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TWO-COLOR SOFT X-RAY GENERATION AT THE SXFEL USER FACILITY BASED ON THE EEHG SCHEME

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Abstract

We study the two-color soft x-ray generation at the Shanghai soft X-ray Free Electron Laser (SXFEL) user facility based on the echo-enabled harmonic generation (EEHG) scheme. Using the twin-pulse seed laser with different central wavelengths, an preliminary simulation result indicates that two-color soft x-ray FEL radiation with wavelengths at 8.890 nm and 8.917 nm can be obtained from the ultraviolet seed laser. The radiation power is about 600 MW and the time delay is adjustable.

INTRODUCTION

The free electron laser (FEL) has served as a prominent tool for the state-of-the-art research in many scientific frontiers ranging from physics, to chemistry and biology [1, 2]. Through the well-known pump-probe technique [3], the ultrahigh intensity, ultrashort, FEL radiation pulses can be applied to measure ultrafast phenomena inside matter. Typically, the pump-probe technique will use two laser pulses with adjustable time delay and different central wavelengths. The pump laser will give the system a perturbation to excite some reactions within the sample. The probe laser will then reach and interact within the sample after a certain time. By observing the modulation of the probe laser, one can retrieve the state of the system. Changing the time delay between the pump and probe laser pulses, the evolution of the reaction can be "filmed" as a movie while it decays back to the equilibrium state.

The FEL based pump-probe technique extends the photo energy coverage up to vacuum ultraviolet (VUV) or x-ray range, which enables the stimulation and investigation of the inner-shell electronic energy level transition [4]. Therefore it can be used to study the material structure and the ultrafast process in the atomic and molecular scale. The most important FEL based pump-probe scheme termed as the two-color FEL is based on the novel achievements developed recently in the high gain FEL research area. Basically, the two-color FEL is aiming to provide two ultrashort FEL radiation pulses with the time delay and the central wavelength could being adjusted continuously and separately.

The two-color FEL is of great interests in the scientific communities. Several schemes have been proposed and demonstrated experimentally in LCLS, SACLA and FERMI [5–8]. These schemes are generally based the self-amplified spontaneous emission (SASE) or the high gain harmonic generation (HGHG) [9]. However, the SASE FEL has poor temporal coherence and power stability as the radiation initiates from the shot noise. And the HGHG FEL can hardly reach the x-ray wavelength range due to the limitation of the frequency up-conversion efficiency. In this paper, we study the two-color soft x-ray generation at the Shanghai soft X-ray Free Electron Laser (SXFEL) user facility based on the echo-enabled harmonic generation (EEHG) [10, 11].

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LAYOUT AND MAIN PARAMETERS

The schematic layout of our design is shown in Fig. 1. It is basically a conventional EEHG configuration, consisting of a two stage energy modulation section, M1 and M2, two dispersion sections, DS1 and DS2, and a long undulator section, R. The electron bunch obtained from the LINAC upstream will interact with Seed1 in M1 to get an energy modulation with an amplitude A1 = 2.78. Then the electron beam is sent through the strong dispersion section DS1 with R56 = 10 mm to stretch the longitudinal phase space of the electron beam to form periodic structures. Seed2 will imprint another energy modulation into the electron bunch with the amplitude A2 = 1.39. And the second dispersion section DS2 with R56 = 0.34 mm will convert the energy modulation into harmonic density modulation. The bunched electron beam will then go through the radiator R to generate FEL radiation.

Seed1 is a long pulse seed laser so that it can cover the whole electron bunch during the first energy modulation process in M1. Seed2 is a twin-pulse seed laser with the two pulses of different central wavelengths and a certain time interval. Due to the principle that the FEL radiation generated in the EEHG is at the high harmonics of the seed laser, the two-color FEL radiation can be eventually obtained. The wavelength of Seed1 is 266.7 nm. The wavelengths of the two pulses in Seed2 are respectively 266.7 nm and 267.5 nm. The EEHG FEL is tuned at the 30th harmonic of the seed laser. Therefore the intended two-color soft x-ray FEL radiation ia at 8.890 nm and 8.917 nm. The time delay of the two-color soft x-ray FEL can be adjusted through the time intervals between the two pulses in Seed2. According to our design of the optical system, the wavelength tunable range of the two pulses in Seed2 is 266.7 nm ± 2 nm. And the time delay can be adjusted between 0 and 1 ps. The main parameters of our design are shown in Table 1.

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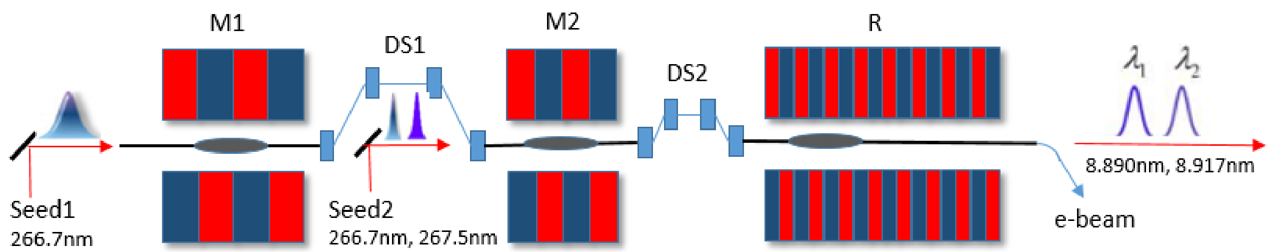

Figure 1: The schematic layout of our design.

Table 1: Main Parameters of Our Design

Parameters	**Value**
Beam energy [GeV]	1.6
Charge [pC]	500
Slice energy spread [%]	0.01
Normalized emittance [µm·rad]	1.0
Full Bunch length [fs]	800
Peak current [A]	700
Seed1 wavelength [nm]	266.7
Seed1 pulse length [ps]	1.0
Seed1 power [MW]	100
Seed2 wavelength [nm]	266.7/267.5
Seed2 pulse length [fs]	100/100
Seed2 power [MW]	100/100
M1: $N_p \times \lambda_u$ [cm]	20×8
M2: $Np \times \lambda_u$ [cm]	10×8
DS1: R56 [mm]	10
DS2: R56 [mm]	0.34
R: $N_s \times N_p \times \lambda_u$ [cm]	$8 \times 75 \times 4$
FEL wavelength [nm]	8.890/8.917

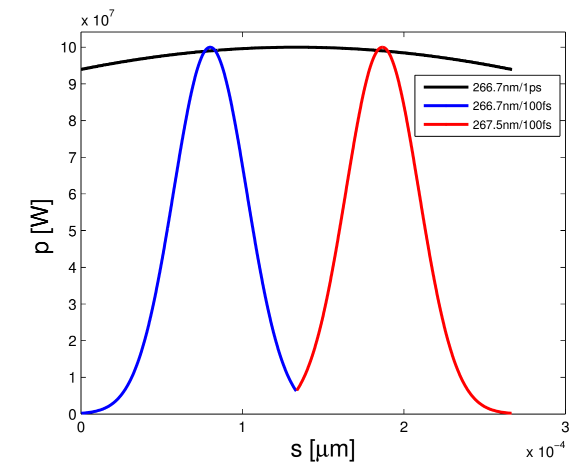

Figure 2: Seed laser pulse: Seed1 266.7 nm/ 1 ps (black). Seed2 266.7 nm/ 100 fs (blue), 267.5 nm/ 100 fs (red) and the time delay is about 400 fs here.

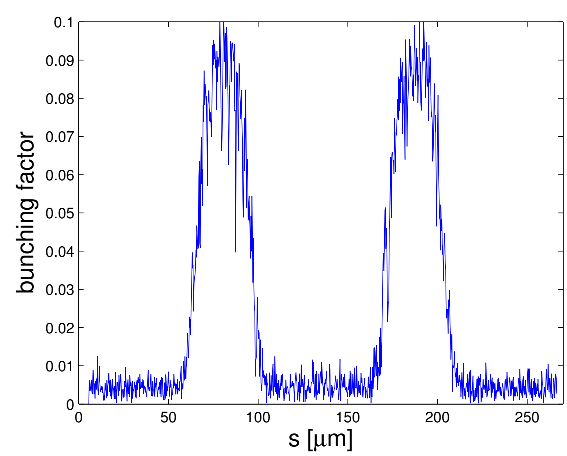

Figure 3: 30th harmonic bunching factors of the seed laser.

FEL SIMULATION

Using the typical beam parameters of the Shanghai soft X-ray Free Electron Laser (SXFEL) user facility, we present the two pulses two-color soft x-ray generation. Assuming an ideal electron beam is generated at the entrance of M1. The energy modulation processes in M1, M2 and the FEL amplification processes in R are conducted on the basis of the Genesis code.

Fig. 2 illustrates the characterization of the seed laser used in M1 and M2. The central wavelengths of the two short pulses in Seed2 are 266.7 nm and 267.5 nm. The time delay here is set to be about 400 fs. By continuously and separately adjusting the central wavelength and the time interval of this two pulses in Seed2, we can control the output FEL radiation property to be desired wavelengths and time delays.

The 30th bunching factors of the seed laser at the entrance of the radiator R are depicted in Fig. 3. Through the optimization conditions of the EEHG scheme, up to 10% bunching factor of the 30th harmonic of the seed laser can be achieved. The bunched electron beam will then be used for the simulation and optimization for the final FEL radiation. The gain length of these two part bunched electrons is about 1.28 m. The total undulator length in R is 24 m. To satisfy the resonant conditions for both of the two-color radiation pulses, we give the initial electron bunch a 0.1% energy chirp. The undulator bandwidth is also enlarged and the two FEL radiation pulses can be amplified simultaneously.

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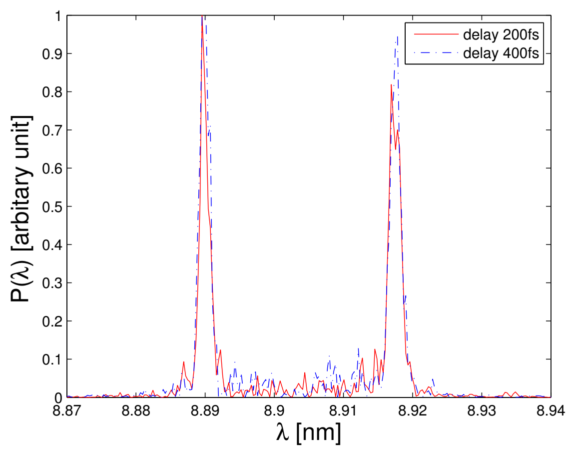
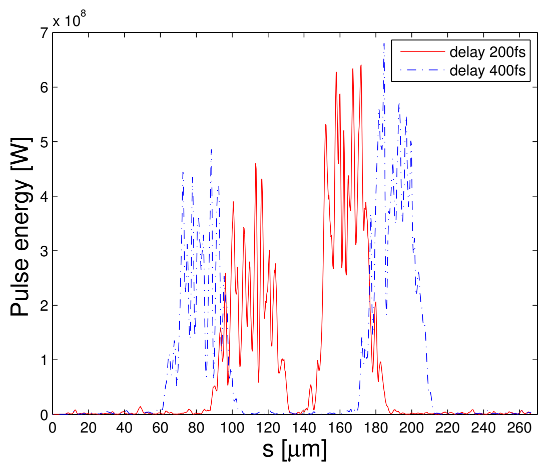


(a) Spectra



(b) Power

Figure 4: Two pulses two-color soft x-ray FEL radiation at the wavelengths of 8.89 nm and 8.917 nm with 200 fs (red) and 400 fs (blue) time delay. (a) Spectra. (b) Power.

The simulation results shown in Fig. 4 demonstrate the spectra and the radiation power of the two-color soft x-ray FEL radiation at the wavelengths of 8.890 nm and 8.917 nm with 200 fs and 400 fs time delay. The photo energy gap is about 0.4 eV. The radiation power is about 600 MW. The fluctuation of the radiation power may result from the inveracious noise occurring in the simulation processes.

CONCLUSIONS

The preliminary studies of the two-color soft x-ray generation at the SXFEL user facility based on the EEHG scheme are presented in this paper. Using the twin-pulse seed laser with different central wavelengths at 266.7 nm and 267.5 nm, about 600 MW two-color soft x-ray FEL radiation with wavelengths at 8.890 nm and 8.917 nm can be obtained eventually. The photo energy gap is about 0.4 eV and is adjustable by tuning the central wavelength of the seed laser. The time delay of the two FEL pulses is determined by the time interval of the two pulses in Seed2. The results of 200 fs and 400 fs are given. The electron beam energy chirp is optimized to satisfy the resonant conditions for both the two parts of the electron beam.

Further, we will study the dependence of the two-color FEL radiation power and spectrum on the variation of the photo energy gap. And the three-dimensional start-to-end simulation based on the SXFEL user facility is necessary for the conceivable test experiments.

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