Absorbance-Modulation Interference Lithography Enhanced by a Planar Silver Lens

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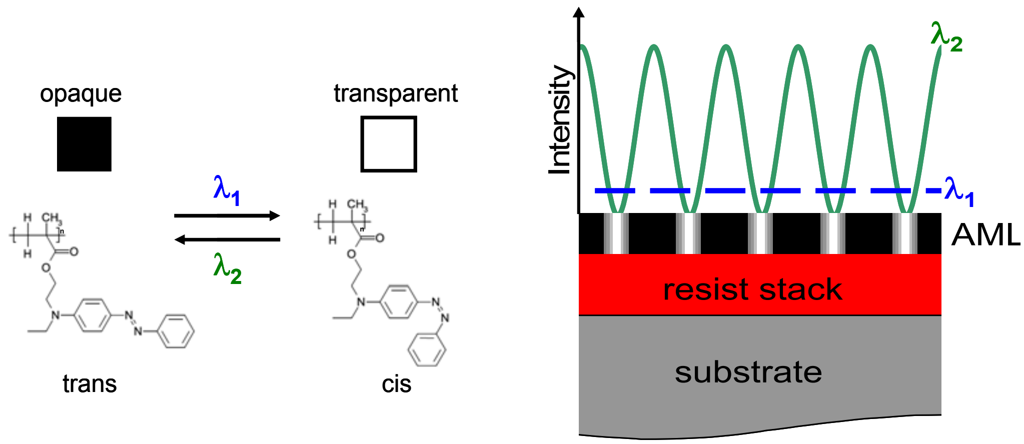
The resolution of far-field optical lithography is typically limited by diffraction, requiring the use of shorter wavelengths and higher numerical apertures to improve performance. This has resulted in the exponential increase in complexity and cost of state-of-the-art optical lithography systems. Recently, it has been shown that sub-diffraction limited patterns can be achieved by using an absorbance-modulation layer (AML) between the far-field optics and photoresist[1]. The AML is composed of photochromic molecules that can be optically switched from an opaque state (trans) to an transparent state (cis) via exposure to λ_1 and switched back, cis→trans, via λ_2 (Fig. 1a). In absorbance-modulated interference lithography (AMIL), shown in Fig. 1b, a standing wave of λ_2 combined with uniform illumination of λ_1 forms an absorption grating in the AML with transparent regions at the optical nulls of λ_2. This effectively creates an optically-reversible photomask on the surface of the photoresist. Similar to near-field optical lithography, this results in the image being no longer formed solely by the diffraction-limited low spatial frequencies, but also by the evanescent high spatial frequencies in the exposing wavelength (λ_1).

Using the AML as the photomask eliminates the challenge of achieving intimate contact that is problematic for most near-field lithographic systems. However, AMIL is still plagued by many other problems associated with near-field lithography, such as limited contrast and depth of focus. It has been shown that planar silver lenses can relax some of these limitations, resulting in practical contrast and depth of focus values for sub-diffraction limited features[2]. Therefore, we propose integrating a planar silver lens into the resist stack used for AMIL.

In this paper we present experimental results demonstrating the performance enhancement achievable by integrating a planar silver lens with AMIL. We explore the effects of illumination polarization and silver lens structure on contrast, depth of focus, and resolution of AMIL. These experiments are performed using a modified Lloyd's mirror interference lithography setup, shown in Fig. 2, where the source for λ_1 is the 405 nm peak of a mercury lamp and for λ_2 is a 532 nm solid-state laser.

1. T.L. Andrew, H.Y. Tsai, and R. Menon, Science **324**, 5929 (2009).
2. D.O.S. Melville and R.J. Blaikie, J. Vac. Sci. Technol. B **22**, 3470 (2004).



(a) **(b)**

Fig. 1: (a) The azobenzene-based photochromic molecule that makes up the AML layer undergoes a trans-to-cis transition when exposed to λ_1 (405 nm) causing the layer to become transparent to λ_1. Likewise, when exposed to λ_2 (532 nm) the molecule switches back to the trans state, becoming opaque. (b) In AMIL, two-beam interference and flood illumination are used to form a standing wave of λ_2 and uniform intensity of λ_1, respectively, on the surface of the AML. This results in the formation of transparent regions centered at the optical nulls of λ_2. By controlling the intensity ratio of λ_1 to λ_2 it is possible to control the width of these transparent regions, therefore, controlling the width of the printed feature.

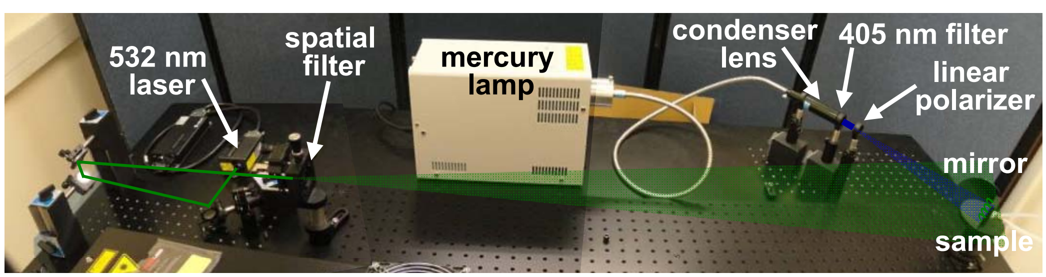


Fig. 2: Photograph of the modified Lloyd's mirror setup used for AMIL. Flood illumination of λ_1 (405nm) is achieved by using a mercury lamp fiber light. The output of the fiber passes through a uniform-illumination condenser lens, a 405 nm optical filter and linear polarizer before arriving at the sample surface. For λ_2 a 50 mW continuous-wave diode-pumped solid-state laser is used operating at 532 nm. This laser beam travels though a spatial filter and is expanded before being incident on the mirror and sample holder, forming a standing wave on the sample's surface.