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Two-color XFEL operation at SACLA

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1. Introduction

SACLA (SPring-8 Angstrom Compact free-electron LAser) is an XFEL (X-ray Free-Electron Laser) facility built in 2011 at the SPring-8 campus [1]. SACLA covers the photon energy range between 4-15 keV. Since March 2012, the facility has been open to public use and many application experiments in diverse scientific fields have been performed.

XFEL uses stimulated emission from electron beams of a relativistic energy. The electron beam is accelerated in a linear accelerator and generates spontaneous emission in undulators, in which periodical magnetic fields are applied to wiggle the electron beam. Through this wiggling motion inside the undulators, the electron beam can interact with the electromagnetic fields of spontaneous emission, and then the electromagnetic fields are exponentially amplified under a certain condition. This process is called SASE (Self-Amplified Spontaneous Emission).

The photon pulses of XFEL have full wavelength tunability, sub-10-fs pulse durations and more than 10 GW peak power. These features are beneficial to explore ultrafast phenomena, for which a pump-probe technique has been conventionally used so far combining XFEL and a synchronized short-pulse laser. While in the two-color XFEL operation, two pulses are both provided from XFEL without temporal jitters, and the wavelengths of each pulse are independently tunable in X-rays [2].

2. Two-color operation

The wavelength of XFEL is determined by the electron beam energy, the period and magnetic field strength of the undulator. In SACLA, there are 21 undulators installed. The length of each undulator is 5 m and their magnetic fields have a period of 18 mm. The field strength of each undulator is variable by changing the gap between two magnet arrays facing to each other in the undulator. In normal single-color operation, the magnetic field of all 21 undulators are set at the same value except for a small gap taper to compensate the energy loss of the electron beam.

Figure 1 shows a schematic of the undulator setup for two-color operation. The 21 undulators are grouped into two sections divided by a chicane and the field strengths (K_1 and K_2) of each section are set to different values. The chicane detours and delays the electron beam with respect to the photon pulse from the first undulator section. Thus the temporal separation between the two pulses can be precisely adjusted by controlling the amount of the electron beam delay at the chicane.

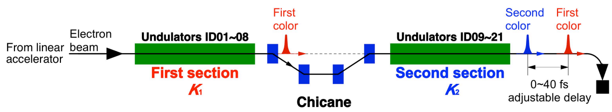

Figure 1　Schematic of the undulator setup for two-color operation. K_1 and K_2 represent the magnetic field strengths of the first and second undulator sections respectively.

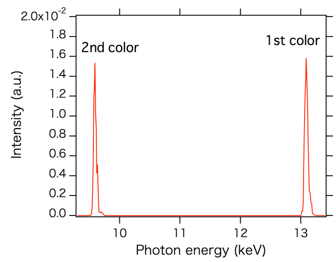

Figure 2　Spectrum of two-color XFEL measured by scanning a monochromator. K_1=1.7 (1.01 T), K_2=2.15 (1.28 T) and the electron beam energy was 7.8 GeV. The pulse energies of each photon pulse were about 40 μJ.

Figure 2 is an example of the two-color XFEL spectrum. The first color is emitted from the first undulator section upstream of the chicane and the second color from the second undulator section. The maximum separation of the two wavelengths is about 30 % and these wavelengths can be freely adjusted within this range.

As in a conventional atomic laser, XFEL saturates due to the increased energy spread of the electron beam by the SASE process. Once XFEL saturates in the first section, no amplification occurs in the second section. Thus the number of the undulators used in each section should be optimized to obtain desirable intensities of two color pulses.

3. Conclusions

The two-color XFEL operation realizes a jitter-free X-ray photon source to investigate ultrafast phenomena. It will provide an invaluable tool for user experiments and the developments of new experimental methodology are expected in future.

References

[1] T. Ishikawa et al., Nat. Photon. **4** (2010) 641.
[2] T. Hara et al., Nat. Commun. **4** (2013) 2919.