Modeling of Near- and Far-field Diffraction from EUV Absorbers Using Physics-informed Neural Networks

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Abstract — Extreme ultraviolet (EUV) light with a wavelength of about 13.5 nm is used in modern semiconductor technology for the lithographic fabrication and optical characterization of nanostructures. The predictive simulation of the use of EUV light for these applications requires the accurate modeling of light scattering from small objects such as absorbers on masks for EUV lithography. Various electromagnetic field solvers have been adapted and used for the modeling of scattering of EUV light, but are inappropriate to address large-scale technology problems with sufficient efficiency. In recent years, deep neural networks have been used to support rigorous simulations with better initial values, to replace single interaction steps, or even the entire simulation [1]. However, these data-driven networks require a large amount of rigorously simulated or measured data [2]. To address these limitations, we explore the potential of physics-informed neural networks (PINN) to simulate the diffraction of EUV light from typical absorbers.

The developed method solves Maxwell’s equations without any training data, so incorporating only the physical knowledge to the loss function. The application of PINNs to electromagnetic scattering and imaging problems requires the implementation of the specific incident field and boundary conditions (BC) including perfectly matched layers, reflective surfaces, and periodic BCs. The obtained solutions are evaluated in the near field and in the far field (diffraction efficiency and phase of diffracted light).

Our simulation results demonstrate that PINN can approximate the diffracted light in the vicinity of EUV absorbers with high accuracy. The performance of PINN was compared to that of the rigorous numerical solver based on the Waveguide method [3]. We evaluated the PINN prediction accuracy for scatterers with realistic EUV absorber thickness and typical EUV absorber materials, e.g., presently used tantalum-based materials (TaBN) and promising candidates for the next generation of EUV lithography (low-n-low-k and low-n-medium-k). Figure 1 reveals the predicted near field in the vicinity of a TaBN absorber to the result obtained with the Waveguide solver. Extracted diffraction efficiencies and phase differences of TaBN and other absorber materials are presented in Table 1.

Table 1: Calculated far-field metrics for different absorber materials (Waveguide vs. PINN (error)). Absorber size: 27.0 nm × 54.0 nm.

<table>
<thead>
<tr>
<th>Absorber Material</th>
<th>Diffraction efficiency (ref. vs. pred. (absolute error))</th>
<th>Phase difference between ±1st and 0th orders (° (ref. vs. pred. (error%)))</th>
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<tbody>
<tr>
<td></td>
<td>±1st order</td>
<td>0th order</td>
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<tr>
<td>TaBN</td>
<td>0.09771 vs. 0.09765 (0.00034)</td>
<td>0.45520 vs. 0.45113 (0.00407)</td>
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<tr>
<td>low-n-low-k</td>
<td>0.24574 vs. 0.24494 (0.00081)</td>
<td>0.24718 vs. 0.24390 (0.00328)</td>
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<tr>
<td>low-n-medium-k</td>
<td>0.19577 vs. 0.19572 (0.00051)</td>
<td>0.21462 vs. 0.21285 (0.00177)</td>
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</table>

The outcomes of our study demonstrate that the PINN model showcases good performance in terms of generalization, convergence behavior, and stability. Differently from numerical solvers, once trained, PINN can simulate light scattering in several tens of milliseconds independently from problem complexity. Based on the obtained results, the perspectives on the use of PINNs in EUV imaging simulations will be discussed.

1Refraction index.
2Extinction coefficient.
Figure 1: Evaluation of PINN prediction accuracy by comparison of simulated near $E$-field for illumination with a plane wave. Use case: TaBN absorber (27.0 nm × 54.0 nm box with black contours) in a vacuum. (a) ground truth obtained by Waveguide numerical solver; (b) prediction by PINN; (c) pixel-based metrics calculated from image difference: mean absolute percentage error (MAPE) and mean squared error (MSE).

REFERENCES