Ultra-high NA, High Aspect Ratio Interference Lithography with Resonant Dielectric Underlayers

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Recent work has shown that a dielectric resonant reflector underlayer can achieve high aspect ratio imaging for immersion interference lithography in the ultra-high numerical aperture (UHNA) regime where evanescent fields are responsible for the exposure [1]. This has been demonstrated using HfO as the resonant dielectric underlayer and here we present simulation and preliminary experimental results for new potential candidate dielectric underlayer materials that can accommodate UHNA, high aspect ratio imaging, and are better geared for the semiconductor industry. In addition, experimental results of subsequent lift-off pattern transfer onto high aspect ratio lines, generated using a dielectric resonant reflector underlayer, are presented.

Figure 1 shows simulation results of UHNA imaging (NA = 1.8) with a solid-immersion Lloyd's mirror interference lithography (SILMIL) system using a YAG prism as the solid immersion medium and a 405 nm, TE polarized, light source, corresponding to 56-nm half-pitch resolution. Figure 1(a) shows an optical stack consisting of 113 nm photoresist upon a Si substrate and Figure 1(b) shows an optical stack consisting of a 112.5 nm photoresist layer on a 22 nm GaN underlayer followed by a 100 nm SiO_2 layer and a Si substrate. Both optical stacks produce a 56 nm half-pitch grating but only the resonant underlayer system achieves 2:1 (height:half-pitch) aspect ratio lines. We have found other candidate materials achieve similar results at an NA of 1.8 including GaP, SiC and SiN.

Gapping capability allows precise measurement of prism/optical stack separation via frustrated total internal reflection [2]. Integrating this method with our SILMIL system allows greater reproducibility and reliability when performing evanescent-coupling. This additional control provides the ability to now explore pattern transfer techniques with sub-wavelength, high aspect ratio lines. We present preliminary experimental results from this system for UHNA, high aspect ratio imaging using dielectric underlayer materials from our survey. Figure 2(a) shows an AFM image of a ~55 nm half-pitch silver grating produced via lift-off pattern transfer onto high aspect ratio lines produced using an HfO resonant underlayer. Figure 2(b) shows an accompanying SEM image of this sample. This is the first demonstration of lift-off patterning at such a deep sub-wavelength UHNA imaging regime, corresponding to better than $\lambda/7$ in this case.

[1] P. Mehrotra, C.A. Mack & R.J. Blaikie, *Opt. Express* **21**(11), 13710 (2013).
[2] S. Zhu, A.W. Yu, D. Hawley & R. Roy, *Am. J. Phys* **54**(7), 601 (1985).

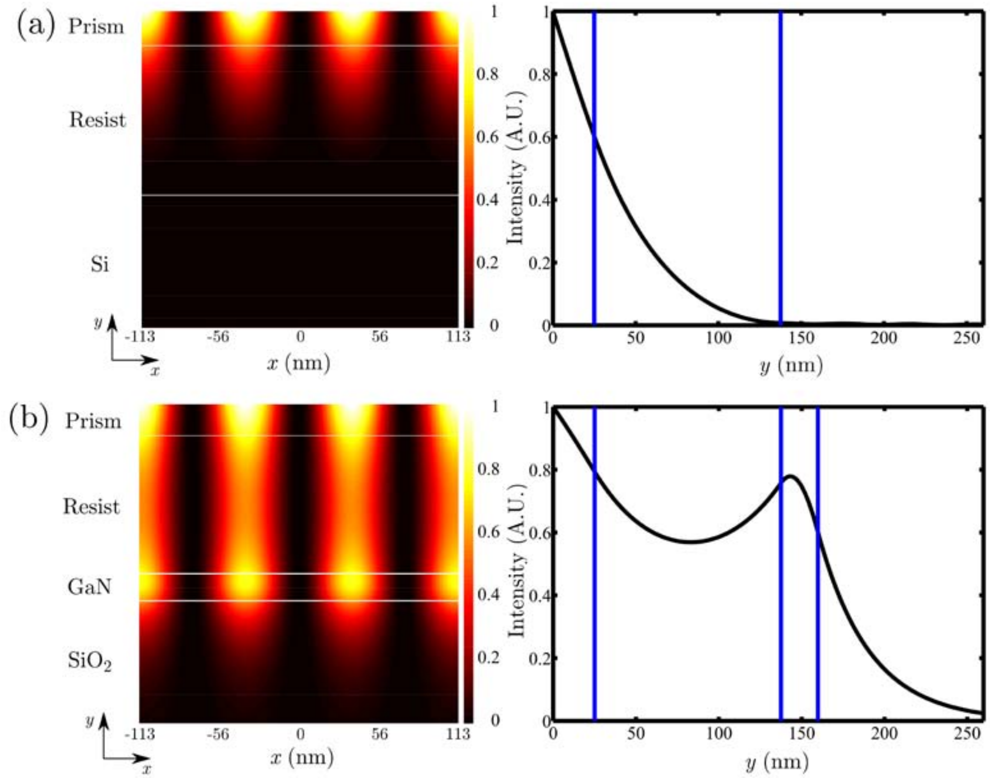

Figure 1: Ultra-high NA imaging (NA = 1.8) simulation with 405 nm TE polarized light. The left images show an electric field intensity plot through the optical stack. The right images show an electric field intensity trace centered on the line of maximum intensity in the *y*-direction. Results for (a) an optical stack without a resonant underlayer and (b) an optical stack with a GaN dielectric resonant underlayer.

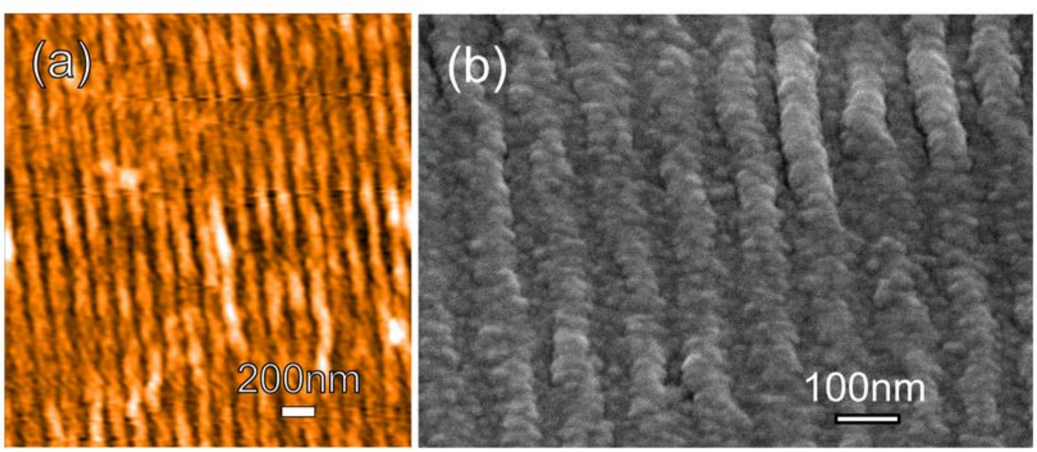

Figure 2: Images of a ~55 nm half-pitch silver grating produced through lift-off pattern transfer onto high aspect ratio lines generated with a dielectric resonant underlayer. (a) AFM plan view topography image (b) SEM image at a 45 degree tilt angle.