OBSERVATION OF INTENSE TERAHERTZ SYNCHROTRON RADIATION PRODUCED BY LASER BUNCH SLICING AT UVSOR-II

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Abstract

A laser bunch slicing experiment has started at the UVSOR-II electron storage ring. An ultra-short pulse laser system was introduced, which can be synchronized with the RF acceleration of the ring. A laser transport line was constructed by utilizing existing light ports for free electron laser. An undulator which is also used for the free electron laser can be tuned to the laser wavelength and is used for modulator. Intense terahertz pulses synchronized with the laser injection were successfully observed at an existing infrared beam line located downstream of the undulator section. The intensity of the terahertz pulses was proportional to the square of the peak intensity of the electron beam. This clearly indicates that the terahertz pulses were coherent synchrotron radiation originating from longitudinal density structure of the electron bunch produced by laser bunch slicing.

INTRODUCTION

Coherent synchrotron radiation (CSR) in terahertz region can be produced by using electron bunches shorter than the radiation wavelength. The first observation was carried out by using short electron bunches provided by a linear accelerator [1]. Since then, terahertz CSR has been produced on many linear accelerators. In these years, terahertz CSR has also been observed in many storage rings [2]. In some cases, the rings are operated with small momentum compaction factor, to make the electron bunch length as short as the radiation wavelength. In other cases, CSR is emitted from electron bunches much longer than the radiation wavelength. The origin of the CSR in these cases is micro-structure on the longitudinal density distribution of the electron bunches which is produced either artificially or spontaneously.

The laser bunch slicing is a technology to produce micro-structures on electron bunches [3] and it is successfully demonstrated at a few light sources [4, 5]. In this scheme, an ultra-short laser pulse interacts with an electron bunch in an undulator and produce energy modulation in the bunch. As the laser pulse width is much shorter than the bunch length, only a small part of the bunch is modulated. As the bunch is proceeding in the ring, the modulated part is separated from the bunch and a dip is created, whose width is almost same as the laser pulse width. An electron bunch with such a mico-structure emits intense coherent radiation in wavelength comparable to the width of the structure. If we use sub-pico second laser pulses, we can produce CSR in terahertz region.

A 750 MeV synchrotron light source, UVSOR-II, is equipped with an infrared beam-line, which is the world most powerful especially in far-infrared region [6]. In 2004, we started CSR experiments, aiming to provide intense terahertz radiation to users through this beam-line. Soon after, we succeeded in detecting intense bursts of terahertz radiation in single bunch operation with very high beam current [7]. In 2005, we installed an ultra-short pulse laser which could be synchronized with the electron bunches. By using this laser, we have started a laser bunch slicing experiment. In this paper, we will describe the experimental setup and some early results.

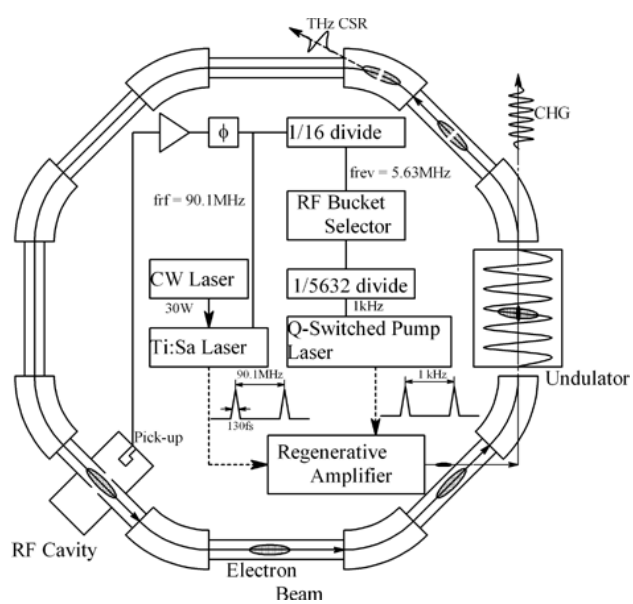

Figure 1: Schematic drawing of the laser bunch slicing system.

EXPERIMENTAL SETUP

The laser system is composed of a mode-lock Ti:Sa laser and a regenerative amplifier as illustrated in Figure 1. The former generates laser pulses synchronized with electron bunches and the latter generates intense ultra-short laser pulses with energy of 2.5 mJ/pulse and

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repetition rate of 1 kHz. The energy modulation produced by this laser was estimated as shown in Figure 2. The laser can produce energy modulation whose amplitude is comparable or even larger than the momentum acceptance of the storage ring.

Table 1: Main parameters of the Ti:Sa laser

Wave Length	800 nm
Pulse Energy	2.5 mJ
Repetition Rate	1 kHz
Pulse Width	130 fsec ~ 1 psec

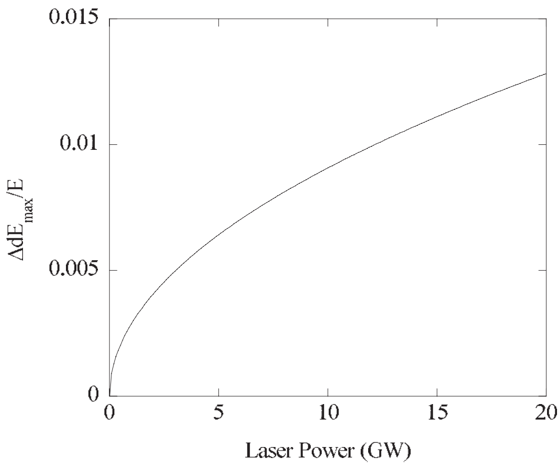

Figure 2: Amplitude of energy modulation versus laser peak power estimated by assuming appropriate focussing of the laser beam in the modulator.

The laser pulses are introduced to the ring through a laser transport line constructed by utilizing existing light ports normally used for an optical cavity of free electron laser (FEL) [8]. The laser pulses and the electron bunches interact in an undulator, which is normally used for the SR experiments and the FEL. In the experiment, this variably polarized undulator is operated in horizontally linear-polarized mode and its fundamental is tuned at the laser wavelength, 800 nm. The basic parameters are listed in Table 2.

Table 2: Main parameters of the undulator (modulator) during the laser bunch slicing experiment

Number of Periods	21
Period Length	110 mm
Pole Length	2.35 m
Polarization	Linear (horizontal)
Deflection Parameter	6.18

After the interaction, the laser pulses were extracted to an optical station normally used for the FEL. Beam diagnostic equipments prepared for the FEL, such as a streak camera and so on, were used for the special and temporal alignment between the laser beam and the electron beam.

As the electron bunch is proceeding in the ring, micro-structure is created and CSR is emitted. In this experiment, the ring is operated with a low emittance optics (normal optics for users runs) in which the dispersion function is distributed over the ring, including the modulator section [9]. The ring is normally operated at 750 MeV for SR users. However, for this experiment, it was operated at 600 MeV, which is the beam injection energy. The lower energy is preferable to tune the undulator at the laser wavelength, 800 nm. The ring is operated in the single bunch mode. Main parameters of the ring are listed in Table 3.

The CSR is observed at an infrared beam line, BL6B, normally opened for users [6]. This beam line is located downstream of the undulator section. Two bending magnets are in between. The beam line equipped with a magic mirror which can collect synchrotron radiation from a bending magnet with a very wide aperture, 215 mrad in horizontal and 80 mrad in vertical. The collected terahertz radiation is introduced to an liquid He cooled InSb bolometer, which is sensitive to the wavelength region between 0.2 mm to 3.0mm with a fine temporal resolution of a few micro-second.

Table 3: Main parameters of the UVSOR-II storage ring during the laser bunch slicing experiment

Electron Energy	600 MeV
Circumference	53.2 m
Natural Emittance	17.4 nm-rad
Natural Energy Spread	3.4×10^{-4}
RF Frequency	90.1 MHz
Revolution Frequency	5.6 MHz
Natural Bunch Length	3.1 cm (r.m.s)
Bending Radius	2.2 m

EXPERIMENTAL RESULTS

We have observed intense terahertz pulses which were synchronized with the laser injection of 1 kHz, as shown in Figure 3. The normal synchrotron radiation in same wavelength region was also observed between the intense pulses, although they were in the background level. The intensity per pulse is 10^4 – 10^5 times higher than that of the normal synchrotron radiation.

The detector output for the individual terahertz pulse is shown in Figure 4. The pulse width is a few micro-second, which is almost as short as the temporal resolution of the detector. The measurements were done for a beam current much lower than the threshold beam current of the spontaneous terahertz bursts described in Ref. [7].

The intensity of the terahertz pulses was measured by changing the beam current. As shown in Figure 5, the intensity is proportional to square of the peak current of the electron beam which was obtained experimentally by using a streak camera. This result clearly indicates that the observed radiation is CSR.

The spectrum of the CSR was also measured and the results indicated that it was much softer than the normal synchrotron radiation. The more details of the experimental results will be described in a separated paper [10].

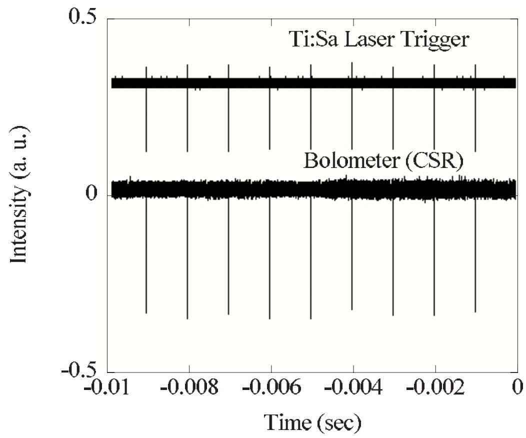

Figure 3: Terahertz pulses induced by the laser injection. The lower curve is the output signal (negative) of the terahertz detector and the upper the laser trigger signal.

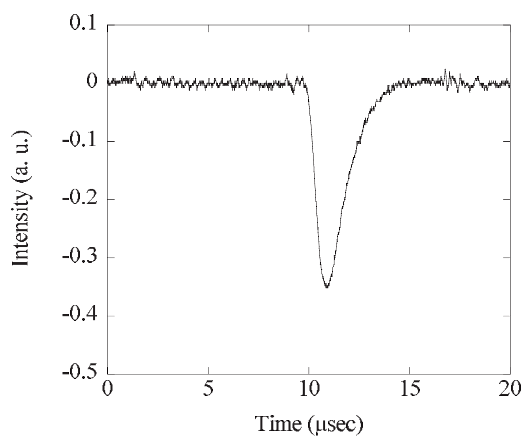

Figure 4: Detector output signal (negative) for individual terahertz pulse.

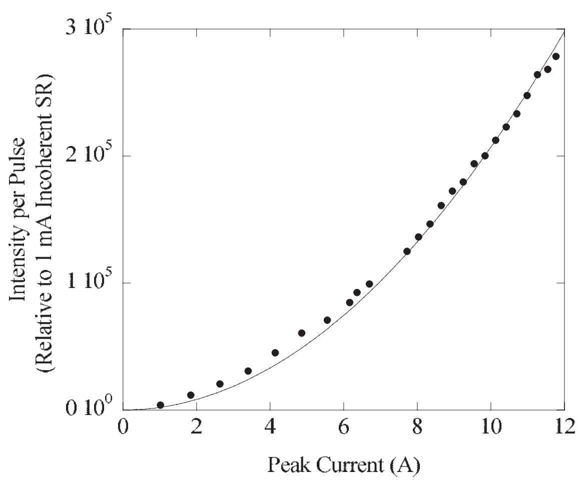

Figure 5: Terahertz intensity per pulse versus peak current of electron bunch. The solid line is a best-fit square curve.

SAMMARY

- A laser bunch slicing system was constructed at the UVSOR-II storage ring, utilizing a newly introduced Ti:Sa laser and the existing equipments for the free electron laser.
- Intense terahertz pulses synchronized with the laser injection were successfully detected at an existing infrared beam-line by using an InSb bolometer..
- The intensity of the terahertz pulses is proportional to the square of the peak intensity of the electron bunches.
- The duration of the terahertz radiation for each laser injection is too short to observe even with the bolometer with a good temporal resolution of a few micro-second.

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