Fresnel zone plates as X-ray lenses by electron beam lithography with HSQ resist

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The broad applications of X-ray synchrotron radiation (SR) source require high quality lenses in the SR optics. One kind of the diffractive focus lenses is Fresnel zone plates (FZPs) whose quality is represented by the specifications such as the outermost zone width (image resolution requirement), the aspect ratio of the zone width against the height (image contrast requirement) and the zone (line) edge roughness (small dispersion requirement), etc. Nanofabrication techniques for FZPs have been developed for decades mainly by electron beam lithography (EBL) with either PMMA or ZEP to form templates for the subsequent Au electroplating process. Although great successes have been achieved in EBL with both resists, there are still unavoidable defects in the generated resist templates. For example, when the zone-width (the resist line-width) is shrunk down to 100 nm, thin resist lines with high aspect ratio fall caused by surface tension in the developer. To overcome this difficulty, extra structures as the radius lines are added to the zone plate pattern, as shown in figure 1. This extra structure apparently introduces scattering of X-ray through the transparent zones, deteriorating the image quality.

In this paper, we describe our EBL effort to avoid using the extra radius lines in resist by replacing PMMA (ZEP) with hydrogen silsesquioxane (HSQ), known as flowable oxide (FOX) delivered by Dow Corning Ltd. Based on our earlier results in EBL with HSQ, high aspect ratio HSQ lines with smooth sidewall can be achieved by a hot developing process [1]. In this work, we extend this study to the applications of zone plate fabrication. High resolution vector e-beam writer (VB6 HR), supplied by Vistec Ltd, is used for the EBL on the Fox resists at the tension of 100 keV and beam current of 500 pA. At the process development stage, Si substrate coated with 10 nm Cr/50 nm Au as seed layers is used. Processing study of lithography parameters is carried out by using 100 nm grating pattern instead of zone plate ones, considering grating structures are easy to be inspected by scanning electron microscope (SEM). Figure 2 shows the SEM micrograph of HSQ gratings with cross-sectional view. Well defined 100 nm lines/spaces grating in HSQ with high aspect ratio can be achieved thanks to the hot developing process in TMA238 developer at 50 °C. It has been found that well cured HSQ lines by focused e-beam radiation have strong mechanical strength to survive the surface tension in the developing process, as shown in figure 3. The zone-width of 100 nm without using radios lines as supporting structures are successfully achieved (figure 4).

In summary, using our earlier developed hot developing process for EBL in HSQ, we have successfully patterned Fresnel zone plates without the need of radius lines as the supporting structures. So far, the aspect ratio of 5/1 has been achieved. This process should have prospect for high resolution FZPs because HSQ is reportedly a high resolution e-beam resist. FPZs with 50 nm resolution should be feasible.

[1] Yifang Chen, Jia-rui Tao and Xingzhong Zhao, Microelectronic Engineering, vol. 83, p1119, 2006.

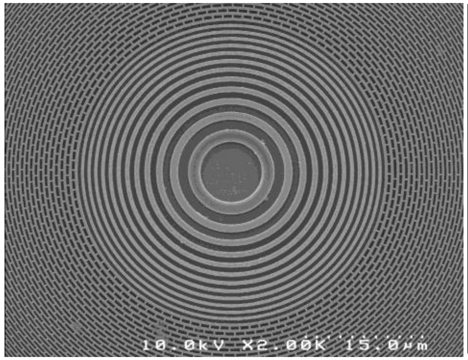

Figure 1. Fresnel zone plate in PMMA resist. To avoid the fall of resist lines, radius structure is added.

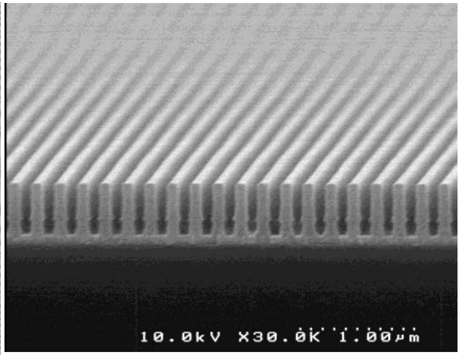

Figure 2. SEM micrograph for 100 nm HSQ lines/spaces standing on metal seed layer after hot development in TMA238 at 50 °C, showing very strong mechanical strength.

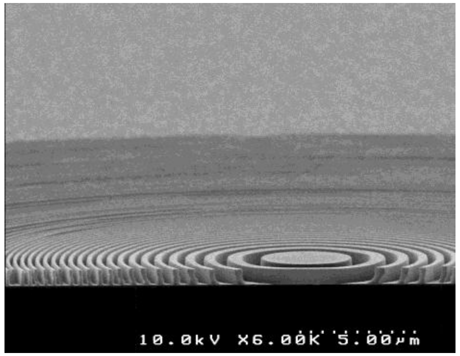

Figure 3 Cross sectional view of the resist profile in a zone plate pattern. The resist lines do not fall even for 100 nm line-width.

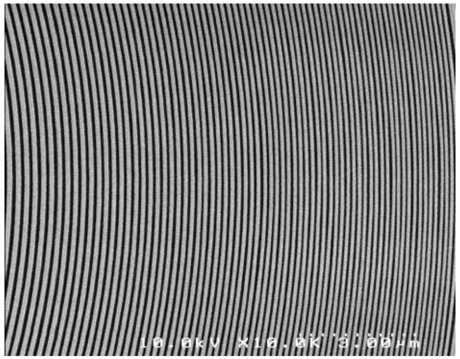
Figure 4 The narrow zone area of the Fresnel zone plate, showing the 100 nm HSQ lines do not fall.