Beyond EUV Lithography for Reaching Future Technological Nodes

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Extreme ultraviolet (EUV) lithography at 13.5 nm wavelength has been considered as the main candidate for reaching the future technological nodes of the roadmap of the semiconductor industry[1]. Lithography at this wavelength is expected to be the semiconductor industry's main patterning scheme for the next decade, after which it reaches the resolution limit. Afterwards, reduction of the wavelength will relax the challenging requirement of NA and k values and therefore lithography at 6.x nm wavelength is proposed as a next-generation technology[2], coined as beyond EUV (BEUV) lithography, owing to the availability of sources and multilayer optics.

For the first time, to the best of our knowledge, we present lithography at 6.5 nm wavelength for patterning structures with half-pitch (*HP*) smaller than 22 nm. We use interference lithography (Fig. 1), which induces minimum imaging artifacts, and explore the properties and performance of several high-resolution inorganic and chemically amplified resists. We quantify BEUV lithography performance by evaluating crucial parameters such as critical dimension, line-edge-roughness, exposure latitude, and Z factor, and compare with EUV lithography at 13.5 nm (Fig. 2). We have seen that the lithography performance is crucially dependent on the photoresist backbone chemistry, yet by correct choice of the chemical composition, BEUV patterning could also be obtained with high quality. We, moreover, discuss the contribution of different physical limitations, such as shot noise and flare that might hinder the utilization of BEUV for fabrication at the diffraction limit.

Our experiments have been performed at the Swiss Light Source (SLS) synchrotron facility at Paul Scherrer Institute, where world-record resolution in photon-based patterning has been held for several years. Using synchrotron radiation for carrying out these experiments provides tunability of the wavelength with very high spatial and temporal coherence. The combination of our high-resolution broadband mask technology and the precise performance tool at the XIL-beamline has enabled nanopatterning at the photoresist resolution limits. Should BEUV lithography prove to meet necessary requirements of the semiconductor industry, it could be developed as a standard method of sub-10-nm patterning, when EUV lithography reaches its resolution limits.

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[1] G. Tallents, E. Wagenaars, and G. Pert, Nature Phot. **4**, 809 (2010).
[2] C. Wagner and N. Harned, Nature Phot. **4**, 24 (2009).

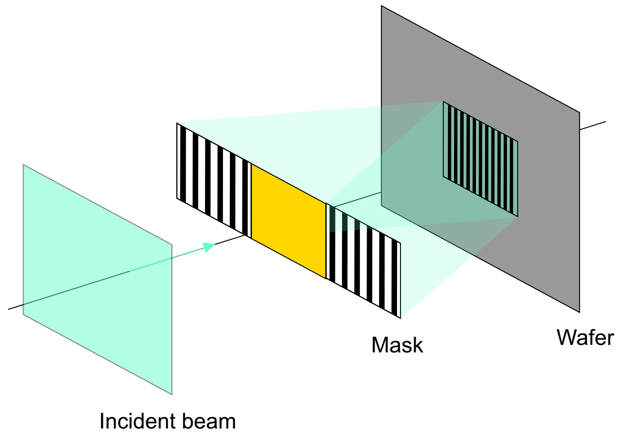

Figure 1: High-Resolution Interference Lithography: The incident synchrotron beam is diffracted by two gratings. The diffracted beams interfere at the spincoated wafer and create gratings with twice periodicity as those of the mask. This method has no depth-of-focus, is optics free, and the gratings could be fabricated with minimum roughness, thus induces minimal artifacts that hinder lithography at the resolution limit.

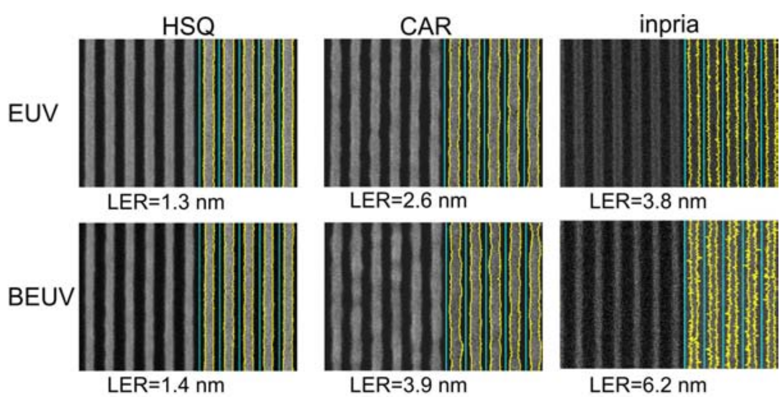

Figure 2: High Resolution Lithography at EUV and BEUV: SEM images of *HP*=22 nm line/space patterns of different photoresists exposed at EUV (top) and BEUV (bottom). Yellow lines show the analyzed profile, overlaid on the corresponding lines and the average LER is stated below each image. The photoresists we study are hydrogen silsesquioxane (HSQ), an organic chemically amplified resist (CAR), and Inpria.