Soft x-ray varied-line-spacing gratings by near field holography with an electron beam lithography-written mask

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High-precision varied-line-spacing gratings (VLSGs) are indispensable in soft X-ray flat-field spectrometers, which are widely used in plasma diagnosis, synchrotron radiation, and so on. Soft X-ray VLSGs with high-accuracy of groove density distribution and low stray light are preferable.

Holographic lithography and mechanical ruling are two representative methods for soft X-ray VLSGs. Although holographic lithography shows advantages of low stray light, holographic lithography is more less flexible in groove density distribution than mechanical ruling. To meet the increasing requirements of soft X-ray VLSGs, two fabrication methods based on electron beam lithography have been developed. Since EBL is expensive and time consuming, pattern transfer techniques are required to employ the EBL-written masks repeatedly. In one of the methods, nanoimprint is utilized to replicate the VLSG patterns from an EBL-writing mask [1]. In the other method, near field lithography (NFH) was proposed to fabricate diffraction gratings [2]. NFH can adjust the duty cycle of the photoresist mask of a soft X-ray VLSG by the optimization of exposure and development parameters of NFH. Therefore, NFH results in a simplified process compare to nanoimprint. Recently we have proposed a dynamic NFH method (i.e. displacing grating substrate ~70 μm) for soft X-ray VLSGs to suppress Rowland ghost from EBL-written mask [3].

In this work we present the comparison of the effect of the static and dynamic NFH on the grating qualities at soft X-ray wavelengths. The grating fabricated by dynamic NFH morphologies exhibits more uniform groove parameters and smoother line edge roughness (Figures 1 and 2). Additionally, the difference of in-plane efficiencies of both gratings is due to groove parameter different instead of different NFH modes (Figure 3(a)). However, the off-plane efficiencies of the grating fabricated with dynamic NFH displays lower stray light than that with static NFH (Figure 3(b)). It indicates that part of stitching error of the EBL-written mask has been suppressed. With the introduction of dynamic NFH, soft X-ray VLSG with reduced the stray light is achieved compared to its EBL-written mask.

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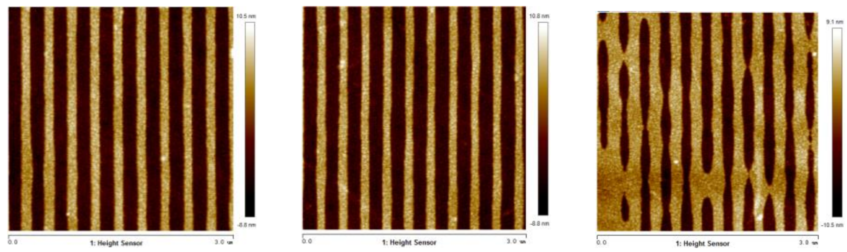
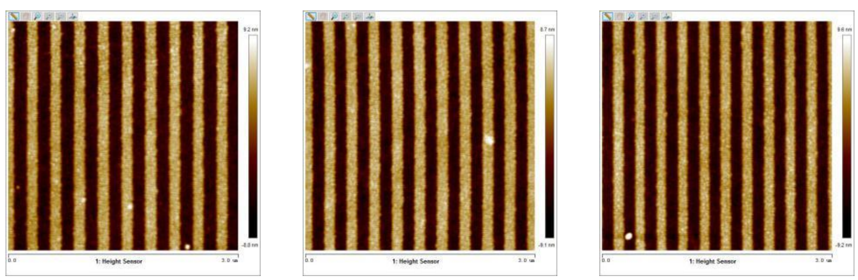
[1] D. L. Voronov, E. M. Gullikson,and H. A. Padmore, Opt. Express 25, 23334 (2017).
[2] E.-B. Kley and T. Clausnitzer, Proc. SPIE 5184, 115 (2003).
[3] D. Lin, H. Chen, Z. Liu, K. Dietrich, S. Kroker, T. Kaesebier, Y. Liu Y, E.-B. Kley, Y. Hong, Optics Letters 43, 811 (2018).



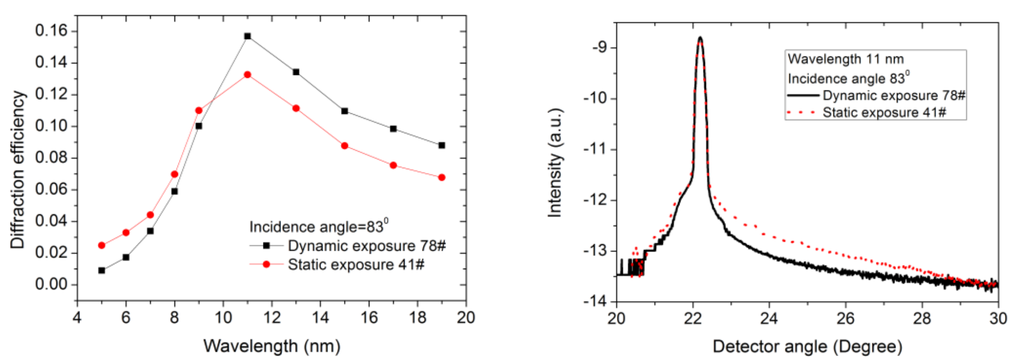
(a) 8 mm left to the center (b) center position (c) 8 mm right to the center

Figure 1: AFM images of XVLSGs with static exposure during NFH. The average depth and duty cycle of the XVLSG is 10.2 $\pm$0.8 nm and 0.38$\pm$0.034, respectively.



(a) 8 mm left to the center (b) center position (c) 8 mm right to the center

Figure 2: AFM images of XVLSGs with dynamic exposure during NFH. The average depth and duty cycle of the XVLSG is 9.4 $\pm$0.8 nm and 0.48$\pm$0.028, respectively.



(a) (b)

Figure 3 (a) Measured in-plane efficiencies of two XVLSGs as a function of wavelength, and (b) measured off-plane intensity of the two XVLSGs as a function of detector scanning angle. The two XVLSGs were fabricated with static and dynamic exposure during NFH, respectively.