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Development of Hard X-Ray Split-Delay Optics Based on Si(220) Crystals

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1. Introduction

The successful operation of x-ray free-electron lasers (FELs) such as SPring-8 Angstrom Compact free-electron Laser (SACLA) in Japan provides novel x-ray sources with great properties: an unprecedented peak brilliance, full transverse coherence, and a duration down to a few femto-seconds, which offer great promise for exploring new scientific possibilities in ultrafast science with hard x rays. A split-delay optics (SDO), which can provide two replica FEL pulses with time delay precisely controlled, enables us to investigate ultrafast dynamics induced by intense x rays in currently unreachable time scale of up to nanosecond. A mirror-based SDO using a geometrical splitter [1] has successfully contributed to the progress on ultrafast measurements with soft x-ray FELs. Usage of a similar SDO for hard x-ray FELs, however, includes some problems such as a small critical angle (i.e., a huge system is required) and strong scattering from the mirror edge. We proposed a SDO based on the Bragg diffraction from Bragg-case FZ-Si(220) crystals, in which an FEL pulse is reflected with a large angle and a high spectral reflectivity. Combination with a focusing mirror system enables to generation of a high power density field while precise tuning of crystal angles is required. Here we present the details of the SDO and requirements for overlapping replica beams.

2. Crystal Components and Configuration of SDO

The schematic crystal configuration of the hard x-ray SDO is depicted in Fig. 1. The SDO contains two thin crystals as a beam splitter/merger (BS, BM), two thick crystals (BR1, BR2) and two channel-cut crystals (CCs). Thin and channel-cut crystals were fabricated with an etching technique using atmospheric-pressure plasma [2]. Time delay between two pulses is geometrically determined by path-length difference in the upper and lower branches, and is tunable with translation of BRs along each 2θ axis. The two delay-branch set-up realizes to reach a time delay of 0. The active range of photon energy is 6.5–11.5 keV according to the acceptance of CCs. Both replica pulses can be focused in the same spot by a set of focusing mirrors owing to the co-axial configuration.

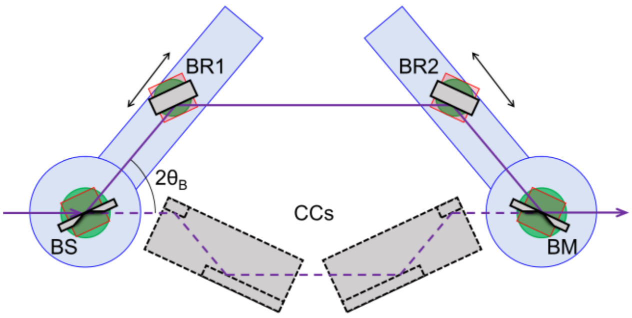

Fig. 1 Schematics of the hard x-ray SDO. See text for details.

3. Tuning of Crystal Angle

Requirements and Tolerated Angular Error

The SDO will be operated at BL3 of SACLA in which a two-stage 50-nm-focusing system has been installed [3]. To perform successful experiments with the SDO, the pointing displacement on samples between a pair of replica pulses should be suppressed in <5 nm (10% of the focal size). According to the demagnification ratio of 2000, such a displacement corresponds to that of 10 μm on the source plane, 100-m downstream of the SDO. Therefore, the tolerated angular error is estimated to be ±0.1 μrad.

Influence of Angular Error on Each Crystal

Horizontal and vertical displacements are mainly due to angular errors along χ and ω axes, respectively. The ω angle can be easily tuned because reflectivity of each crystal is sensitive to each ω angle unlike χ angle. Usually each crystal, furthermore, includes a miscut between the surface and lattice plane, which makes tuning of χ angles complicated. Even if BS and BRs have unknown χ errors, the exit pulses can be paralleled by tuning of χ angle of BM while the pointing position shifts from the original. Although tuning of χ angles of BS and BRs is also required, it is easier than that of BM. A replica pulse passing through CCs (the lower branch) is completely parallel.

4. Conclusions and Future Plans

A SDO based on Si(220) crystals combined with a focusing mirror system is under development. To achieve a good spatial overlap between a pair of replica pulses, angles of all crystals (especially BM) are tuned with an accuracy of ±0.1 μrad. We will confirm the feasibility of precise tuning at the 1-km-long beamline BL29XUL of SPring-8.

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