USE OF THE CEBAF ACCELERATOR FOR IR AND UV FREE ELECTRON LASERS*

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Abstract

The CEBAF superconducting linac is capable of accelerating electron beams suitable for driving high-power free-electron lasers. The 45 MeV injector linac with a 6 cm period wiggler can produce kilowatt output powers of infrared light (3.6–17 μm), while the 400 MeV north linac can produce ultraviolet light ($\sim$ 200 nm) at similar powers. The FELs require the addition of a high-peak intensity electron source ($\sim$ 60 A peak current) and extraction beam lines to wigglers with appropriate electron and photon optics. FEL operation is compatible with simultaneous baseline CEBAF nuclear physics operation. A design for a CEBAF-based FEL facility has been developed. The current status of the FEL project is reported.

Introduction

The CEBAF 4 GeV electron accelerator complex is proceeding expeditiously toward completion of construction. The accelerator [1] will include a 45 MeV injector linac (already operational) and two 400 MeV linacs (one nearly complete) connected by recirculation arcs to obtain 4 GeV in five recirculations. The linacs will be the highest-energy, highest-intensity superconducting radio-frequency (SRF) linacs and will provide unique opportunities for exploring possible SRF applications.

In particular, SRF linacs may provide superior performance as free-electron laser (FEL) drivers. With small additions to the CEBAF facility, the 45 MeV injector can drive an infrared (IR) FEL and the 400 MeV North linac could drive an ultraviolet (UV) FEL. The FELs could operate simultaneously with baseline CEBAF nuclear physics beam, without interference, and provide kilowatts of FEL light, which could be provided to an industrial user facility. In this paper, we describe the proposed CEBAF FELs, discuss their required additions, and outline current and future FEL activities.

Description of the CEBAF FELs

We are proposing the addition of an IR and an UV FEL to CEBAF. The additions are described in [2,3] and updated parameter lists for both FELs are shown in Table 1.

Both FELs require the addition of a high-peak current source (120 pC, 2 ps long bunches at 7.485 or 2.495 MHz) [4,5,6]. We propose to insert a new high-current photoemission source in parallel to the existing NP source (0.13 pC at 1.5 GHz). The added source–which includes a photocathode gun, prebuncher and an ~10 MeV quarter-cryomodule–will produce beam which can be combined in a chicane with the NP beam for simultaneous acceleration through the injector. The NP and FEL beams are independently phased to permit tunable energy difference.

The IR FEL is driven by 50 MeV FEL bunches from the CEBAF injector. At the end of the injector linac cryomodules, the FEL bunches are separated from the NP beam in an energy separation chicane and diverted into a separate transport through the IR wiggler, which is centered in a 20.026 m optical cavity in the injector tunnel. The electromagnetic wiggler will be tunable and the IR FEL will be able to provide 3.6 to 17 μm light at kW power levels. Third-harmonic operation of the IR FEL is also possible, and will enable kilowatt power levels at wavelengths down to 1.2 μm.

For UV FEL operation both NP and FEL beams proceed through the injector and north linacs. The FEL and NP beams will be separately phased so that the FEL beam will be at 400 MeV at the end of the north linac while the lowest-energy NP beam is at 445 MeV. Energy separation in the north spreader magnet diverts the FEL beam into a transport channel, which carries the FEL beam into the UV wiggler, which is centered in a 60 m optical cavity at the end of the north linac tunnel. Tunable UV light ($\sim$ 150–300 nm) at kW levels is obtained.

The beam transports for both FELs are detailed in [3,7]. The basic components for both FELs (beam transport, wigglers and optical elements) will be placed in available space in the CEBAF tunnel, displaced from the NP beam line. The light output from both FELs can be transmitted to ground level and routed to a proposed FEL user laboratory. Figure 1 shows a schematic view of the CEBAF accelerator with the FEL facilities. Locations of the IR FEL, UV FEL and FEL user laboratory are indicated. Figure 2 shows expected light output power as a function of wavelength for the combined IR and UV FEL facility.

FEL Constraints and Features

The FELs are specifically designed for concurrent non-interfering operation with NP operation. Various beam interference effects, rf power and control constraints, wakefield effects and beam transport issues have been studied to insure compatibility [8]. Dedicated FEL operation, during interruptions in NP operation, will also be possible.

The wiggler design for both FELs is a conventional electromagnetic one. Wiggler construction in 1.5 m modules is planned so that modules can be combined for longer wigglers and adapted for optical klystron operation. The optical system for the IR FEL would be a near-concentric cavity. For the high-power UV FEL, a ring-resonator is

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planned; also reflectivity at short wavelengths ($\lambda < 200$ nm) may be difficult, and require specialized solutions.

Simulations by W. B. Colson and collaborators have confirmed that the CEBAF FEL parameters will produce high gain and high power [9,10,11]. The simulations also confirm the value of the flexibility inherent in the modular EM wigglers.

Recent Progress and Current Status

The Front End Test for the CEBAF injector has been completed [1]. It demonstrated that the injector can reliably accelerate high-intensity beam to full energy (45 MeV), while maintaining small emittance, short bunch-length, and small momentum spread. The results confirm that the injector meets its necessary design goals for NP operation, and that the injector could be extended to FEL use. A further commissioning test incorporating most of the north linac (up to 285 MeV) has been initiated.

A detailed design for the FEL front-end has been developed. The design includes the combination chicane for the FEL and NP injectors, and PARMELA simulations show adequate pulse formation with combination for both beams [6].

A design for the FEL facility has been produced [3], which includes the front-end, beam transport design, and FEL performance simulations. The design was developed with guidance from the CEBAF Industrial Advisory Board (IAB). The IAB is composed of representative users from industrial partners, who insure that the resulting FELs will produce light of importance to industrial research and development, and who will contribute to the formation of the FEL user laboratory.

Development of this hardware is proceeding at a pace consistent with CEBAF's prime mission and the availability of funds. Research and development for the high-peak intensity source has been initiated, to be followed by wiggler and optical cavity development when resources are available. A FEL user facility has been designed for industrial research and technology development, and industrial partners have offered \$9M in in-kind contribution to support technology development at this facility. The Commonwealth of Virginia has also pledged \$5M in matching funds. A proposal to DOE is pending.

Future Directions

Successful development of the CEBAF FELs will serve as the basis for the further use of SRF in high-intensity light sources. At CEBAF, beam from the complete linac (800 MeV or higher energy) could be used to drive an x ray FEL. The CEBAF experience will also be used as a basis for the design and construction of dedicated SRF FEL facilities for laboratory or industrial applications.

References

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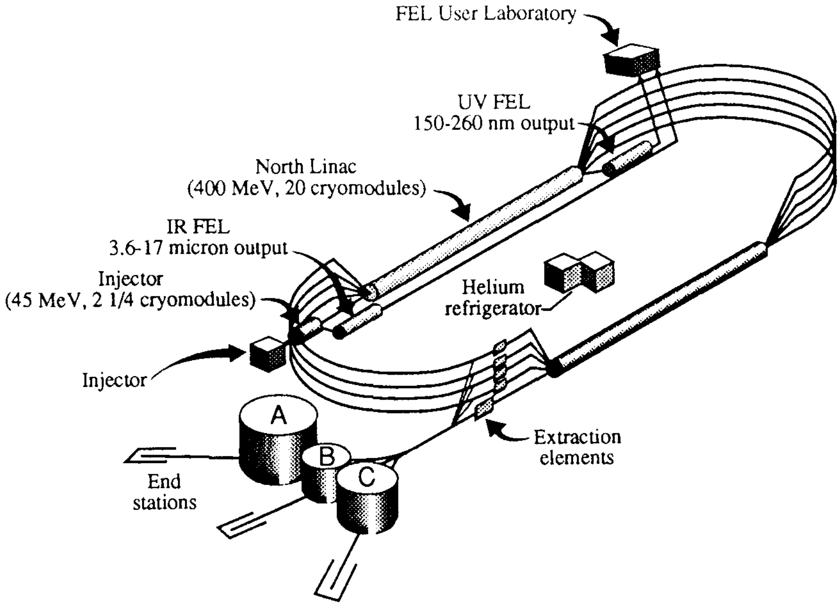

Figure 1 Proposed IR and UV free electron lasers and user laboratory at CEBAF.

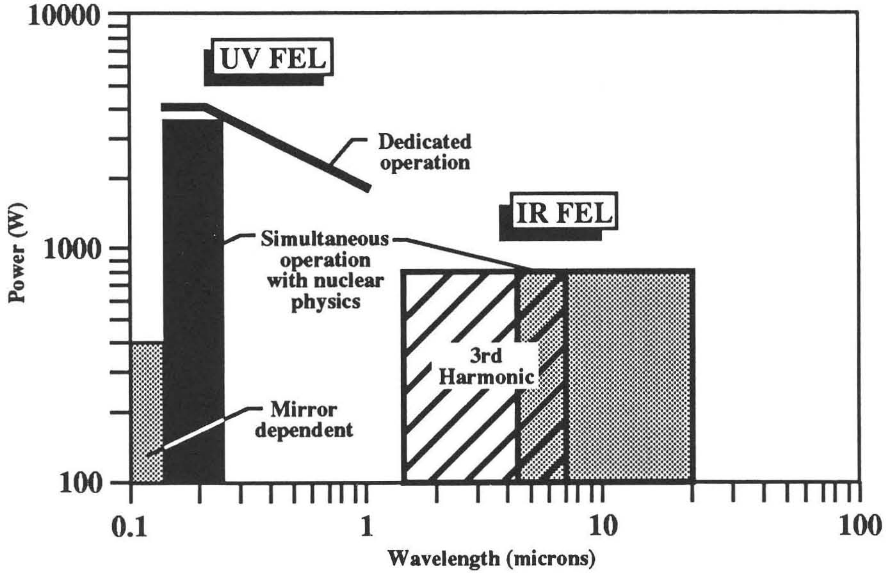

Figure 2 CEBAF FEL power output vs. wavelength.

Table 1
CEBAF FEL Specifications

	IR	UV
Electron kinetic energy (E)	50 MeV	400 MeV
Pulse repetition frequency	7.485 MHz	2.495 or 7.485 MHz
Charge/bunch (Q)	120 pC	120 pC
Momentum spread (σ_p/p)	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$
Bunch length (τ) (4σ)	2 ps	1 ps$^{a)}$
Peak current (I_p)	60 A	120 A$^{a)}$
Normalized emittance (ϵ_n)$^{b)}$	15 mm-mrad	15 mm-mrad
Wiggler length (L)	1.5 m	2·1.5 m to 4·1.5 m
Wiggler wavelength (λ_W)	6 cm	6 cm
Number of periods (N_W)	25	50 to 100
Type	electromagnetic	electromagnetic
$K_{\rm rms}$ (maximum)	2.14	2.14
$K_{\rm rms}$ (nominal)	1.75	1.76
Maximum field ($B_{\rm max}$)	0.54 T	0.54 T
Gap ($2h$)	10 mm	10 mm
Rayleigh length (R_L)	0.75 m	1.5 m to 3.0 m
Optical mode waist (ω_0)	1.7 mm @ 12.5 μm	0.31 mm @ 200 nm
Optical cavity length ($L_{\rm cav}$)	20.026 m	60.078 m
Output wavelength range (λ)	3.6–17 μm	100–260 nm
Extended λ range (with dedicated use or third harmonic)	1.2–25 μm	100–1860 nm
Peak power $^{c)}$	60 MW	480 MW
Average power $^{c)}$	0.9 kW	1.2 or 3.6 kW

a) With magnetic bunch compression to 1 ps; without compression $\tau = 2$ps, $I_p = 60$ A

b) $\sigma_x = \sqrt{\beta_x \epsilon_n / \gamma}$

c) Assumes nominal 1/2 N_W efficiency