STATUS OF FS-FIR PROJECT OF THE PAL*

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Abstract

At the Pohang Accelerator Laboratory (PAL), a femto-second far infrared radiation (fs-FIR) facility is under construction. It is a THz radiation source using 60-MeV electron linac, which consists of an S-band photocathode RF gun with 1.6 cell cavity, two S-band accelerating structures, two chicane bunch compressors. As the radiation sources, we will use the optical transition radiation (OTR) and a 1-m long undulator. We installed the gun and measured the characteristics. In this article, we will present the status of photocathode RF gun development and the linac design as well as the simulation results.

INTRODUCTION

Coherent radiation can be produced from the electron bunches when the target radiation wavelength is longer than or equal to the electron bunch length. Therefore, using the femto-second electron bunches, we can generate coherent THz electromagnetic wave – FIR radiation. There were many studies to make subpicosecond electron bunch and make coherent radiation from these electron beams [1,2].

The total spectral radiation power from a mono-energetic bunch of N electrons is

$$P(\lambda) = P_0(\lambda)[N + N(N-1)f(\lambda)], \qquad (1)$$

where $P_0(\lambda)$ is the radiation power from a single electron and $f(\lambda)$ is the form factor, which becomes $f(\lambda) = \exp(-4\pi^2\sigma_z^2/\lambda^2)$ for a Gaussian distribution with the standard deviation σ_z. From Eq. 1, we can see that the coherent radiation power is N times ($10^8 \sim 10^{10}$) stronger than the incoherent case.

A laser photocathode RF electron gun is a very attractive electron source for supplying relativistic electron bunch with low emittance and high peak current. We decided to build an fs-FIR linac facility using the S-band photocathode RF electron gun. The linac has two S-band accelerating structures, two chicanes for compressing electron bunches and the final energy will be 60 MeV. At the end of the linac, OTR (optical transition radiation) and 1-m undulator will be located as the FIR radiation sources.

OTR is emitted when a charged particle passes through an interface between two media with different dielectric constants [3]. For a relativistic electron incident on a perfect conductor, the emitted radiation energy distribution in a frequency range $d\omega$ and a solid angle $d\Omega$ is given by [4]

$$\frac{d^2W}{d\omega d\Omega} = \frac{e^2\beta^2}{4\pi^2 c}\frac{\sin^2\theta}{(1-\beta\cos\theta)^2}, \qquad (2)$$

where θ is the emission angle with respect to the normal to the interface. From Eq. 2, we can find that the intensity vanishes at $\theta = 0$ and has a broad peak at $\theta \sim 1/\gamma$. Coherent radiation energy obtained from N electrons is

$$\frac{dW_N}{d\omega} = N^2 \frac{dW_1}{d\omega}\left|f(\omega)\right|^2 \qquad (3)$$

where $dW_1/d\omega$ is the radiation energy generated by single electron and $f(\omega)$ is the form factor defined in Eq. 1. Since, the bunch length and corresponding coherent radiation wavelength increase as electron number increases, there should be a compromise between the radiation bandwidth and the radiation energy.

Undulators are also used for THz radiation sources [5]. A planar undulator will be installed at the end of the linac to produce narrow-band far-infrared radiation. The main parameters of the undulator are listed in Table. 1.

Table 1: The parameters of the undulator

Type	Hybrid
Period	10 cm
Number of Period, N_u	10
Length	1.0 m
Gap	20 – 80 mm
Radiation Wavelength	10 – 450 μm

PHOTOCATHODE RF GUN

The S-band PC RF gun is installed in Gun Test Stand (GTS) at the PAL which will be used as the injector for PAL fs-FIR facility [6]. The fabricated type is a 1.6 cell BNL GUN-IV type with a resonant frequency of 2.856 GHz. The laser system is installed in the clean room with class 1000 dust control and 0.25 ºC temperature stability. The laser system consists of the Spectra-Physics "Tsunami" oscillator, regenerative amplifier with the gain medium of Ti:Sapphire, second and third harmonic generator, and a pulse stretcher. The output wavelength is 267 nm (UV region) and the peak energy at the wavelength of interest is 250 μJ. The pulse width can be changed from 0.5 ps to 10 ps by dispersive pulse broadening through prism pairs.

An integrated current transformer (ICT) and a Faraday cup are installed for the beam charge measurements at the gun exit. Position of ICT is about 45 cm from the cathode. The phosphor screen #1 is located after the ICT, 56 cm from the cathode. The screen can measure the beam sizes while varying the field of the focusing solenoid.

* Work supported by the Ministry of Science and Technology of Korea
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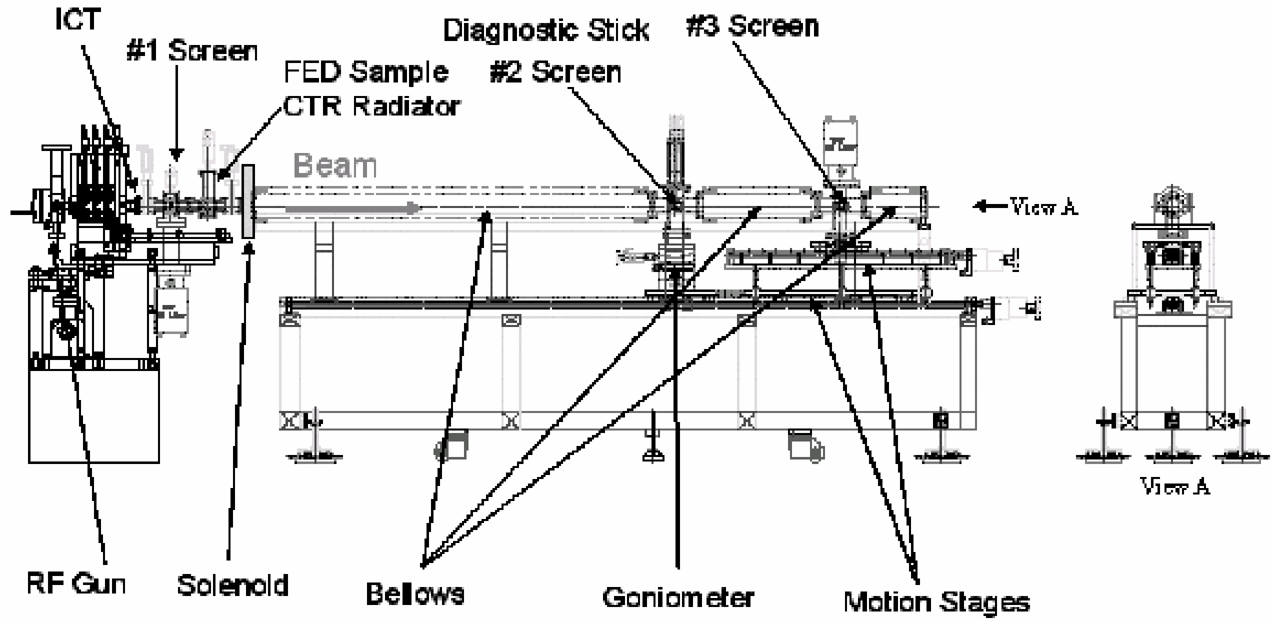


Figure 1: Schematic diagram of experimental setup of the gun test stand for fs-FIR facility.

The minimum beam size at the #1 screen is 175 μm. Screens #2 and #3 on the emittance-meter can be moved from 1.3 m to 2.8 m from the cathode along the beam pass. The #2 screen chamber consists of a Faraday cup for beam charge measurement, slits with slit widths of 30, 40, 50 μm for beamlet making, and the phosphor screen. With the #2 screen we can measure the beam sizes at various positions for transverse emittance measurement, and with the #3 screen the beamlet size of the position is measured. The transverse beam size at the #2 screen is measured to be 450 μm.

Figure 1 shows the schematic diagram of experimental setup of the gun test stand for fs-FIR facility. Figure 2 shows the picture of tunnel with GTS setup where the fs-FIR facility will be installed and Figure 3 shows the phosphor screen images of the electron beam from GTS. Table 2 lists the current electron beam parameters.

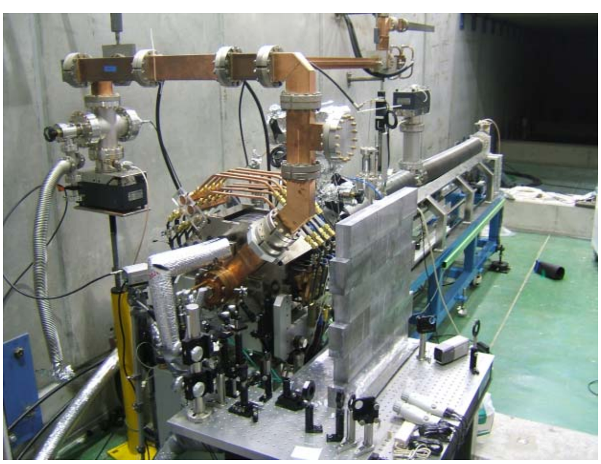
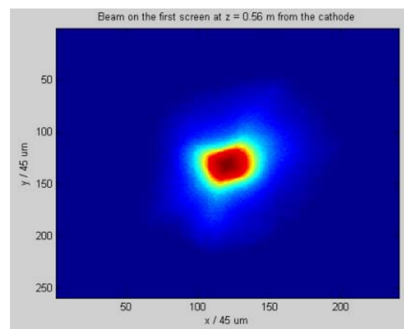
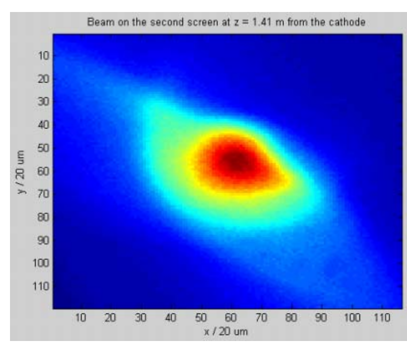


Figure 2: View of GTS setup in the tunnel.



(a)



(b)

Figure 3: Phosphor screen images of the beams at (a) 0.56 m and (b) 1.41 m from the cathode.

Table 2: Current parameters of the electron beam from GTS

Energy	~ 2 MeV
Initial Phase	30 º
Charge	320 pC
Laser Spot Diameter (hard edge)	3 mm
Laser Pulse Length (FWHM)	6 ps
Normalized RMS emittance	4 mm mrad

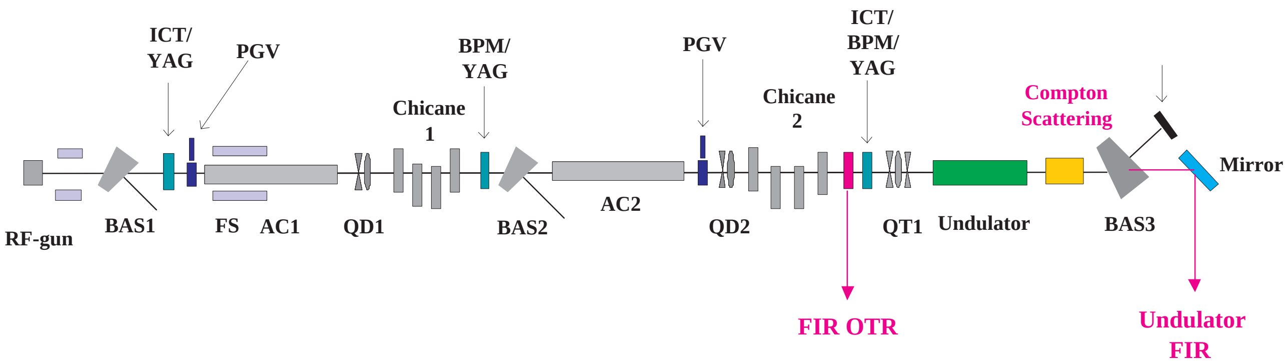


Figure 4: Layout of FIR linac. (QD: quadrupole doublet, FS: focusing solenoid, AC: accelerating column, QT: quadrupole triplet, BAS: Beam energy analyzer, and YAG: YAG screen).

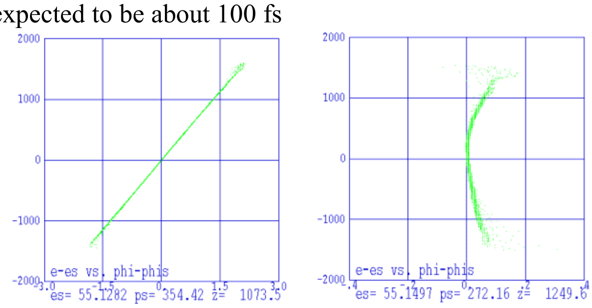
LINAC DESIGN

60 MeV electron linac for the FIR facility is under construction at the PAL. Figure 4 depicts the layout of the linac [7]. The linac consists of an S-band photocathode RF gun, two S-band accelerating structures (AC1 and AC2 in Fig. 4), two chicane bunch compressors and 1-m long planar undulator. Chicane-1 which is located between AC1 and AC2 will be used for undulator radiation, and Chicane-2 located after AC2 will be used for OTR.

The PARMELA code simulation shows that the beam with 0.2 nC can be compressed down to about 30 fs in rms by Chicane-2 for OTR and about 50 fs by Chicane-1 for undulator radiation. Figure 5 shows the bunch profiles before and after Chicane-2. The rms bunch length is 920 fs before the chicane and 29 fs after the chicane. The beam energy at Chicane-2 is 55 MeV, and the bending angle and R_{56} are 10 ° and -2.07 cm respectively.

In the PARMELA code simulation, the coherent synchrotron radiation (CSR) effect in the chicane was not considered. CSR in the chicane deteriorates the electron beam energy distribution, which causes an increase of emittance and bunch length. The CSR effect will be reviewed using other simulation codes such as ELEGANT.

Beam dynamics design was performed for higher charge of 0.5 nC. As the result, the bunch length is expected to be about 100 fs



(a) (b)

Figure 5: PARMELA simulation for bunch compression by Chicane-2 from (b) to (a). *es*: the synchronous particle energy, *phis*: the synchronous particle phase. The vertical axis is $e - es$ in MeV and the horizontal axis is $phi - phis$ in degrees. One degree corresponds to about 1ps.

SUMMARY

A coherent femto-second THz radiation source using 60-MeV electron linac is under construction at the PAL. Two kinds of radiation sources will be prepared – OTR and undulator radiation. As a wide-band radiation source, OTR is chosen rather than bending magnets in which case the radiation stability becomes very sensitive to the beam energy jitter.

As the electron injector, photocathode RF gun is chosen and the gun test stand (GTS) has been set up. With the GTS, many studies are being done for the performance improvement.

The FIR facility will be mainly used for the experiments using THz radiation. Also, a space is reserved after the undulator which will accommodate Compton back-scattering experiment in the future.

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