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Chirped Pulse Amplification of HGHG-FEL at DUV-FEL Facility at BNL

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Abstract

The DUV-FEL facility has been in operation in High Gain Harmonic Generation (HGHG) mode for one year producing 266 nm output from 177 MeV electrons. In this paper we present preliminary results of the Chirped Pulse Amplification (CPA) of HGHG radiation. In the normal HGHG process, a 1 ps electron beam is seeded by chirped 9 ps long 800 nm Ti:Sapphire laser. The electron beam sees only a narrow fraction of the seed laser bandwidth. However, in the CPA case the seed laser pulse length is reduced to 1 ps, and the electron beam sees the full bandwidth. We introduce an energy chirp on electron beam to match the chirp of the seed pulse, enabling the resonant condition for the whole beam. We present measurements of the spectrum bandwidth for various chirp conditions.

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Keywords: CPA, FEL, HGHG, seed laser, accelerator, high gain

1. Introduction

There is great interest in producing lasers with a pulse length in femtosecond region. In general, to serve FELs the photo-cathode electron guns produce 4-5 ps beams. These beams can be compressed to 1 ps or less; however, it is not trivial to compress the beams down to femtosecond level. By producing a frequency chirp along the pulse, we can use conventional laser pulse compression to shorten the pulse duration down to the femtosecond level [1].

The accelerator consists of a Ti:Sapphire laser

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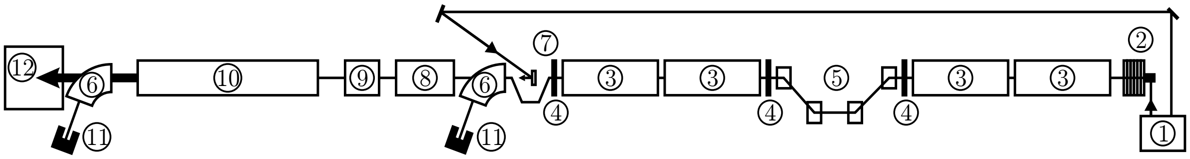

Fig.1: The NSLS DUV-FEL layout: 1-gun and seed laser system, 2-RF gun, 3-linac tanks, 4-focusing triplets, 5-magnetic chicane, 6-spectrometer dipoles, 7-seed laser mirror, 8-modulator, 9-dispersive section, 10-radiator (NISUS), 11-beam dumps, 12-FEL measurement area.

system, a 1.6 cell RF photo-cathode gun, 4 SLAC-type linac tanks and a 4-dipole chicane (Fig 1). A photo-cathode RF gun is illuminated by the tripled Ti:Sapphire laser at 266 nm producing 300 pC charge, 4-5 ps FWHM bunch length, and a 4.5 MeV energy electron beam with normalized emittance of 4-5 mm-mrad. The first two linac tanks accelerate the electron bunch with the second tank off-crest by 23^o to introduce an energy chirp. A 4-dipole chicane compresses the bunch to about 1 ps FWHM.

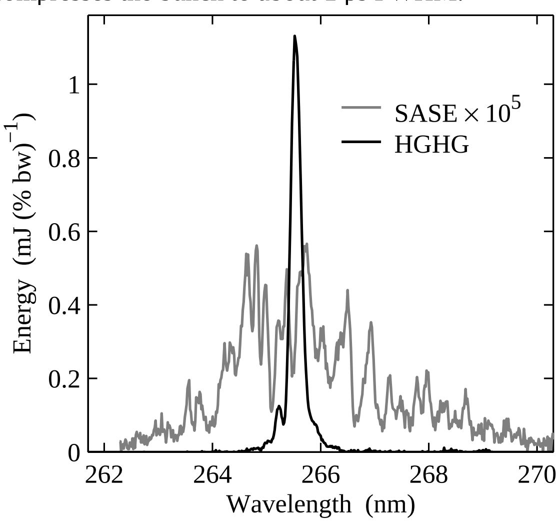

Fig. 2 The spectrum of HGHG (black) at normal operating conditions (no electron energy chirp and long seed pulse) and SASE spectrum (grey)

During the past year HGHG-FEL reached saturation at 266 nm with the seed at 800 nm. The typical output energy is about 100 µJ with 1 ps pulse length. Energy fluctuation is measured to be about 7 %, which is mostly due to the machine performance. The spectrum is measured to be very narrow (0.23 nm) (Fig. 2) and output is transversely and temporally Fourier-Transform limited [2]. The third harmonic at 88 nm accompanied by 266 nm fundamental is being used in a novel Chemistry experiment since January 2003 [3].

2. Experimental Procedure for CPA

In this experiment the seed laser pulse length is adjusted to 1 ps FWHM, which is chosen to be same as electron bunch length. The proper delay is introduced to the seed laser pulse to establish synchronization with the electron beam. This way the electron bunch sees the full bandwidth of the seed laser. However, the usual 1% bandwidth of the seed laser is not supported by the FEL process. The resonant condition for the an FEL is

$$\lambda = \frac{\lambda_w}{2\gamma^2}(1 + K^2/2) \qquad (1)$$

In order to satisfy the resonant condition along the bunch we need to introduce an energy chirp so that every slice within the electron bunch would be resonant. The Eqn 1 yields relation between wavelength chirp of the seed laser and energy chirp of the electron as

$$\frac{\Delta\gamma}{\gamma} = -\frac{\Delta\lambda}{2\lambda} \qquad (2)$$

Thus we need to introduce an energy chirp that is equal to the half of the laser wavelength chirp. The energy of the electron beam after linac tanks is

$$E = E_{T1} + 34\cos(\phi_2) + 52\cos(\phi_3) + A_{Tank\,4}\cos(\phi_4) \qquad (3)$$

where each term represents the energy gain at each linac tank, the angles are the tank phases measured with respect to the crest of the RF. The phase of the tank2 is set to –22 to -26° by the compression requirements. Tank 3 is operated on crest and tank 4 is varied to produce different energy chirps along the beam. The amplitude of the tank4 is adjusted so that total energy is the resonant energy for HGHG-FEL. The energy chirp can be expressed from Eqn. 3 as

$$\frac{\Delta E}{E} = -\frac{34\,\omega \sin(-22)\,\Delta t_{uncomp}}{E} - \frac{A_{Tank\,4}\,\omega \sin(\phi_4)\,\Delta t_{comp}}{E} \quad (4)$$

where ω is the RF frequency, $\Delta t_{uncomp} \cong 5\,\text{ps}$ and $\Delta t_{comp} \cong 1\,\text{ps}$ are uncompressed and compressed electron bunch lengths respectively. Fig. 3 shows FWHM percentage energy chirp as a function of tank4 phase angle. We observe a good agreement between the measurement and the calculation. We measure spectrum of the HGHG output at each electron energy chirp condition.

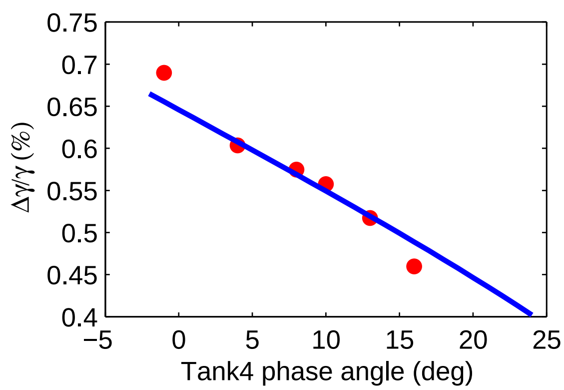

Fig. 3. FWHM energy chirp of electron beam as function of tank4 phase. Blue curve is calculation and red dots are measurement.

3. Spectrum Measurements

We scan the tank4 phase from 24° to –2° and measure the spectrum at each case. This way chirp per picosecond slope is varied and we expect to have widest bandwidth when the chirp slope is half of the seed laser wavelength chirp slope. Fig. 4 shows the spectra for different chirps. Note that the smoothness of the chirped spectra indicates that the electron density profile is smooth.

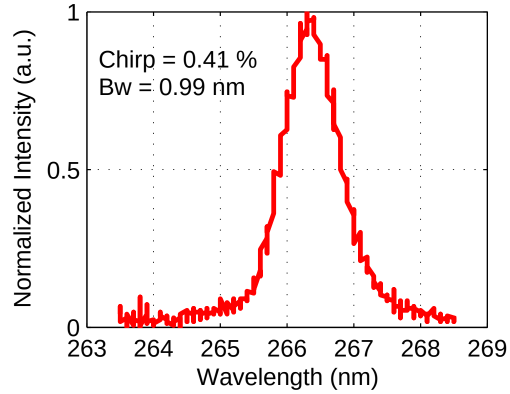

Fig. 4-a Spectrum of CPA-HGHG for a chirp of 0.41 %

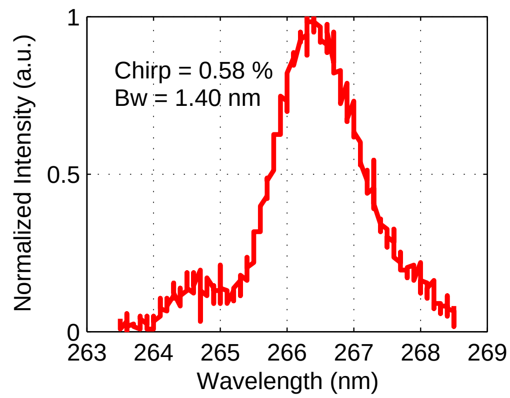

Fig. 4-b Spectrum of CPA-HGHG for a chirp of 0.58 %

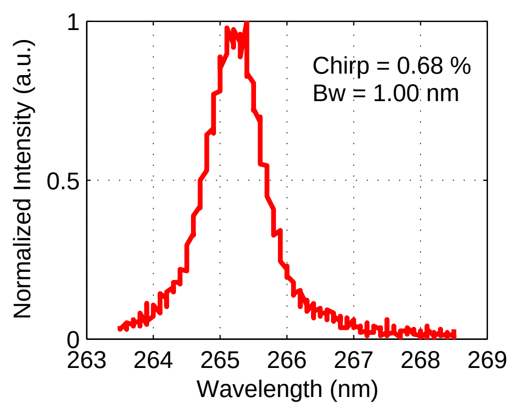

Fig. 4-c Spectrum of CPA-HGHG for a chirp of 0.68 %

We plot bandwidth as a function of chirp in Fig. 5.

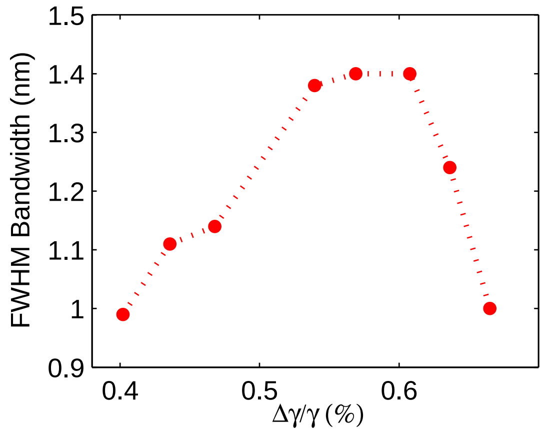

Fig. 5 HGHG bandwidth vs. percent energy chirp of the electron beam

We see a clear peak in Fig.5 showing that when the chirp of the electron beam is matched to the seed laser chirp, HGHG bandwidth is the widest. We measure the widest spectrum at a chirp of 0.58 %. The typical bandwidth of the seed laser is about 1 %. We measured the seed laser FWHM bandwidth during the experiment as 5.5 nm that is about 0.7 %. Thus we expect to have the largest bandwidth at 0.35 % chirp and the bandwidth should be one third of the seed bandwidth that is 1.8 nm. The fact that we introduced more chirp to the electron beam than 0.35 % might suggest that the electron bunch length is longer than what we measured by zero-phasing technique [4]. The measured widest bandwidth of 1.4 nm is not far from the expected value of 1.8 nm. One of the critical issues during the experiment is the longitudinal jitter of the system. We estimate this time jitter is about 0.3 picosecond between the electron beam and the seed laser pulse. Considering 1 ps long electron and photon beams, 0.3 ps jitter is significant for the performance of the system. The fluctuations were larger than usual HGHG condition for this experiment. This jitter could also be the reason for not having the full bandwidth of 1.8 nm, because the electron beam would be seeing different bandwidth at every shot. This is also consistent with the wavelength fluctuation that was observed. We accumulated a number of spectrum data for the same chirp conditions and chose the ones with high output. Currently we are planning a method, which would reduce this jitter by illuminating the cathode with HGHG output at 266 nm. This would reduce the jitter by the compression ratio, which is about 4-5 times.

We are in the process of building a compressor to shorten the CPA-HGHG output and a SPIDER to analyse the output in more detail.

4. Conclusion

First steps toward the Chirped Pulse Amplification HGHG-FEL have been taken. Spectrum widening has been observed when the electron beam is properly chirped. The results are encouraging for the future compression out the CPA-HGHG output. to produce pulses with pulse length in femtosecond region.

5. Acknowledgement

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