Rocking Curve Imaging for Diamond Radiator Crystal Selection

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Abstract

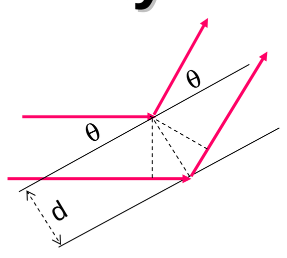
The combination of low atomic number, high crystal packing density, and very high Debye temperature makes diamond the best material for use as a bremsstrahlung radiator in the coherent bremsstrahlung (CB) process, a process that is uniquely suited for generating highly polarized high-energy photon beams for photonuclear experiments. The crystal quality of the diamond radiator has a vital effect on the polarization and other properties of the photon beam and the best large-area diamond monocrystals currently available, both natural and synthetic, contain many defects that can degrade their performance as CB radiators. The diamonds used for this study were synthetic type Ib samples produced through the HPHT process by the firm Element Six. They were examined using the double crystal rocking curve imaging method in a synchrotron X-ray beam. Dislocation densities were calculated from the measured rocking curve peak position maps in the way proposed by Ferrari et al[1]. It is shown that dislocation is one major defect that affects the rocking curve width in local regions. The most significant contribution to the whole-crystal rocking curve width for thin crystals is the systematic variation of the peak position across its surface. This is interpreted in terms of a large-scale bending of the entire crystal. Data supporting this interpretation are presented, and possible explanations for the bending and methods for its mitigation are discussed.

Diamond Requirements for GlueX

- Minimum size: **5 mm x 5 mm**
- Orientation: **[100]**
- Orientation error: **5° maximum**
- Mosaic spread: **20 μr r.m.s. maximum** (integrated over the whole crystal)
- Thickness: **20 μm maximum**
- Variation in thickness: **±5 μm maximum**

Extracting mosaic spread from X-ray rocking curve peak widths

$\lambda = 2\, d \sin(\theta)$

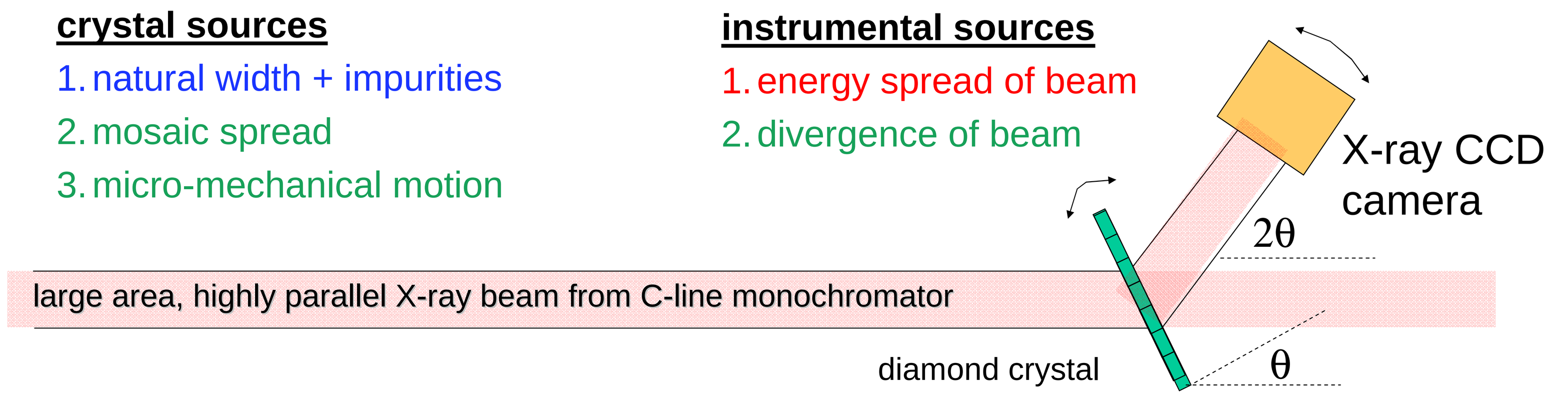


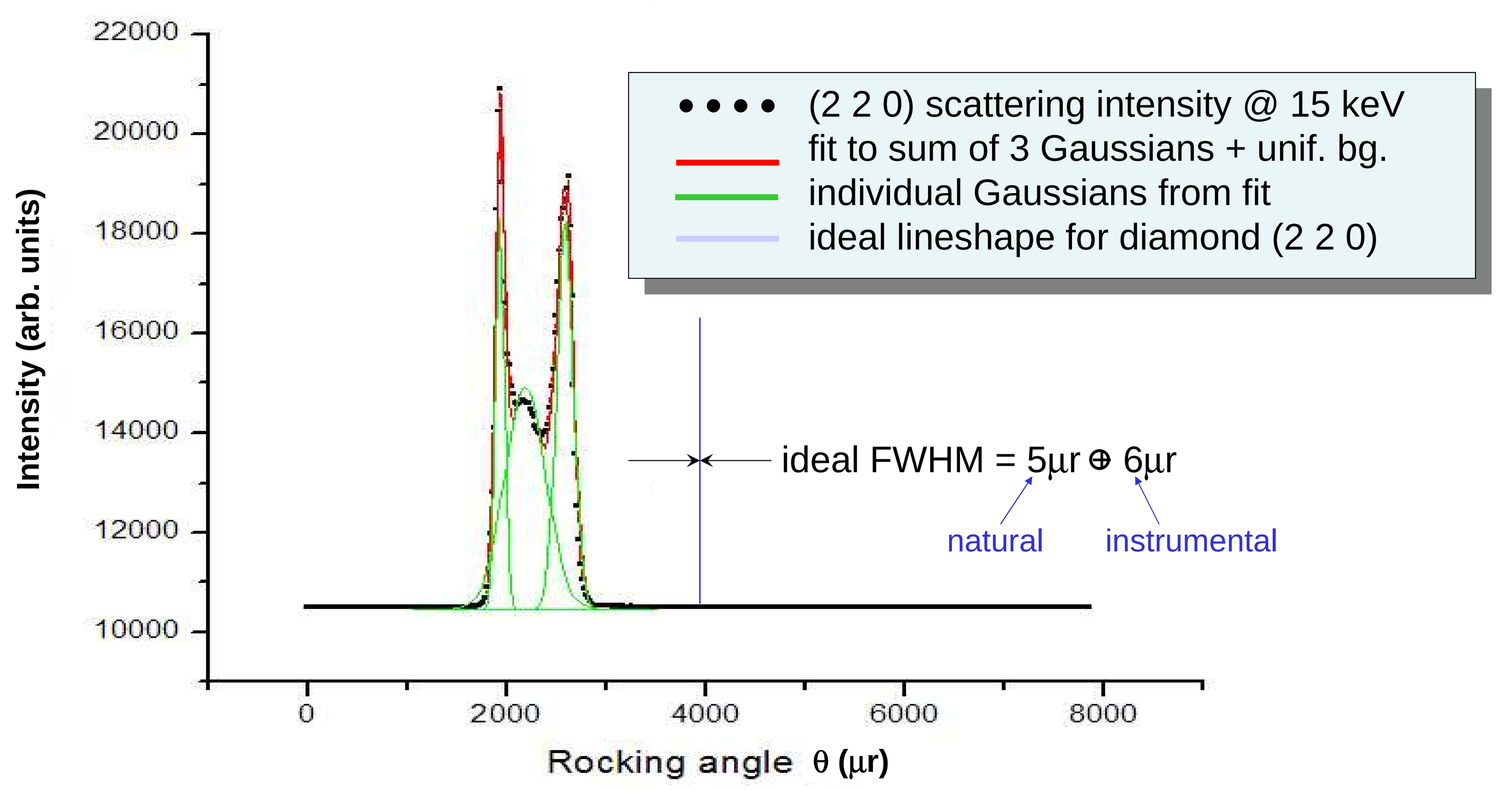
crystal sources

1. natural width + impurities
2. mosaic spread
3. micro-mechanical motion

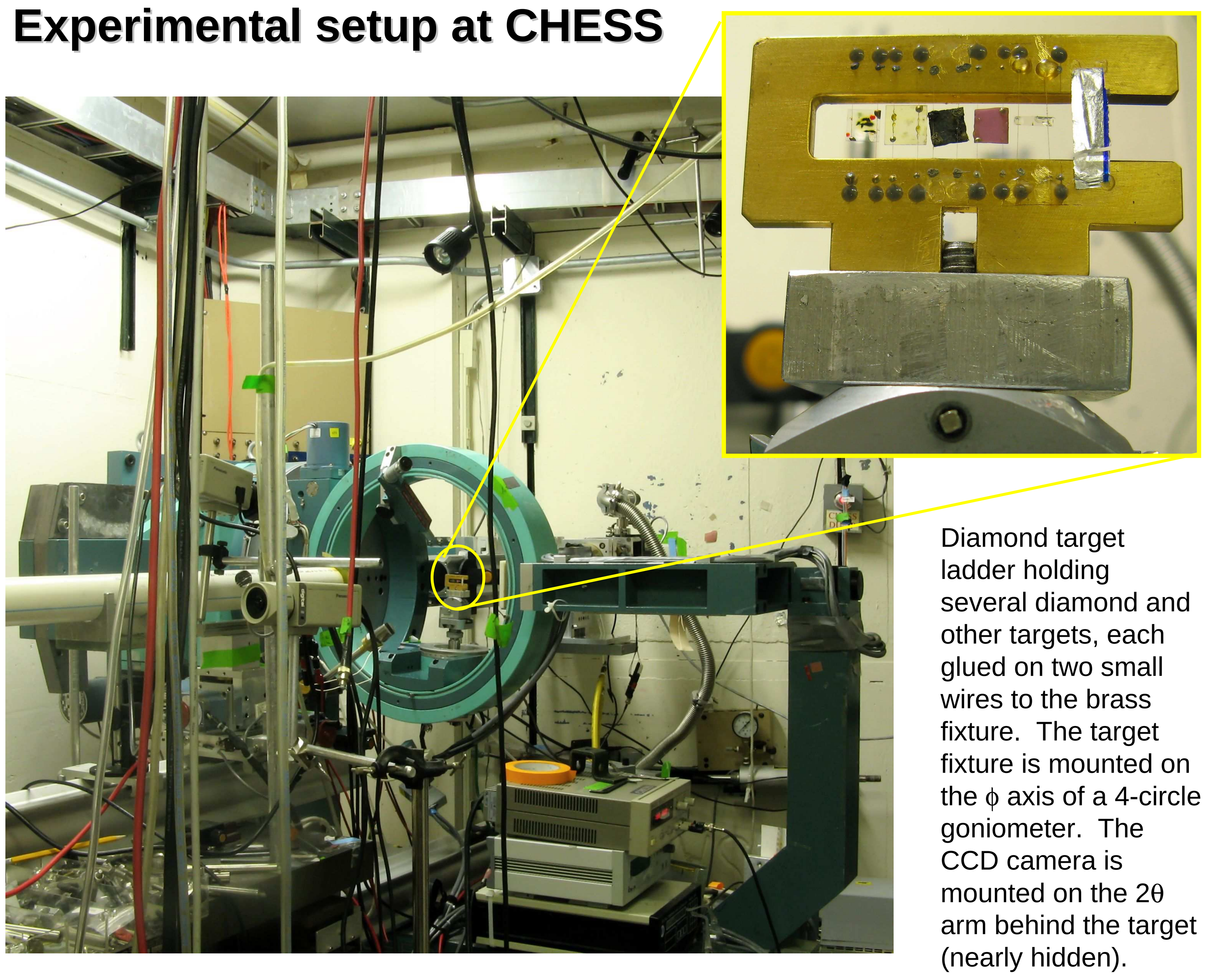
instrumental sources

1. energy spread of beam
2. divergence of beam

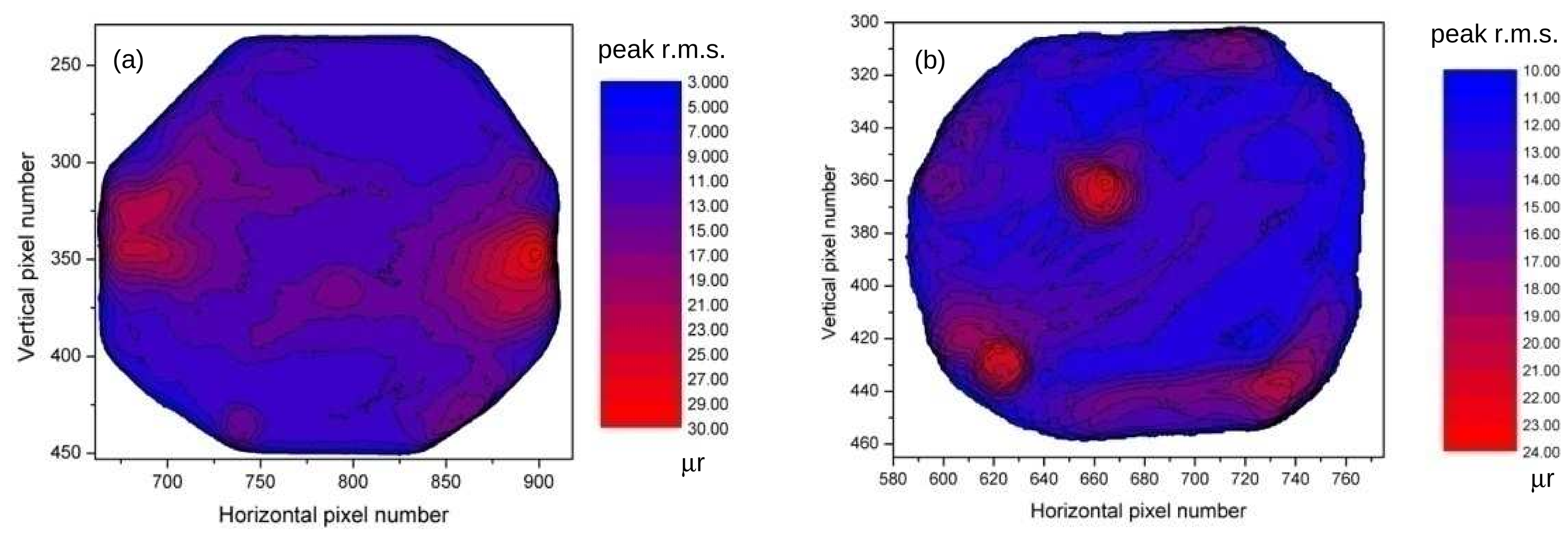




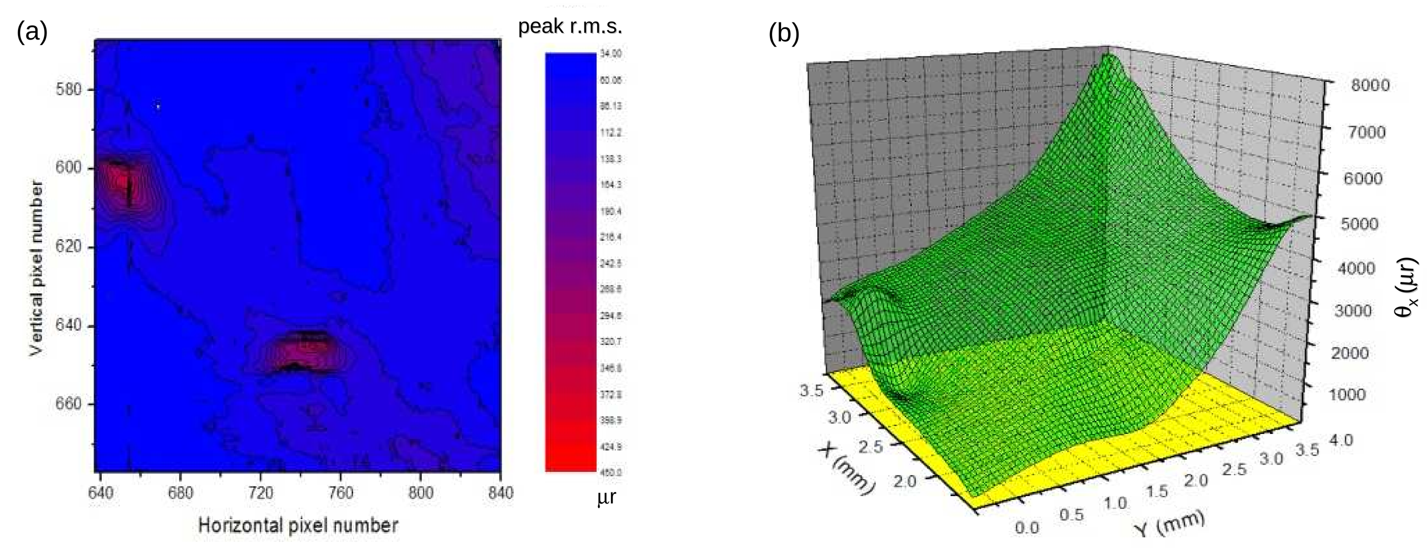
Experimental setup at CHESS



Diamond target ladder holding several diamond and other targets, each glued on two small wires to the brass fixture. The target fixture is mounted on the ϕ axis of a 4-circle goniometer. The CCD camera is mounted on the 2θ arm behind the target (nearly hidden).

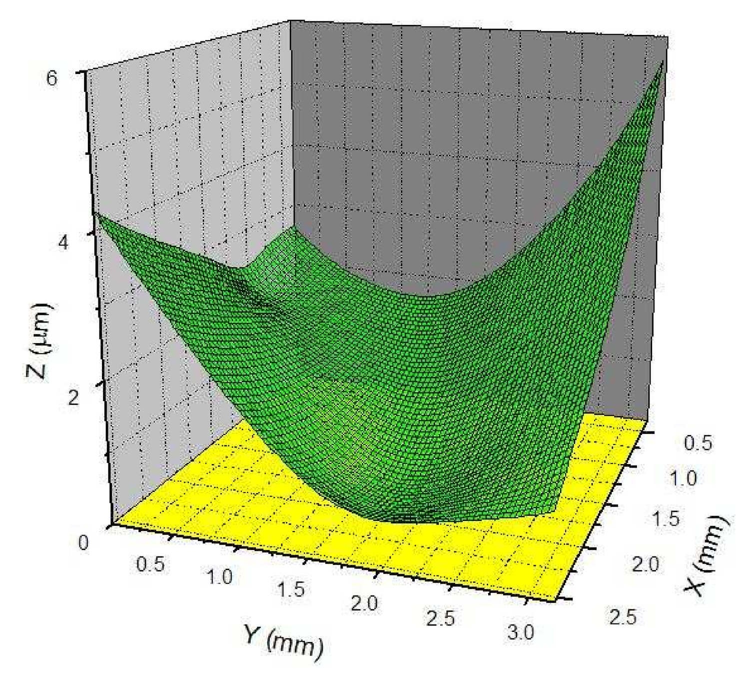


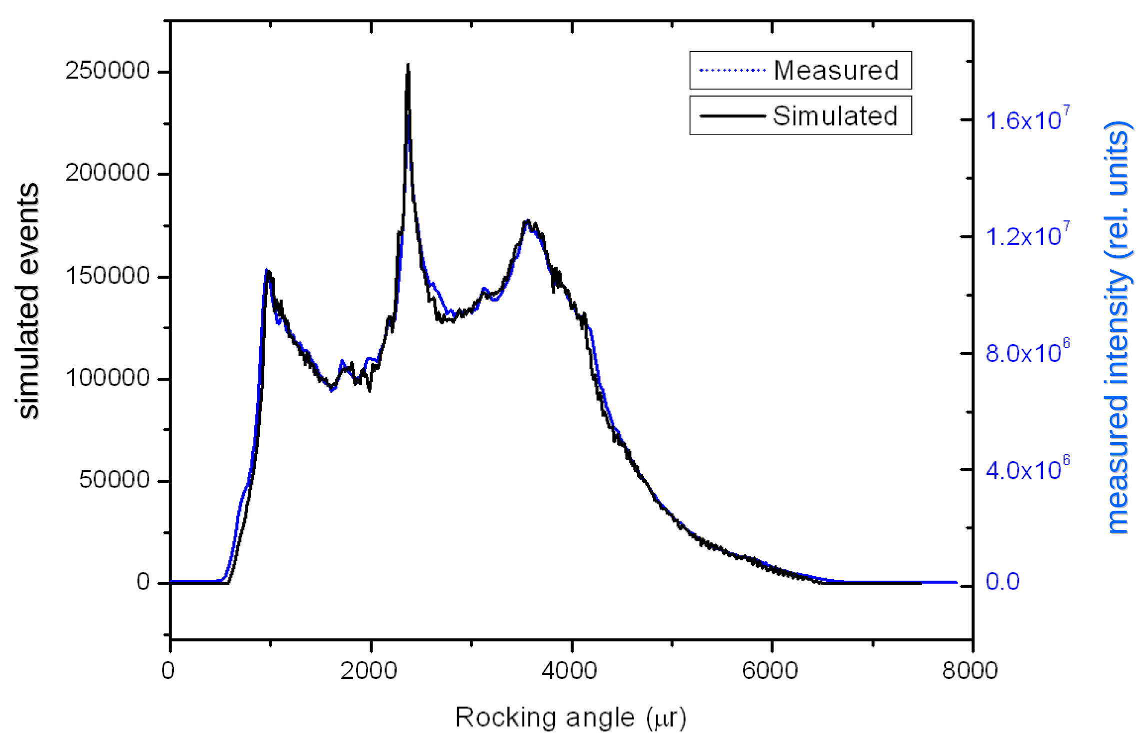
Maps of rocking curve width for the (2,2,0) planes of two diamond crystals 100 microns thick, taken with 15 KeV X-rays. Each pixel subtends a region on the diamond that is 23 microns (horizontal) x 24 microns (vertical). Both of these crystals meet the rocking curve width requirement of less than 20 μr r.m.s.



Maps of rocking curve width (a) and peak position (b) of a 20 micron thick diamond taken with the (2,2,0) planes at 15 KeV. Note that even though the peaks are locally quite narrow, there is a large shift in the peak position across the face of the crystal. This is interpreted as large-scale mechanical bending of this thin crystal. The shift in peak position from pixel to pixel in (b) is large enough that the curvature inflates the peak width measured for a single pixel, especially in the upper right corner of the two figures. The r.m.s. resolution of the camera optics is 2.2 pixels. The horizontal axes in (b) are expressed in mm units to facilitate comparison with the figure below.

The figure at the right shows the calculated crystal shape of the 20 micron diamond, extracted from analysis of the rocking curve data for the (2,2,0) and (2,-2,0) planes shown above. The figure below shows the whole-crystal rocking curve for the 20 micron diamond as measured for the (2,2,0) planes (dotted line) and as simulated using the computed shape of the crystal planes shown in the figure at the right. The agreement between these two curves provides a cross-check of the consistency of the method, as well as a qualitative estimate of its systematic error.





Conclusions

From the results obtained for the 20 micron diamond, it is clear that crystal warping is a major issue that needs to be understood and resolved before crystals of these dimensions can be used as CB radiators. The crystal warping may be caused by non-uniformly distributed defects, by surface damage that occurs during the lapping and polishing steps in the diamond wafer production, or perhaps by the stress induced by crystal mounting fixture. Using a thicker crystal will help to mitigate some of these effects, but unfortunately, the optimum CB performance requires the diamond radiator to be very thin in order to reduce the effects of multiple scattering of the electron beam in the diamond radiator. Further studies are needed to determine what is causing the observed curvature and how it may be reduced, perhaps through additional post-processing steps or improved mounting techniques.

The above results clearly demonstrate that rocking curve imaging is a very powerful method for assessing the suitability of diamond crystals for use as CB radiators. The resulted 2D maps of rocking curve width as well as the rocking curve peak position can serve as a monitor of the crystal quality for the whole crystal and for local regions. It was confirmed by the measured variation of rocking curve widths across the samples studied that the defect distribution is non-uniform in these samples. For the thinnest diamond sample studied, crystal warping contributes significantly to the rocking curve width for the region to be sampled by the electron beam in the coherent bremsstrahlung process. Therefore it is essential that X-ray measurements to verify the suitability of a diamond for use as a CB radiator be performed after the diamond has been polished to its final thickness and mounted in its final fixture.

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