Characterization of Nano-grating Profiles using Standard Ellipsometry and Deep Neural Networks

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In-situ measurement of nano-grating profiles is of great importance in the semiconductor industry. Recently, as a popular and powerful tool, deep learning is applied to infer key parameters of gratings from measured spectral and ellipsometry information. Compared with conventional characterization techniques, such as scanning electron microscopy (SEM) and atomic force microscopy, deep-learning-based methods possess the advantages of high efficiency and high throughput. However, most reported methods of this type rely on Muller matrix ellipsometry [1] or some special optical measurement systems [2], which is typically expensive and not commonly available. Moreover, geometric models used in these methods are over-simplified and usually limited to a single patterning method or material, hindering their adoption in practical applications.

In this research, we propose a new method based on deep neural networks and gradient descent method to fully reconstruct the profile of nano-gratings using standard ellipsometry data (i.e., ψ and Δ). As shown in Figure 1(a), twelve parameters are adopted to describe the grating. The application of round corners, waist width, and refractive index makes the model compatible with various kinds of patterning techniques and different resists. Figure 1(b) illustrates the architecture of the algorithm. To relieve the problem of multiple solutions, seven sets of spectra from different azimuthal angles are fitted simultaneously as an additional constraint, which can improve the accuracy and stability of our method. Notably, these azimuthal angles can be arbitrarily selected within a predefined range. The candidate solution is updated by the gradient descent algorithm to minimize the mean square error (MSE) between predicted and measured spectra. As a demonstration, samples made by interference lithography are tested. To emulate measurement data, simulated ellipsometry spectra are added with Gaussian noise. Yellow dashed lines shown in Figure 2 display the inferred profile, which is consistent with SEM images. The mean absolute errors (MAE) of profiles for three gratings are 7, 9, and 9 nm respectively. MSEs of fitted and target spectra are only 15.4, 1.8, and 0.5.

1. K. Meng, B. Jiang, and K. Youcef-Toumi, *Appl. Surf. Sci.* **570**, 151219 (**2021**).
2. T. Li, A. Chen, L. Fan, M. Zheng, J. Wang, G. Lu, M. Zhao, X. Cheng, W. Li, X. Liu, H. Yin, L. Shi, and J. Zi, *Light: Sci. Appl.* **10**, 154 (**2021**).

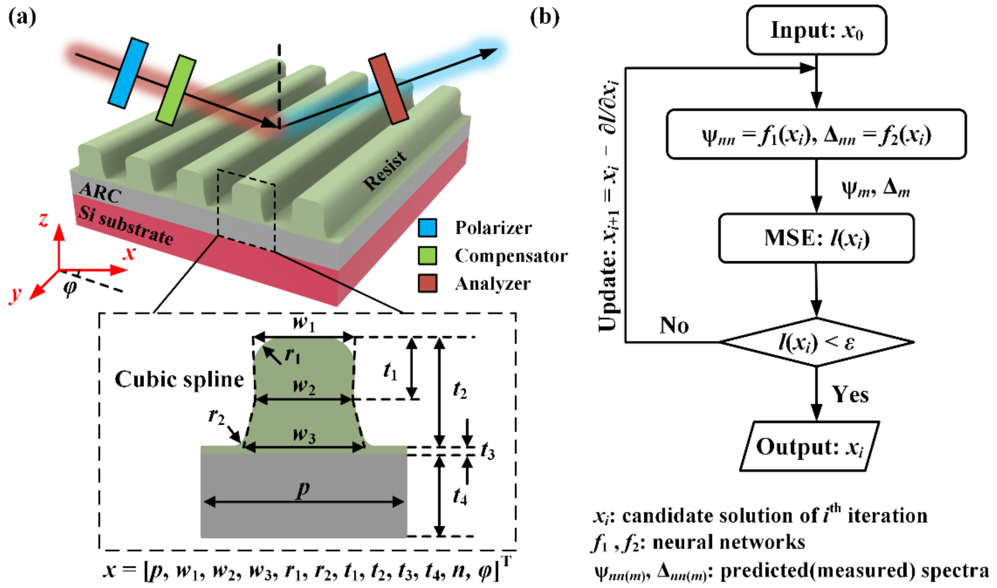

Figure 1. (a) Schematic of a standard ellipsometer (top inset) and model of the grating profile (bottom inset). Twelve parameters are used to describe both geometric and optical properties (refractive index *n* of resist) of measured gratings. (b) Flow chart to iteratively infer satisfactory parameters from measured ellipsometry data.

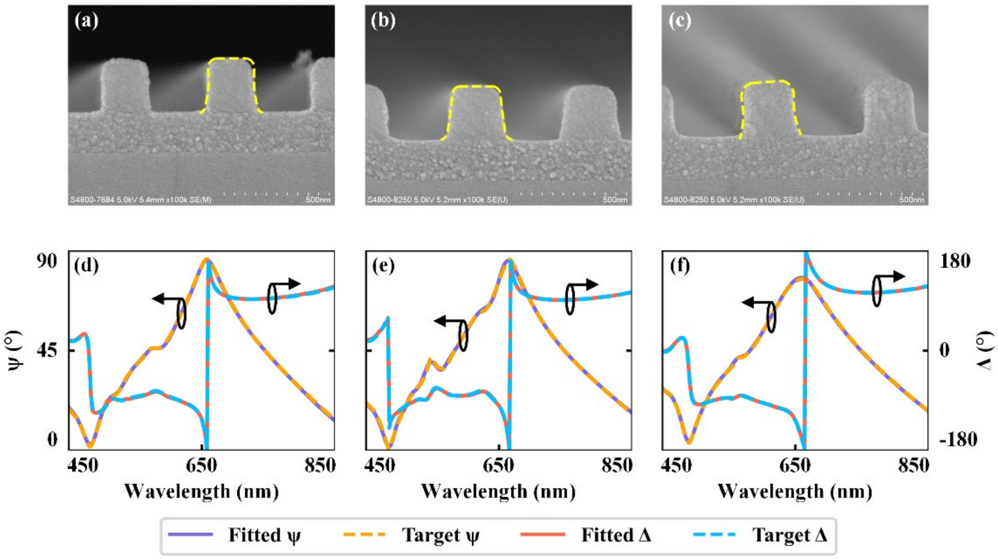

Figure 2. (a) – (c) Comparisons between SEM images and profiles (yellow dashed lines) inferred by the proposed method. (d) – (f) Ellipsometry data of fitted (solid lines) and measured (dashed lines) results under azimuthal angles near 0°.