BLAZE GRATINGS WITH A RIBBED BACK SLOPE

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Abstract

Binary relief phase-modulated gratings provide symmetrical diffraction of the incoming light beam. Asymmetrical gratings, e.g. asymmetrical triangular blazed gratings, are characteristic by an asymmetrical diffraction behavior, where one of the first diffraction orders is more important than the other one. Electron beam lithography is a suitable and flexible tool for patterning of such kind of gratings. High quality results can be readily obtained when the period of the grating is relatively large and the relief depth is relatively low, this is the case of gratings with a small blaze angle. As the blaze angle increases, the quality of result suffers from several patterning-related issues. One of the problems is a reflection of the incoming light beam from the back slope (anti-blaze facet) of the blaze grating. We propose a novel configuration, with a ribbed modulation of the back slope. This modulation is perpendicular to the direction of the grating grooves. This paper presents an analysis of the proposed blazed grating configuration. E-beam pattern generators were used to prepare a few samples of blaze gratings with a ribbed back slope. One part of the experiment was performed with a Gaussian-shaped beam and another one with the variable-shaped beam. Results of the experiment are presented. Finally, we discuss the optical performance of two blaze gratings with similar parameters, one of them is with the flat back slope and another one is with the ribbed back slope.

Keywords: Nano patterning, blazed diffraction grating, Gaussian-type beam, variable-shaped beam, electron beam writer

1. INTRODUCTION

Asymmetrical gratings, e.g. asymmetrical triangular blazed gratings, are characteristic by an asymmetrical diffraction behavior, where one direction of diffraction orders is more important than the other one. Electron beam lithography is a suitable and flexible tool for patterning of such kind of gratings [1], [2]. However, the realization of high quality blazed profile with the surface roughness in the 10-nm range is not easy, mainly if the high writing speed is required [3]. Furthermore, electron scattering during the exposure process plays an important role and its influence on grating profile quality must be handled with care [4]. Quality results can be obtained when the period of the grating is relatively large and the relief depth is relatively low, this is the case of gratings with a small blaze angle. As the blaze angle increases, the quality of result suffers from several patterning-related issues. One of the problems is a reflection of the incoming light beam from the back slope of the blaze grating. We propose a novel configuration of a blazed grating, with a ribbed modulation of its back slope.

2. METHOD

Relief of the blazed grating is basically composed of two slopes: a front slope and a back slope. The front slope should be as flat and smooth as possible. Generally, the back slope is required to be almost perpendicular to the surface of the structure because such configuration reduces the bending of incoming light into subsidiary diffraction orders. Even in the optimal case the back slope of the blazed grating partially influences the amount of light directed to the subsidiary diffraction orders.

In this paper we propose an asymmetric blazed grating with modification of the back slope, see **Figure 1**. The structural modification of the back slope consists in adding the notches forming the secondary perpendicular grating with the period higher than the main period of the blazed grating. This secondary grating is basically performed vertically with respect to the main plane of the blazed grating. The secondary grating is also partially nested into the front slope of the blazed grating; the rate of this nesting is represented by a modulation depth factor.

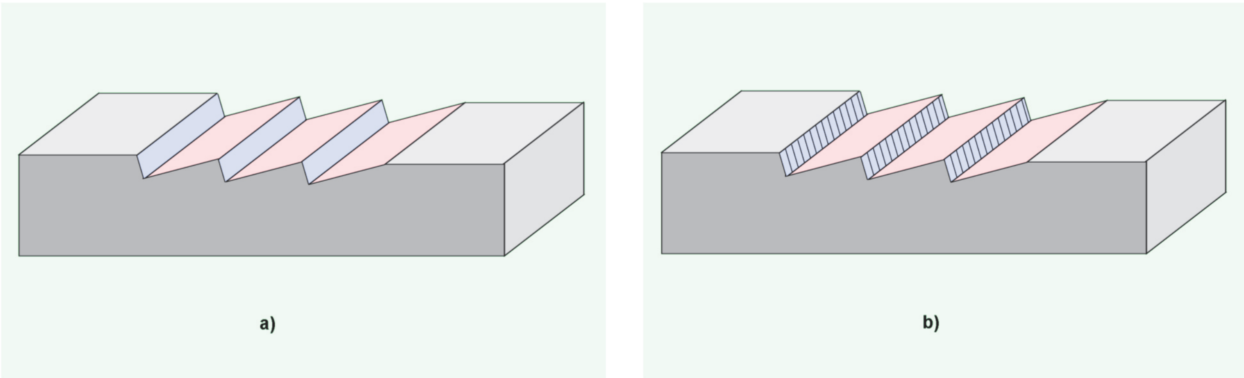


Figure 1 Blazed grating schematically: (a) standard configuration; (b) ribbed back-slope configuration

3. EXPERIMENT

We performed two experiments in order to validate the presented method of modification the back slope of the blazed grating.

3.1. Short period sample experiment

The first experiment was performed using the variable shape e-beam pattern generator BS600 working with the electron energy of 15 keV. Three variants were prepared: one variant (variant 0) with the flat back slope and two variants with the ribbed back slope. A small detail of the edge of the structure layout is depicted in **Figure 2**. Each pattern fills in the square area of 2 mm × 2 mm. The gratings are designed to have a period of 2000 nm and the depth of 270 nm; the blazed relief is approximated by 8 levels, thus one step is 250 nm wide and 39 nm deep. The perpendicular period of the ribbed back slope was selected to be 1000 nm (variant 1) and 500 nm (variant 2) respectively. The modulation depth was 250 nm in both cases, i.e. the width of just one exposure level. The maximum exposure dose was adjusted (accordingly to previously performed dose test) to 25 µC/cm². The exposure was performed to the top part of the 1600 nm thick PMMA resist layer coated on the silicon wafer. The nAAc developer (12 minutes) was used for revealing the blazed relief.

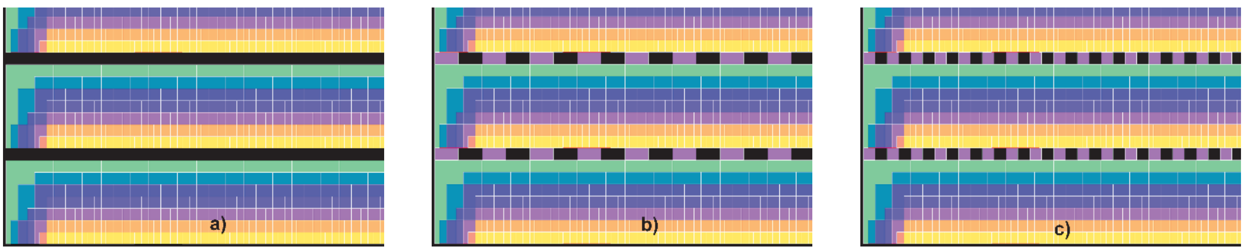


Figure 2 Layout of the first sample experiment with period of 2000 nm: a) standard configuration; b) and c) ribbed back-slope configuration with perpendicular period of 1000 and 500 nm respectively

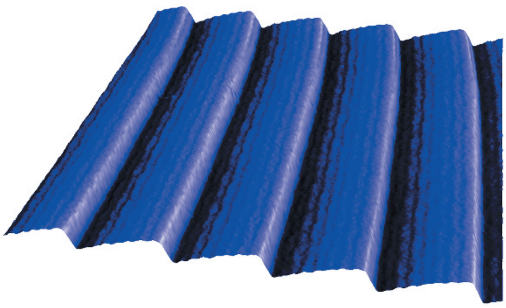
3.2. Long period sample experiment

The second experiment was performed using the Gaussian e-beam pattern generator EBPG5000plusES working with the electron energy of 100 keV. The gratings are designed to have a period of 25 µm and a variable depth according to the exposure dose in the range 1000-8000 nm; the nominal value should be 3000 nm. The blazed relief is approximated by 64 levels, thus one step is 391 nm wide and 48 nm deep. Modulation of the back slope was performed by thin perpendicular notches of 500 nm × 100 nm with separation distance of 500 and 1000 nm, respectively. The notches are positioned just on the back slope edge from the unexposed side. Thus, the nominal modulation depth was 500 nm. The maximum exposure dose was in the interval 180-300 µC/cm^2. The exposure was performed to the thick PMMA resist layer (10 µm) spin coated on the silicon wafer.

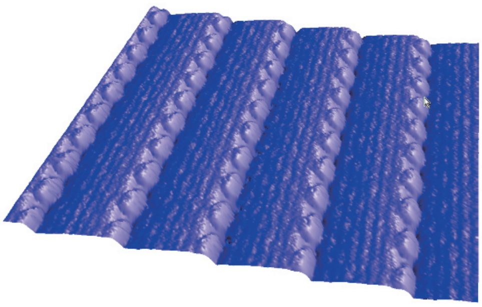
4. RESULTS AND DISCUSSIONS

4.1. Short period sample results

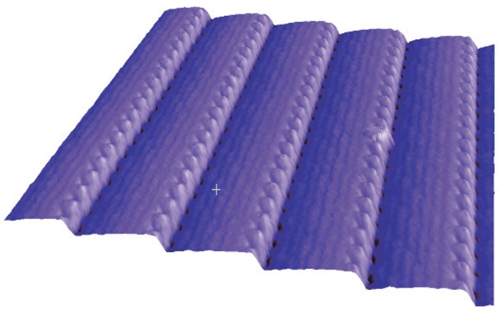
The relief of the first sample from the BS600 pattern generator was measured using the atomic force microscope. **Figure 3** shows the relief of three performed variants: variant 0 with the plane back slope, variant 1 with the ribbed back slope and the perpendicular period of 1000 nm, and variant 2 with the ribbed back slope and the perpendicular period of 500 nm. Measured profile depth was approximately 260-290 nm.



a)



b)



c)

Figure 3 AFM profiles of blazed grating samples with period of 2000 nm: a) standard configuration; b) and c) ribbed back-slope configuration with perpendicular period of 1000 and 500 nm respectively

We performed measurements of light power bended to appropriate diffraction orders (-2; -1; 0; +1; +2). Three samples of period 2000 nm and the depth of ~ 270 nm (*cf.* **Figure 2** and **Figure 3**) were measured (the variant 0 with the flat back slope, the variant 1 with the ribbed back slope and the cross period of 1000 nm, and the variant 2 with the ribbed back slope and the cross period of 500 nm). Measurement was performed at the wavelength 632 nm and both polarisations; see **Table 1**. The 3rd orders are directed almost along the structure plane in this measurement configuration, so the results for these diffraction orders were unconvincing and they are disregarded in the following analysis.

Table 1 Results of energy distribution in diffractive orders, measured at wavelength of 632 nm, both TE and TM polarizations

Diffraction order	Efficiency ratio (arb.u.)					
	var.0, TE	var.0, TM	var.1, TE	var.1, TM	var.2, TE	var.2, TM
+2	0.01	0.05	0.02	0.01	0.01	0.03
+1	0.70	0.57	0.66	0.59	0.57	0.67
0	0.08	0.15	0.09	0.14	0.02	0.12
-1	0.07	0.03	0.03	0.05	0.10	0.03
-2	0.07	0.05	0.04	0.03	0.09	0.04
Sum	0.93	0.86	0.85	0.81	0.79	0.90

The first order efficiency is in all cases slightly above 60 % what is in accordance with the interval 60-70 % reported in [1]. We observed a negligible decrease in the efficiency of the main diffractive order (+1) in the case of the blazed gratings with the ribbed back slope (variants 1 and 2) with respect to the case of the flat back slope (variant 0). Also, the sum of measured diffraction order is somehow decreased in the variants 1 and 2 because a part of energy is directed to perpendicular diffractive orders. On the other hand, the decrease of zero order (variant 2) and the decrease of the negative orders (-1 and -2, variant 1) present an interesting result. It is to be noted that this improvement is not as important as originally expected.

4.2. Long period sample results

Here the results of the sample performed using the EBPG5000plusES pattern generator are described. **Figure 4** shows a view of a ribbed back slope (light area) of the grating with period 25 microns and the height of relief approximately 7600 nm. The upper dark part of the image is a top of the resist layer while the lower dark area is the surface of the silicon substrate. The perpendicular period is 1000 nm in this case. It may be observed that the intended modulation of the back slope is visible only to the depth of some 3 microns. The deeper part of the back slope seems to lose the modulation due to electron scattering effects in the resist.

Figure 5 shows a detail of the interface between the top of the resist layer and the modified back slope, in this case the perpendicular period is 500 nm. This result seems to be of low interest from the optical grating point of view. Nevertheless, it might be interesting for study of electron scattering events and especially in the evaluation of the forward scattering model and its parameters [5].

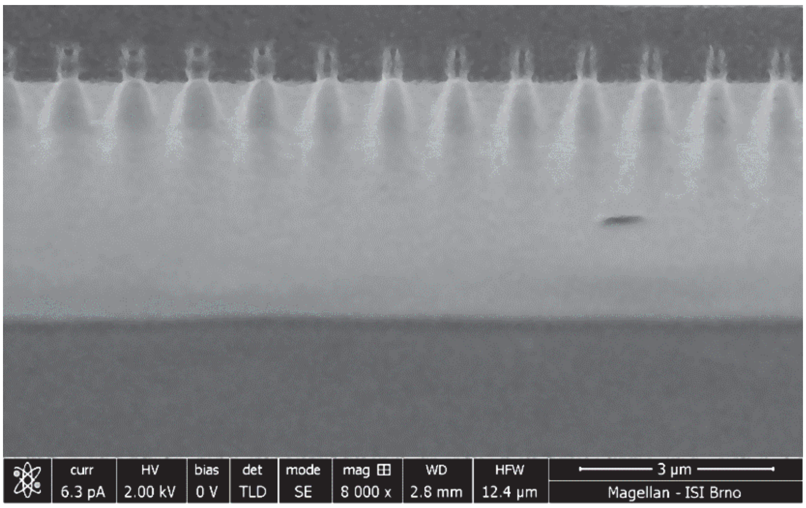


Figure 4 SEM image of a back slope, height 7600 nm (sample tilt 30 degree)

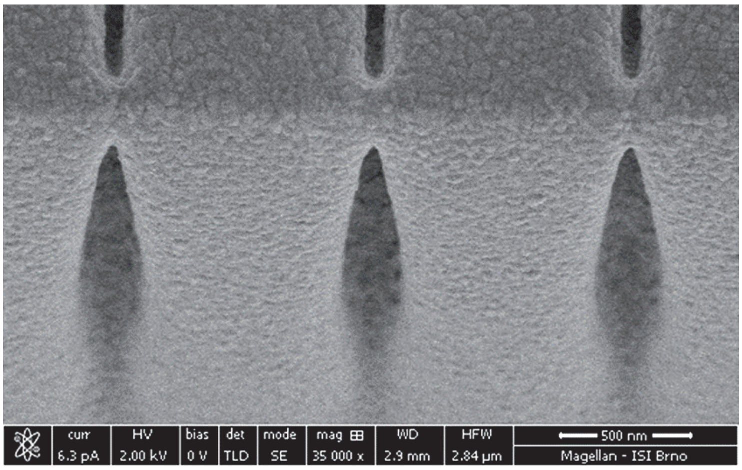


Figure 5 Detailed SEM image of a back slope, height 7600 nm (sample tilt 30 degree)

5. CONCLUSIONS

We presented a method that is intended to reduce subsidiary diffraction orders of blazed gratings. Two samples were prepared in order to validate this concept: the first one was performed using the variable shape electron beam pattern generator at 15 keV and the second one was performed using the Gaussian electron beam pattern generator at 100 keV. Measurements performed on the first sample confirmed the reduction of intensity in subsidiary diffraction orders, however the performance was improved only partially.

ACKNOWLEDGEMENTS

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