Measurement of X-ray Pulse Widths by Intensity Interferometry

Ultrafast X-ray pulses provide a powerful probe for investigating structural dynamics in biological and material sciences. The upcoming linac-based undulator sources are capable of generating brilliant X-ray pulses of ~100 femtoseconds (fs). Although measurement of such ultrafast pulse width is crucial, no methods applicable to hard X-rays are currently available. In this report, we show that intensity interferometry, which is a technique initially developed by Hanbury-Brown and Twiss [1] and recently extended to the X-ray region [2,3], is capable of measuring X-ray pulse width (32 ps in FWHM) at SPring-8 [4]. Notably, the method can be easily extended to fs region by using simpler monochromators.

Most hard X-ray sources that are either currently available or under development including self-amplified spontaneous emission (SASE) free electron laser (FEL) in the linear regime, are considered to generate chaotic light. In this case, intensity interference is observed as an enhancement of the coincidence rate between the two detectors that receive the spatially and temporally coherent portions of the beam. In particular, when the method is applied to pulsed beam, the enhanced ratio includes information on the temporal pulse width s_t with respect to the longitudinal coherence time σ_t. Because the coherence time σ_t is directly given by the energy bandwidth ΔE of light, evaluation of the enhanced ratio with knowledge of the bandwidth enables to determine the pulse width s_t.

Experiments were performed using beamline **BL19LXU**, which is equipped with a 27-meter undulator, the most brilliant X-ray source currently available. The experimental setup is shown in Fig. 1. A monochromator consisting of 4-bounced asymmetric reflections (horizontal diffractions of Si 11 5 3, asymmetric angles α = 78.4°) was used as

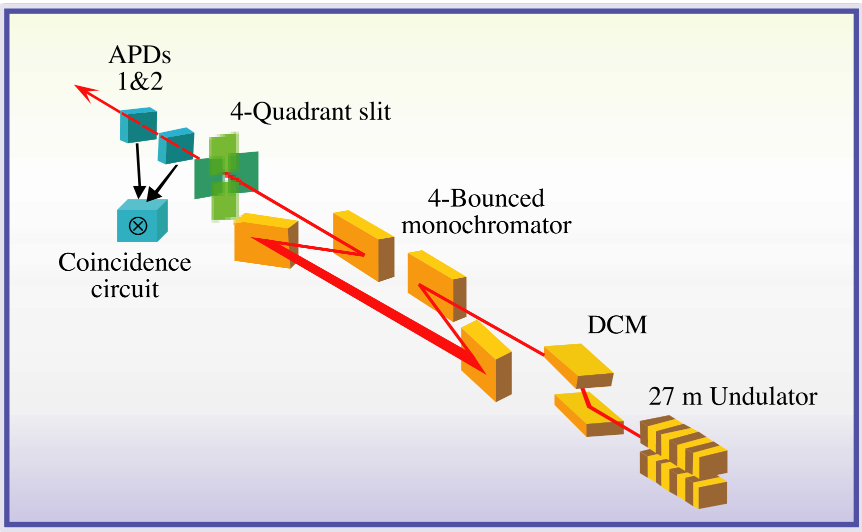

Fig. 1. Schematic view of the experimental setup. Undulator radiation is premonochromatized with a Si 111 double crystal monochromator (DCM). The 4-bounced monochromator and the 4-quadrant slit were employed to extract the longitudinally and transversely coherent portion of the beam, respectively. Two semi-transparent avalanche photo diodes (APDs) were aligned in tandem on the light axis. Outputs of the detectors were connected to the coincidence circuit.

an energy filter. The energy bandwidth was controlled by slight shift of the incident energy. A 4-quadrant slit was employed to the extract spatially coherent area of the monochromatic beam. The true coincidence rate, C_S, and the accidental one, C_N, were measured with coincidence circuits and an electric delay of 4.79 μs that corresponds to the revolution frequency of the storage ring.

The enhancement $R = C_S/C_N - 1$ of the coincidence rate is given by the inverse of the temporal mode number M_t, which means an average number of intensity fluctuation in a single pulse. We plotted the mode number M_t as a function of the bandwidth ΔE, as shown in Fig. 2. Assuming that the pulse envelope and the temporal coherence profiles are of both Gaussian distributions, M_t is given by $[1+(s_t/\sigma_t)^2]^{1/2}$ from theory, where s_t is the pulse width in FWHM and σ_t is the coherence time given by $(2\ln 2)h/(\pi\Delta E)$ (h is the Planck constant). The data were fitted with one fitting parameter, that is, the pulse width s_t. The width was determined to be 32.7±1.6 ps in FWHM. This value was compared to that measured with a streak camera, 32 ps [5]. This level of agreement was excellent.

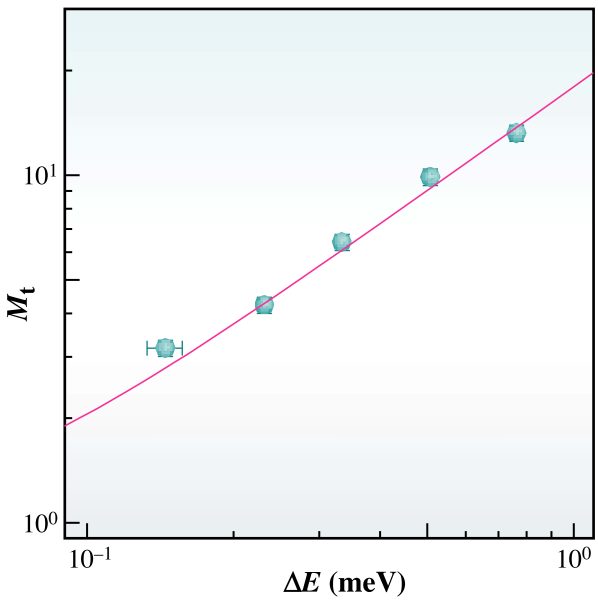

Fig. 2. The longitudinal mode number M_t vs. the energy bandwidth ΔE. The line shows the fit result with a pulse width st of 32.7 ps.

Intensity interferometry combined with various X-ray monochromators is capable of determining X-ray pulse widths in the timescale from ns down to fs. This is because the monochromators can cover a wide range of bandwidth from 10^{-4} to 10 eV, which corresponds to values of σ_t between 10 ps and 0.1 fs. Importantly, the method can be easily extended to faster pulse regions because the optics required are much simpler than those used in the present work. The time resolution is unaffected by the timing jitter of the incident pulses and of the trigger signal. This method provides a unique technique for characterizing ~100-fs pulse profiles generated with the forthcoming linac-based, coherent X-ray sources, in addition to much faster X-ray pulses produced by proposed slicing technique of chirped pulses or ultrafast Bragg switches.

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References

[1] R. Hanbury-Brown and R. Q. Twiss, Nature (London) **177** (1956) 27.
[2] E. Ikonen, Phys. Rev. Lett. **68** (1992) 2759; Y. Kunimune *et al*., J. Synchrotron Rad. **4** (1997) 199; E. Gluskin *et al*., *ibid*. **6** (1999) 1065.
[3] M. Yabashi *et al.*, Phys. Rev. Lett. **87** (2001) 140801.
[4] M. Yabashi, K. Tamasaku and T. Ishikawa, Phys. Rev. Lett. **88** (2002) 244801.
[5] H. Ohkuma *et al.*, Proc. of the 2001 Particle Accelerator Conference, Chicago, (2001) 2824.
[6] M. Cornacchia *et al.*, Linac Coherent Light Source (LCLS) Design Study Report. *Report SLAC-R-524* (Stanford Linear Accelerator Center, Stanford, California, 1998); R. Brinkmann *et al.*, DESY Report DESY97-048 (Deutsches Elektronen Synchrotron, Hamburg, 1997).