Metrology of Three-Dimensional Nanostructures using Scatterometry

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Three-dimensional (3D) periodic nanostructures exhibit a range of advantageous properties across multiple domains when compared to their bulk counterparts. Bagal et al. demonstrated that periodic nanostructures could achieve Young's modulus vs density scaling approaching theoretical limits, enabling lightweight yet mechanically rigid structures.[1] Similarly, Premnath et al. showed that such structures can be manipulated to yield designable optical refractive index, making them attractive for applications in photonics.[2] The mass production of these nanostructures has been demonstrated through roll-to-roll (R2R) fabrication using phase mask lithography;[3] however, their metrology remains challenging. Traditional characterization techniques, such as scanning electron microscopy (SEM) and X-ray–based methods, are time-consuming and require destructive sample preparation, rendering them unsuitable for in-line, large-scale fabrication or routine product quality control.[4] In this work, we present scatterometry as a practical and advantageous alternative that overcomes many of these limitations.

In this study, we investigate the high-throughput metrology of 3D periodic nanostructures using hyperspectral scatterometry measurements. We show that variations in structural geometry produce distinct reflectance responses and that enable accurate structural reconstruction. Figure 1 (a) shows the fabrication method of the samples where SU-8 resist is exposed to a flood exposure at normal incident. A PDMS phase mask generates a three-dimensional interference pattern, which is subsequently baked and developed.[5] The resulting structure is a 3D periodic architecture with a repeating pattern in the lateral directions and variation along the depth, cross sectional SEM shown in Figure 1 (b). The structure can be approximated using finite-difference time-domain (FDTD) simulations to model diffraction through the mask, yielding a qualitatively similar representation when simple thresholding is applied, which is also shown in Figure 1 (b).

For scatterometry measurements, the fabricated structures are illuminated with broadband light at incident angle, and their reflectivitance spectra are measured using a line-scan hyperspectral camera, as shown in Figure 2 (a). Figure 2 (b) shows the scatterometry results for structures fabricated under different exposure conditions, with the primary variation being exposure dose. We will present the details of the sample fabrication process, optical modeling, and the design of the scatterometry metrology system. In addition, we will discuss reconstruction methods used to recover the 3D structural geometry from the measured data using optical simulations.

Figures

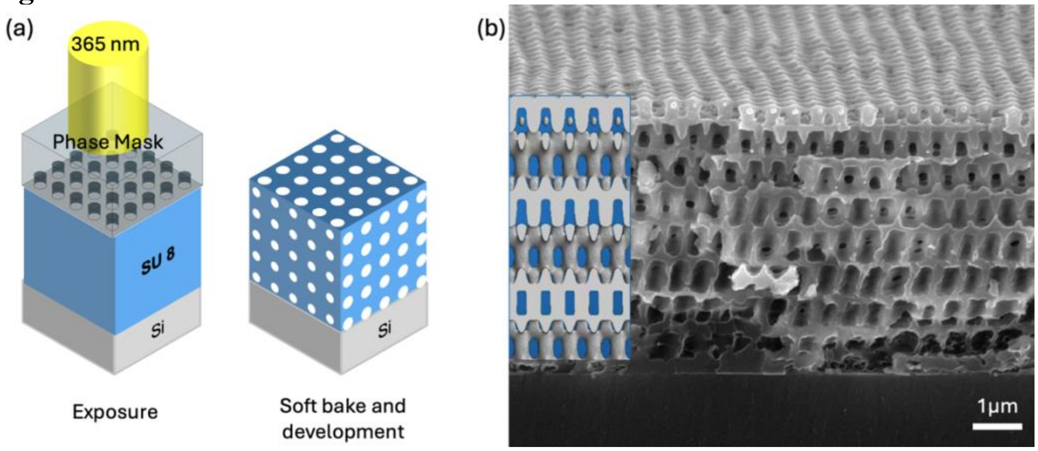

Figure 1. (a) Structure Fabrication Method(b) Cross section of Fabricated Periodic Nanostructures in SU-8

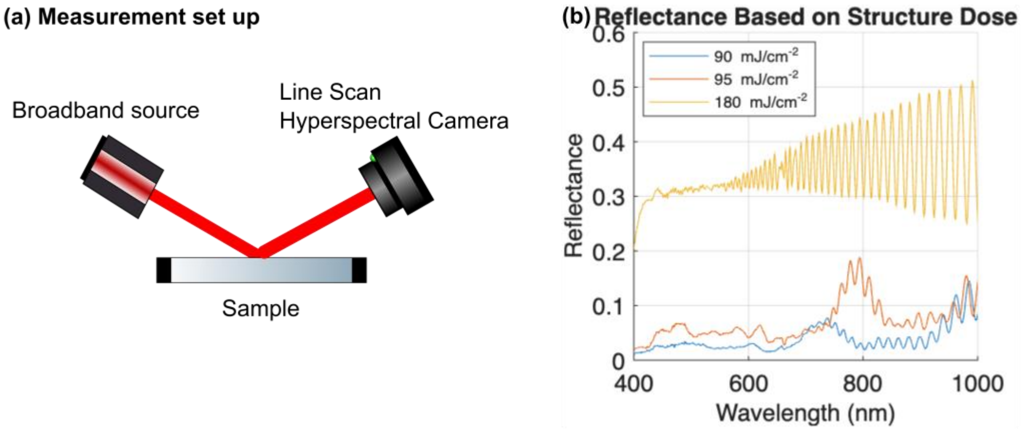

Figure 2. (a) Schematic of Scatterometry measurements of samples. (b) Sample Scatterometry Measurements of 3D Periodic Nanostructures with Different Features based on exposure dose using the line scan set up.

References

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