A SYNCHRONIZED FIR/VUV LIGHT SOURCE AT JEFFERSON LAB *

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Abstract

We describe a dual free-electron laser (FEL) configuration on the UV Demo FEL at Jefferson Lab that allows simultaneous lasing at FIR/THz and UV wavelengths. The FIR/THz source would be an FEL oscillator with a short wiggler providing nearly diffraction-limited pulses with pulse energy exceeding 50 microJoules. The FIR source would use the exhaust beam from a UVFEL. The coherent harmonics in the VUV from the UVFEL are outcoupled through a hole. The FIR source uses a shorter resonator with either hole or edge coupling to provide very high power FIR pulses. Simulations indicate excellent spectral brightness in the FIR region with over 100 W/cm^{-1} output.

INTRODUCTION

Though subpicosecond lasers are routinely used in research, many experiments require the use of two synchronized lasers with very different wavelengths. As an example, one might pump a sample with a Ti:sapphire laser and then probe with an X-ray FEL. We propose here to use a far infrared (FIR) to THz laser synchronized to an ultraviolet/vacuum ultraviolet (UV/VUV) oscillator in order to allow experiments to be carried out in which a sample is pumped in the UV or VUV wavelength range and then probed by far-infrared to THz wave radiation after a known delay. In this case the longer wavelength is sufficiently powerful to be the pump as well.

DESCRIPTION OF THE FEL FACILITY

Over the last 20 years we have developed the concept of a UV FEL device operating in the wavelength range from 230-400 nm [1]. A drawing of this device is shown in figure 1. The accelerator uses the same injector and linear accelerator as the IR Upgrade FEL [2]. During UV operation the injector is operated at lower charge (60 pC) to provide a geometric emittance less than the laser wavelength divided by 4π. Operation at a higher charge is certainly possible but requires a different injector setup and is less efficient due to the larger emittance.

The UV Demo FEL first lased in the fall of 2010 and showed extremely good performance at 400 nm. Both the gain and efficiency exceeded the values predicted by simulations. This is probably due to non-Gaussian distributions providing higher peak brightness than the projected distributions indicated. This was accomplished with a 60 period undulator lent by Cornell University. In the past year this device was replaced with a 64 period undulator on loan from Argonne National Laboratory. Initial lasing was achieved using a 325 kV gun voltage in the photocathode injector. The accelerator is now operating with a 350 kV gun voltage, which provides a brighter electron beam.

Free-electron lasers naturally emit coherent radiation at the odd harmonics of the resonant wavelength. When the FEL is operated at 3 eV, for example, there is light emitted at 9 eV and 15 eV. At these photon energies there are very few transparent materials, so the best way to take advantage of these VUV harmonics is to lase with an output coupler in which a hole is drilled. The third harmonic radiation is then transmitted through the hole and transported using reflective optics to a user station. The output coupling can be varied in this setup by changing the radius of curvature of the upstream mirror. This has already been demonstrated on the UV Demo laser at 10 eV.

Far Infrared/Terahertz Laser Layout

One interesting experiment that users have expressed an interest in carrying out requires pulses at 10 eV and 0.040 eV. We have based out initial design on these photon energies. The UV FEL would be operated at 372 nm and the outcoupled third harmonic would be at 124 nm (10 eV). The FIR wiggler would be tuned to operate at 31 microns (40 meV). Downstream of the UV and IR FELs there are debunching chicanes used to increase the bunch length and thus increase the distance between the first dipole magnet after the FEL and the downstream resonator optic. This keeps the intensity of coherent synchrotron radiation on the resonator optic low. In the new configuration we intend to modify these chicane magnets so that the electron beam travels along a zigzag path and the dispersion in the middle of the chicane insertion is small. The inner dipoles would be run slightly stronger than the outer dipoles to achieve this orbit. The basic layout is sketched in figure 2.

To simplify the construction of the THz FEL we would like to modify the electron beam transport as little as possible. One possible design then would be to have two mirrors with holes in them that allow the electron beam to continue in a straight line after the UV FEL. It turns out that this is not a reasonable design due to the rather large cavity losses one would have in such a resonator. A chicane would be good except that this device would be expected to work even when the UV FEL is lasing, and the beam would get very large in the direction of the dispersion. We do not have enough space to put in an achromatic transport in a chicane. We therefore chose a “zigzag” architecture so that the dispersion averages out to

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zero in the wiggler and the dispersion is small throughout the wiggler insertion (<3 cm).

The angle of the wiggler with respect to the UV beam path is only 25 mrad. This offsets the mirrors of an 8 meter resonator by 10 cm, which is just sufficient for clearance of a 10 cm diameter resonator mirror. The vacuum chamber for the wiggler is approximately 3 meters long so the separation between the UV mode and the electron beam is 38 mm at either end of the vacuum chamber.

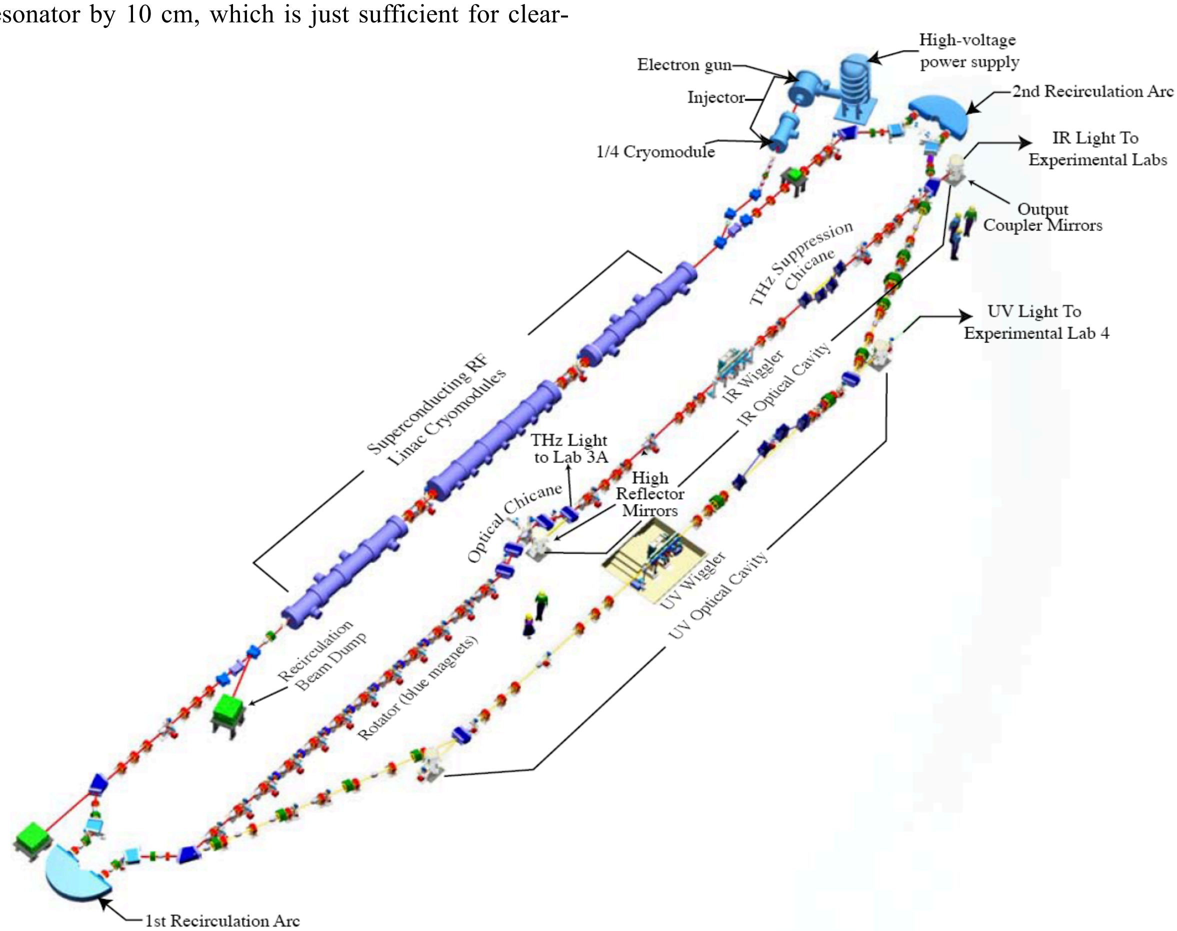

Figure 1: Layout of the IR/UV FEL facility at Jefferson Lab. The injector and linac feeds both FELs. The corner magnets can be set to half strength or full strength to send the electron beam into one FEL or the other. Both FELs have 32 meter long optical resonators and permanent magnet variable-gap wigglers. Both can have THZ suppression chicanes installed after the FELs. The FIR/THz laser would go in place of the THz chicane on the UV FEL.

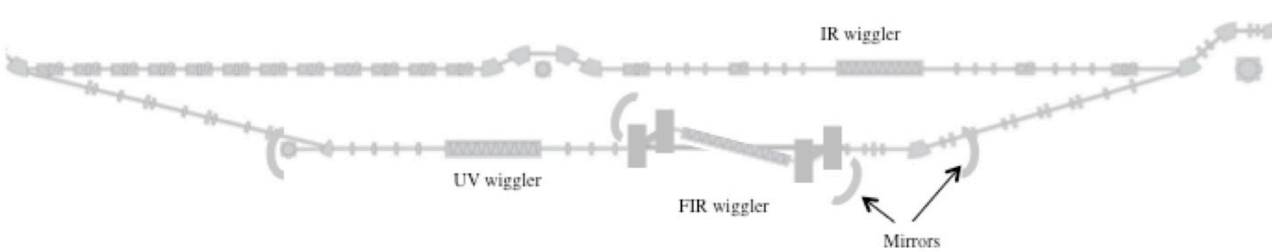

Figure 2: Proposed layout for the THz/FIR FEL downstream of the UV wiggler. Note that the angles in the zigzag are greatly exaggerated and that the actual bend angle would be vertical.

SIMULATIONS

The parameters for the electron beam, optical resonator and wiggler are given in table 1. The output coupling could be either hole coupling or edge coupling. Unlike a shorter wavelength device, the gain is increasing with decreasing wavelength so a hole-coupling scheme is better matched to the wavelength variation. Decreasing the wavelength increases both the gain and the output coupling. The resonator at 31 microns is an open resonator with very small diffractive losses. At longer wavelengths, one might have to go to a waveguided resonator to better confine the mode.

The laser was simulated using a one-dimensional FEL code for two different energy spreads. The first was for when the UV laser is not lasing. This is useful for getting the FIR FEL to lase and optimizing the lasing. Once the FIR FEL is optimized, the UV FEL can be turned on and the *rms* energy spread should increase to 0.9%.

Table 1: FIR-FEL Wiggler, Resonator and Electron Beam Parameters

Parameter	Value
Electron energy	135 MeV
Bunch charge	135 pC
Bunch length (*rms*)	0.18 psec
Peak current	300 A
Repetition rate	18.7125 MHz
Energy spread (UV not lasing)	0.5%
Energy spread (UV lasing)	0.9%
Emittance	8 mm-mrad
Wiggler wavelength	20 cm
Number of periods	12
Peak wiggler field	3.5 kG
Rayleigh range	108 cm
Losses	3%
Output coupling	1%
Laser wavelength	31 µm

Assumptions of the Simulation

The simulation is based on the one-dimensional slowly varying envelope approximation equations. Though Haselhof has shown that these are not as bad an approximation as one might think [3], the wavelength here is only one sixth of the *rms* electron bunch length. Thus, the SVEA approximation is not necessarily accurate. The simulation also assumes that the pulse is Gaussian in time and this is almost never true for a linac-based accelerator. Future work will explore the applicability of the SVEA by using a new code developed by Brian McNeil [4]. This code does not make any slowly varying envelope approximation. The other task is to use start-to-end simulations to derive a more realistic longitudinal profile than a simple Gaussian. We already know that the beam has some coherence in the wavelength range of 7 to 13 microns. We expect that there will be significant structure at 31 microns. This must be taken into account in any simulation. The simulation results are weakly dependent on the transverse emittance and the energy spread.

Most users are interested in narrow spectral bandwidth and will therefore want to operate on the shorter side of the cavity length detuning curve. With the UV laser on and the cavity length set to 3 microns from the synchronous length, the spectrum is 2.4% or 8 cm^{-1} FWHM. This is very usable for experiments. Even halfway out on the detuning curve the power is close to 1 kW, so the spectral brightness is over 100 W/cm^{-1}. The pulse energy is over 50 µJ in a 1 psec pulse, which is sufficient to pump many systems. The exhaust energy spread is over 9% full width, which is close to the energy acceptance of the energy recovery arc. It may not be possible to operate with CW beam at the peak of the detuning curve due to the large energy spread. Operation with the UVFEL off will also be limited to shorter cavity lengths.

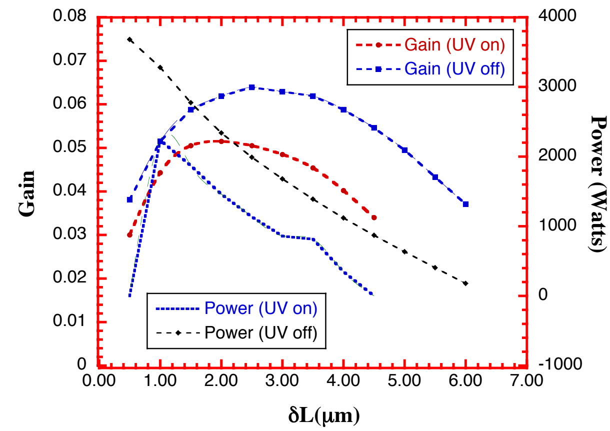

Figure 3: Gain and power vs. cavity length for the parameters in table 1. The energy spread increases when the UV is on, reducing both the gain and power. The energy spread was assumed to be 0.5% rms or 0.9% rms for non-lasing and lasing respectively.

The gain margin is small in this setup. One can make up for this a little bit by increasing the charge. The gain is linealry proportional to the charge and does not grow much more slowly than linear with charge despite the increase in the emittance and energy spread.

CONCLUSIONS

A dual wavelength simultaneous source of VUV and far infrared pulses with subpicosecond pulse lengths appears to be quite feasible. Future work will look at the effects of microstructure on the beam and longer wavelength designs.

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