# Enhancement of hyper-NA imaging through selective TM polarization

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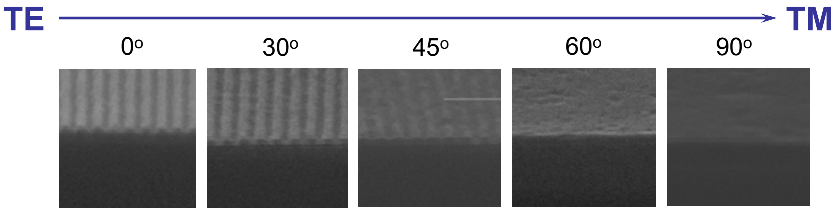
Whether considered solely through illumination or controlled to some extend further down the imaging train, selective polarization has become a necessary component of hyper NA lithography. While the interference of transverse electric (TE) polarized diffraction energy results in imaging with no inherent loss in contrast, the same is generally not true for transverse magnetic (TM) polarization. Contrast falls of with increasing angles as 1/cosθ, which presents problems for imaging at numerical apertures approaching and exceeding 1.0. The additional phase terms present with TM polarization which are responsible for this loss are seen in the comparison of the electric field to the TE state, shown in Equations 1 and 2 below.

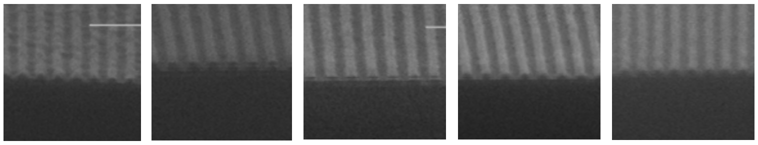
$$E_{TE_{total}} = (e^{ikz\cos\theta} + r_{TE}e^{-ikz\cos\theta})\cos(kx\sin\theta)\hat{y} \qquad [1]$$

$$\begin{aligned} E_{TM_{total}} &= 2\left(e^{ikz\cos\theta} - r_{TM}e^{-ikz\cos\theta}\right)\cos(kx\sin\theta)\cos\theta\hat{x} \qquad [2] \\ &- i2\left(e^{ikz\cos\theta} + r_{TM}e^{-ikz\cos\theta}\right)\sin(kx\sin\theta)\sin\theta\hat{z} \end{aligned}$$

where *r* represents the term upon reflection at the resist/substrate boundary. The image degradation with TM polarization is not is not inherent, however, and the loss in image contrast can be recoverable. By controlling the resist/substrate interface reflectivity, high modulation for TM polarization can be maintained for angles up to 90° in a photoresist. Figure 1 shows how this can be accomplished. Images in photoresist are compared for a numerical aperture of 1.20 (resulting in an interference angle of 45°). TE polarized imaging is represented by a polarization angle of 0° and TM is represented as 90°. Partial polarization is shown in the images between these two states. Two photoresist stack conditions are depicted, one where reflection at the resist/substrate boundary are suppressed with a BARC layer and another where the reflection is enhanced by coating the photoresist over a reflective Si substrate. Whereas there is the expected loss of image contrast with increasing polarization angles for suppressed reflection, the loss is not nearly as large for the enhanced reflection case. This is further shown by comparing the measured modulation of the two cases in Figures 2 and 3, where contrast for the reflective substrate case is increased to a value of at least 0.50. These results can potentially impact the design of illumination, possibly away from most recent TE-only schemes for oblique imaging angles (high NA). We will present several cases of TM illumination combined with tuned substrate reflectivity for 0.93NA, 1.20NA, and 1.35NA and compare results to TE illuminated cases. The ultimate goal is to achieve a flat response through polarization angle at the large imaging angles.



With reflection eliminated



With highly reflective substrate

**Figure 1**. Imaging comparisons for 1.2NA resist images using reflection control and reflection enhancement at the resist/substrate interface.

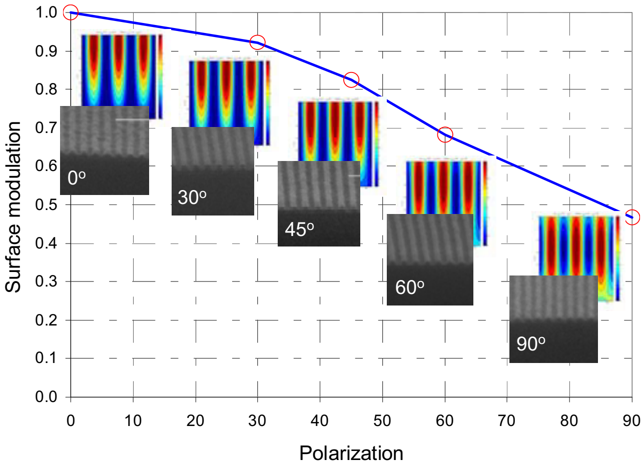


**Figure 2**. Contrast (modulation) through polarization angle for TM illumination using a reflective substrate.

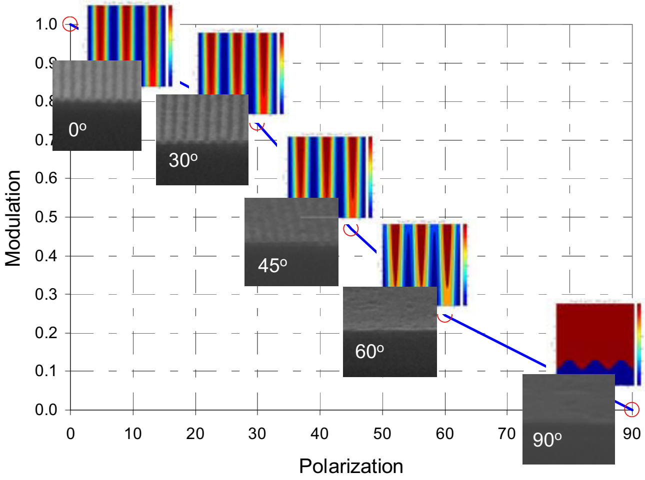


**Figure 3**. Contrast (modulation) through polarization angle for TM illumination using a an anti-reflective