Defect Tolerant Extreme Ultraviolet Lithography

Lukasz Urbanski, Jorge J. Rocca, Carmen S. Menoni, Mario C. Marconi
Engineering Research Center for Extreme Ultraviolet Science and Technology
and Electrical and Computer Engineering Department
Colorado State University, Fort Collins, Colorado 80523
urbanski@engr.colostate.edu
Artak Isoyan
Synopsys, Inc., Hillsboro, Oregon 97124
Aaron Stein
Center for Functional Nanomaterials, Brookhaven National Laboratory, P.O.
Box 5000, Bldg. 735,Upton, NY 11973-5000,USA

We present a defect tolerant Extreme Ultraviolet (EUV) lithography technique based on the utilization of the Talbot effect. The method renders error-free prints, regardless of existence of defects in the mask. The technique combined with coherent illumination from a compact EUV laser makes up a robust and compact lithography tool for nanopatterning.

The defect tolerant lithography technique relies on the generalized Talbot effect[1]. When a transparent mask with a periodic structure is illuminated with a coherent beam a replica of itself is obtained at specific locations from the mask determined by the periodicity of the mask and the wavelength of illumination. These locations are referred to as the Talbot planes. This coherent imaging effect was used by Zanke et. al. for patterning photonic crystals in what was defined as coherent diffraction lithography[2].

The Talbot mask is composed of a regular array of diffractive cells (or tiles) arranged in a periodic pattern. The Talbot image is formed by the diffraction in a large number of tiles, and consequently a small defect in the mask that compromises a small surface compared with the surface of the mask does not degrade the final image. This effect was discussed by Dammann et al. to render faulty images of periodic objects[3]. In order to assess the extent of defect tolerance, we have fabricated a set of masks with a defect, as shown in figure 1. The masks were composed of periodically tiled cells of an arbitrary shape. The defect in the mask was formed by changing the design of a single cell in one case and the entire row of cells in the other. Subsequently, the masks were illuminated with coherent EUV light and the Talbot images were recorded in a photoresist-coated silicon wafer. The recording plane was situated at a distance corresponding to the first Talbot plane. The patterned resist was then developed and analyzed. Figure 2 are atomic force microscope scans of the prints produced by the masks shown in figure 1 revealing the complete absence of the defect. The influence of the size of the defect on the quality of the printed image is analyzed.

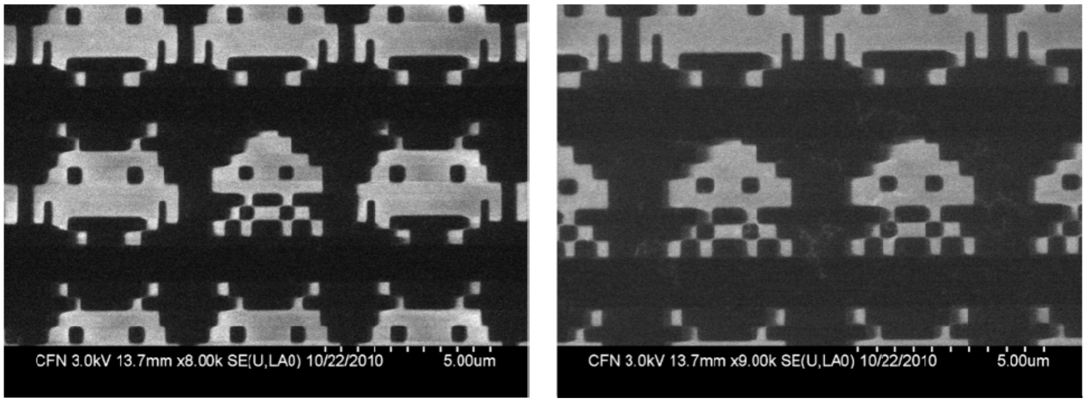
---

[1] Isoyan, A., et al. J. Vac. Sci. Technol. **B27**, 2931, (2009)

[2] Zanke, C., M.H. Qi, and H.I. Smith, J. Vac. Sci. Technol. **B22**, 3352, (2004).

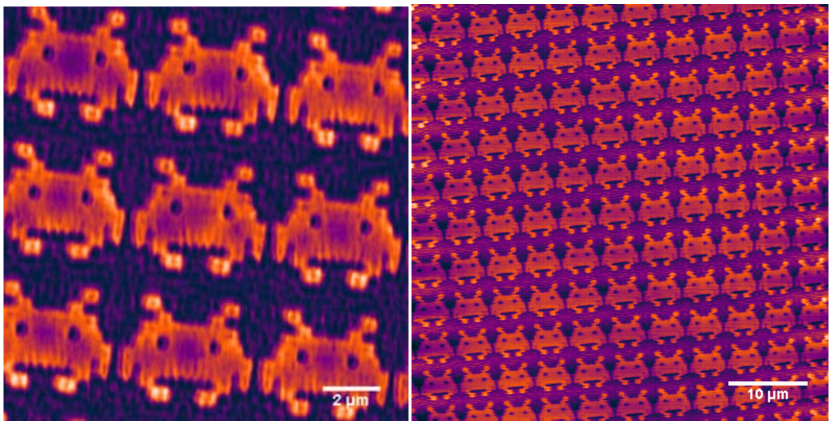
[3] H. Dammann, G. Groch, M. Kock. Appl. Opt. **10**, 1454, (1971)

This work was supported by the National Science Foundation, award ECCS 0901806, the NSF ERC for Extreme Ultraviolet Science and Technology, award EEC 0310717. This research was carried out in part at the Center for Functional Nanomaterials, Brookhaven National Laboratory, which is supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. DE-AC02-98CH10886.



(a) (b)

Figure 1: Electron microscope scans of different masks. Defect planted in a single tile (a), defect planted in an entire row of tiles (b).



(a) (b)

Figure 2: Atomic force microscope scans of the patterned resist. Both, single tile defect (a) and entire row of defects (b) resulted in defect-tolerant printing.