High-Contrast Images Obtained with Displacement Talbot Lithography

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Periodic patterns such as linear gratings and two-dimensional arrays of holes on a hexagonal grid are required in many applications, especially in photonics. Such patterns can be lithographically produced by the self-imaging of gratings, using the so-called Talbot effect [1]. With this well-known method, a photoresist-coated substrate is precisely positioned at one of the self-image planes in the transmitted light-field of an illuminated grating. However, the depth of field (DOF) of the self-images is smaller than $p^2/2\lambda$ (where p is the grating period and λ is the illumination wavelength) which severely limits the use of the technique, especially for printing high-resolution structures with periods below 1 micrometer.

We have recently introduced a modification of this classical method in which the wafer is not kept stationary during exposure but is instead moved towards the mask by a full Talbot period ($2p^2/\lambda$) in order to record an "integral" image (Fig. 1) [2]. The "integral image" obtained in this technique that we call Displacement Talbot Lithography (DTL), does not depend on the absolute position of the wafer with respect to the mask; and thus is free of the DOF limitation. The surprising result of this integral is that it produces a high-contrast image. In this paper we present simulation and experimental results illustrating the properties of the high contrast images obtained.

The simulations and experiments were performed using a mask pattern consisting of 300 nm-diameter holes on a 600 nm-period hexagonal grid (Fig 2a). The mask was made using standard Cr-on-quartz technology and e-beam writing. The integral image (integrated over one Talbot period) determined from the electromagnetic simulation is shown in Fig. 2b and the intensity profile of this DTL image is shown in Fig. 3. The results demonstrate that high-contrast images can be formed with the DTL technique. Lithographic exposures were performed using a PHABLE system designed and realized for implementing the DTL technique. The mask was illuminated by a collimated UV beam and the substrate-to-mask distance was varied by one Talbot period during the exposure. Uniform patterns were obtained over sample areas larger than several square centimetres. The diameter of the holes formed in a standard photoresist as a function of exposure dose is shown in Figure 4, which demonstrates the excellent exposure latitude resulting from the high contrast of the image.

The high contrast and large DOF of the images obtained with the DTL technique from standard Cr-on-quartz masks and using a non-contact exposure scheme make it a practical and robust technology for patterning of large areas with sub-micron periodic structures. Possible applications include diffraction gratings used in spectroscopy, fiber Bragg gratings, wire-grid polarizers, photonic crystals and anti-reflection structures.

References:

1. C, M, Qi, and H. I. Smith, J. Vac. Sci. Technol. B 22(6), (2004).
2. H. H. Solak, C. Dais, F. Clube, MNC 2010, 23rd International Microprocesses and Nanotechnology Conference, November 9-12, 2010, Fukuoka, Japan.

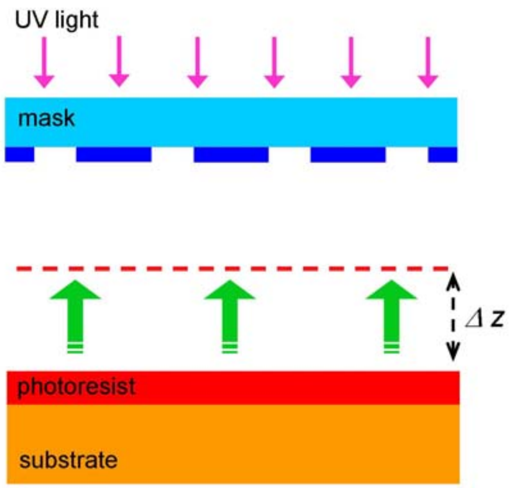

Fig 1 DTL scheme: a photoresist coated substrate is moved towards the mask by one Talbot period during exposure to record an integral image.

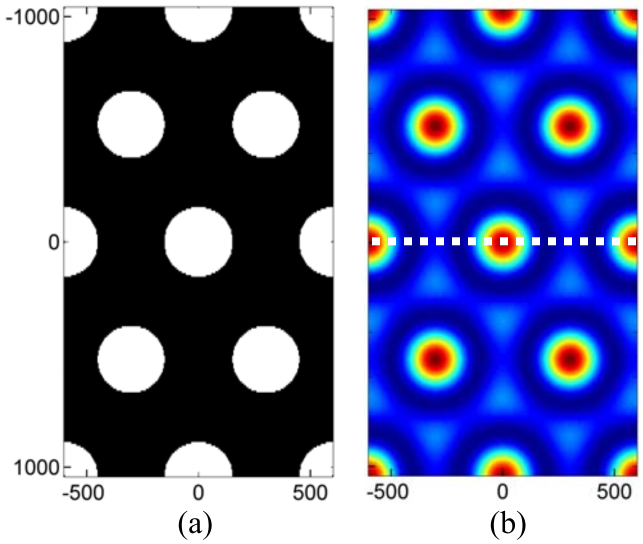

Fig 2 (a) Schematic view of the mask used in simulations and the experiments: a hexagonal array of 300 nm diameter holes in an opaque screen. (b) Simulated DTL image. Note the same symmetry and lattice constant as the mask.

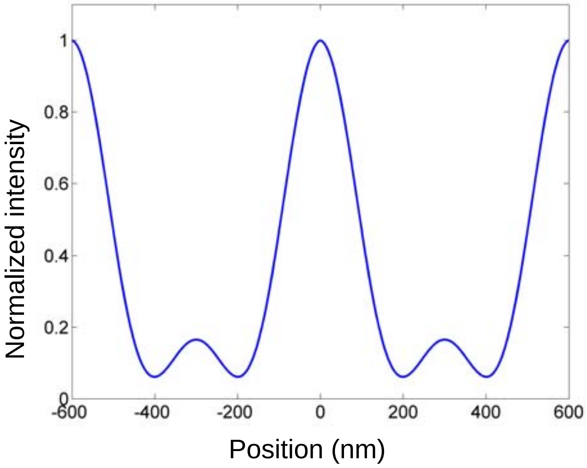

Fig. 3 Profile of the DTL image along the dashed line shown in Fig 2(b).

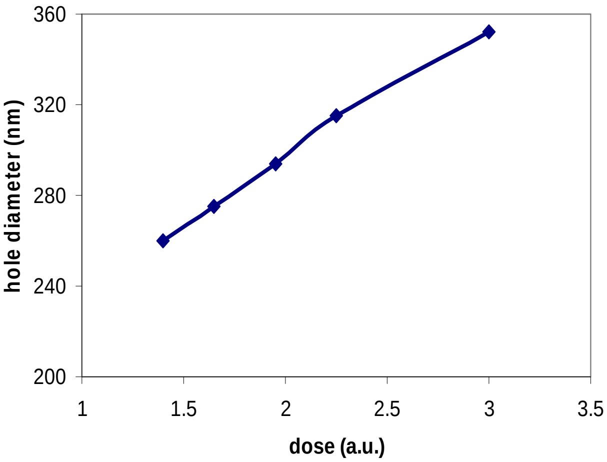

Fig. 4 Experimentally measured exposure dose latitude: hole diameter in resist as a function of exposure dose.