Ultra-high-Numerical Aperture Interference Lithography at High Aspect Ratios using Surface States on Effective Gain Media

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The exponential decay of evanescent images at ultra-high numerical apertures (*NA*s) makes pattern transfer extremely difficult. We present a method using reflection resonances from effective gain medium surface states beneath the resist to significantly improve the evanescent field in the ultra-high *NA* regime.

Evanescent fields may be enhanced by surface states such as the surface plasmon polariton[1,2], however severe limitations such as the use of TM polarization (considered "bad" in lithography) and the lack of available metals with the required permittivity makes this an infeasible approach[3]. We developed theory to find that the enhancement is simply a result of energy extraction from the incident beam and its redistribution in the photoresist cavity[2]. Upon solving the Fresnel reflection equations for the TE polarization (considered "good" in lithography), we found that a material with negative loss (i.e. gain medium) also supports surface states and hence may be capable of providing enhancement. While, a gain medium may seem hypothetical, an effective gain medium (EGM) can be created by stacking a high-index dielectric on a low index dielectric[3].

Using our Solid Immersion Lloyd's Mirror Interference Lithography SILMIL test-bed at λ = 405nm[2,4], [Fig. 1(a)] we created patterns at a *NA* of 1.824. Figure 1(b) illustrates 55 nm half-pitch or λ/7.3 features with 20 nm depths. For the same dosage however, Fig. 2 illustrates 100 nm image depths using our EGM. This significant enhancement is due to an EGM beneath the resist made up of a 90.3 nm layer of Hafnium Oxide (n = 2.025) on SiO_2 (n = 1.5). We believe these are the first results to demonstrate ultra-high *NA* patterning with high aspect ratios (AR) (note mildly visible resist collapse in Fig. 2(a) due to this) through evanescent field and energy redistribution in a resist cavity. Fig. 3 presents a feasible design at λ = 193 nm with the use of a sapphire prism based solid-immersion system[5] to pattern 26 nm half-pitch (NA = 1.85, λ = 193 nm) structures with 82.5nm depth (AR = 3.2).

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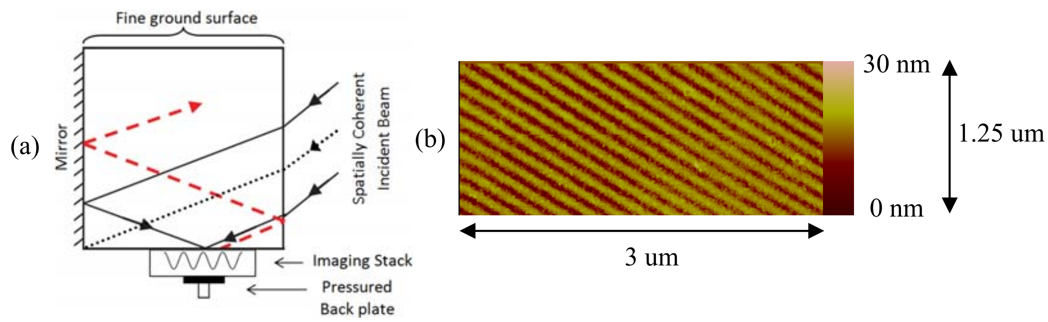

Figure 1: SILMIL Setup and Operation (a) SILMIL Test-bed for Ultra-high-*NA* Interference Lithography and (b) AFM scan of 55 nm half-pitch (*NA* = 1.824) structures at λ = 405 nm. Minimum dosage resulted in 20 nm image depth

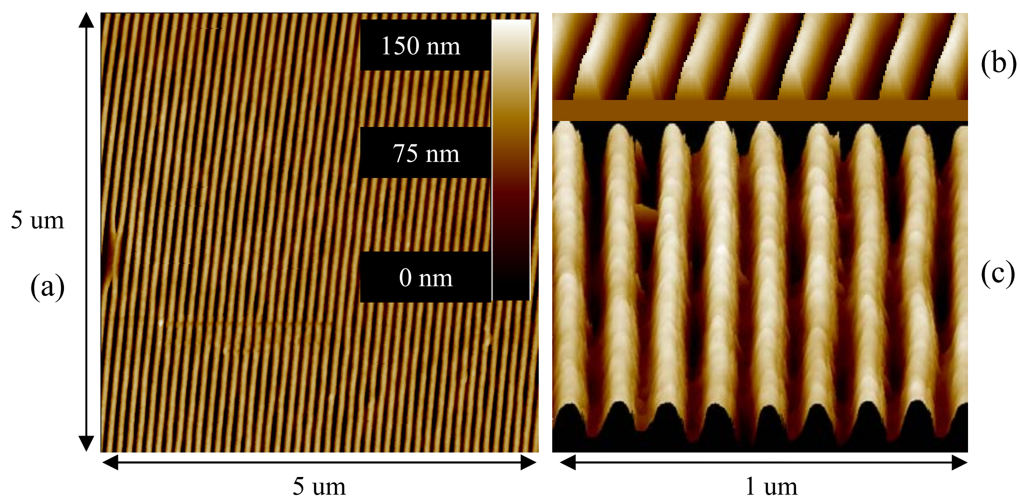

Figure 2: AFM scans with Effective Gain Medium AFM Scans of 55 nm half-pitch (*NA* = 1.824) structures at λ = 405 nm using an effective gain medium underlay made up of 90.3 nm HfO on SiO_2. Minimum dosage resulted in 100 nm image depth (a) 5 um by 5 um scan (b) & (c) Close up scans in perspective view

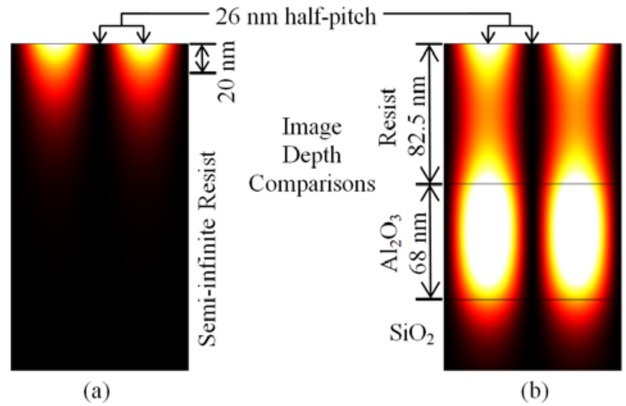

Figure 3: Design Example at λ = 193 nm Imaging of 26-nm (half-pitch) evanescent features into (a) semi-infinite lossy resist giving 20-nm image depth, and (b) 82.5 nm thick lossy resist on an effective gain medium made up of 68 nm of Al_2O_3 (Sapphire) on SiO_2, giving an image depth of 82.5 nm.