NANOMETER PATTERNING AND HOLOGRAPHIC IMAGING USING TABLE-TOP EUV LASER

P.W. Wachulak [1*#], A. Bartnik [1], C.S. Menoni [2], J.J. Rocca [2], H. Fiedorowicz [1], and M.C. Marconi [2]

[1] Military University of Technology, Institute of Optoelectronics, ul. Kaliskiego 2, 00-908, Warsaw, Poland
[2] Colorado State University, Electrical and Computer Engineering, 1320 Campus Delivery, Engineering Res. Center Fort Collins, CO 80523, USA

Keywords: holography, interferometric lithography, EUV laser

**) e-mail: wachulak@gmail.com*

Manipulation in the scales comparable to the sizes of molecules and even atoms is currently a very attractive. Nanopatterning and nano-meter resolution imaging are very important to control the matter on these small scales. Nanopatterning allows for surface modifications while nano-meter resolution imaging acts as a feedback mechanism used to evaluate the results.

A nanometer scale periodic patterns obtain with Interference Lithography (IL) were realized in commercial photoresists (PMMA and HSQ) with typical size below 100 nm using a compact nanopatterning tool based on a Lloyd's mirror interferometer. The EUV source used was a table top capillary discharge laser $\lambda = 46.9$ nm producing pulses with an energy of approximately 0.4 mJ and duration of 1.2 ns FWHM. High spatial coherence radius – 570 μm at 1.7 m from the laser output and temporal coherence, for $\Delta\lambda/\lambda \approx 1\times10^{-4}$ equal to 470 μm, allowed for parallel imprint of the dense arrays of holes and nano-pillars with feature size as small as 58 nm, shown in Fig. 1a) for PMMA resist, imprinted over the large area of 0.5×0.5 mm^2 [1].

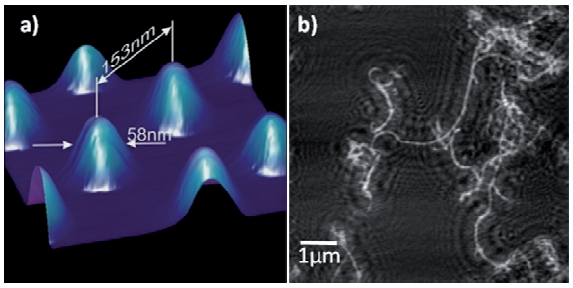

Figure 1. Example of the nanopattern in PMMA obtained using EUV light and IL technique (a) and reconstructed hologram of carbon nanotubes with resolution of 46 nm (b).

Using the EUV laser a high resolution holographic imaging was performed in a Gabor in-line scheme with a wavelength resolution. Low numerical aperture holograms of an AFM tips were imaged with a resolution of ~160 nm [2, 3], while high NA hologram of carbon nanotubes, used as an object, was numerically reconstructed with a spatial resolution of 45.8 +/- 1.9 nm based on a knife-edge technique and independently assessed by a Gaussian filtering and correlation method [4]. The result of the reconstruction is shown in Fig. 1b). These experiments were performed at Colorado State University.

Next step in high resolution imaging will be designing and prototyping the EUV microscope based on an incoherent plasma source with gas puff target built at Military University of Technology [5]. The microscope will utilize the diffraction optics, namely Fresnel zone plates, for imaging the object with high magnification and sub-100 nm resolution.

The results show that EUV lasers combined with IL schemes have potential to become a useful compact alternative for printing nanometer features in a university laboratory environment. Short wavelength of the EUV laser opens a possibility for sub-50 nm holographic imaging and may become a photon based, high resolution imaging method complimentary to scanning electron microscopy and atomic force microscopy especially with further development of even shorter wavelength EUV sources in "water window" region. New existing and future sources at MUT may also substantially contribute to the high resolution EUV imaging in the near future.

Acknowledgements: This work was supported by the National Science Foundation ERC for Extreme Ultraviolet Science and Technology, Award Number EEC-0310717.

[#]) This work was done during the Ph.D. studies at Colorado State University, Fort Collins, USA, under the supervision of Prof. Mario C. Marconi.

References:

[1] P.W. Wachulak, M.G. Capeluto , C. S. Menoni, J.J. Rocca, M.C. Marconi, *Opto-electr. Rev.* **16** (4) (2008) 444–450.

[2] P.W. Wachulak, M.C. Marconi, R.A. Bartels, C.S. Menoni, J.J. Rocca. *Optics Express* **15** (2007) 10622-10628.

[3] P.W. Wachulak, R.A. Bartels, M.C. Marconi, C.S. Menoni, J.J. Rocca, Y. Lu, B. Parkinson. *Optics Express* **14** (2006) 9636.

[4] P.W. Wachulak, M.C. Marconi, R.A. Bartels, C.S. Menoni, J.J. Rocca, *J. Opt. Soc. Am. B* **25** (11) (2008) 1811.

[5] H. Fiedorowicz, A. Bartnik, R. Jarocki, R. Rakowski, M. Szczurek, H. Daido, N. Sakaya, M. Suzuki, H. Nagatomo, H. Tang, Ch.I. Woo, Y. Tohayam, S. Yamagami, T. Nakayama, *Proc. SPIE*, vol. 3767(1999) 10–20 .