SPECTRAL CHARACTERISTICS OF THE SEEDED FEL USING HIGHER HARMONIC GENERATION IN GAS AT THE SCSS TEST ACCELERATOR

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Abstract

Seeding a FEL with high harmonic generation from a Xenon gas cell at the SCSS test accelerator was successfully demonstrated at a wavelength of 160 nm (the 5th harmonic of a Ti: sapphire laser) in December 2006 [1]. After the improvement of the accelerator performance in 2007, we performed detailed studies of the spectral characteristics of the seeded FEL [2]. Compared to the spiky spectrum of SASE, the seeded FEL can produce a quasi-Gaussian spectrum with a single peak. In addition, the lasing wavelength is fixed at the wavelength of the seed, even if the deflection parameter K-parameter of the undulator is varied in a certain range. Therefore, it is expected that the spectral stability becomes much better than SASE against the fluctuation of undulator fields or beam energy.

INTRODUCTION

The single-pass FEL amplifier is able to amplify the spontaneous radiation with SASE (Self-Amplified Spontaneous Emission) process in short wavelength region where resonator type FELs are not applicable [3]. In recent years, the SASE-FELs in the VUV region have been successfully operated [4, 5]. Also in the X-ray region, some projects are in progress such as LCLS in the U.S., European-XFEL in Germany, XFEL of SPring-8 in Japan [6, 7, 8].

XFEL of SPring-8 adopts unique technologies; a low-emittance thermal cathode electron gun, C-band accelerators and in-vacuum undulators. For demonstration of SASE-FEL using these technologies, the SCSS test accelerator with an electron beam energy of 250 MeV has been constructed, and it succeeded in lasing at a wavelength of 49 nm in June 2006 [9].

One disadvantage of the SASE-FEL is relatively short temporal coherence with respect to the electron bunch length. In the SASE process, the spontaneous emission from the electron bunch is self-amplified during a single passage in undulators. Then, many SASE processes take place in various parts of the electron bunch independently, since the temporal coherent length of the emission is normally much shorter than the length of the electron bunch. Consequently the spectrum has a complicated spiky structure which varies from pulse to pulse. This can bring severe limitations for some user applications.

Laser seeding is a technique to control the lasing process by using a coherent seed light of an external source [10]. The seed light is amplified in a same manner as SASE. However, the output radiation is expected to have good coherence as the seed light. As a result, it would be possible to realize a stable lasing wavelength, a narrow bandwidth and higher spectral peak intensity.

After the success of lasing by SASE in the SCSS test accelerator, a seeding system has been introduced using a High Harmonic generated in Gas (HHG) as an external seed source.

EXPERIMENTAL SETUP

SCSS Test Accelerator

The SCSS test accelerator is composed of a thermal cathode electron gun, two bunchers, two S-band accelerators, two magnetic chicanes (one for electron bunch compression, and the other for introducing He-Ne alignment laser and the seed laser), two C-band accelerating structures, two undulator sections and a beam diagnostics system. The HHG system is installed in the accelerator tunnel close to the magnetic chicane upstream of the undulators [11].

The operation parameters of the accelerator for the seeding experiment are as follows; an electron beam energy of 150 MeV, an electron bunch length of 4 ps (FWHM), a sliced emittance of 0.7 π mm-mrad, an electron bunch charge 0.3 nC and a repetition rate 10 Hz. The parameters of the SCSS test accelerators in the seeding experiment are shown in Table 1.

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Table 1: Parameters of the SCSS test accelerator in the seeding experiment

Beam energy	150 MeV
Bunch length	4 ps (FWHM)
Sliced emittance	0.7 π mm-mrad
Bunch charge	0.3 nC
Repetition	10 Hz
Lasing wavelength	160 nm
Undulator period length	15 mm
Undulator period number	300 × 2 segments
Undulator K value	1.3

Seeding System

HHG is obtained by an interaction between the high intense laser and a rare gas. In this seeding system, Xenon is used as a gas medium. The pressure in the gas cell, whose length is 9 cm, is adjusted by a leak valve. A mode-locked Ti:sapphire laser, at a 800 nm wavelength with a pulse energy of 50 mJ, a pulse duration of 130 fs and a repetition rate of 10 Hz, is focused in the rare gas cell by using a plano-concave lens of 7.5 m focal length. Currently 5th harmonic (160 nm) of Ti:sapphire laser is used as the seed light. The seed pulse from HHG is transported into the accelerator by two concave SiC mirrors and two plane multilayer mirrors optimized for the wavelength of 160 nm. The concave mirrors are used for adjusting a focal point of the seed light in the undulators and the plane mirrors are used to align the seed light and the electron bunch in the undulators transversely. The multilayer mirrors also act as a spectral filtering for reducing the intensity of the fundamental and the other harmonics for lowering the level of parasitic light. At the downstream of the undulators, a band-pass filter of 160 nm, a VUV sensitive photodiode and a spectrometer are installed. After the HHG chamber, a differential pumping system is installed and it is connected to the vacuum system of the accelerator. The installation of the seeding system is shown Fig. 1.

Overlapping Between Seed Light and Electron Bunch

To realize a high-precision temporal synchronization between a few 10 fs pulse of the seed light and a 700 fs pulse of the electron bunch, temporal synchronization modules, electric delay modules and an optical delay are installed. It was confirmed that a timing jitter between the laser pulse and the reference RF signal of the main linac (5712 MHz) is about 1.3 ps RMS. An up-grade of the system is under study for reaching a higher synchronization level.

A streak camera (FESCA-200) is used to check the longitudinal overlap between them. In order to improve the temporal synchronization between the seed light pulses and the electron bunches, the electron bunches were longitudinally stretched from 700 fs of the normal operation mode to 4 ps.

The electron beam profile monitors utilizing OTR (Optical Transition Radiation) located upstream and downstream of the undulators are used for the transverse alignment between the seed light and the electron bunch.

EXPERIMENTAL RESULTS

Spectrum of Seeded FEL

Fig. 2 shows the single shots spectra of the seeded FEL, the SASE and the seed light after one undulator. The seeded FEL radiation exhibits a Gaussian profile such as the seed's one, whereas SASE is very spiky. The SASE spectral width (1.1 nm FWHM) is roughly twice larger than the seeded FEL one (0.5 nm FWHM). The seeded FEL is slightly narrower than the seed itself. Measurements were performed with a spectrometer coupled to a Acton CCD camera.

Fig. 3 is the spectra after two undulators. It is clearly seen that the spectral width of the seeded FEL is much narrower than that of SASE. In addition, there is no spiky structure.

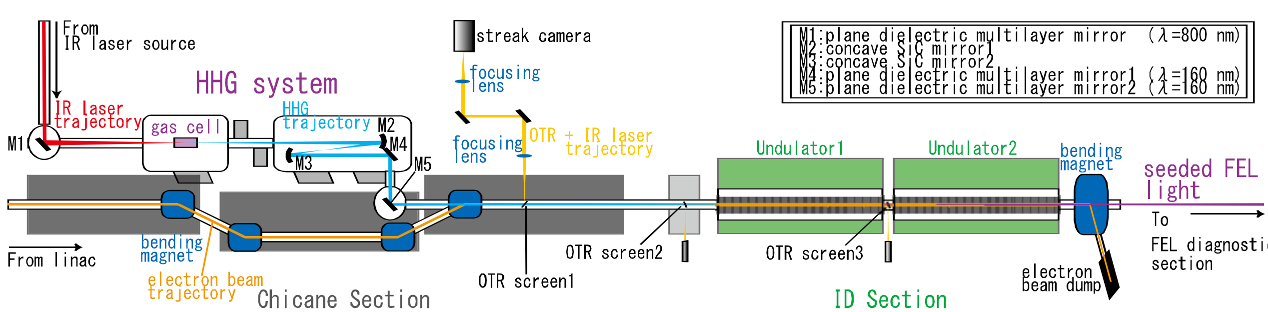

Figure 1: Layout of the seeding FEL at SCSS Test Accelerator.

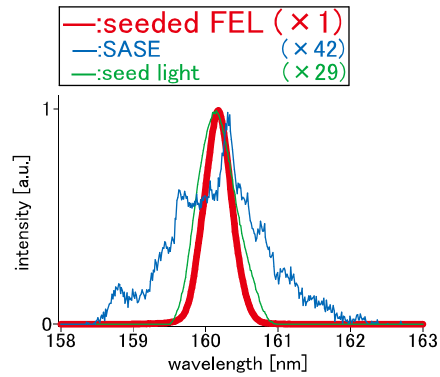

Figure 2: Comparison of spectra between seeded FEL and SASE after one undulator.

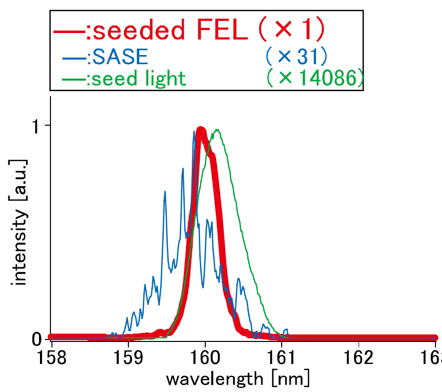

Figure 3: Comparison of spectra between seeded FEL and SASE after two undulators.

Dependence of Lasing Wavelength and Intensity of Seeded FEL on K Value of Undulators

The lasing wavelength was measured as a function of the deflection Parameter (K) of the undulators. Fig. 4 shows the lasing wavelength of the seeded FEL and of the SASE radiation with one undulator. In SASE, the lasing wavelength changes linearly with respect to K. It corresponds to the FEL resonance condition for small variations of K.

On the other hand, in the seeded FEL, it is fixed at the wavelength of the seed light within the spectral resonance between the undulator radiation and the seed light against a change of K value in a certain range. This means that the lasing wavelength of the seeded FEL is more stable compared to that of SASE-FEL even if there is a fluctuation of the electron beam energy or magnetic field strength of undulators.

Fig. 5 shows variation of the lasing wavelength and intensity as a function of K value after the second undulator. K value of the first undulator is fixed to 1.386. In this case, the seeded FEL wavelength also doesn't change with K value. In addition, the seeded FEL wavelength is more stable than SASE-FEL.

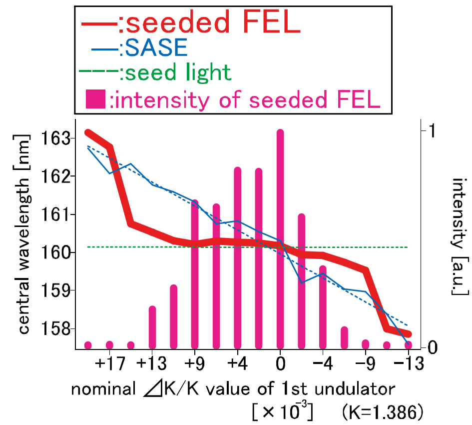

Figure 4: Dependence of the lasing wavelength as a function of K value of the first undulator. The gap of the second undulator is fully opened.

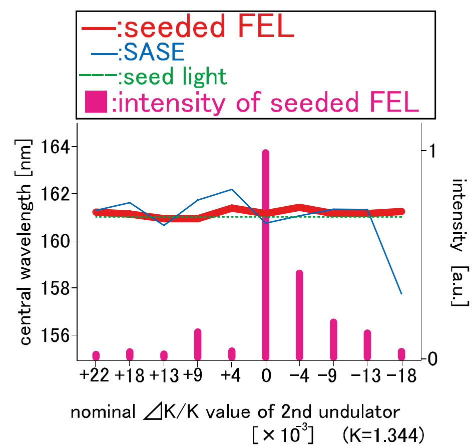

Figure 5: Dependence of lasing wavelength as a function of K value of the second undulator. K value of the first undulator is fixed to 1.386.

CONCLUSION

The spectral characteristics of the seeded FEL at the wavelength of 160 nm were studied in detail at the SCSS test accelerator. The spectrum of the seeded FEL has a single peak of quasi-gaussian shape, which contrasts with the spiky spectrum of the SASE-FEL. The spectral width of the seeded FEL is narrower than that of SASE. The lasing wavelength of the seeded FEL is more stable than the SASE-FEL against the fluctuation of beam energy or magnetic field of the undulator.

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