Unprecedented Stability Achieved at PAL-XFEL

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Fig. 1: Aerial view of PAL-XFEL.

The hard X-ray free electron laser at the Pohang Accelerator Laboratory (PAL-XFEL) (see Fig. 1) in the Republic of Korea achieved saturation of a 0.144 nm free electron laser (FEL) beam on November 27, 2016, making it the third hard X-ray FEL (XFEL) in the world[1], following the Linac Coherent Light Source (LCLS) at SLAC in 2009 and the Spring-8 Angstrom Compact free electron Laser (SACLA) in 2011. The user-service operation of PAL-XFEL started officially on June 7, 2017 (see http://pal.pstech.ac.kr/paleng).

PAL-XFEL consists of a 10 GeV S-band normal conducting linac delivering an electron bunch to two undulator lines (a hard X-ray undulator line (HX1) and a soft X-ray undulator line (SX1)). The hard XFEL line contains five acceleration sections, three magnetic bunch compressor chicanes (BC1, BC2, and BC3H), and an achromatic dogleg transport line with a bend angle of 0.5° to the hard X-ray undulators. Twenty undulator segments were installed in HX1, and seven segments were installed in SX1. We adopted European XFEL undulator designs, such as a 5-m-long, planar, permanent magnet and an out-vacuum variable-gap undulator, and modified our magnet design according to the PAL-XFEL undulator parameters. A self-seeding section consisting of four dipoles and a diamond crystal monochromator is located immediately after the eighth undulator of HX1.

For stable operation of a hard XFEL, a stable electron beam in terms of energy, time, and orbit is required, and its lower jitter is favorable for higher performance of the FEL and better time resolution of pump-probe experiments. Efficient self-amplified spontaneous emission (SASE) operation at the shortest wavelengths of PAL-XFEL requires the orbit to be straight to within a few micrometers inside the undulator line, which is achievable only by performing BBA (beam-based alignment). We devised an FEL lasing procedure based on electron-BBA that incorporates the undulator K-tuning method used in photon-BBA.

The hard XFEL operation procedure established at PAL-XFEL using e-BBA and incorporating undulator radiation spectrum analysis proved to be highly reliable and

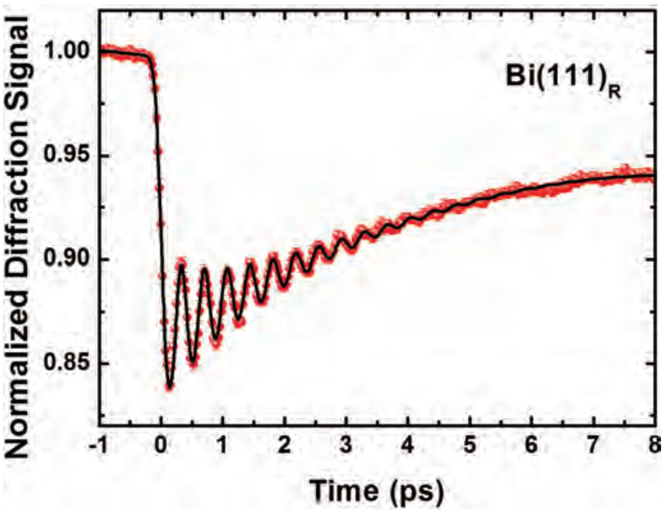

Fig. 2: Bi(111) Bragg diffraction intensity modulation as a function of time delay between an optical excitation pulse and XFEL probe, which was obtained without a timing-jitter correction.

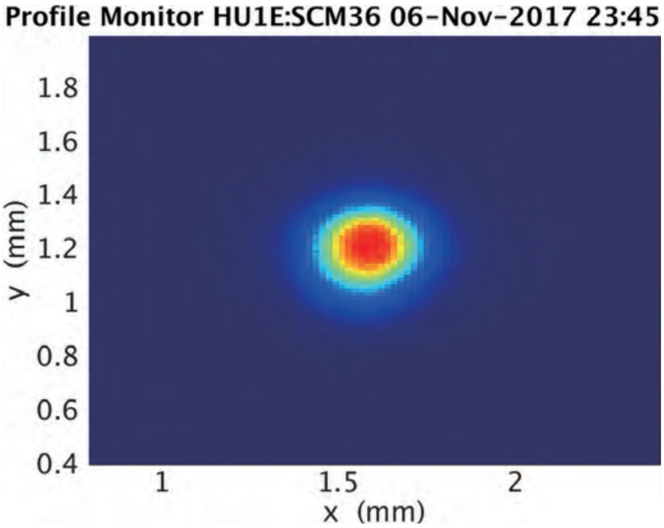

Fig. 3: Beam image of the 14.5 keV FEL.

robust, and essential for the variable-gap undulators. The state-of-the-art design of the klystron modulators and a reference timing system used for the electron linear accelerator along with the reliable FEL lasing procedure facilitate the achievements of reliable FEL lasing as well as the 20 femto-second timing stability of the FEL photon beam. This consistent timing stability enabled us to observe Bi(111) phonon dynamics without using a timing-jitter correction. Figure 2 shows the measured Bi(111) Bragg diffraction intensity modulation at XSS (X-ray scattering and spectroscopy) in PAL-XFEL.

The state-of-the-art design of the electron linear accelerator along with the reliable FEL lasing procedure enabled us to achieve our unprecedented FEL performance, excepting the FEL pulse energy (~4 mJ is available at LCLS):

- FEL position stability: 8~9% of beam size
- FEL power stability: ~ 4.0% RMS
- E-beam energy jitter: < 0.02 %
- E-beam arrival time jitter: < 20 fs
- FEL pulse energy: ~1 mJ at 9.7 keV
- Saturated FEL up to 15.0 keV

PAL-XFEL was designed to generate a 12.4 keV FEL with the possibility of electron beam energies up to 11.0 GeV, with which a 16 keV FEL could be generated with the same undulator parameter K of 1.87 for 12.4 keV. It is also possible to increase the photon energy up to 20 keV with a lower K sacrificing the FEL intensity. Efforts to generate lasing at higher photon energy resulted in the recently achieved FEL saturation of 14.5 keV, which is the brightest FEL at this photon energy that has ever been achieved in the world (see Fig. 3). Details of the result will be published soon.

References

[1] Kang, H.-S. et al. Hard X-ray free-electron laser with femtosecond scale timing jitter. Nat. Photon. 11, 708–713 (2017).

Heung-Sik Kang is a staff scientist of Pohang Accelerator Laboratory, Korea. He obtained his Ph. D. from Seoul National University in 1988. He participated in the construction of PLS (1992-1995) and PAL-XFEL (2011-2016). He is currently the accelerator division leader of PAL-XFEL.