Table top Patterning of Arrays of nano-dots with extreme ultraviolet laser interferometric lithography

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Multiple exposure interferometric lithography (IL) using a table-top set up based on a compact λ= 46.9 nm capillary discharge laser was used to print patterned arrays of nano-dots with different geometry using exposure times of less than 1 minute.

The illumination source used in this work is a compact λ= 46.9 nm Ne-like Ar capillary discharge laser. When operated at repetition rates of several Hz this table-top laser produces an average output power in excess of 1 mW with a high degree of spatial and temporal coherence.

IL was implemented by illuminating a flat mirror in the Lloyd's configuration with the extreme ultraviolet (EUV) laser output, as illustrated in figure 1. Beam interference gives rise to a sinusoidal intensity pattern of period d, defined by the wavelength of the light λ and the incidence angle θ according to $d=\lambda/(2 \sin \theta)$. The sample, consisting of a Si wafer coated with poly-methyl methacrylate (PMMA), was mounted at the edge of the mirror in a motorized rotation stage. Controlled rotation by an angle α around an axis normal to the sample's surface allowed for multiple exposures. The Lloyd mirror interferometer system was housed in a vacuum chamber $0.45\times0.55\times0.40$ m^3 that was differentially pumped with respect to the laser to maintain a pressure of approximately 10^{-5} Torr. The entire EUV interferometry instrument has a footprint of 0.7×2.6 m^2.

To pattern an array, the PMMA coated sample was initially exposed to produce an interference pattern consisting of regular lines. This was followed by a second exposure in which the sample was rotated in situ by an angle α. The photon dose applied in each exposure, calculated as the energy per unit area, the incidence angel θ and the sample rotation α provide an extra degree of control over the shape of the imprinted features. For a dose of 10 mJ cm^{-2}, which can be obtained with about 20 laser shots, the photoresist is only activated along lines coincident with the interference maxima, leaving at the crossing points small regions where small holes are developed as shown in the atomic force microscope (AFM) image of figure 2. If the applied dose is increased to 32 mJ cm^{-2} the activated volume generates, after development, a regular array of trenches in two perpendicular directions that leave small non-activated spots at the intersections. Figure 3 shows an AFM image of a very regular array of cone-shaped dots with a period of 150 nm and a diameter at full width half maximum (FWHM) of approximately 60 nm. The inset in the figure shows the measured profile at a higher magnification where the period and the FWHM of the cone-shaped dots are indicated. The height of the cones corresponds to the penetration depth of the 46.9 nm light in the PMMA, approximately 30 nm. These periodic patterns printed with exposure times of 30-50 seconds cover surface areas of 0.5×0.5 mm^2.

Other motifs can be obtained changing the rotation angle α and the incidence angle θ between exposures, as indicated in figure 4 for oval shaped nano-dots.

These results show that table-top EUV lasers combined with interferometric lithography are a useful compact alternative for printing nanometer size features. The table top EUV-IL approach, used in concert with compact table top lasers, brings into a laboratory setting the high resolution printing capabilities of EUV light that until recently was restricted to large synchrotron facilities.

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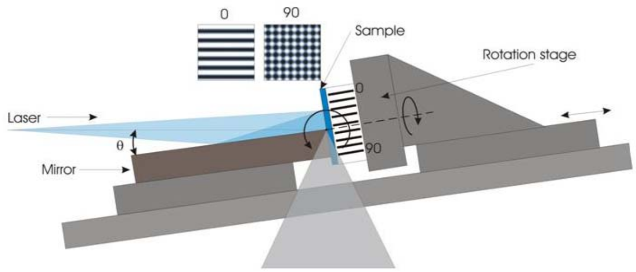

Fig. 1. Lloyd's mirror set up for multiple exposures. The sample is rotated an arbitrary angle α around an axis perpendicular to the sample's surface to obtain different motifs. The interferograms shown correspond to a rotation of $\alpha = \pi/2$

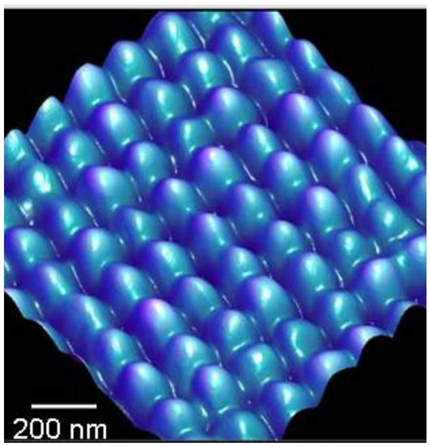

Fig. 2. Array of holes patterned in PMMA by double exposure with a Lloyd's mirror configuration, $\alpha = \pi/2$ and 10 mJ cm^{-2} photon dose.

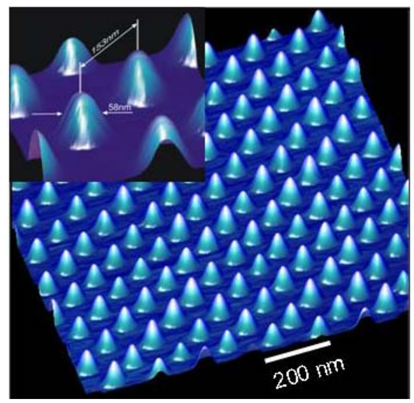

Fig. 3. Array of cone-shaped nano-dots patterned in PMMA by double exposure with a Lloyd's mirror configuration, with $\alpha = \pi/2$ and 30 mJ cm^{-2} photon dose. The inset is a magnified view of the array, showing the cone-shaped nano-dots. The FWHM of the nano-dot is approximately 60 nm and the period is nominally 150 nm.

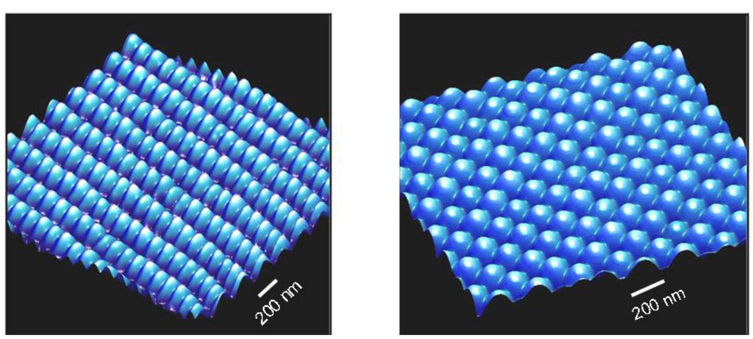

Fig. 4. Left: Array of nano-dots patterned in PMMA by double exposure with a Lloyd's mirror configuration, with $\alpha = \pi/6$. Right: Array of nano-dots with different periodicity in the x-y directions obtained by changing the incidence angle θ between exposures.