Phase shifting mask for high-throughput high-contrast patterning with Displacement Talbot Lithography (DTL)

Christian Dais[1], Francis Clube[1], Harun H. Solak[1], Kimio Itoh[2], Yukio Taniguchi[2], Morihisa Hoga[2]

[1] Eulitha AG, 5232 Villigen PSI, SWITZERLAND
Phone: +41 56 310 4279 email: christian.dais@eulitha.com

[2] Dai Nippon Printing Co., Ltd. 250-1, Wakashiba, Kashiwa-shi, Chiba-ken
277-0871, JAPAN

Displacement Talbot Lithography (DTL) has recently been introduced as a new method for patterning of large areas with sub-micron periodic structures [1]. DTL is based on the Talbot effect (or self-imaging of gratings). DTL overcomes the limited depth of focus of self-images by longitudinally displacing the wafer during exposure to integrate the diffracted field propagating from the mask. In previous work Cr-on-quartz type masks have been used with the DTL method for printing 2D arrays such as an array of holes on a hexagonal grid [2]. In this paper we show that clear phase shifting masks can be used not only to multiply the throughput of a DTL system by a significant factor but also to increase the contrast of the DTL image.

A large-area phase mask has been designed and fabricated to print a periodic 2D structure over a 4” wafer. The pattern on the mask consisted of pillars etched into a fused silica substrate. The pillars had diameter and height of 250 nm and 400 nm respectively, and were patterned on a square lattice with 500 nm period. An SEM image of the pattern prior to the removal of the Cr hard mask that was used in the fused silica etch process is shown in Fig. 1(a).

The optimum height and diameter of the pillars was determined through complete electromagnetic simulations of the DTL image formed with near-UV illumination. Figs. 1(b) and 1(c) show respectively the simulated mask pattern and the resulting DTL image. The image consists of intensity peaks on a square grid that is rotated by 45° with respect to that in the mask. The period of the peaks is reduced with respect to the mask pattern by a factor of square root of 2. The contrast of the image calculated as functions of the pillar diameter and height are shown in Fig. 2. The corresponding contrast values of the DTL image generated by the equivalent Cr (amplitude) mask that consists of clear holes etched in a Cr film are shown in Fig 2(a) for comparison.

The large-area phase mask was used in a PHABLE exposure system to perform full-field, DTL exposures of the 4”-diameter mask pattern onto wafers coated with a commercially-available, i-line-sensitive positive resist. SEM images of the structures obtained are shown in Fig. 3 for two exposure doses. The results demonstrate that the exposure dose latitude is suitable for a production process. In addition, the exposure dose was compared to that required for exposing the same pattern when using instead a Cr mask consisting of holes opened in a square lattice with the same symmetry. While successful patterns were also obtained with the Cr mask the dose needed was 4-5 times higher than with the phase mask. Therefore our simulations and experimental results show the significant benefits of using phase masks with the DTL method.

References:

1. H. Solak, C. Dais, F. Clube, Optics Express, Vol.19, No.11 (2011).
2. C. Dais, F. Clube, H. Solak, K. Itoh, Y. Taniguchi, M. Hoga, EIPBN 2011, Las Vegas Nevada.

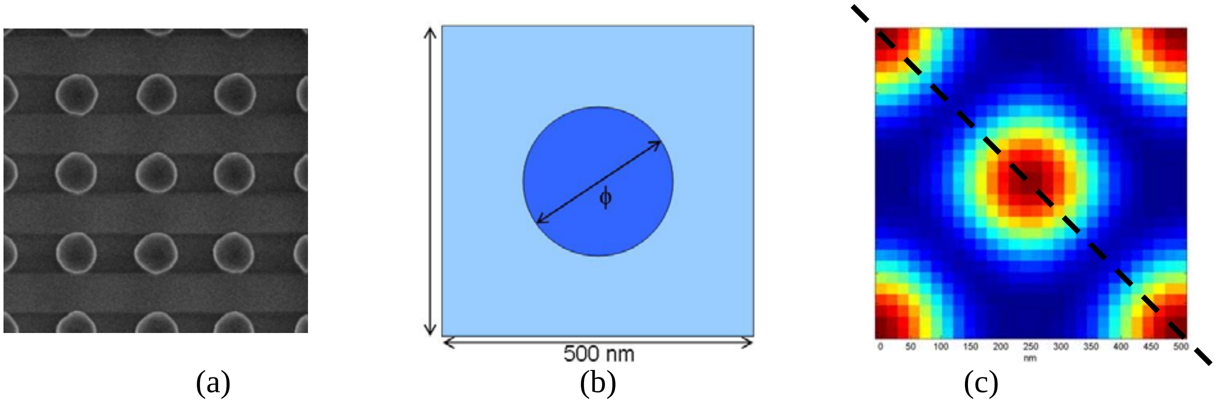

Fig. 1 (a) SEM image of the phase mask fabricated for this study. The mask pattern covered an area of 4” diameter for full-field exposure of 4” wafers. (b) The layout of the unit cell of the designed and implemented phase-mask. The central circular region represents the phase shifting pillar. (c) An example of the simulated DTL image formed by the phase mask.

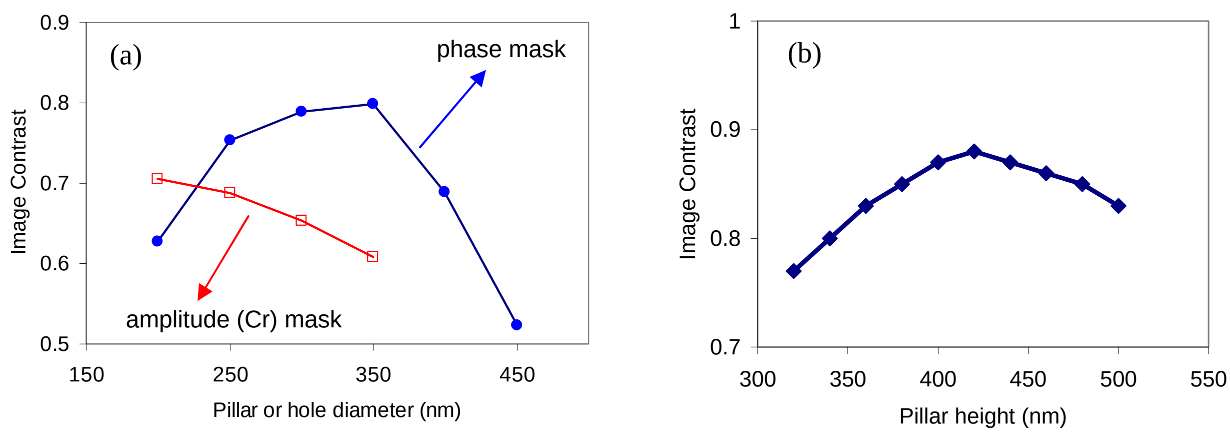

Fig. 2 (a) DTL image contrast as a function of structure size. Open squares and solid circles show the calculated DTL image contrast as a function of diameter of holes in a Cr film and phase shifting pillars etched in quartz, respectively. Pillar height is 330 nm for the latter case. (b) DTL image contrast as a function of pillar height for a fixed pillar diameter of 300 nm. In all cases image contrast was calculated along the dashed diagonal line shown in Fig 1(c).

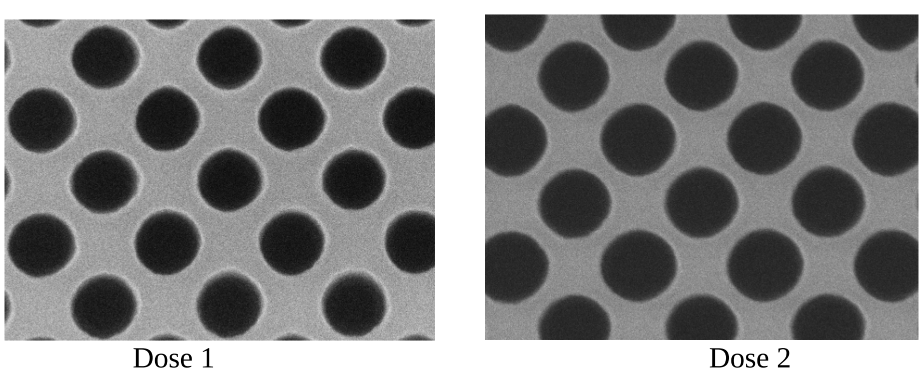

Fig 3 DTL exposures as a function of exposure dose for two doses. The exposure dose was increased by 25% between the two exposures.