Optical patterning of features with spacing below the far-field diffraction limit using absorbance modulation

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In conventional AMOL technique a thin layer of photochromic film is used on top of a photoresist layer on silicon wafer and this is simultaneously illuminated with a standing wavelength, λ_2 (visible 633nm, confining beam), and a standing wavelength, λ_1 (ultraviolet 325nm, writing beam) [1]. It is observed that these materials can change states between transparent (closed) and opaque (open) by illuminating with the appropriate wavelengths [Fig.1 (a)]. When this photochromic layer illuminated with both wavelengths simultaneously, a sub-wavelength transparent region (or aperture) is formed, at the node of the confined beam λ_2, though which photons of λ_1 penetrate and create an optical nano probe. As indicated in Fig. 1(b), a barrier layer comprised of polyvinylalcohol (PVA) is necessary to protect the photoresist from the overlying photochromic layer. After exposure, the photochromic and the PVA layers must both be removed prior to development as illustrated in Figs. 1(c) and 1(d). This can potentially be damaging to the photoresist. In this abstract, we propose a new technique, which avoids this extra step and hence, allows for a more benign processing of the photoresist.

In this new AMOL technique the sample has three layers on top of a bare quartz slide. The stack comprises of a quartz slide, a layer of photochromic molecules, a layer of Poly (vinyl) Alcohol (PVA) and finally a layer of photoresist. The sample is simultaneously illuminated with a standing wavelength, λ_2 (visible 647nm, confining beam), and a standing wavelength, λ_1 (ultraviolet 325nm, writing beam) from the back of the sample so that the stack is similar to conventional AMOL sample [Figs.1 (e-g)]. As shown Fig1.g the photoresist is developed without removing the photochomic and PVA layers. Multiple exposures on the same sample are also carried out using this new process [Figs.2 (a-e)]. This technique initially enables patterning of isolated lines of width 60nm for an exposure wavelength of 325nm. 60nm corresponds to $\lambda_1/5.4$. The far-field diffraction limit is given by half the period of the standing wave at λ_1, *i.e.*, 140nm. Furthermore, by moving the optical pattern relative to the sample, we demonstrate patterning of closely-spaced lines, whose spacing is as small as 119nm.This corresponds to $\lambda_2/5.44$ which indicates that absorbance modulation enables patterns whose spacing can be smaller than the far-field diffraction limit of the optical system.

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[1] T. L. Andrew, H-Y. Tsai and R. Menon, *Science*, **324**, 917 (2009).

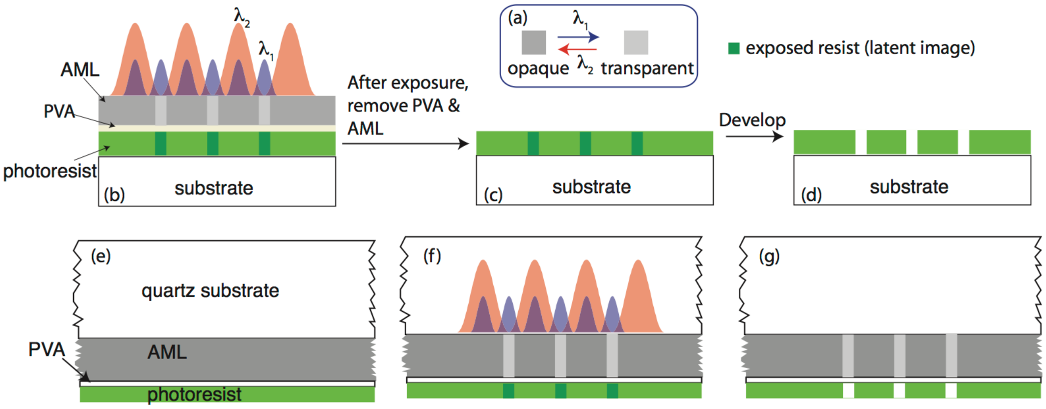

Figure 1: Schematic of absorbance-modulation-optical lithography (AMOL) based on photo-switching of the photochromic layer (a) using the conventional process (b)-(d) and using the new process (e)-(g).

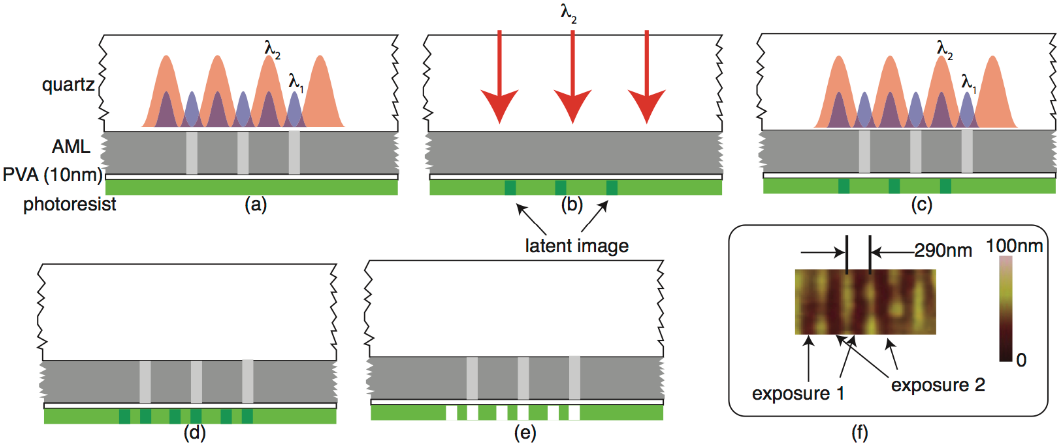

Figure2: Schematic of multiple exposures for patterning dense features using AMOL. (a) Exposure with standing waves at λ_2 and at λ_1 results in isolated lines of exposed resist. The sample is then exposed to a uniform illumination at λ_2, which converts the AML completely into the opaque form. The sample is stepped with respect to the optics and a second exposure with standing waves at λ_2 and at λ_1 is conducted. This results in dense lines as illustrated in (d) and after development in (e). (f) Atomic-force micrograph of dense lines whose approximately spacing is half that of the period (570nm) of the λ_2 standing wave.

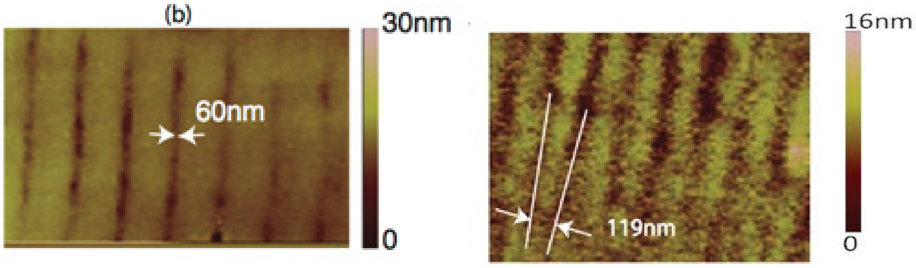

Figure 3: Atomic-force micrograph of (a) Lines in developed resist after a single exposure. (b) Sample that was exposed twice with a small rotation in between.