EUV Achromatic Talbot Lithography: a Method for High-Resolution Patterning of Nanostructures over Large Areas

D. Kazazis, L.-T. Tseng, and Y. Ekinci
Laboratory for Micro- and Nanotechnology,
Paul Scherrer Institute, 5232 Villigen-PSI, Switzerland
dimitrios.kazazis@psi.ch

Patterning at the nanoscale has been the focus of attention of scientists and engineers in the recent decades especially for applications in electronic devices and CMOS downscaling. Beyond that, there has been a strong interest in patterning periodic structures at the nanoscale with multidisciplinary applications such as templated nanowire growth, plasmonic devices, magnetic media, solar cells etc. Most periodic patterning for structures below 100 nm is primarily done with electron beam lithography (EBL), a serial and hence slow method.

Achromatic Talbot lithography (ATL)[1] is an alternative, parallel patterning technique, based on the Talbot effect. When periodic transmission gratings are illuminated with monochromatic light, self-images of the grating are produced at given distances Z_T. In the case of light with a bandwidth $\Delta\lambda$, the self-images smear out and finally overlap at a distance Z_A resulting in a stationary intensity pattern with a large depth-of-focus, as shown schematically in Fig. 1. Taking advantage of the EUV wavelength (13.5 nm) and the large spatial coherence of synchrotron radiation, one can pattern large-area periodic structures (>0.5x0.5 mm^2 in one exposure) in a parallel and efficient fashion.[2,3] Several cm^2 areas can be patterned by stitching fields in a step-and-repeat exposure.

Achieving high-quality periodic patterns, especially deep nanoscale (<10 nm radius) and dense ones (<70 nm pitch), requires not only a high-brightness light source, such as a synchrotron, but also the development and nanofabrication of high-quality transmission masks, capable of providing uniform patterns. In this work, we attempt to investigate the resolution limits of ATL for dot/hole arrays based on simulations of the aerial images produced by several different masks, as shown for example in Fig. 2(a) for a mask with nanoholes and in Fig 2(b) for a mask with nanorings. We also present the nanofabrication of high quality ATL masks on 100 nm thin Si_3N_4 membranes utilizing high aspect ratio, dense, and sub-50 nm diameter resist pillars as seen in Fig. 3(a). Finally, real EUV exposure results of sub-10 nm radius dots with sub-70 nm pitches are presented and compared with the simulations. A typical Talbot pattern in HSQ resist is shown in Fig. 3 (b) with dots of 12 nm radius and 71 nm pitch. This work opens up the path to many applications that require dense and nanoscale periodic structures, ranging from pure, all the way to applied science and engineering.

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[2] W. Karim, S. A. Tschupp., M. Oezaslan et al., Nanoscale **7**, 7386 (2015).

[3] D. Fan, E. Buitrago, S. Yang et al., Microelectron. Eng. **155**, 55 (2016).

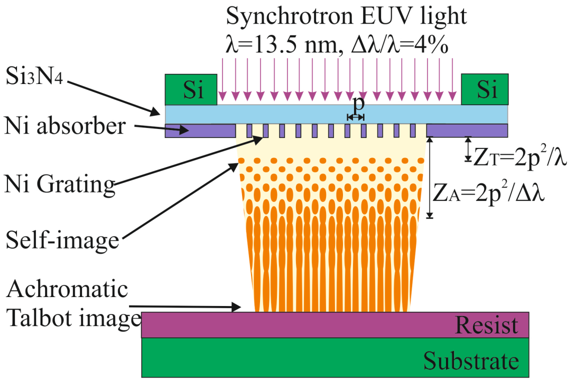

Figure 1: Schematic view of achromatic Talbot lithography: Self-images of the diffraction grating are produced at Talbot distances Z_T and they smear out and merge after the achromatic Talbot distance Z_A.

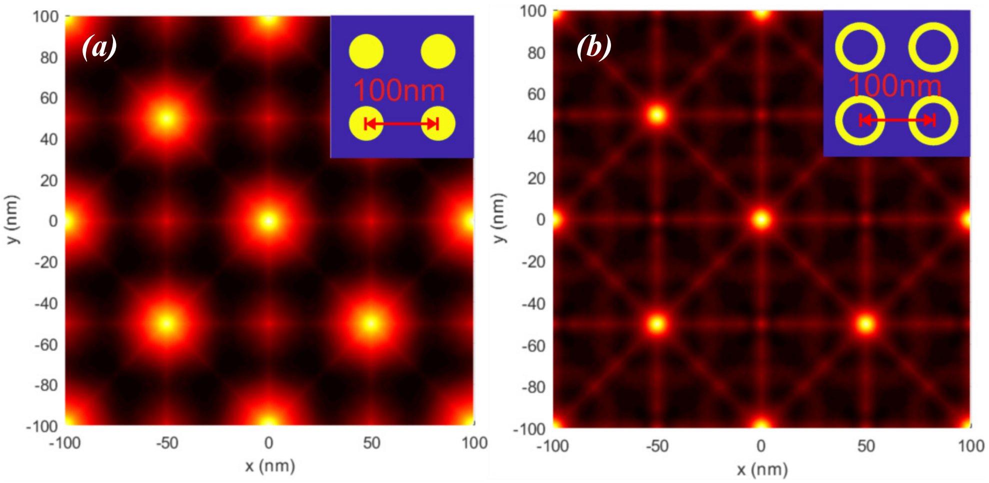

Figure 2: ATL aerial image simulations: (a) Simulated aerial image of an array of 48 nm holes with 100 nm pitch. The result is a square array rotated by 45° and a pitch of $\frac{100\ nm}{\sqrt{2}} \cong 71\ nm$. *(b)* Simulated aerial image of an array of rings (outer/inner diameter: 48/68 nm). The result is again a similar array a with sharper intensity profile. The insets show the mask layout.

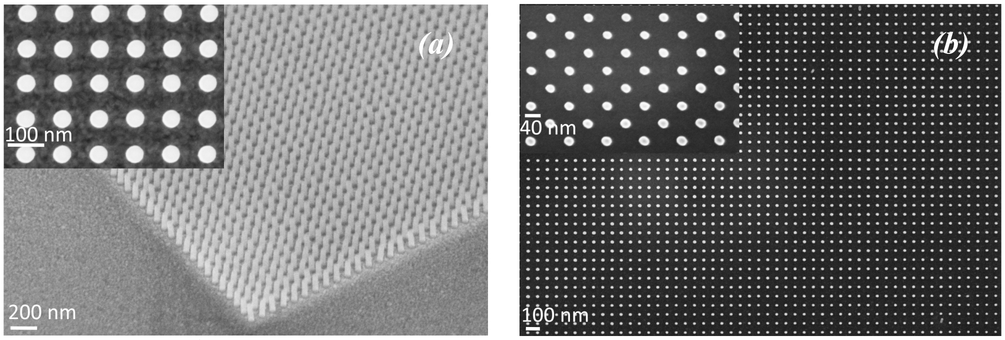

Figure 3:(a) 45° SEM image of 24 nm radius HSQ pillars ~170 nm high, used as a mold for Ni electroplating. A top-down image is shown in the inset. *(b)* 12 nm radius HSQ resist dots with a pitch of 71 nm obtained with the ATL mask of (a).