

Document Version

Final published version

Citation (APA)

Gouder, M., Zhang, F., Du, M., & Witte, S. (2025). Ptychographic imaging ellipsometry with visible and extreme ultraviolet light. In *2025 Conference on Lasers and Electro-Optics Europe and European Quantum Electronics Conference, CLEO/Europe-EQEC 2025 (2025 Conference on Lasers and Electro-Optics Europe and European Quantum Electronics Conference, CLEO/Europe-EQEC 2025)*. IEEE. <https://doi.org/10.1109/CLEO/EUROPE-EQEC65582.2025.11110555>

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Ptychographic imaging ellipsometry with visible and extreme ultraviolet light

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The chemical and structural properties of a specimen can often be inferred by determining its complex refractive index. Ellipsometry is the standard method to measure the complex refractive index [1]. In ellipsometry, the complex refractive index is retrieved by acquiring absolute reflectivity changes for different states of the incident light (varying polarization or angle of incidence). While ellipsometry works well for bulk and thin-film specimens without transverse structure, imaging an object with spatially varying refractive index is difficult. Scanning ellipsometry uses a tightly focussed beam which requires accurate knowledge of the beam properties and more complex analysis. Furthermore, the signal is averaged over the spot size, limiting spatial resolution. Other implementations like imaging ellipsometry require an imaging setup with high-NA optics, which lead to measurement errors caused by aberrations and other defects. This becomes especially problematic when decreasing the wavelength in the extreme ultraviolet (EUV) regime, to improve spatial resolution.

Here, we use ptychography [2, p. 819], which is a lensless imaging technique, to image the complex refractive indices of a multi-layer specimen [3]. In our setup, we use a weakly focused coherent light source in the visible range to scan across a specimen. At each scan position, a coherent diffraction from the illuminated area on the specimen is captured with a camera. Using these diffraction patterns, we use an iterative algorithm (PIE) [4] to reconstruct both the probe and the reflectivities of the specimen. We repeat the measurement and reconstruction at different angles and polarization states.

Based on these reconstructions, we show how to retrieve high-resolution maps of the complex refractive indices. We define a physical model that describes the reflection in the sample plane, and use automatic differentiation to solve for the refractive indices. In contrast to ellipsometry, we also acquire the spatial phase change, which forms a strong constraint in the model, increasing the accuracy of the refractive index reconstructions. The phase information can also be used to retrieve height differences between layers.

As a lensless imaging approach, ptychographic imaging ellipsometry can be extended to extreme ultraviolet wavelength as well. We are currently working on an experimental demonstration of this concept using a high-harmonic source, and will present first results towards this goal.

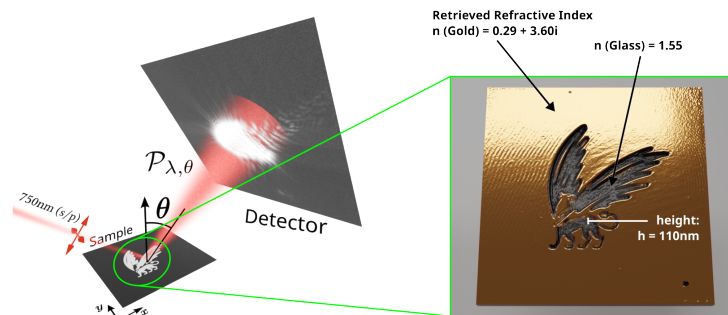


Fig. 1 Depicted experimental setup for visible light (750 nm), illuminating a sample. Upon illumination, the reflected diffraction pattern is captured by a detector. On the right, an artistic 3D render of the reconstructed sample is shown, where the height corresponds to the retrieved height (not to scale). The sample shown here consists of a ≈ 110 nm Gold-layer with features, that was fabricated on a glass substrate. Retrieved complex refractive indices for the Gold- and Glass-layer as well as the relative thickness of the Gold-layer are derived directly from the algorithm. Side length of rendered reconstruction: 2 mm.

References

- [1] R. M. A. Azzam, N. M. Bashara, and S. S. Ballard, "Ellipsometry and Polarized Light," *Physics Today*, vol. 31, no. 11, pp. 72–72, Nov. 1, 1978, ISSN: 0031-9228. DOI: 10.1063/1.2994821.
- [2] P. W. Hawkes and J. C. H. Spence, Eds., *Springer Handbook of Microscopy* (Springer Handbooks). Cham: Springer International Publishing, 2019, ISBN: 978-3-030-00068-4 978-3-030-00069-1. DOI: 10.1007/978-3-030-00069-1.
- [3] M. Gouder, M. Du, and S. M. Witte, "Ptychographic imaging ellipsometry," in *Computational Optics 2024*, SPIE, 2024, PC130230B.
- [4] J. M. Rodenburg and H. M. L. Faulkner, "A phase retrieval algorithm for shifting illumination," *Applied Physics Letters*, vol. 85, no. 20, pp. 4795–4797, Nov. 15, 2004, ISSN: 0003-6951, 1077-3118. DOI: 10.1063/1.1823034.