High-heat-load tests of a water-cooled diamond monochromator

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Introduction

Undulators at the Advanced Photon Source (APS) produce x-ray beams with total power and power density incident on the first optical component of the order of 1 kW and 100 to 300 W/mm^2, respectively. Monochromators subject to these extreme power loads require novel cooling approaches and/or materials to mitigate thermally induced distortions and, thus, to preserve the undulator beam quality. One approach is to select materials and operating regimes that result in favorable thermophysical properties (i.e., higher thermal conductivity k and lower thermal expansion coefficient α). Liquid-nitrogen-cooled silicon and water-cooled diamond crystals have a ratio α/k roughly 40 times lower than that of room-temperature silicon. In this report, we will discuss thermal tests of a water-cooled diamond monochromator.

Methods and Materials

The tests were carried out on the Synchrotron Radiation Instrumentation Collaborative Access Team (SRI-CAT) sector 1 undulator beamline. We conducted two sets of experiments. The first, in May 1996 and January 1997, measured the performance of the diamond crystal under the power load produced by the standard APS 3.3 cm-period undulator [1,2]. The second set, in October 1998 and April 1999, subjected the diamond to the load delivered by two 3.3 cm undulators installed in tandem in the sector 1 straight section [3]. The beam size (defined by the white beam slits) was 2 mm H by 1.2 mm V. The maximum power incident on the monochromator was 280 W for the single-undulator run and 700 W for the double-undulator configuration. In both instances, the diamond first crystal straddled a 3 mm wide trough in a water-cooled copper holder, with a thin layer of Ga/In eutectic between the diamond and the nickel-plated holder to ensure good thermal contact. The diamond second crystal was mounted on an uncooled copper holder for the single-undulator experiments and on a water-cooled holder for the double-undulator tests. For the first set of tests, we used synthetic type Ib(111) diamond plates manufactured by De Beers. The plates were 7 mm by 5 mm and 0.4 mm thick and exhibited a mosaic spread/strain of the order of 5 arcseconds over the whole plate and approximately 2–4 arcseconds under the beam footprint. In the double-undulator experiments, we used synthetic type IIa(111) plates manufactured by Sumitomo. These plates were 10 mm by 5 mm by 0.5 mm thick, with mosaic spread of 3–4 arcseconds over the whole plate and 1–3 arcseconds under the beam footprint.

Results

To gauge the performance of the monochromator, we measured the width of the double-crystal rocking curve for the (111) and (333) reflections as a function of the power and power density absorbed by the diamond first crystal. We took data at a fixed gap of 11 mm and varied the absorbed power and power density by changing the monochromator energy. We also measured the response when both the energy and the gap were changed in conjunction so that either the first or third harmonic of the undulator radiation corresponded to the monochromator energy. Figure 1 shows the full width at half maximum (FWHM) of the (111) double-crystal rocking curve as a function of energy for one undulator and for two undulators at 11 mm gap (all April 1999 data). The deviation of the single-undulator data from theory is due to the mosaic spread/strain of the crystals. The double-undulator data also shows some added thermally induced mounting strains, but no appreciable widening due to thermal strain in the first crystal.

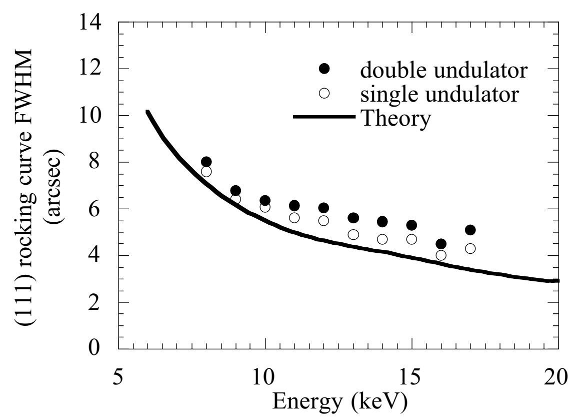

Figure 1: FWHM of the (111) double-crystal rocking curve as a function of energy for one and two undulators at 11 mm gap.

Discussion

The maximum power and power density absorbed by the first crystal were 37 W and 4.3 W/mm^2 for the single-undulator run (January 1997), and 140 W and 17 W/mm^2 for two undulators (April 1999). Under these conditions, finite element analysis calculations predicted a maximum thermal strain of less than 0.8 and 1.2 arcseconds, respectively, in good agreement with the data. Thus, we expect that the water-cooled diamond monochromator will perform well under the highest heat load conditions currently envisaged at the APS. In fact, such a monochromator has been installed for routine operations on the SRI-CAT sector 3 undulator beamline for over 2.5 years.

Acknowledgments

We wish to acknowledge the assistance of the SRI-CAT sector 1 staff. Use of the Advanced Photon Source was supported by the U.S. Department of Energy, Basic Energy Sciences, Office of Science, under Contract No. W-31-109-Eng-38.

References

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