Design and Construction of a Compact Infra Red Free Electron Laser CIRFEL

J. KRISHNASWAMY, I.S. LEHRMAN, J. SHEEHAN, R.L. HEUER, M.F. REUSCH, and R. HARTLEY
Grumman Aerospace Corporation
4 Independence Way
Princeton, N. J. 08540-6620

Abstract

The 5-15 micron Grumman Compact Infra Red Free Electron Laser CIRFEL which will produce extremely short pulses of tunable radiation under construction is described. Electron pulses are produced at a repetition rate of up to 10 Hz by the illumination of a single crystal <001> LaB6 photo cathode with a photon injector, a 6-10 psec, 349 nm (frequency tripled Nd-YLF) laser mode locked to the 20th subharmonic of 2856 MHz. Photoelectrons are further accelerated and guided to the superconducting microwiggler by a robust beam transport system through an achromatic bend. The ~ 10 MeV electrons interact with the optical radiation inside of a near symmetric laser cavity. The FEL output will be coupled out through a hole in one of the cavity mirrors. The CIRFEL system is expected to be delivered in 1994.

I. INTRODUCTION

The compact IR Free Electron Laser under construction by Grumman will be assembled at the Princeton University's Physics Department under a Joint Research Agreement and will serve as a platform for advanced research in Physics and Engineering. The facility will be used initially by groups working in the area of multi-photon dissociation for pollution control and biophysics. The CIRFEL system is described, summarizing the progress made with each system component.

II. SYSTEM DESCRIPTION

The CIRFEL system comprises of the following system components, (1) High brightness photocathode electron gun, (2) Photo-injector laser, (3) 30 MW S-Band RF source, (4) the beam transport system, (5) the FEL microwiggler, (6) the FEL optical cavity, and (7) associated support hardware sub-systems. Figure 1 shows the layout of the CIRFEL which occupies two levels with the photoinjector and the high power RF system on one level, and the rest of the system on the ground floor.

A. High Brightness Photocathode Electron Gun

The high brightness photocathode gun designed for CIRFEL is an extremely bright source of electron beams and is specified by the parameters shown in Table 1. The Photoelectron source comprises of a 6 mm diameter LaB6 cathode illuminated by a photon injector and is situated in a 3.5 cell, Pi mode RF cavity, which produces a very high gradient (60 to 80 MeV/meter) on its surface. The "electrodeless emission" of electrons is controlled by the laser and allows extremely smooth control of the spatial and temporal profiles, and the electron current. The cathode is also heated from the rear to a temperature below the thermionic emission level so as to present an extremely clean surface to obtain a high degree of repeatability with the lowest possible emittance. A cold model of the gun cavity has been tested and the the final version of the gun is being fabricated.

Table 1
Electron Beam Specifications

Beam Energy	< 7 - 13 MeV
Total Charge	1 - 2 nC
Pulse Width(FWHM)	5 - 7 psec
Normalized Emittance	< 6 Π mm-mrad
Slice Emittance	~ 1 - 3 Π mm-mrad
Peak Current	> 150 A
Energy Spread	0.2 - 1.5% Selectable

B. Photoinjector Laser

In order to optimize the efficiency of photo-emission and to have control over the characteristics of the emitted electrons, a photo injector laser which meets exacting specifications and repeatable performance is required. The electron gun is in the process of being fabricated. The photo-injector consists of an oscillator, an isolator, a pulse slicer and two stages of amplification. A schematic of the photon seed laser system is shown in Figure 2. The mode locked, diode pumped oscillator operates in the TEM00 mode with 1% energy stability and less than 1psec RMS phase jitter over 10-20,000 Hz. The >200 mW output from this laser is produced at a frequency of 142.8 MHz and single pulse pulse widths of 10 psec or less at 1047 nm. The oscillator feeds into the ampfliers separated by a passive Faraday isoator. Before being fed into the amplifiers the light pulses go through a pulse slicer which will select a variable range of 200 to 1400 pulses for amplification. The two stage amplifier system amplifies the 10 Hz pulse train to >0.13mJ per pulse at 1047 nm after 5 passes. The beam will then be down collimated and frequency tripled for an expected 20 microjoules in 5 - 7 psecs at 349 nm. The near collimated beam produced by this system is transported to the CIRFEL system at ground level by turning and steering mirros with reflectivities optimized for 45 degree incidence and p-polarization. The beam is then expanded in a telescope and then focussed with a long focal length refractive optics

0-7803-1203-1/93$03.00 © 1993 IEEE

followed by a half wave plate so as to optimize incidence angle of the polarized light on the cathode. Optical elements to correct the unequal pathlengths reaching the cathode illuminated at shallow angle to the normal at the cathode surface are being studied.

The oscillator has been completed and has met all the specifications for being integrated into the amplifier, frequency multiplier system. The beam delivery optics from the photo-injector to the cathode has been worked out except for the details of the optical element to correct path length.

C 30 MW S-Band RF source

The RF power feed to the gun and booster cavitties is based on a ITT 2960 Klystron. Variable attenuation and variable phase features are incorporated into the design. The RF source is presently under construction. The master oscillator has been fabricated and tested.

D. The Beam Transport System

The beam transport system is shown in Figure 1. A zero current achromat is designed for the chosen achromat bend radius. A beam size is chosen at the entrance of achromat and with TRACE 3D the beam is symmetrized so that it has an alpha=0 at the center. Enough drift spaces are left on either side of the magnets for their corners. The bends are not sectors and the entrance angle is 22.5 degrees. The source beam is guided into the achromat via telescope, a pair of lenses and drift spaces and the post achromat focussing system guides the beam to the wiggler. The system is still in the process of being refined to take into consideration the conditions at the slit and tune the system for space charge effects. The system design has been confirmed with PARMELA. The quadrupoles and the steering magnets have been acquired and the dipoles are being fabricated. Automation of the magnetic measurements and preliminary measurements on the quadrupoles have been completed.

E. The Microwiggler

Initial experiments will be carried out with a permanent magnet wiggler. The mechanical design has taken into consideration the incorporation of a superconducting wiggler in the final design whose parameters are as shown in Table 2. An alternative pulsed microwiggler with normal conductors is also under investigation.

F. The FEL Optical Cavity

The preliminary design under study consists of a near concentric, near symmetric stable cavity, a choice near universal in FEL optical cavities. This design superposes the optical field on the electron beam as effectively as possible for as large a distance along the electron trajectory in the wiggler. The cavity will consist of totally reflecting mirrors which can be used over a wide wavelength range, especially in the 5 to 12 micron range. The method of coupling light will be by a intercavity Brewester plate or a hole coupling through one of the mirrors. A preliminary set of optical elements, and optical parameters have been determined using the lowest order Gaussian optical mode. The FEL wiggler cavity vacuum is sealed using ZnSe windows set at Brewster angle for the initial working wavelength.

Table 2
FEL Microundulator

Undulator Period	7 - 8 mm
Number of Periods	50 (tapering possible)
Yoke Material	1066 Iron
Conductor	Superconducting Wire or Copper Sheet
Peak Field	4 kGauss
Field Error	~ 0.3 % RMS
Number of Passes to saturation	~ 30
Energy extraction	1% (untapered)

G. Support Sub-systems

The support subsystems comprises of (1) The vacuum system, (2)The power supply for magnet control, (3) the master control system, (4) the photo injector laser and electron beam diagnostic system, (5) the cryogenic system, and (6) the FEL optical cavity control hardware/software system. The CIRFEL control system software is written using National Instruments' LabView software package, running on a MacIntosh Quadra 950 with a GPIB (IEEE-488) interface card and a GPIB bus extender. The design is still in very preliminary stages. In the normal mode of operation, the software checks the operator input for any changes to settings for power supplies or other devices. If such changes are detected, the appropriate device is reset. The devices are cycled through the control strategy and after each control cycle the output levels are read for all devices and the display updated. If appropriate, the level of each is checked against its setting and a tolerance specification and a warning is issued if necessary. All devices will be controlled through the operator console via the virtual representation of the system .

III. CONCLUSIONS

The CIRFEL when it becomes operational will provide Fourier transform limited pulses in the TEM00 mode, infra red radiation with the characteristics shown in Table 3.

IV. ACKNOWLEDGMENT

This work is supported by the Grumman Aerospace Corporation.

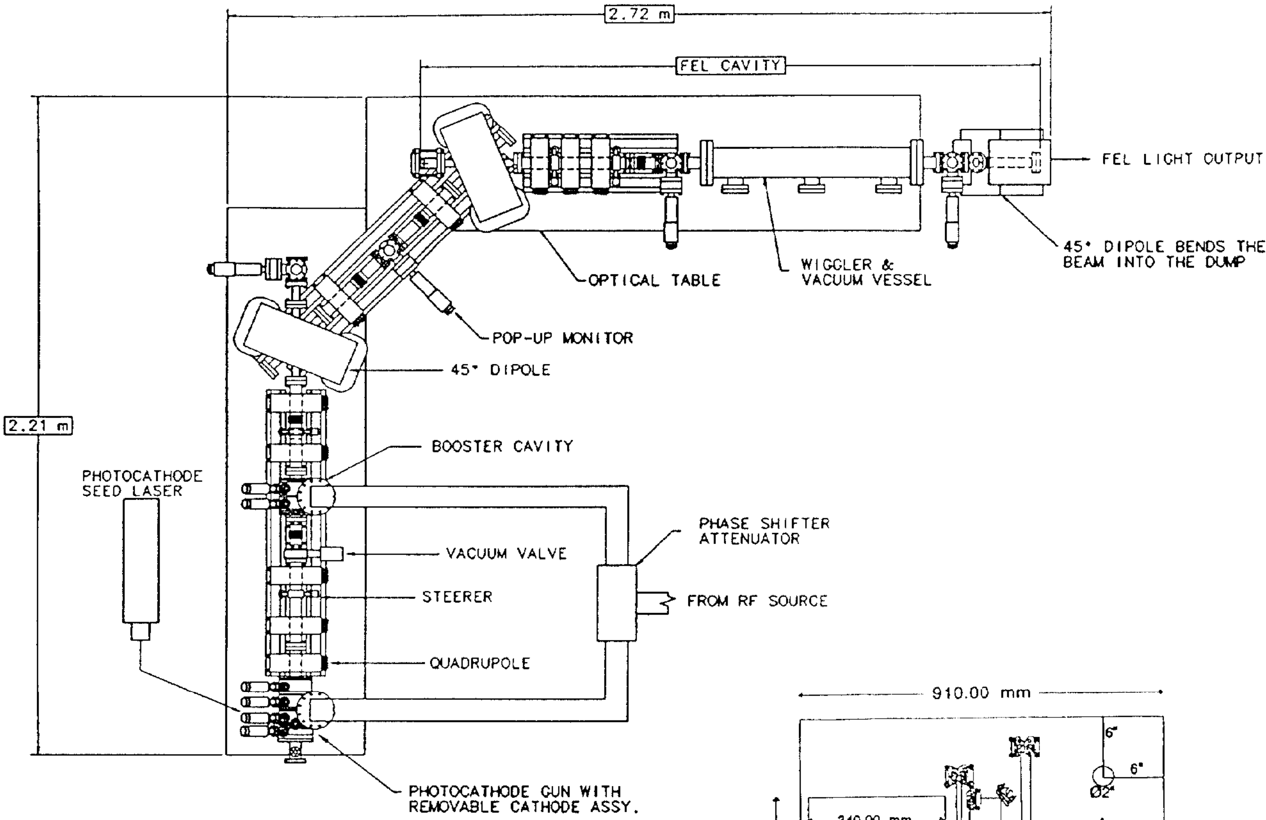

Figure 1. CIRFEL System Layout

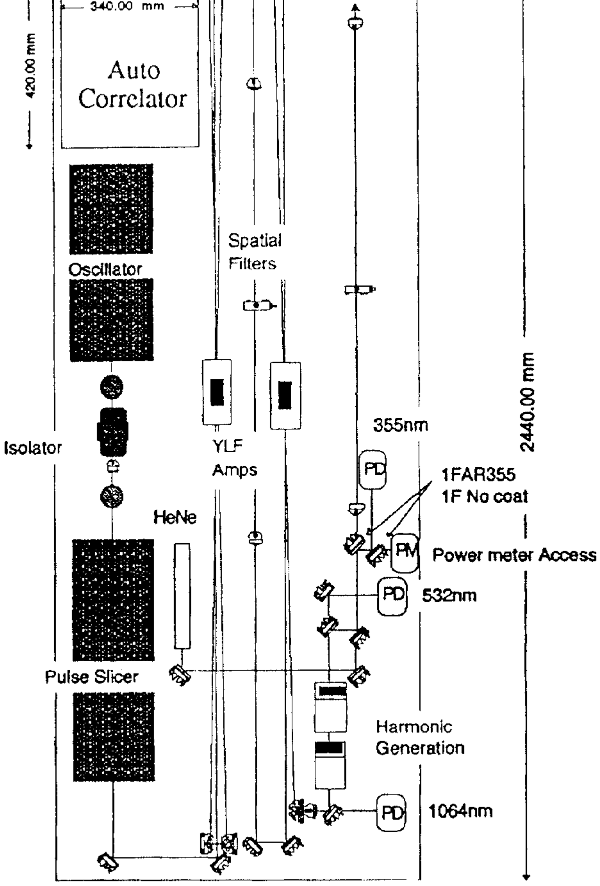

Figure 2. Photocathode Drive Laser

Table 3
FEL Laser Pulse *Specifications

Radiation Wavelength	5.3 - 14 μ m
Pulse Width (FWHM)	5 - 10 psec
Energy / pulse	> 100 μJ
Pulse Separation	7 nsec
Peak Field	4 kGauss
Pulses / macropulse	200 - 1400
Repetition Rate	1 - 10 Hz
Maximum Average Power	` 1.5 W

* Fourier transform limited pulses in TEM 00 mode