Diamond Double-crystal Monochromator for SPring-8 Undulator Beamlines

A high-heat-load monochromator has been a key optical component for the undulator beamlines of the third-generation synchrotron facilities. In 1997, we installed silicon double-crystal monochromators for all standard the undulator beamlines of SPring-8 [1]. The first crystal with a pin-post cooling channel was directly cooled by water [2]. In 2000, we developed a closed-loop circulation system of liquid nitrogen (LN_2) with helium refrigerators [3]. This LN_2 cooling system was installed for a number of beamlines by 2005, because we can simply use a silicon block in contact with a copper block in the LN_2 temperature range (i.e., indirect cooling). However, a serious drawback is the high cost for installation, running, and maintenance.

Diamond crystal has been considered as one of the best candidates for a high-heat-load monochromator. Diamond shows a high transmissivity of X-rays and an excellent thermal property, which is evaluated using the ratio of thermal conductivity to thermal expansion. This ratio for diamond at room temperature (RT) is ~30 times better than that for silicon at the RT. Thus, diamond can manage an incident power of hundreds of watts simply by indirect cooling by water, which enables a high-performace, moderate-cost monochromator. Diamond is also promising as a monochromator of X-ray free-electron laser (XFEL), because only hard materials consisting of light elements are sustainable under strong irradiation.

We have installed diamond double-crystal monochromators to upgrade three undulator beamlines (**BL09XU**, **BL10XU**, **BL39XU**) of SPring-8 by 2006. High-quality diamond (111) crystals in type IIa, which are the results of a collaboration with Sumitomo Electric Industries Ltd. [4], have been mounted on copper crystal holders in the Bragg geometry. The typical size of the crystal is $10 \times 4 \times 0.4$ mm^3. An edge-cooling design was adopted to reduce excess heat load from undiffracted X-rays. Special attention has been paid to crystal mounting. A thermal mounting method, which employs a heated indium sheet for glue, was developed to maintain a sufficient thermal contact with a negligible mounting stress [5].

Moreover, a new monochromator mechanism was installed to upgrade BL39XU in the spring of 2006 (Fig. 1). A notable departure from the SPring-8 standard monochromator (SSM) mechanism [1] is (i) a Bragg angle range of 4.5 to 45 degrees (3 to 27 degrees for the SSM), which corresponds to a photon energy range of 4.3 to 38.3 keV with diamond 111 diffraction. The energy range is the same as that of the SSM with silicon 111 diffraction. This modification enables us (ii) to design the translation mechanism of the first crystal to be compact and (iii) to omit an additional weight-compensation mechanism possibly resulting in instability.

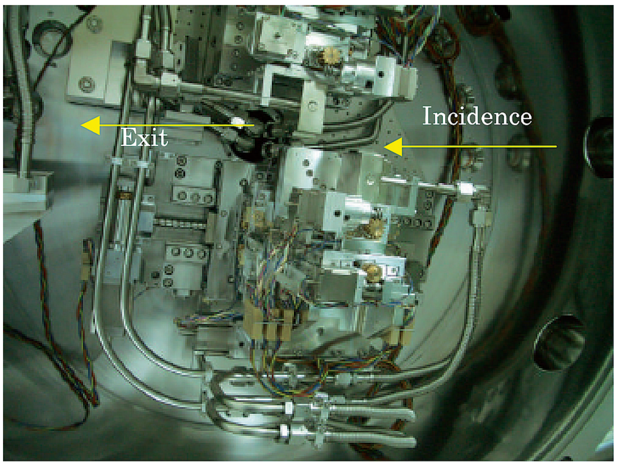

Fig. 1. Mechanism of diamond double-crystal monochromator.

Detailed performance was evaluated at BL39XU [5]. Figure 2 shows the photon flux of the monochromatic beam measured at the exit of the Be window. The size of the front-end slit was 1.0(h) × 0.7(v) mm^2 with a storage-ring emittance of $\varepsilon = 3$ nm·rad. The agreement between the measurement and a calculation carried out by the simulation code SPECTRA is excellent below 20 keV. For a comparison, the flux with the LN_2 cooled silicon DCM was measured at **BL29XU**. The flux of the diamond reaches 60% of that of the silicon.

Figure 3 (a) shows deconvoluted angular widths $\Delta\theta_d$ from the measured rocking curve width to the calculated width. $\Delta\theta_d$, which relates to lattice distortion, is nearly constant with the photon energy (the incident power). In particular, $\Delta\theta_d$ at E = 15 keV with the third and the first harmonic radiations is unchanged; however, the incident power of the former (370 W, a power density of 450 W/mm^2) is four times larger than that of the latter (below 100 W), as shown in Fig. 3 (b). The thermal deformation of the crystal is negligible even at a high heat load.

We investigated a long-term angular stability by repetitive measurements of the rocking curve of the first crystal. The angular shift of the first crystal, measured with a front-end slit size of 0.5 × 0.5 mm^2 (an incident power of 95 W), is kept smaller than 1 μrad after the 3 hour irradiation. This level is sufficiently acceptable for high-resolution spectroscopic experiments.

We conclude that the diamond monochromator is a reasonable alternative to the LN_2-cooled silicon monochromator, when considering the balance between the final performance and the required cost, particularly for spectroscopic and diffraction applications at the energies lower than 20 keV.

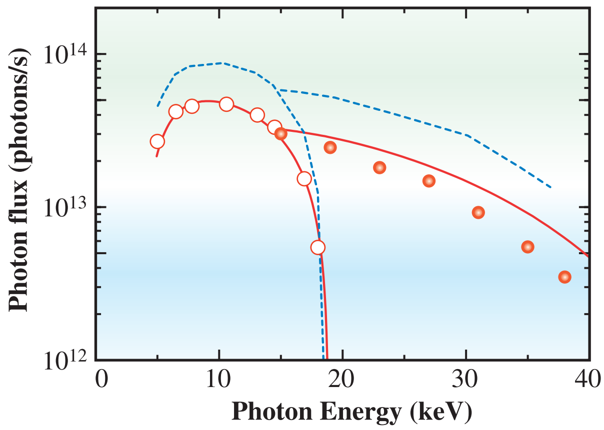

Fig. 2. Photon flux of monochromatic beam with diamond DCM. The open (solid) circles show the measured flux for the first (third) harmonic of the undulator radiation, and the red solid line shows the calculated flux. The blue dashed lines are the measured results for the LN_2-cooled silicon monochromator.

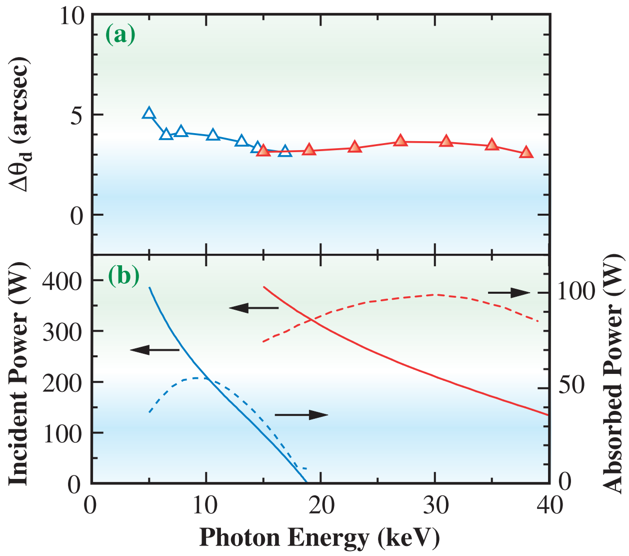

Fig. 3. **(a)** Deconvoluted rocking curve widths *vs* photon energy. The open triangles (the solid triangles) are for the first (third) harmonic radiation. **(b)** Incident power (solid line, left axis) and absorbed power (dashed line, right axis) *vs* peak photon energy. The blue (red) line shows the result for the first (third) harmonic radiation.

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References

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