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Improvement for HHG-seeded EUV Free Electron Laser with Timing Measurement System by EO Sampling

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Abstract: Using an arrival timing measurement system based on the EO (Electro-Optic) sampling technique, we improved a hit rate of seeded FEL (Free Electron Laser) pulse, which satisfies the spatio-temporal overlap between the seeding HHG (Higher-order Harmonic Generation) pulse and the electron bunch, at the SCSS test accelerator. HHG -seeded FEL was operated over half a day with a 20-30 % effective hit rate. The output pulse energy was 20 μJ at a wavelength of 61.2 nm.
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We have demonstrated a seeded FEL (Free Electron Laser) combined with high-order harmonics generated from an ultrafast Ti:Sapphire laser [1] at the SCSS test accelerator (SCSS) [2]. FEL based on the SASE (Self-Amplified Spontaneous Emission) scheme has spike structures on its temporal and energy spectra. For generation of the full-coherent FEL pulse with single peak in the longitudinal domain, we tested a scheme to utilize external seeding optical laser pulse. Our seed source was HHG (High-order Harmonics Generation) pulse at a wavelength of 61 nm, which is the 13th order harmonics of Ti:Sapphire laser (800 nm).

For operating the seeded FEL using the external laser source, it is important to synchronize between the seeding laser pulses and the electron bunches. Therefore, both the arrival timing of the electron bunch and the seeding pulse should be overlapped at the entrance of the undulator section. The feedback system, to control timing drift and non-destructive monitor of the relative timing between the seeding laser pulse and the electron bunch, is crucial for keeping the optimized seeding condition for stable operation of seeded FEL. We applied the Electro-Optic (EO) multiplexing technique for monitoring the relative overlapping [3]. Utilizing the EO-probe pulse optically split from the HHG-driving laser pulse, the arrival time difference (relative timing) of the seed laser pulses and the electron bunches was under control and thus fixed at the optimal seeding condition. The polarization of the EO-probe laser pulse is modulated at the EO crystal (ZnTe), when the electron bunch passes nearby the crystal. The polarized splitter works as a converter from polarization modulation to intensity moderation on its spectrum (spectral decoding). Thanks to the linearly chirped pulse, the profile of the intensity spectrum is equivalent to the temporal laser pulse that corresponds one to the electron bunch charge distribution. Our results show that real-time measurement of arrival timing can be realized by monitoring the peak wavelength of the EO-signal's spectrum.

2. Experimental setup

A schematic drawing of our HH-seed EUV FEL at the SCSS, which combined with the EO probing system for locking the seed timing, is shown in figure 1. The Ti:Sapphire laser source is located outside the accelerator tunnel.

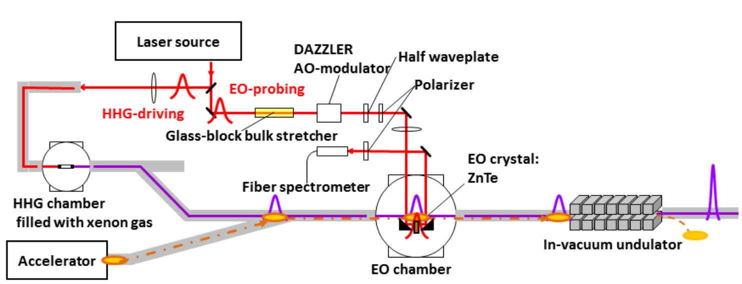

Fig. 1. Experimental setup of seeded FEL with EO-sampling feedback at EUV-FEL accelerator: relative positioning in transverse and timing in longitudinal of electron bunch with respect to arriving timing of a seeding HH pulse are monitored at entrance of the first in-vacuum undulator to keep in a best seeding condition.

The common laser source is operated at 30 Hz and provides the original pulse with pulse energy of 120 mJ and pulse duration of 180 fs. The laser pulse is split into two pulses in the tunnel. One is the HHG-driving pulse as FEL-seeding source, which is focused into the gas cell to generate HHG pulse. The HHG pulse is led into the undulator and overlapped with the electron bunch the other is the probe pulse for the EO sampling detector. This pulse is primarily stretched with a linear chirp to 5 ps through a bulk stretcher. An AO (Acousto-Optics) modulator (DAZZLER) is able to control phase and amplitude spectra independently. Waveplates and the first linear polarizer are used to optimize the incidence polarization of the probe laser pulse at the EO crystal. After passing through the EO crystal, the encoded signal is picked up by a polarizer and decoded by a spectrometer.

Changing the difference of optical pass length between the HHG and the EO-probing pulses at the EO crystal, the arrival timing deference of the two pulses is adjusted and kept constant at the seeding condition with feedback. Positioning the EO signal at a certain wavelength on the spectrum of the EO-probe pulse, the origin of relative timing between the HHG-pulse and the electron bunch is defined as the optimized seeding condition. When the timing of the seeding laser pulse drifts away from the best seeding condition, the timing delay unit of the laser oscillator keeps at the origin of the relative timing automatically.

3. Experimental results

As a result, we obtained HHG-seeded FEL pulses with spectral bandwidth of 0.06 nm (FWHM). Thanks to the EO-sampling arrival timing reference, we could compensate the long-term drift of arrival timing, and enhance a successful hit rate. For a quantitative evaluation to select a successful seeded FEL pulses, we defined an "effective" hit rate. If the spectral peak intensities of the seeded FEL pulses are larger than four times the standard deviation of the peak SASE intensities, we define the events as an "effective" hit. Successful seeding is characterized with normalization to the standard deviation of the peak SASE as $I_{seed} - \overline{I_{SASE}} > 4\sigma_{SASE}$, where I_{seed} and $\overline{I_{SASE}}$ are the peak intensity of the seeded FEL with an effective hit and the averaged peak intensity of SASE, respectively, and σ_{SASE} is the root mean square of the fluctuation. In the case of our former experiment in 2010, according to this definition, the effective hit rate was calculated as 0.3%. Figure 2 shows the correlation data plot between the normalized intensity and the central wavelength in the data of 10,000 shots with seeded FEL operation in 2012. In Fig. 2, the red points represent the seeded pulses with effective hits, which exceeded $4\sigma_{SASE}$. The blue points, which are less than $4\sigma_{SASE}$, are defined as the ineffective hits. The central wavelength of the seeded FEL ($>4\sigma_{SASE}$) is distributed from 61.5 to 62.0 nm. We achieved the effective hit rate was 24% and pulse energy to 20 μJ. Our definition of the effective hit rate is useful to judge the seeding quality in user experiments.

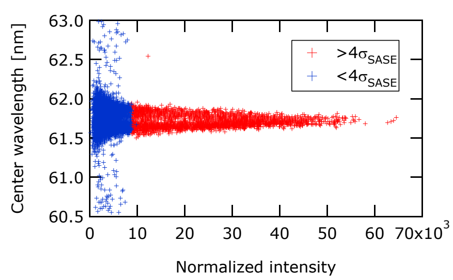

Fig. 2. Correlation data plot between normalized intensity and central wavelength with seeded operation. Here, σ_{SASE} is standard deviation of the SASE-FEL intensity fluctuation. Effective seeded FEL pulses are defined as large as 4 σ_{SASE} (red) for user experiments.

4. Conclusion

By using the EO sampling based arrival timing measurement system, we improved the hit rate of the HHG seeded FEL from 0.3 % to 24 %. The seeded FEL was operated over half a day.

5. References

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