THE UPGRADE OF THE DUV-FEL FACILITY AT THE BNL

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Abstract

The DUV-FEL linac is upgraded from 200 to 300 MeV to enable the HGHG FEL to produce 100 μJ pulses of 100 nm light. This will establish the DUV FEL as a premier user facility for ultraviolet radiation, and will enable state-of-the-art gas phase photochemistry research. Further more, the upgraded facility will also enable several critical R&Ds for future X-ray FELs, such as cascaded and higher harmonic HGHG (n>5), and experimental demonstration of the emittance spoiler for the LCLS .

The upgraded HGHG will operate at the 4^{th} harmonic with the seed laser at 400nm. The increase of the electron beam energy will be accomplished by installing a 5^{th} linac cavity and two 45 MW klystrons. New HGHG modulator and dispersion sections vacuum chambers will be manufactured to accommodate new matching optics and 8^{th} harmonic HGHG. The status of the DUV-FEL upgrade and other beam physics R&D opportunities are presented..

INTRODUCTION

The Deep Ultra Violet Free Electron Laser (DUV-FEL), a laser linac facility at Brookhaven National Laboratory (BNL), is the world's only facility dedicated to laser-seeded FEL R&D and its applications. The high-gain harmonic generation (HGHG) FEL at the DUV-FEL reached saturation at 266 nm with 800 nm seeding [1] in 2002. Experiments were carried out at the DUV-FEL to further characterize the properties of the HGHG FEL and to demonstrate its fully coherence, stability and controllability. The narrower spectrum and better stability of the HGHG, compared to a self amplified spontaneous emission (SASE) FEL, were observed. Both the second and third harmonic HGHG FEL outputs were experimentally characterized using a vacuum monochromator. The pulse energies for both harmonics (133 and 89 nm, respectively) were measured to be about 1 μJ, which is about one percent of the fundamental value at 266 nm. A two-photon absorption auto-correlator with 100 fs resolution was developed to characterize the HGHG output pulse length. It was experimentally demonstrated that, the HGHG can produce output pulses with lengths from 1 ps down to 250 fs by varying the seed laser pulse length.

The first chemical science experiment – ion pair imaging, was successfully completed [2] at the DUV-FEL. The ion pair imaging experiment used the HGHG's third harmonic output (89 nm) to study the super excited states of methyl fluoride, a highly flammable gas. Velocity-mapped ion images of the fluoride ion, obtained using intense, coherent, sub-picosecond pulses of 86-89 nm light, revealed a low translational energy, implying a very high internal excitation in the molecule's methyl cation cofragment.

A series of workshops [3] was held at the NSLS to further explore the potential of the DUV-FEL facility, and to identify the future opportunities for chemical science, beam physics and FEL. The participants of the July 2003 NSLS Chemical Dynamics Workshop identified that, a VUV source with following properties will be a truly unique source for chemical science and other applications:

- Photon energy > 10 eV as a universal probe.
- Peak power > 10^{12} W/cm^2 for nonlinear process.
- 5x10^{13} ph/pulse for high sensitivity and single molecule detection.
- Pulse duration ~100 fs for time-resolved dynamics studies.
- Fully coherence for quantum physics and coherent control.

The workshop participants enthusiastic recommended that, the DUV-FEL facility be upgraded to make the FEL fundamental ~100 nm with the properties listed above.

Further more, the upgraded DUV-FEL should be able to enable several critical R&Ds for future X-ray FELs, such as cascaded and higher harmonic HGHG (n>5), and experimental demonstration of the emittance spoiler for LCLS [4].

In the rest of this report, the DUV-FEL upgrade options , status, and beam physics R&D opportunities with the upgraded facility will be discussed.

THE DUV-FEL UPGRADE

The DUV-FEL accelerator system consists of a 1.6-cell photo injector driven by a Ti:Sapphire laser system, and a four-section 2856 MHz SLAC-type traveling wave linac that is capable of producing a 200 MeV electron beam. The facility's magnetic chicane bunch compressor produces sub-picosecond-long electron bunches with a peak current of a few hundred amperes. The high-brightness electron beam travels down the 10 meter-long undulator to generate UV light with a fundamental wavelength of 266 nm. There are two options for the DUV-FEL to reach 100 nm fundamental. One is to replace the NISUS undulator with a shorter period one, such as VISA undulator; the other is to increase the electron beam energy (Fig.1).

After carefully considering cost, shutdown time and future experimental capabilities, the electron beam energy upgrade to 300 MeV was chosen. The longer period

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NISUS undulator will make the cascaded HGHG easier to realize in the future.

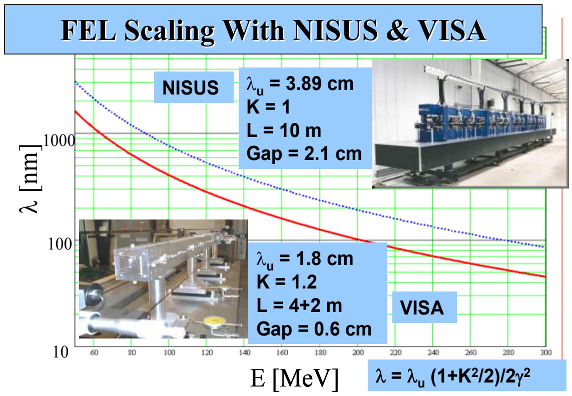

Fig. 1: The DUV-FEL output wavelength vs. beam energy for the two undulators.

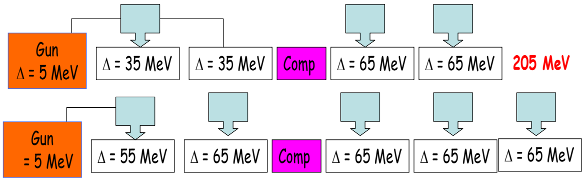

Fig. 2: The old (top) and upgraded (bottom) DUV-FEL linac configurations.

The old and upgraded DUV-FEL linac configurations are plotted in fig.2. The upgraded HGHG will operate at the 4th harmonic with the seed laser at 400nm. The increase of the electron beam energy will be accomplished by installing a 5th linac cavity and two 45 MW klystrons. New modulator and dispersion sections vacuum chambers will be manufactured to accommodate new matching optics and 8th harmonic HGHG. To make space for the new linac, two quadrupole doublets were removed. A new quadrupole triplet was installed immediately after the HGHG seeding station to achieve the beam matching for the FEL (fig.3). Fig.4 plots the electron beam envelops from the bunch compressor to the end of HGHG amplifier.

Various options for the HGHG seed laser injection were also investigated. A four-steering-magnet chicane was used for HGHG seed injection before the upgrade. The electron beam was displaced about 8 mm at the HGHG seeding station. The two steering magnets for the seed chicane before the seeding station were removed because of the space limitation. The on-line laser seed injection using a mirror with a center hole was simulated. For the hole size of 3 mm diameter, about 80% of the seed laser energy will be lost. A chicane is adopted for the upgrade with a new beam steering scheme. A special steering magnet was designed so it can be install on top of the exit cell of the newly installed linac. The diagnostic dipole magnet will be used for the seed chicane with a opposite polarity power supply.

For the upgraded DUV-FEL to be able to reach the 8th harmonic, significant modifications of the HGHG modulator were made. The minimum gap for the modulator before the upgrade is about 1.6 inch, and the gap for the 8th harmonic will be 0.93 inch. A new motor drive mechanism was installed to achieve such small gap. Fig.5 plots the pulse wire measurements for the electron beam trajectories inside the modulator. The trim magnets at both ends of the modulator will be adjusted to correct the trajectory error for the higher harmonic operation.

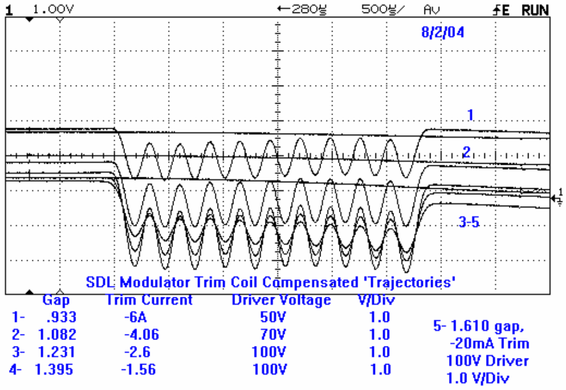

Fig. 5: The pulse wire measurements for the electron beam trajectories inside the HGHG modulator with trim magnets. 1 – 8th harmonic, 2 – 7th, 3 – 6th, 4 – 5th.

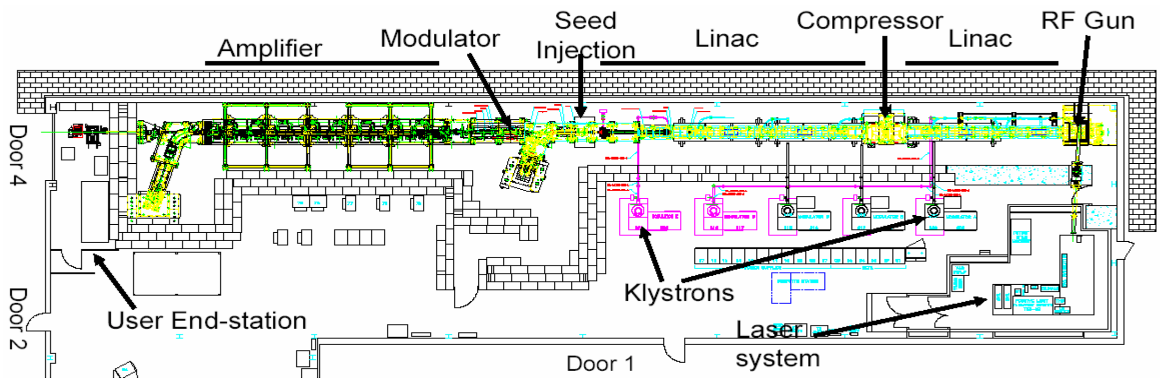

Fig. 3: The DUV-FEL layout after the upgrade.

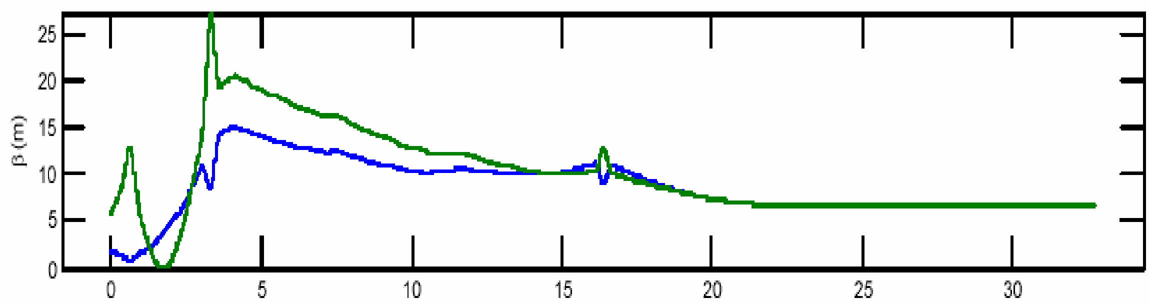

Fig. 4: The transverse electron beam envelops along the beam line, the HGHG amplifier (NISUS undulator) entrance is downstream 21 m from the starting point.

In order to accommodate the tunable HGHG [5] and laser heater [6] experiments, a much stronger HGHG dispersion magnet is needed. The OK-4 dispersion magnet on-loan from Duke was installed at the DUV-FEL. The maximum R_{56} will increase from 0.35 mm to 4.2 mm after the upgrade.

The all hardware for the upgrade is installed; the initial energy of the electron beam after the upgrade will be limited to about 250 MeV. The reason for that is, one of the klystron tubes was damaged in May 2004. The RF conditioning will start in early September of 2004. Electron beam commissioning is expected shortly after. The 4^{th} harmonic HGHG with 800 nm seed laser will be commissioned in early December of 2004. 130 nm HGHG will be commissioned in early 2005.

BEAM PHYSICS AND FEL R&D

The future R&D opportunities in FEL and beam physics are discussed briefly in this section.

1. Seeded FEL R&D: though the basic properties and advantages of the HGHG have been experimentally demonstrated, there are still many significant challenges to realize a X-ray FEL based on the HGHG. The large gap of the longer wavelength of the HGHG seed laser and the X-ray users desired requires staging several HGHGs, i.e., cascaded HGHG. We are exploring the possibility of two-staged cascaded HGHG experiment in collaboration with other groups. The proposed experiment will demonstrate the staging and fresh bunch techniques.

To reduce the complexity of the cascaded HGHG, a higher harmonic HGHG is desired. The higher electron beam energy after the upgrade will make it possible to study the 8^{th} harmonic. Higher harmonic HGHG will also make it possible to investigate the degradation of HGHG output, which scales as the square of the harmonic number.

2. Other FEL R&D: The upgraded DUV-FEL offers other unique opportunities for the FEL R&D. Two experiments now under consideration are emittance spoiler [4] and FEL gain enhancement by the inverse Free Electron Laser (IFEL) micro-bunching [7]. Preliminary estimation shows that, the FEL output pulse length will be reduced from 1 ps to about 200 fs using emittance spoiler.

The HGHG modulator introduces electron beam energy modulation via IFEL interaction. The large dispersion magnet installed will allow us to optimize the electron beam micro-bunching. A factor of 3 to 6 in peak current enhancement is expected by the IFEL micr-bunching.

3**. High-brightness electron beam R&D**: The importance of electron beam quality becomes increasing critical as the FEL going shorter wavelength. The gain length measurement is one of the most powerful tools to determine the 6-D quality of the electron beam. The upgraded DUV-FEL facility will continue the BNL tradition in high-brightness electron beam R&D. The proposed experimental program will cover from electron beam generation, compression to the preservation. An BNL/LCLS/SPAC collaboration is established to study the longitudinal laser pulse shaping on the transverse emittance. The experiment will take advantage of the broad bandwidth of the DUV-FEL laser system. We will also to carry out the feasibility studies of generating the femto-second kilo-Ampere electron beam using the longitudinal emittance compensation technique[8].

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