A new high-aspect-ratio diamond dry-etch process for hard x-ray FEL radiation zone plates

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During the last years it has become important to develop zone plates that can be used with the new and upcoming x-ray free electron laser (FEL) sources.[1,2] Apart from the usual challenges with producing x-ray zone plates, i.e., sub-100-nm high-aspect-ratio periodic patterning, the new and demanding requirement on the zone plates is the capability to withstand the high heat load that these high-brightness sources will put on the optics.[3,4] Diamond is considered to be the optimal zone plate material to meet these demands.

In this work we report on a new tungsten-hardmask-based diamond dry-etch process suited for making very high-aspect-ratio diamond structures. A tri-layer mask consisting of the electron beam resist Zep 7000, a Cr hardmask and a thick (>300 nm) W mask is initially prepared on a 100 µm thick CVD-diamond substrate. The substrate will both serve as the zone plate material and as a support structure with efficient heat removal. The fabrication process starts with e-beam lithography for the pattern definition. Cl_2/O_2 reactive ion etching (RIE) is then used to transfer the pattern into the Cr layer. Cryogenic (-20 °C) SF_6/O_2 RIE is subsequently used to anisotropically etch into the thick W layer. The final pattern transfer into the diamond is then done with O_2 RIE. Figure 1 show 2.6 µm high gratings with 100, 80, and 60 nm half-pitch respectively. The 100 nm and 80 nm half-pitch gratings are of excellent quality and the aspect ratios are 26:1 and 30:1, respectively. To our knowledge this is the highest aspect ratio ever reported for periodic diamond structures with these small dimensions. The 60 nm half-pitch grating is of worse quality and demonstrates the present process limitation in terms of smallest pitch and aspect ratio. Figure 2 shows a fabricated diamond zone plate. The diameter is 75 µm and it has an outermost zone width (half-pitch) of 100 nm. The remaining W thickness is 200 nm and the etched diamond depth is 3.2 µm. In the paper we will present the details of the process and discuss improvements to further increase resolution, pattern quality and aspect-ratio of these diamond nanostructures.

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1. See, e.g., LCLS Conceptual design report, Stanford 2002; European XFEL Technical design report, Hamburg 2007; and SCSS Conceptual design report, Japan 2006; for information on the FEL facilities.
2. H. N. Chapman et al., Nat. Phys. **2** 839 (2006).
3. R. A. London et al., in: R. Tatchyn, K. F. Andreas, T. Matsushita (Eds.), Optics for Fourth-Generation X-Ray Sources, SPIE Press, San Diego, USA, 2001, pp. 51–62
4. D. Nilsson, A. Holmberg, H. Sinn, and U. Vogt , Nucl Instrum Meth A, Vol. **621**, 620 (2010).

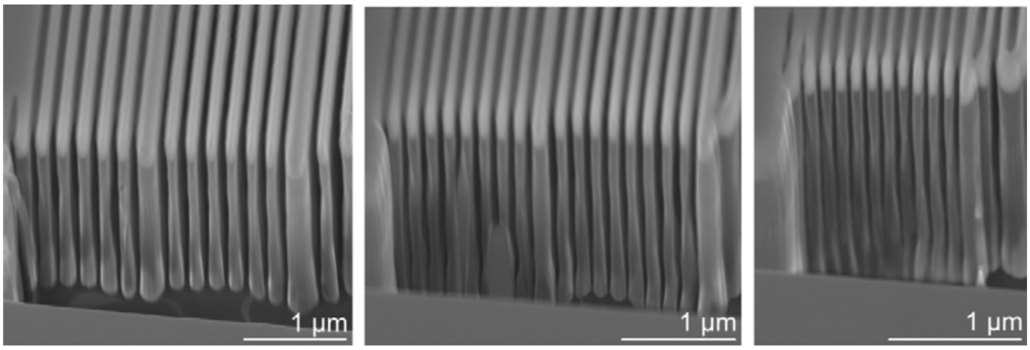

Figure 1. Diamond gratings with 100, 80, and 60 nm half-pitch, and a height of 2.6 µm. The bright layer on the top is the remaining 200 nm W hardmask.

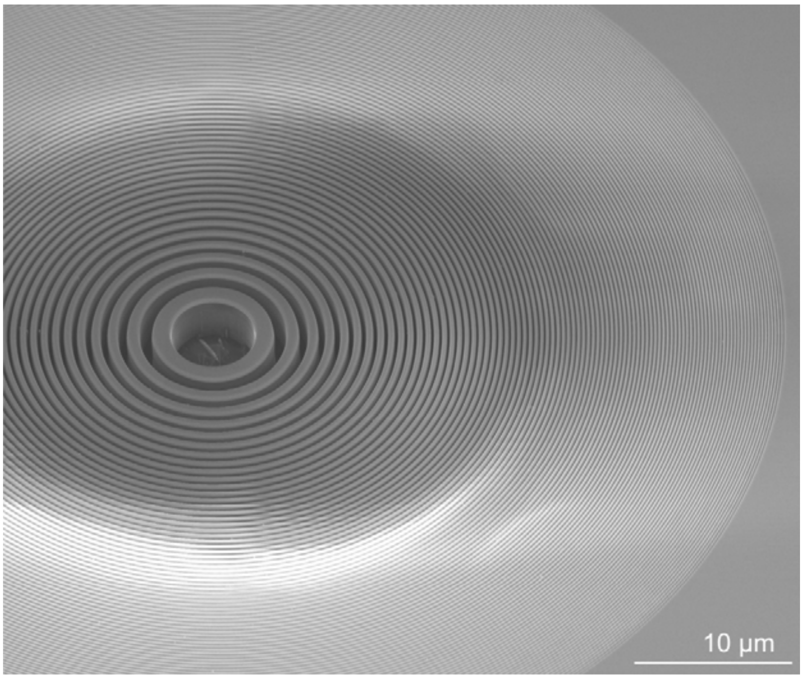

Figure 2. A diamond zone plate made for high-heat-load x-ray FEL applications. The diameter is 75 µm and it has an outermost zone width of 100 nm. The thickness of the diamond layer is 3.2 µm.