Status of the Jefferson Lab IR/UV High Average Power Light Source*

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Abstract

Jefferson Lab is in the process of building an upgrade to our Free-Electron Laser Facility with broad wavelength range and timing flexibility. The facility will have two cw free-electron lasers, one in the infrared operating from 1 to 14 microns and one in the UV/VIS operating from 0.25 to 1 micron [1]. In addition, there will be beamlines for Thompson-backscattered femtosecond X-rays, and broadband THz radiation. The average power levels for each of these devices will exceed any other available sources by at least 2 orders of magnitude. Timing of the available laser pulses can be continuously mode-locked at least 4 different (MHz) repetition rates or in macropulse mode with pulses of a few microseconds in duration with a repetition rate of many kHz. The status of the construction of this facility and a review of its capabilities will be presented.

1. DESIGN

The Jefferson Lab IR Upgrade FEL[2] is an evolutionary derivative of the JLab IR Demo FEL[3]. It thus retains the approach used in the earlier machine – that of a low peak, high average power wiggler-driven optical cavity resonator with an energy recovering SRF linear accelerator driver operating at high repetition rate. The 10 kW design goal will be achieved via an increase in both drive beam power (doubled current and quadrupled energy) and FEL extraction efficiency (from 0.5% to 1%). Primary electron beam specifications for the IR Demo and Upgrade are listed in Table 1.

Table 1: IR Demo and Upgrade Parameters

Parameters	Demo	Demo Achieved (11/2001)	Upgrade
energy (MeV)	35-48	20-48	80-210
I_{ave} (mA)	5	5	10
FEL rep. rate (MHz)	18.75-75	18.75-75	3.9-125
Q_{bunch} (pC)	60	135 @ 37.5 MHz	135 @ 75 MHz
bunch σ_l (psec)	0.4	0.4 @ 60 pC	0.2 @ 135 pC
I_{peak} (A)	60	60 @ 60 pC	270 @ 135 pC
$\sigma_{\delta p/p}$ (%)	0.5%	0.25% @60 pC	0.5%
ε_N (mm-mrad)	<13	5-10 @60 pC 25 @135 pC	<30
η_{FEL}	0.5%	>1.4%	1%
ΔE_{full} after FEL	5%	6-8%	10%

Figure 1 illustrates the machine design. It comprises a 10 MeV injector, a linac consisting of three Jefferson Lab

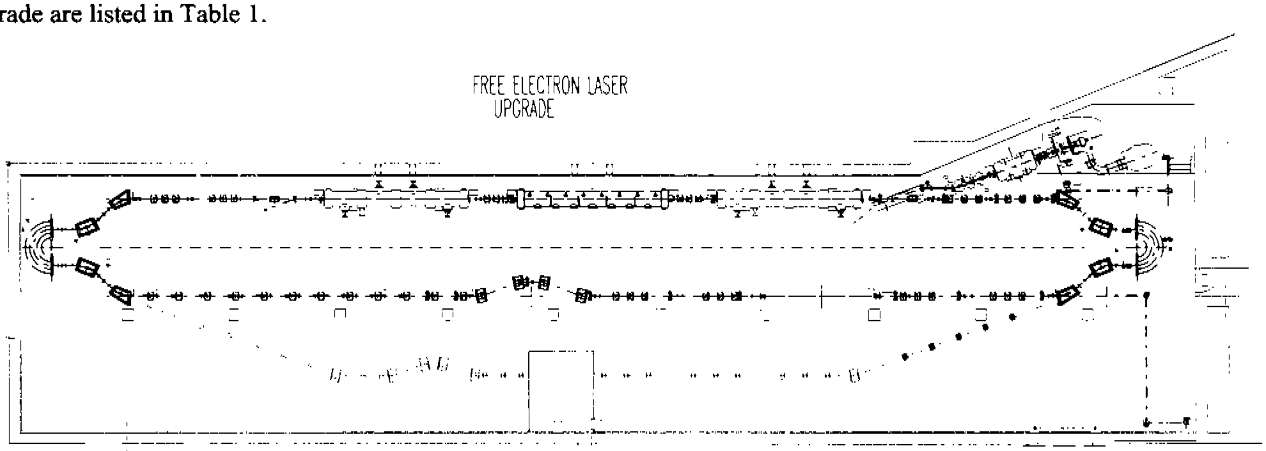

Figure 1. Layout of the IR/UV Upgrade. The electron beam is accelerated in two SRF cavities and injected into a 3-cryomodule accelerator. The beam is turned 180 degrees in a Bates style bend and matched into one of two wigglers (IR or UV) across a buncher chicane. The exhaust beam is turned 180 degrees and reinjected into the accelerator shifted by 180 degrees in RF phase with respect to the accelerated beam. Weak chicanes merge the injected and energy recovered beams and separate the accelerated and decelerated beams.

cryomodules generating 80 to 210 MeV of energy gain, and a recirculator. The latter provides beam transport to, and phase space conditioning of, the accelerated electron beam for the FEL and then returns and prepares the drive beam for energy recovery in the linac.

The injector is a direct upgrade of the IR Demo injector [4] from 5 mA at 10 MeV to 10 mA at 10 MeV. The current will be doubled by an increase of the single bunch charge from 67 pC to 135 pC while maintaining the 75 MHz repetition rate. Adequate injector performance has already been demonstrated at the elevated bunch charge. Improvements in the standoff capability of the photocathode may allow even brighter source performance.

The linac comprises three cryomodules; the first and third incorporate conventional five-cell CEBAF cavity designs, and the central module is based on new seven-cell JLAB cavities [5]. The beam is accelerated (energy recovered) off crest (off trough) so as to impose a phase energy correlation on the longitudinal phase space used in subsequent transport to longitudinally match the beam to the required phase space at the wiggler (dump).

The energy recovery transport consists of a second Bates-style endloop followed by a six quad telescope[6]. The beam is matched to the arc by the second telescope of the FEL insertion; the energy recovery telescope matches beam envelopes from the arc to the linac acceptance. Because energy recovery occurs off-trough, the imposed phase-energy correlations are selected to generate energy compression during energy recovery, yielding a long, low momentum spread bunch at the dump. Simulations indicate that the Upgrade will tolerate an energy spread of 15% – compressing it to a final spread of order ±1% – despite the larger ratio of final to initial energy.

To provide flexibility and allow operation over a range of IR wavelengths, an optical klystron was chosen with two wigglers of 12 periods separated by a dispersion section with 40 periods of path-length delay at the highest wiggler strength. The wiggler period is 20 cm and the maximum rms K^2 is 16.

The optical resonator is similar to the one used in the IR Demo FEL. To accommodate a longer wiggler, the resonator length has been increased to 32 m. Changes in waist size with mirror heating will be eliminated by using a deformable high reflector. Calculated gain and power are shown in Figures 2 and 3 for operation of the optical klystron as a 25 period wiggler. Both power and gain are very weakly dependent on the emittance and energy spread.

A collision point between the photons and the subsequent electron pulse is located in the middle of optical cavity so copious production of femtosecond X-rays will result from Thompson scattering. In addition, the short electron pulses will generate substantial power in the THz region in each bend. A port to outcouple that radiation has been included before the wiggler.

Installation of the infrared machine has been proceeding since the shutdown of the IR Demo in November 2001. Completion of the installation is expected in October 2002 with commissioning to follow. The UV portion of the machine will follow the IR by about one year.

ACKNOWLEDGMENTS

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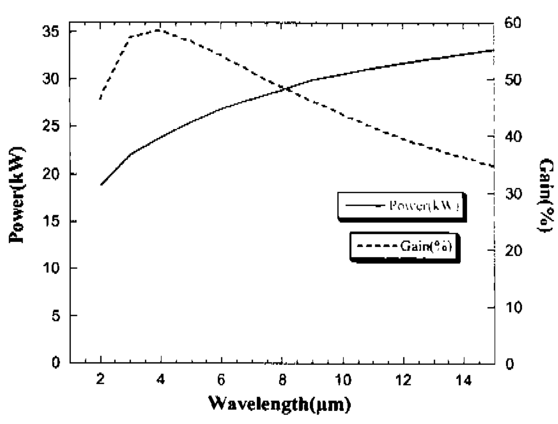

Figure 2: Gain and Power calculated for the IR Upgrade when the optical klystron is operated with minimum dispersion.

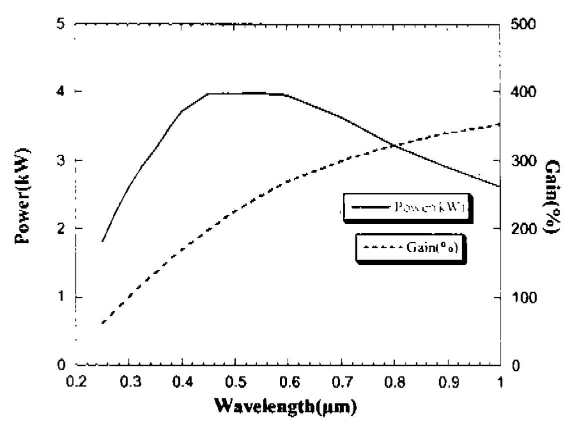

Figure 3: Gain and Power calculated for the UV Upgrade.