A novel beam width doubling double crystal monochromator - some preliminary findings

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Abstract. The maximum useable beam width at the Biomedical Imaging and Therapy (BMIT) beamline at the Canadian Light Source (CLS) is suitable for most imaging applications. But access to a wider beam would benefit many programs especially computed tomography where the beam width defines the largest sample that can be imaged. A double crystal bent Laue monochromator capable of doubling the width of the incident beam is proposed; this is possible by taking advantage of symmetric off-axis, or skew reflections in the crystals. A preliminary experiment to establish proof of concept for this design has been completed using a double crystal unbent Laue system. Results are presented showing the beam width doubling from 28.3mm to 56.6mm and the effect of the skew reflections on the monochromaticity of the exit beam. Further work on this monochromator will include an investigation into the choice of reflections, a study of the effect on the change in energy across the exit beam, the development of strategies to minimize the effect of the beam overlap region downstream from the monochromator and the development of an alignment process for the double crystal bent Laue system.

1. Introduction
The Biomedical Imaging and Therapy bend magnet beamline (BMIT-BM) at the Canadian Light Source (CLS) currently offers a wide range of imaging techniques to support various biomedical research applications. Once commissioned, the insertion device beamline (BMIT-ID) will provide additional imaging opportunities - in particular, imaging of large animals.

The maximum useable width of beam that arrives at the imaging point in the experimental hutches was defined when the beamline was initially designed and is approximately 25cm for BMIT-ID. This is adequate for most imaging applications, but a wider beam width would benefit many experimental programs. For example, imaging techniques that involve computed tomography (CT) require a beam that is wider than the object in all projections. Similarly, a wider imaging beam will be essential for large animal imaging.

Beam magnification systems based on asymmetric Bragg crystals have been used with some success to increase imaging beam dimensions [1][2]. But the imaging energies used at BMIT range from 40keV to 100keV and the dimensions of the Bragg crystals required to achieve the desired
magnification would be very large. This would also be true of other conventional optic components such as mirrors.

In this work, a compact, double crystal bent Laue monochromator capable of doubling the width of the incident beam is proposed; this is possible by taking advantage of symmetric off-axis, or skew reflections in the crystals. The objective of this work is to complete a preliminary experiment to establish the proof of concept for this idea.

2. Methodology
The proposed monochromator is possible under the proper diffraction conditions and is shown in figure 1.

![Figure 1. Beam width doubling double crystal monochromator in the Bragg configuration.](image)

If the first crystal is oriented such that a mirror plane is vertical and parallel to a white incident beam, then diffracted beams from reflections on each side of the mirror plane will be of the same index type and energy. If those beams then strike a second matched parallel crystal, the result will be a diffracted beam that propagates parallel to the incident beam. If the incident beam is sufficiently wide enough to allow the two diffracted beams to just touch when they strike the second crystal, the exit beam from the second crystal will be double the width of the incident beam. This would be true in both the Bragg (reflection) and Laue (transmission) geometry.

Consider a pair of (2,2,0) reflections as an initial choice of skew reflections. A (1,1,1) wafer has six (2,2,0) type lattice planes perpendicular to the [1,1,1] direction: (2,-2,0), (2,0,-2), (0,2,-2) and their inverses. If the surface normal to the crystal is identified as the [1,1,1] direction (x) and the horizontal direction (y) is chosen as the [0,-2,2] direction, then the vertical direction (z) is [4,2,-2]. On either side of the vertical [4,2,-2] direction are the [2,0,-2] and the [2,-2,0] reflections located symmetrically 30 degrees away from the z axis in the y-z plane. These reflections are available for diffraction in the Laue (transmission) geometry. If the crystal is rotated about the y axis, simultaneous diffraction from the (2,0,-2) and (2,-2,0) lattice planes at an energy will occur. The magnitude of the diffraction vector for the reflections and the magnitude of the diffraction vector for the difference between the reflections will be the same. Similarly, the angle between the incident beam and the diffracted beam as well as the angle between each of the diffracted beams will be the same.

While the drift distance and the vertical offset of this monochromator are relatively large, they are acceptable given that the outcome is a beam that is twice the width of the incident beam. Downstream of the monochromator, the exit beams will continue to diverge horizontally resulting in a small region of beam overlap. As well, a variation in energy across the diffracted beams will be seen; this is a direct result of using off-axis or skew reflections.

3. Experimental Setup
The experiment was performed using (1,1,1) silicon wafers in the unbent Laue configuration. Iodine was placed in the beamline; the iodine K-edge was used to align the wafers. The experimental setup is shown in figure 2.
Figure 2. Experimental setup for beam width doubling monochromator. C1 and C2 are the crystals; the beam direction is indicated with arrows. The positioning cradles are located beneath the crystal holders.

The first crystal was positioned in the beamline and the [2,2,0] reflections on either side of the vertical mirror plane identified using a fluorescent screen. The crystal was set to the Bragg angle for the iodine K-edge and then rotated around the beam until the diffracted beams were both parallel and level. The second crystal was positioned in the beam downstream from the first crystal and rotated around the beam until the diffracted beams were both parallel and level. The Bragg angle of the second crystal was set to match the first crystal. The beams diffracted a second time causing the exit beam of the monochromator to propagate in a plane parallel to the incident beam. The width of the incident beam was adjusted until the two diffracted exit beams just touched.

4. Results
The images in figure 3 through figure 5 show the progression in alignment of the diffracted exit beams from the monochromator.

Figure 3. Initial alignment of the diffracted beams.

Figure 4. A clockwise roll of the second crystal around the incident beam by 0.5 degrees is shown in (a). A second clockwise roll of the second crystal around the incident beam of 0.5 degrees is shown in (b).

Figure 5. An increase in beam width from 28.0mm to 28.5mm is shown in (a). A decrease in beam width from 28.5mm to 28.3mm is shown in (b).
An incident beam width of 28.3mm resulted in an exit beam width of 56.6mm.

Once both crystals in the monochromator were aligned, the Bragg angle of the second crystal was adjusted to accept energies across the iodine K-edge. Figure 6 shows images of the predicted and experimentally observed energy variations in the doubled beam.

![Figure 6](image.png)

**Figure 6.** The predicted energy variation in the doubled beam is shown in (a); the diagonal lines represent iso-energy lines. The experimentally observed energy variation in the doubled beam is shown in (b).

5. Conclusions and Future Work
The experimental results show that this monochromator is capable of doubling the width of the incident beam. The crystal offset and separation distances are directly proportional to the desired exit beam width. As expected, the energy varies across each of the diffracted beams - and ultimately the doubled beam. In many imaging experiments, the energy variation in the doubled beam will not be of any serious concern; issues may appear however if this monochromator is used for absorption edge imaging experiments.

Future work on this project includes several key areas. The wafers and reflections used for this experiment were chosen because of the ready availability of (1,1,1) wafers and the ease of identifying and using the low order (2,2,0) lattice planes. Further study may reveal that other choices might deliver better performance. The energy variation across the exit beam is much larger in the beam width doubling monochromator than in other monochromators. The effect of this change in energy on various imaging techniques will be examined both theoretically and experimentally. The doubled exit beam is made up of two diffracted beams that continue to diverge and overlap downstream of the monochromator; development of algorithms to decouple the two beams during image reconstruction will be necessary. Alternatively, a chopper that would allow independent imaging with each of the two beams may be implemented simplifying the image reconstruction. Further work on the alignment process will allow the use of bent Laue crystals in the monochromator resulting in an increase in bandwith and a highly focused beam.

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