structural perturbations for nominally 22 nm and 16 nm wide line. The simulations used a commercially available finite difference time domain (FDTD). The sensitivity to several parameters (LW, LH and SWA) was studied. Both large and small perturbations of these parameters were applied to features with baseline design rules. The OIRs of the differential TSOM images were calculated as the difference between the perturbed state and the baseline state and compared to a noise threshold (OIR = 1) to predict the minimum sensitivity of TSOM to changes in the parameters. In this report, we focus on the small perturbations to determine the minimum threshold for TSOM sensitivity to the specified parameter. The results summarized in Fig. 2(b) show that TSOM has the ability to detect sub-nanometer differences in the dimensions.

3. Conclusion

In summary, experimental work demonstrates sub-nanometer dimensional sensitivity using the TSOM method, even with visible wavelengths. The simulations demonstrate the potential usefulness of TSOM for 3D shape process monitoring of lines as small as 16 nm. Sensitivity to various perturbations appears sufficient and distinct. In addition to economical metrology hardware, the substantially smaller area targets needed result in further potential cost savings. If paired with scanning electron microscopy, scatterometry (optical critical dimension) or other widely-used tools, an inexpensive tool such as TSOM could be a key component of a good hybrid metrology solution.

4. References

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