THz RADIATION SOURCES BASED ON RF-LINAC AT CHIANG MAI UNIVERSITY

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Abstract

A THz radiation source in a form of coherent radiation from short electron bunches has been constructed at the Plasma and Beam Physics (PBP) research facility, Chiang Mai University. The accelerator system consists of an RF-gun with a thermionic cathode, an alpha-magnet as a magnetic bunch compressor, and a SLAC-type linear accelerator. Coherent transition radiation emitted from short electron bunches passing through an Al-vacuum interface was used as the THz radiation source. This THz radiation can be used as a source of the THz imaging system and THz spectroscopy. Details of the accelerator system and THz radiation production will be presented. A plan for extension to accommodate Free Electron Lasers (FEL) optimized for mid-infrared and far-infrared/THz radiation will also be discussed.

INTRODUCTION

THz radiation is electromagnetic radiation spectrum which has wavelength of 1000µm to 100 µm (300 GHz - 3 THz) and lies in gap between Microwave and Infrared. In the past, this gap is unexplored region but nowadays technologiesand applications of THz radiation were developed rapidly and were reviewed in [1-4]. A THz facility based on femtosecond electron bunches has been established at the Plasma and Beam Physics research facility (PBP), formerly the Fast Neutron Research Facility (FNRF), Chiang Mai University. Figure 1 shows a schematic layout of the system.The main components of the system are a thermionic cathode RF-gun, an alpha-magnet as a magnetic bunch compressor, a SLAC-type linear accelerator (linac), beam steering and focusing elements, and beam diagnostic instruments.

The 1-1/2 cell S-band RF-gun was designed and optimized [5] for bunch compression such that the first electron is accelerated and reaches the end of the half-cell just before the field becomes decelerating. It is then further accelerated through the full-cell to reach maximum kinetic energy of 2.0-2.5 MeV at the gun-exit depending on accelerating field gradients. Later electrons feel some decelerating fields and gain less and less overall energyresulting in a well-defined correlation between energy and time for bunch compression. Electron bunches of 20-30 ps from the RF-gun are then compressed in an α-magnet, where the particle path length increases with energy. This allows the lower energy particles, emitted later in each bunch, to catch up with the front for effective bunch compression. The optimized and compressed part of the electron bunch is filtered by energy slits located in the alpha-magnet vacuum chamber and then transported through the linac and the beam transport line to experimental stations. At the experimental station, the bunches are compressed to less than 1 ps [6]. These short electron pulses can be used to produce high intensity THz radiation in the form of coherent transition radiation. Typical operating parameters and electron beam characteristics are shown in Table 1.

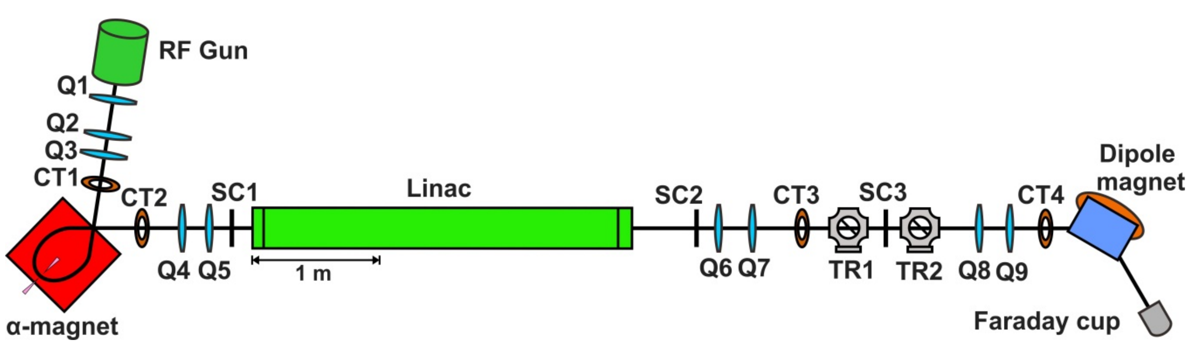

Figure 1: Schematic diagram of the accelerator system at Chiang Mai University for generation of short electron bunches and THz radiation [Q:quadrupole magnet, CT:current monitor, SC:screen, TR: transition radiation].

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Table 1: Operating and Beam Parameters

Parameters	**RF-gun**	**Linac**
Max. beam energy [MeV]	2.5 - 3	10-15
Macropulse peak current [mA]	1000	150
Beam pulse length [μs]	~2	~0.8
Macropulserepetation rate [Hz]	10	10
Number of microbunch/macropulse	5700	2300
Number of electrons/macropulse	1.4×10^9	6×10^8

GENERATION OF THzRADIATION

Total electromagnetic radiation emitted from a bunch of N electrons at radiation frequency ω is

$$I(\omega) = NI_e(\omega)[1+(N-1)f(\omega)],$$

where $I_e(\omega)$ is the radiation intensity from a single electron and the bunch *form factor f(ω)* is the Fourier transformation of the longitudinal bunch distribution squared. As a consequence, the short bunch is suitable and desired for production of broadband radiation spectrum. At a wavelength about or longer than the bunch length, the radiation from an electron bunch becomes coherent and the intensity of coherent radiation, proportional to the number of radiating electrons squared, exceeds greatly that of incoherent radiation at the same wavelength. Electron bunches of around 100 fs can provide broadband radiation in THz regime covering up to 3 THz [7].

The electron beam after acceleration is used to generate THz radiation is in the form of coherent transition radiation (TR). At the experimental station, transition radiationis produced by placing an aluminium foil (Al-foil) in the electron path, representing a transition between vacuum and Al-foil. The Al-foil radiator is 25.4 μm thick and 24 mmin diameter. The radiator is tilted by 45° facing the electron beam direction. The backward transition radiation is emitted perpendicular to the beam axis and transmits through a high density polyethylene (HDPE) window of 1.25-mm-thick and 32-mm diameter.

A copper light cone or a THz lens are used to collect the THz radiation into a room-temperature pyroelectric detector. The radiation energy of 19 μJ per macropulse or a peak power of 24 W was measured by collecting over an acceptance angle of 160 mrad. Experimentally, the transition radiation spatial distribution as well as horizontal and vertical polarizations of radiation were observed using a PYROCAM and a wire-grid polarizer from Graseby-Spec (Model IGP223). The results are shown in Fig. 2. An asymmetry shown up in horizontally polarized beam should very well be a result of the Al-foil orientation which is tilted 45° horizontally as predicted theoretically.

The radiation spectrum measured using a Michelson interferometer is shown in Fig. 3 (dot-line). The available THz radiation covers from 5 cm^{-1} to around 80 cm^{-1} wavenumber (0.15 THz – 2.4 THz). At low frequency (< 5 cm^{-1}), the spectrum was suppressed by effects of the beam splitter and the periodic response is the effect of the pyroelectric detector [8]. The spectrum seem to extend to above 80 cm^{-1} (2.4 THz) where noise becomes dominate. These can be further minimized with better detection and amplification system.

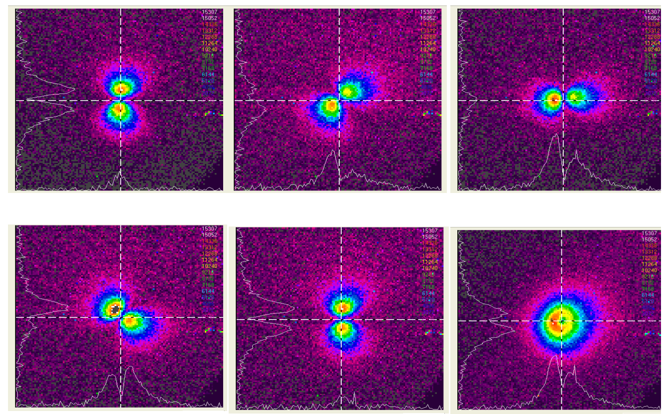

Figure 2: THz transition radiation profiles taken with a polarizer rotated 0, 45, 90, 135, 180 degree respectively. The last profile is taken without any polarizer.

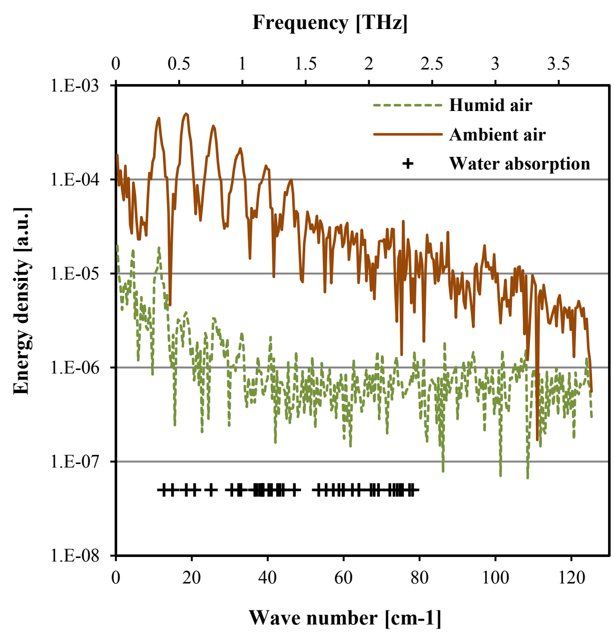

Figure 3: The radiation power spectra taken in humid air (solid) and in ambient air (dot-line).

THz SPECTROSCOPY AND IMAGING

THz spectroscopy can be done easily by measuring power transmission or power absorption of a sample via a Michelson interferometer and the Fourier Transformation. As shown in Fig. 3 (solid), the radiation spectrum taken in humid-air reveals several water absorption lines. Although phase information has been lost in the

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measurement, optical constants of the sample can be obtained by some modeling or Kramers-Kronig calculation [9]. Dispersive Fourier Transform Spectroscopy (DFTS) [11] may also be used for direct determination of optical constants of a sample. In a DFTS setup, a sample is inserted in one arm of the interferometer, causing attenuation and dispersion of the radiation pulse. The attenuated and dispersed pulse can be recorded and its attenuation factor and phase shift can then be recovered. The attenuation and dispersion can be related to optical constants of the sample depending on the optical configuration of the measurements. With the DFTS technique, the phase information can be recovered in measurements using a Michelson interferometer. A THz imaging system has been setup and tested at PBP. For transmission measurement, THz radiation is focused on a sample which is scanned using an xy- translation stage controlled by a computer. The transmission intensity will be detected by a room-temperature pyroelectric detector. Computer program will be employed to calculate and analyze intensity at difference points on the sample for THz image construction. Figure 4 shows an example of THz imaging obtained from the leaf concealed in an envelope.

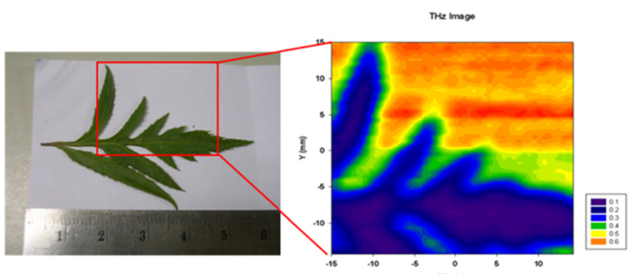

Figure 4: Leaf and its THz image.

FUTURE EXPANSION

As a plan to become a research facility centered on the production and utilization of femtosecond electron pulses and accelerator-based light sources covering the mid and far-infrared regime to wavelengths up to the THz regime. Preliminary designs of the extension have been studied as the diagrams shown in Fig. 5. A planar undulator can be added to the beamline to produce coherent undulator radiation from short electron bunches. The existing beamline can be extended and turned around by a 180^{o} achromatic system to let the electron beam pass through an undulators and an optical cavity as an IR-THz FEL. Figure 6 shows results of a preliminary study of the radiation output from some electron bunch lengths and an undulator (22 periods of 0.077 m period length) with and without FEL optical cavity. The radiation outputs cover well beyond 6 THz spectral range. Details of the study to accommodate the extension are reported in [11-13].

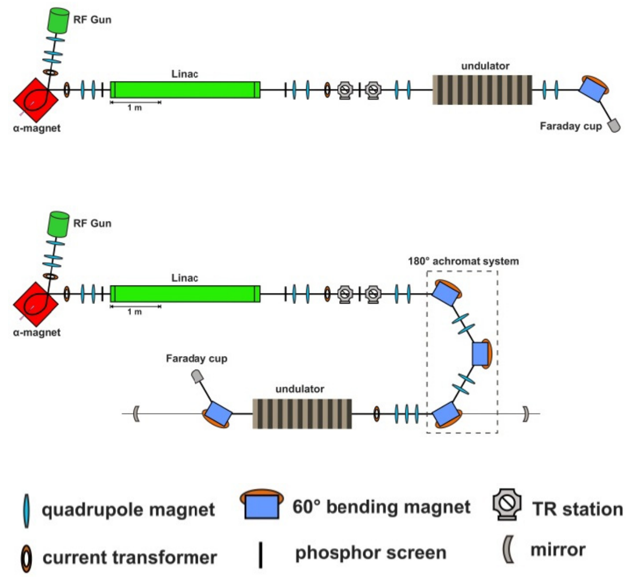

Figure 5: Diagrams for future expansion of the accelerator system with (bottom) and without (top) an FEL cavity.

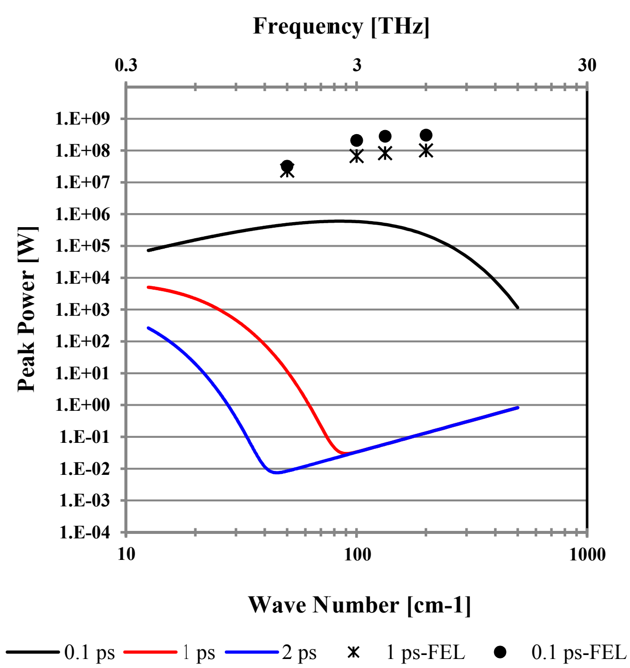

Figure 6: Radiation output from some electron bunch lengths and an undulator (22 periods of 0.077 m period length) with and without FEL optical cavity.

CONCLUSION

Intense THz radiation can be generated in form of coherent transition radiation by using short electron bunches which are available at the Plasma and Beam Physics Research Facility (PBP), Department of Physics and Materials Science, Chiang Mai University. The available THz radiation covers from 5 cm^{-1} to 80 cm^{-1} wavenumber. This THz radiation can be used as a source of the THz imaging system and far-infrared or THz spectroscopy. Plan for future expansion with a planar undulator will allow more coverage of the IR-THz spectrum regime.

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