Linac based fs-THz Program at PAL

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***Abstract*—A 60 MeV electron linac for the source of coherent fs-THz pulses is under construction at PAL, Korea. The electron bunches produced from the photocathode rf gun are accelerated to 60 MeV and compressed down to several tens of femtosecond in a chicane type bunch compressor. Then the relativistic electron bunches are used to generate intense fs-THz pulses by coherent transition radiation (CTR). The radiated THz pulses are extracted from the linac vacuum pipe through a CVD diamond window. The 800 nm fs-laser pulses took up from the fs-regenerative amplifier are sent to the THz laboratory to do THz pump-Optical/IR probe experiment.**

I. Introduction And Background

THE Terahertz (THz, 1THz≈33cm^{-1} or 4meV) region of the electromagnetic spectrum has not been studied much due to the lack of generation and detection methods, but the THz sources have a great potential to be applied in many fields from biology and medicine to physics, chemistry and material science. Recently it has been reported that the dramatically enhanced energy, peak power, and peak electric field of the coherent THz radiation has been generated from the coherent superposition of the radiated fields emitted by ultrafast electron bunches.[1-3] This intense THz source offers great opportunities for studying a variety of science matters including nonlinear optical phenomena.

The fs-THz beamline construction program at PAL (Pohang Accelerator Laboratory), which is scheduled to be completed by the end of 2009, is underway to generate intense fs-THz radiation from 60 MeV linac (linear accelerator). The radiation is expected to cover up to 3THz(~100 cm^{-1}) and the pulse duration to be less than 200 fs. Spectroscopic methods are planned to study chemical and biological reaction dynamics.

II. Results

The relativistic electron beam with the bunch length of shorter than 100 fs will be used to fulfill the goal. Although the relativistic particles emit radiation at all wavelengths, only wavelengths with the same order of the bunch length or longer are to be coherent.

The total radiated spectral power from a bunch of N_e electrons at a wavelength λ is

$$P(\lambda)=p(\lambda)N_e[1+(N_e-1)f(\lambda)],$$

Where p(λ) is the spectral radiation power from a single electron and $f(\lambda)$ is a form factor for an azimuthal symmetric bunch, which is the fourier transform of the actual particle distribution. The first term in the square brackets denotes the incoherent part of the radiation and the second term corresponds to the coherent part of the radiation. The power of the coherent part is N_e times greater than that of the incoherent part when $f(\lambda)\approx 1$. Figure 1 shows the calculated result of the coherent enhancement of synchrotron radiation from a bending magnet at different bunch lengths in rms. The photon flux of coherent radiation is much higher than that of incoherent radiation, i.e. N_e times.

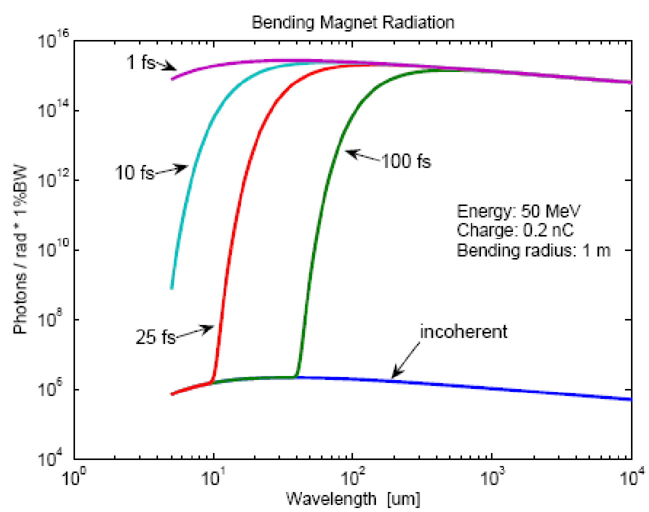

Figure 1: Coherent enhancement of synchrotron radiation from a bending magnet at different bunch lengths in rms.

Coherent enhancement of the radiation depends on the bunch form factor, $f(\lambda)=\left|\int S(x)\exp\{i(2\pi x/\lambda)\}dx\right|^2$, where $S(x)$ is the normalized longitudinal density distribution of electrons in a bunch. The bunch length should be as short as one tenth of the radiation period to get the bunch form factor close to 1. The target bunch length we are pursuing is about 50 fs with 0.2 nC beam, which can generate coherent THz generation below 3 THz.

The linac for generating THz sources is currently under construction. The 266 nm pulses provided by the 3rd harmonic conversion of 800nm Ti:Sapphire amplifier system are to be delivered to the photocathode rf-gun. The beam pointing stabilization unit will provide stable 266 nm UV beam to rf-gun in the linac. The rf-gun produces electron bunches with ~0.5 nC

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charge and up to 60 Hz repetition rate. Figure 2 depicts the layout of the electron linac. The photocathode RF-gun is an electron beam source, and the two S-band accelerating structures (AC1 and AC2) are used to accelerate the electron bunches to 60 MeV, and a chicane type bunch compressor is employed to reduce the width of the electron bunch down to 50 fs with 0.2 nC beam and 150 fs with 0.5 nC beam. Parameters of the linac are listed in Table 1 and the relation between bunch charge and bunch length is listed in Table 2. The emittance is relatively high, 5 mm-mrad, because the bunch length after the RF-gun should be 0.5 ps with 0.2 nC beam charge to get short bunch length after the bunch compression. The design of beam dynamics was carried out by use of the PAMELA code. The electron bunches incident on 1 inch diameter aluminum foil generate fs-THz pulses by coherent transition radiation (CTR). The radiated THz pulses are extracted from the linac vacuum pipe through a 24 mm diameter CVD diamond window.

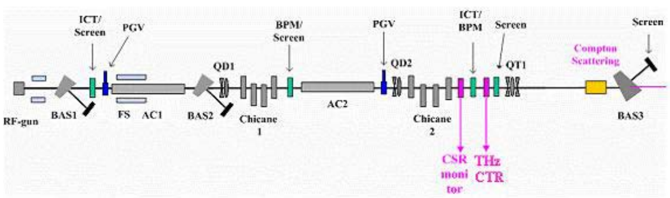

Figure 2: Layout of fs-THz Linac. (QD: quadrupole doublet, ICT: integrated current transformer, FS: focusing solenoid, AC: accelerating column, QT: quadrupole triplet, CTR: coherent transition radiation, BAS: beam energy analyzer)

Parameters	**Value**
Beam Energy	60 MeV
Beam Charge	0.2-0.5 nC
Beam Emittance	5
Beam Pulse Repetition Rate	mm-mrad
	60 Hz max.

Table 1: Parameters of the Linac

Beam Charge	Bunch Length after RF-Gun	Bunch Length after Chicane
0.2 nC	0.5 ps	50 fs
0.5 nC	2 ps	150 fs

Table 2: Relation of bunch charge and bunch length

The beam splitter is used to take up part of the 800nm beam out of the fs-regenerative amplifier, and the 800 nm beam is sent to the THz laboratory through the 4 mm Dia. 10 m delivery pipe to do pump-probe experiment. This 800 nm beam will be delivered to Optical Parametric Amplifier (OPA) to generate from UV (200 nm) to IR (10 μm) beam, and the generated UV or IR beam will be used as a pump or probe source. THz pump-UV/Vis/IR probe experiments as well as UV/Vis/IR pump-THz probe experiments are planned.

By the end of 2008, single cycle coherent fs-THz radiation pulses will be produced from a linear accelerator by coherent transition radiation (CTR). The THz beam delivery system from CTR to the THz laboratory is scheduled to be installed in early 2009. The characterization of the emitted THz pulses is a big part of the work in 2008-2009. Electro-optic sampling in ⟨1 1 0⟩ ZnTe crystal will be used for the coherent detection of freely propagating THz radiation. A single shot electro-optic measurement as well as conventional time-domain electro-optic sampling will be applied. When a linearly chirped optical probe pulse and a THz pulse co-propagate in the electro-optic (EO) crystal (ZnTe), different portions of the THz pulse modulate different wavelength components of the linearly chirped pulse through the Pockels effect. A spectrometer and an array detector combination are to be used to measure the spectral distribution and the temporal THz signal will be extracted from the difference between the spectral distributions of the chirped optical probe pulse with the THz pulse on and off. This single shot method provides greatly improved data acquisition rate.

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