Investigation of diamond single crystals for XFEL monochromators

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The European XFEL will deliver SASE pulses with the peak power of ~20GW. During a 0.6 ms long pulse train, the average thermal load of the SASE beam will reach 10kW on a sub-mm spot [1]. The peak energy dose of the unfocused beam to the optical elements will be close to melt limit for most materials, therefore only low-Z materials can be used due to their smaller photoionization cross-sections. Under these conditions, monochromators for hard X-ray wavelength range become the most critical elements of the beamline optics, since their material should have both high heat load tolerance and high crystal structure perfection.

One of the possible technical solutions is based on a diamond single crystal in Laue diffraction geometry. For heat dissipation, a perfect diamond crystal plate must be bonded to heat sink rings made of CVD diamond. A good thermal conductivity through the boundary between crystal plate and CVD diamond can be provided by a state of the art direct bonding technology [2].

The local strains introduced into the bulk perfect crystals by the bonding process as well as the stress in subsurface layers due to polishing can become critical for the monochromator crystal quality. The aim of this work was to investigate the general quality of bulk synthetic HPHT IIa diamond single crystal intended for bonding and strain in their surface layers. X-ray topography measurements were performed at beamline E2 at HASYLAB using a Si (111) double crystal monochromator.

Figure 1 shows topograms from a HPHT IIa diamond single crystal with (111) surface orientation taken at the X-ray energy of 10 keV, reflection (111) in symmetric Bragg diffraction geometry. The sample proves to have defect-free areas up to 1x1 mm^2, sufficiently large for the projected application.

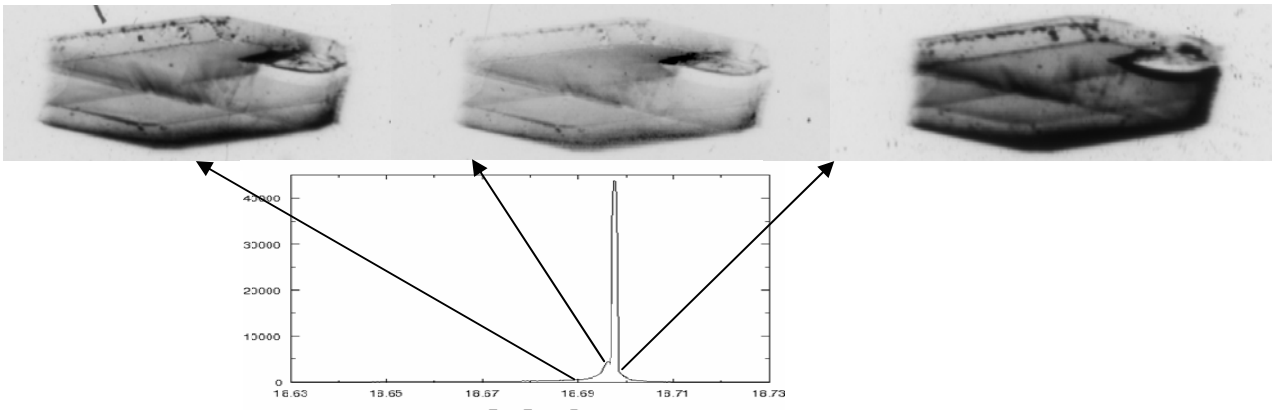

Figure 1: Topograms from (111) HPHT IIa diamond single crystal, (111) Bragg reflection, E=10keV..

The topograms from a crystal with (100) surface orientation (Figure 2) display a higher defect density. The sample consists of large blocks with angular mismatch up to several minutes of arc between them.

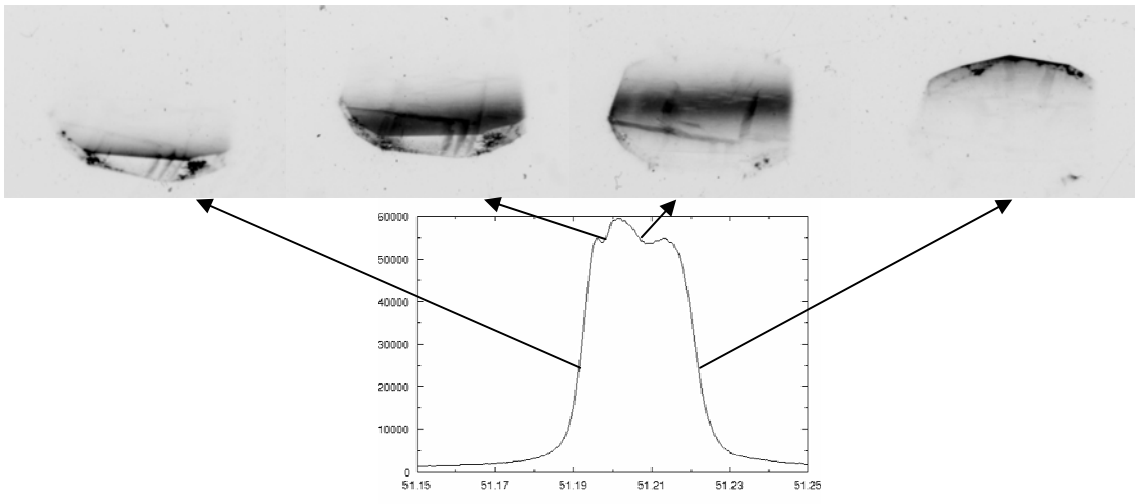

Figure 2. Topograms from (100) HPHT IIa diamond single crystal, (400) Bragg reflection, E=10keV.

To separately probe the crystalline quality of the surface layers, X-ray topography in extremely asymmetric Bragg reflection geometry was used. In this method, the Bragg angle of the diffraction planes is matched to the inclination of these plane to the sample surface in such a way, that the incoming radiation forms a shallow grazing angle to the surface comparable to the critical angle of total external reflection. Surface-sensitive topograms for a polished sample with (100) surface orientation are shown at Figure 3. X-rays with the energy ~7.7 keV and the (220) Bragg reflection was used. The block structure is equivalent to that visible at symmetric (400) topograms. No specific defects that could be attributed to surface polishing can be detected. The origin of a wavy contrast observed at the topogram #2 (Fig.3) has yet to be further examined.

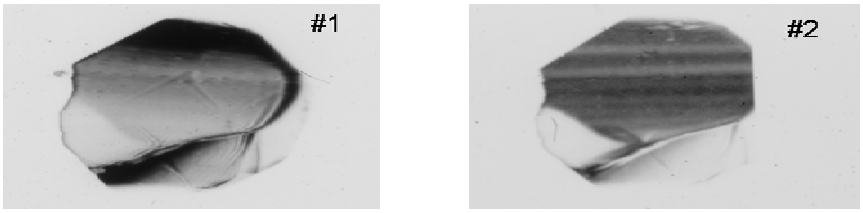

Figure 3. Double crystal topograms in extremely asymmetric geometry were used to probe the lattice quality at the depth ~10nm. Topogram #1 was taken at the critical angle 0.28°, topogram #2 was taken at the angle 0.32°.

The results of the experiments are in a good agreement with white beam topography and rocking curve mapping, carried out on the same samples at ESRF. The experiments show, that:
- crystals have defect free areas up to 2x2mm^2,
- X-ray reflection curves correspond to a near-perfect crystalline quality,
- surface polishing does not introduce additional defects visible in the experiment that are relevant for the application.

References

[1] M. Altarelli, et al. (Eds.) XFEL, The European X-ray Free-Electron Laser, Technical Design Report, DESY 2006-097, Hamburg (2006).

[2] V.Edelman et al, Phys.Stat.Sol.(a) 123, 193 (1991).