At-wavelength metrology and characterization enabling EUV scaling

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Enabling the short- and long-term scaling of extreme ultraviolet (EUV) lithography patterning dimensions, depends on the availability and utilization of at-wavelength (actinic) metrology and characterization techniques. Continuing EUV patterning shrink is limited by our understanding and control of materials, including both mask materials as well as patterning materials. To date, EUV patterning in high volume production has not yet achieved the same low k1 typically accessible in the DUV regime. Phase shift masks are being actively pursued as a pathway to further reduction of k1 in the EUV regime. To this end, actinic characterization of phase shift materials and phase shift masks is essential. Phase in the EUV regime is extremely sensitive to even subtle changes in material characteristics as well as thin-film interference effects. Moreover, as in DUV, the phase of patterned structures deviates from the planar phase due to edge effects often referred to as mask three-dimensional (M3D) effects. Additionally, although the phase of a mask is often referred to as a single scalar term, in EUV, the reality is quite different with substantial and non-linear dependence on both angle and in-band wavelength. In this presentation, we will describe these effects in detail and show direct actinic measurement of these various effects.

Looking even further and considering scaling of numerical aperture (NA) (both high and hyper NA), the general consensus of the EUV community is that stochastics are of utmost concern. Generally, this concern is from the perspective of patterning materials, however, stochastics also play an important role on the mask. In particular, these stochastic effects present during mask manufacturing arise in the form of mask roughness both within the multilayer Bragg structure as well as within the absorber and/or phase shifting materials. These mask level stochastics inevitably get imprinted at the wafer level, ultimately impacting observed stochastic effects at the wafer. In this presentation, we will further describe these effects and demonstrate the correlation between mask level statistical measurements and observed behavior at the wafer level both in terms of stochastic pattern size and focus behavior.