FIRST LASINGS AT VISIBLE AND IR RANGE OF LINAC-BASED FELs AT THE FELI

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SUMMARY

First lasings at 5.5μm and 1.88μm have been achieved in October 1994 and February 1995 at the FELI using two undulators installed at 30-MeV and 80-MeV undulator beam lines of the FELI S-band linac. Lasing on the third harmonics at 0.64μm has been also observed. A thermionic triode gun of the linac emits 500ps pulses of 2.3A at 23.125MHz. These pulses are compressed with a 714-MHz prebuncher, a 2856-MHz standing wave type buncher, and 3-m long accelerating waveguides to 42A x 10ps. The 24-μs stable RF pulses can increase a conversion efficiency from electron beam power to FEL power at short wavelength FELs. At 5.5μm, 1.88μm and 0.63μm, FEL peak power are 3MW, 2MW and 0.3MW, and FEL spectral widths are 0.5%, 0.3% and 0.3%, respectively.

INTRODUCTION

In the past decade, advances in photoinjector technology have improved the beam quality needed for short wavelength FEL oscillations[1-4]. However, major issues with photo-injectors are short-lifetime of the photocathode and cost and complexity of the drive laser. In these five years, however, two FEL oscillations in the short wavelength have been achieved using rf-linacs with the thermionic gun driven by gride pulsers shorter than 1ns, because of long-lifetime, easy-operation, and low cost of the thermionic gun[5,6].

The purpose of this report is to demonstrate first lasings at 5.5μm, 1.88μm and 0.63μm achieved by using the FELI linac with the thermionic gun and two undulators.

6-MeV INJECTOR WITH A THERMIONIC GUN

The FELI linac for IR-FEL facilities consists of a 6-MeV injector and three ETL type accelerating waveguides. The injector is composed of a 150-kV thermionic triode gun, a 714-MHz prebuncher, and a 2856-MHz standing wave type buncher[7]. The gun with a dispenser cathode (EIMAC Y646B model) emits 500ps pulse of 2.3A at frequencies of 22.3125 MHz. The grid pulser is manufactured by the Kentech Instruments, Ltd., England. The 714-MHz prebuncher is made of stainless steel to reduce wakefield effects introduced by the 500-ps beam from the gun. The rf frequency of 714 MHz is chosen 1) to meet a 9-cm long bunched beam from the gun operated by a 120-kV DC voltage and the 500-ps grid pulser, and 2) to make the cavity as compact as possible.

The 2856-MHz buncher is a standing wave type buncher (SWB) consisting of nine cavities made of copper. The peak electric field is 14MW/m for an rf input of 2MW. In order to reduce space-charge effects in bunched pulses as much as possible, a drift space from the SHB to the first cavity of the SWB is designed to be around 40cm. The axial field distribution from the gun to the SWB has been designed to keep a radius of the bunching beam constant from the SHB to the SWB. The maximum field is about 0.21T near the entrance of the SWB. The field distribution delicately affects FEL oscillations.

The diameter ($2r_b$) of the injector beam was observed to be less than 2mm with a 2-mm slit. The energy spectra of the injector beam were also measured with a 90deg-bending magnet. The energy spread (FWHM) is 150keV (2.5%) for a 5.8-MeV electron beam and the beam emittance ($\varepsilon_n=\gamma r_b\theta$) is estimated to be 12πmm mrad[7].

RF SYSTEM FOR FELI LINAC

An rf system for linac-based FELs requires rf sources with long pulse duration and high stability. Our rf sources are a klystron 1VA88R for the 714-MHz prebuncher and a klystron E3729 for the 2856-MHz buncher and three accelerating waveguides. These are modified for a 24-μs pulse operation [8]. A modulator for the klystron 1VA88R uses MOS-FET modules. However, a modulator for the klystron E3729 consists of 4 parallel networks of 24 capacitors and 24 variable reactors, and it has a line-switch of an optical thyristor stack. The stability of the modulator pulses is 0.067%p-p at 24-μs duration[9].

FELI 80-MeV LINAC AND IR-FEL FACILITIES

The layout of the FELI 80-MeV linac, S-type BT lines for undulators and IR-FEL facilities are shown in Fig. 1. To prevent BBU effects, the linearly narrowed iris type accelerating waveguides are used for the FELI linac. The iris diameter of this type is linearly narrowed from a_1 to a_2 ($a_1>a_2$) along the accelerating waveguide with a length of l_w[10]. For instance, parameters of C3 type are a_1=26mm, a_2=22.8mm, and l_w=3m; those of D3 type are a_1=25mm, a_2=21.8mm, and l_w=3m. The configuration of the injector and these waveguides is the injector-C3-D3-C3. Using screen monitors installed at the inlet and outlet of each accelerating waveguide, quadrupole magnets and steering coils, the electron beam size and position are monitored and controlled to pass through the center of accelerating waveguides. Further, using five screen monitors installed in each BT line, the beam size and position are adjusted along

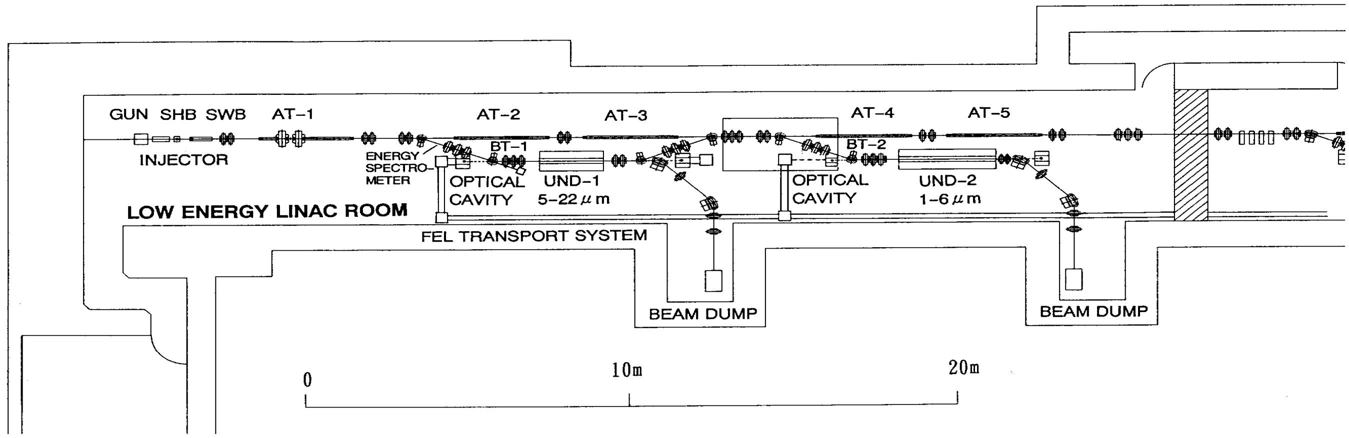

Fig. 1 Layout of FELI Linac, S-type BT lines and IR-FEL Facilities

the axis so as to pass through the center of a narrow vacuum chamber inserted to each undulator[11]. A lattice design of the BT line has been published elsewhere[12]. The beam passing through the undulator is focused and sent to a water dump using two 45deg.-bending magnets. Using variable slit systems installed in the 30-MeV BT line, the first 22.5deg.-bending magnet and a water absorber are used as an energy spectrometer. The energy spread (FWHM) is about 290keV (0.9%) for a 32.2-MeV beams[7]. At the 80-MeV BT line, the energy spread has been also measured but it is about 1% for a 70-MeV beam.

FIRST LASING AT 5.5μm USING THE FEL FACILITY I

First lasing at 5.5μm has been achieved using a 2-m long undulator and a 6.72-m optical resonator installed at the 30-MeV BT line of the FELI linac. Tab. 1 shows the characteristics of the linac beam at the 30-MeV BT line and the undulator 1. Fig. 2 shows a 5.5-μm FEL macropulse shape measured with a HgCdTe detector and an electron beam current pulse measured with a buttom monitor[14]. The laser gain is deduced from the first part of the exponential growth of the FEL pulse. The current pulse is 24μs long. The saturation duration is about 18μs, corresponding to 400 laser micropulses of 10ps. The FEL spectrum was measured with a Czerny-Turner type monochrometer equipped with 120 pyroelectric detectors[15]. The spectrum shown in Fig. 3 is a temporal integration along the laser macropulse.

Tab. 2 shows the characteristics of optical cavities for two undulators[13] and first lasing at 5.5μm.

FIRST LASING AT 1.88μm USING THE FEL FACILITY II

First lasing at 1.88μm has been achieved using a 3-m long undulator and a 6.72-m optical resonator installed at the 80-MeV BT line of the FELI linac. The characteristics of the linac beam at the 80-MeV BT line and the undulator 2 are also shown in Tab. 1, and the characteristics of optical cavity for the undulator 2 and first lasing at 1.88μm are also shown in Tab. 2. Fig. 4 shows a 1.88-μm FEL macropulse shape measured with the HgCdTe detector and a 24-μs, 2856-MHz RF pulse. The 1.88-μm FEL spectrum shown in Fig. 5 is also a temporal integration along the macropulse.

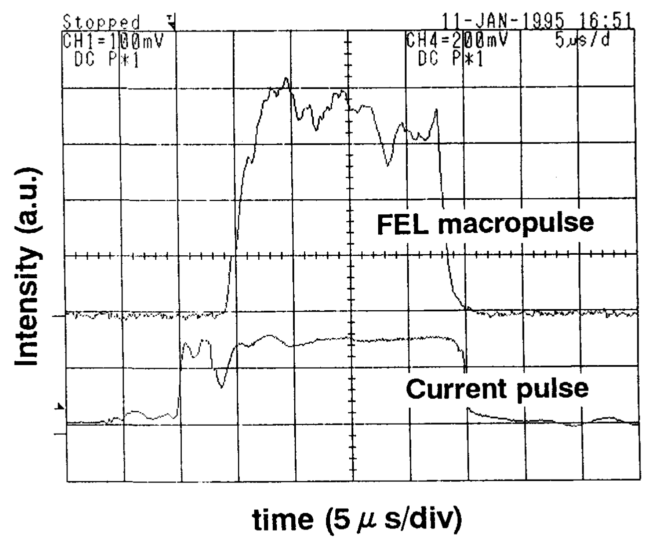

Fig. 2 FEL Macropulse at 5.5μm and Current Pulse

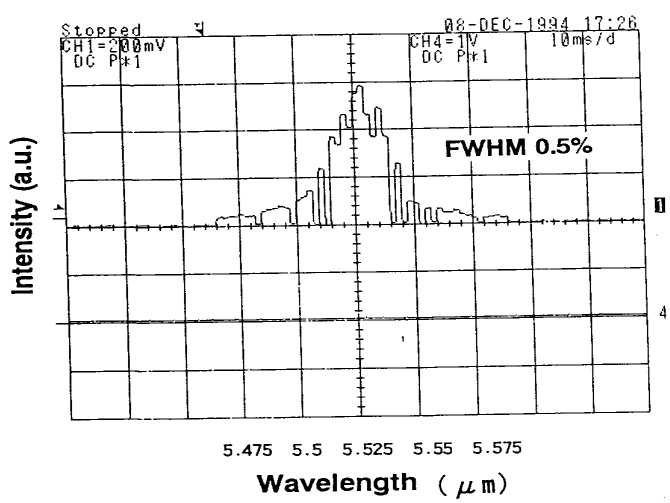

Fig. 3 FEL Spectrum at 5.5μm

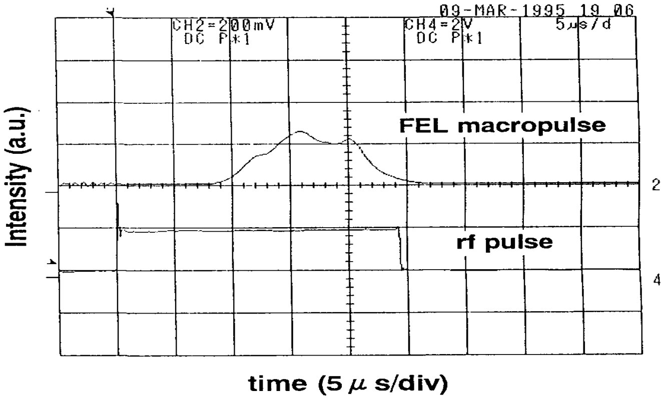

Fig. 4 FEL Macropulse at 1.88μm and RF Pulse

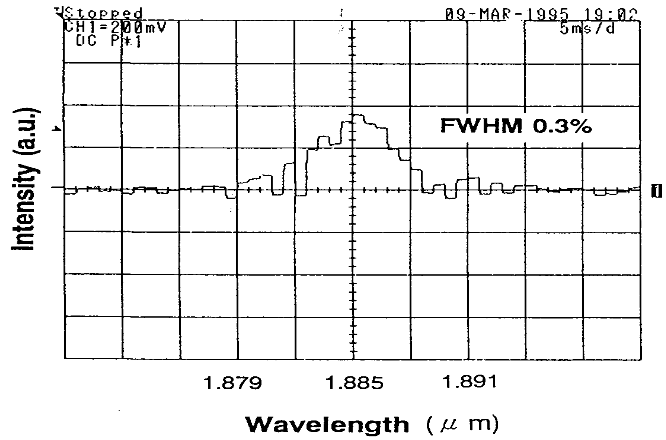

Fig. 5 FEL Spectrum at 1.88μm

Tab. 1 Characteristics of FELI linac beams and undulators

Accelerator	30-MeV BT Line	80-MeV BT Line
Energy E	33.2MeV	68.0MeV
Peak current I_P	42A	42A
Macropulse duration	24μs	24μs
Macropulse separation	0.1s	0.1s
Micropulse duration	10ps	10ps
Micropulse separation	44.8ns	44.8ns
Energy spread(FWHM)	1.0%	1.0%
Emittance(normalized)	~26πmm mrad	~26πmm mrad
Undulator	No.1	No.2
Type	Halbach	Halbach
Length L_u	2m	3m
Number of periods N	58	78
Period length λ_u	3.4cm	3.8cm
Gap	≥14mm	≥20mm
Magnetic field(peak)	0.49T	0.40T
Parameter K	0.5-1.55	0.5-1.4

Tab. 2 Characteristics of optical cavities and lasings

Optical cavity	No.1	No.2
Type	optical mode	optical mode
Length	6.72m	6.72m
Rayleigh length	1.0m	0.36m
g-parameter	-0.93	-0.80
	-0.76	-1.19
Mirror curvature	3.490m	3.734m
	3.827m	3.062m
Mirror type	Au on Cu	Au on Cu
Aperture of an extraction mirror	0.5mmϕ	0.5mmϕ
Lasing on the fundamental		
Wavelength λ	5.5μm	1.88μm
Spectral width Δλ/λ	0.5%	0.3%
Small signal gain	20%	14%
Total cavity loss	0.8%	2.7%
Peak power at the aperture	3MW	2MW
Date of first lasing	Oct. 31, '94	Feb. 27, '95
Lasing on the third harmonics		
Wavelength	0.63μm	
Net gain	3.3%	
Peak power at the aperture	0.3MW	

CONCLUSION

First lasings at visible and IR range have been demonstrated by using a 68-MeV, 42-A electron beam from the FELI linac with the thermionic gun. A visible FEL oscillation at 0.63μm has been also achieved on the third harmonics. A peak power level at 5.5μm reaches up to 60% of the theoretical limit $EI_P/4N$. However, peak power levels at 1.88μm and 0.63μm are a seventh of the limit. Optical properties of these FELs will be described in details elsewhere.

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