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A Cryogenically-Cooled Channel-Cut Crystal Monochromator Using a Helium Refrigerator and Heat Exchanger

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Beamline(s) X25, X13B

Introduction: Silicon crystals at room temperature employed as x-ray monochromators on synchrotron radiation beamlines, when subjected to high power density loading, suffer thermal distortions which compromise their x-ray diffraction efficiency and result in reduction of the inherent beam brilliance. At temperatures below 150 K however, silicon crystals suffer little or no thermal distortions under high power density loading. We have designed and implemented a channel-cut silicon crystal monochromator which is cooled to as low as 50 K with use of a commercial helium refrigerator and circulation system and a custom-designed heat exchanger for the monochromator crystal. We have obtained test results on the high power X25 wiggler beamline as well as on the NSLS X13B in-vacuum undulator (IVUN) beamline.

Methods and Materials: The cooling system employs the model CHCS-200 helium refrigerator and circulation system manufactured by Cryomech Inc. of Syracuse, NY, USA. This consists of two cooling loops, a primary and a secondary. The primary loop circulates cold helium gas at high pressure through a copper heat exchanger plate upon which the silicon monochromator crystal under thermal load is mounted. The heat which is extracted is carried away by the gas, and transferred to cold helium gas in a displacer/expander coldhead heat exchanger that forms part of the secondary loop. The design serves to isolate vibrations of the displacer/expander in the secondary loop from the primary loop which cools the monochromator crystal. The crystal is a silicon channel-cut monolith incorporating a weak flexure bridge connecting the first and second diffracting surfaces, of (111) orientation. The section comprising the first diffracting surface is clamped onto the top of the copper heat exchanger plate, with an indium foil interface in between. Finite element analysis was employed to study and optimize the design. The monochromator is mounted in its own ultrahigh vacuum chamber which forms part of the beamline. The helium supply and return lines pass directly through the center of a rotary vacuum feedthrough which provides the monochromator rotation.

Results: Careful tests of this system were carried out in the X25 experimental station in the presence of the unfocussed wiggler white beam. The monochromator was oriented to diffract 10 keV in the (111) fundamental, and the incident white beam cross section was 13 mm wide x 5 mm high. Shown in Fig. 1 is a measured rocking curve (solid line) using the (111) reflection, with the monochromator sustaining 65 W total incident beam power with a peak beam power density of just below 2 W/mm^2 (its temperature was 85 K). The FWHM is 9.1 arcsec whereas the theoretical value is 7.8 arcsec. Convolution of the theoretical curve (dashed line) with a Gaussian strain function of 3.1 arcsec two-sigma results in a curve (dotted line) which simulates the experimental curve well. Improved sensitivity can be realized by measuring the third harmonic (333) reflection which diffracts 30 keV. The measured (333) rocking curve (solid line) is shown in Fig. 2. It has a FWHM of 3.1 arcsec whereas the theoretical value is 0.4 arcsec. Convolution of the theoretical curve (dashed line) with the same Gaussian strain function used in simulating the fundamental rocking curve results in a curve (dotted line) which simulates the central region of the experimental curve well, but not its tails. We determined that the stress giving rise to the observed strain was of mechanical, not thermal, origin. Even still, this test showed that the thermal slope error arising from the white beam power load was less than 3 arcsec. In the presence of a similar peak beam power density, the existing room-temperature Si(111) monochromator crystal in the X25 beamline, in the absence of compensation of the strain field, sustains a thermal slope error of 12 arcsec. Thus suppression of thermal stress through operation of the monochromator at cryogenic temperature has been demonstrated.

Conclusions: This monochromator and cooling system, with a new mechanical-strain-free channel-cut crystal, have been installed in the X13B beamline. Cryogenic cooling of silicon crystal monochromators using helium gas appears to be a viable general purpose option for insertion device beamlines at medium energy (2-3 GeV) synchrotron radiation sources where up to a few hundred W of total beam power and very high beam power densities (>10 W/mm^2) can be expected. **Acknowledgments**: This work was supported by the US Department of Energy under Contract No. DE-AC02-98CH10886.

Figure 1: Si(111) Rocking Curve at 10 keV

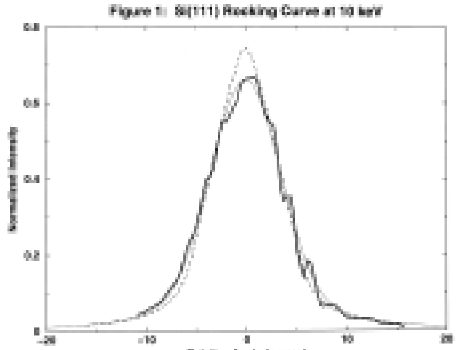

Figure 2: Si(333) Rocking Curve at 30 keV