Self-imaging of complex structures with a Table-top EUV Laser

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EUV interference lithography (IL) has demonstrated to be a very powerful approach for creating periodic patterns using various configurations, allowing the easy exposure of periodic nanostructures with sub-50 nm resolution[1]. Holographic projection lithography is the natural extension of this technique to generate arbitrary structures[2,3], but this lithographic techniques require a coherent source illumination, which in the EUV imposes severe restrictions. The development of compact high flux EUV lasers provides an opportunity to efficiently use interference and coherent imaging for patterning nanometer scale features over large areas[4]. In this work, we report the development of another and **novel high-resolution EUV patterning approach**, capable of patterning large area periodic structures of arbitrary content with nanoscale resolution. It is based on **Talbot imaging** – the Generalized Talbot Imaging, or GTI. The general idea of GTI is illustrated in Fig. 1a: a periodic object, historically a simple linear grating, forms highly accurate real images of itself at distances that are integer multiples of a fundamental unit, the Talbot distance - Z_{nT} (in our experiment Z_T = 1mm). At these locations phase shifts cancel out and the interference of the waves diffracted by the periodic structures recreates the image of the object without the necessity of any optics. We have demonstrated that the combination of a coherent soft X-ray (EUV) source with a nanofabricated Talbot template allows for the extension of nanolithography in an extremely simple set up: the Talbot template embodies both the information to be written in the exposure field, and the image formation system. In its simplicity, Talbot imaging opens the door to novel application of nanolithography of periodic patterns, such as high-density memory chips. The ability to form a projected self-image of a complex periodic object has great interest in semiconductor and device fabrication – if one could extend the imaging to the nanometer region. In this experiment we used a compact Ne-like Ar capillary discharge laser configured to produce pulses with energy of approximately 0.1mJ and about 1.2ns FWHM duration. It can be operated at repetition rates of several Hz producing EUV powers in excess of 1mW with high degree of spatial and temporal coherence. The laser operates in the 46.9nm 3s1P1-3p1S0 transition of neon-like Ar. An alumina capillary 3.2mm in diameter and 27cm in length filled with Ar is excited with a current pulse approximately 22kA, a 10% to 90% rise time of approximately 55ns and a first half-cycle duration of approximately 135ns. The relative bandwidth of the EUV laser is approximately $\Delta\lambda/\lambda=10^{-4}$ yielding a coherence length approximately 470μm. The spatial coherence radius at the recording distance is approximately 740 μm. The whole system easily fits on the top of an optical table.

The Talbot mask was fabricated on a *Si3N₄* membrane patterned using standard electron beam lithography in a 65 nm thick HSQ photoresist layer. The first Talbot plane was located at 1 mm from the mask. The Talbot template was repeated 124 times in the horizontal and vertical directions to provide an effective numerical aperture of 0.28 in order to have a point resolution of 100 nm. Figure 1b is an atomic force microscope scan of the printed patterns in PMMA.

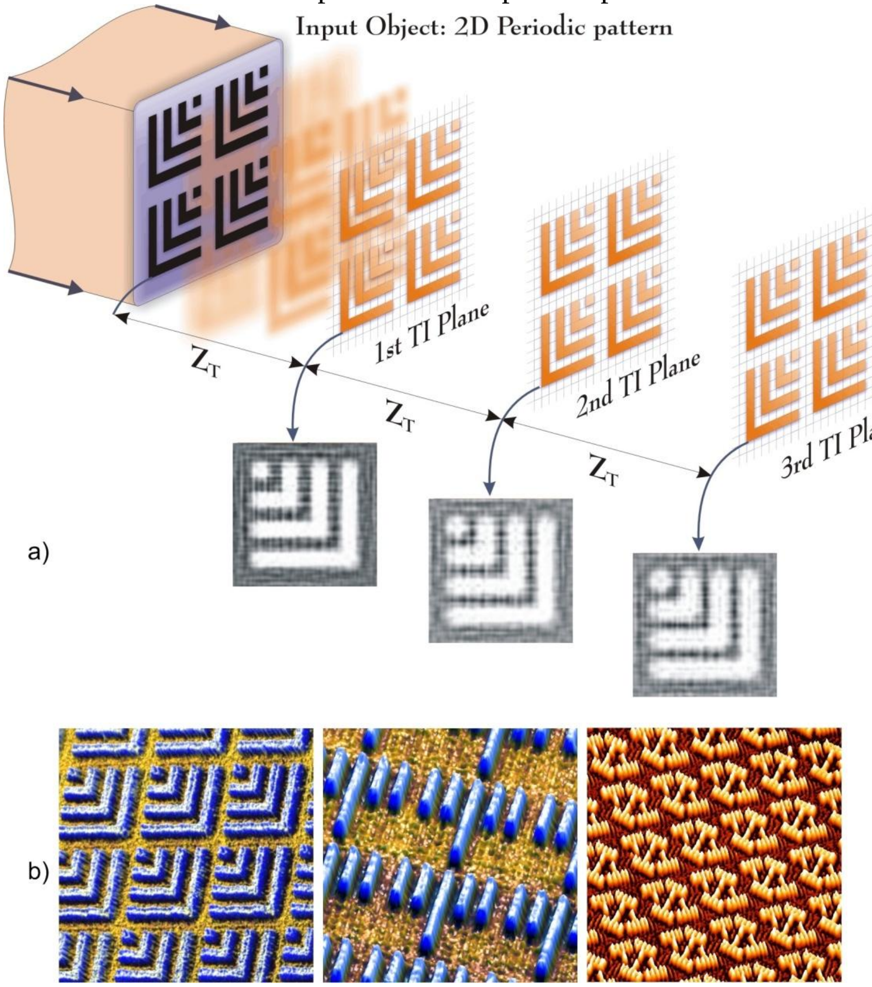

Fig.1. (a) Talbot effect concept: Self imaging of periodic structures. Coherent radiation illuminates the object (mask) to the left, and self-images are created at specific locations. The images shown are modeling results. (b) First experimental results in Soft X-rays (EUV). The Atomic Force Microscope (AFM) images of actual exposures of three different test patterns printed in PMMA resist. Notice the excellent quality of the images at the Talbot planes.

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