STUDY OF THE COHERENT TERAHERTZ RADIATION BY LASER BUNCH SLICING AT UVSOR-II ELECTRON STORAGE RING

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Abstract

Terahertz (THz) coherent synchrotron radiation (CSR) is emitted not only from shorter electron bunches compared with the radiation wavelength but also from electron bunches with micro structures. Formation of micro structures at sub picosecond scale in electron bunches by a laser slicing technique is experimentally studied through observation of THz CSR. The properties of the THz CSR such as intensity or spectrum depend strongly on the shape and amplitude of the micro structure created in the electron bunches. To study in detail the formation of micro structure in electron bunches using the laser slicing technique, we have performed experiments at the UVSOR-II electron storage ring. THz CSR, which contains information on the micro structure, was observed under various laser conditions. The THz CSR spectrum was found to depend strongly on the intensity and the pulse width of the laser.

INTRODUCTION

The laser slicing technique is a method of producing a local dip structure in an electron bunch. In this technique, some electrons in the bunch are knocked out by a short laser pulses. If the laser pulse duration is around sub-pico- or femto- seconds , a dip structure with the size of the laser pulse duration is created in the longitudinal direction and the intense terahertz (THz) coherent synchrotron radiation (CSR) is emitted. Recently, the generation of THz CSR in storage rings by this technique has been reported [1, 2], including our own work [3, 4, 5].

The properties of the THz CSR such as intensity or spectrum depend strongly on the shape and amplitude of the micro structure created in the electron bunches. To study in detail the formation of micro structure in electron bunches using the laser slicing technique, we have performed experiments at the UVSOR-II electron storage ring [6]. THz CSR, which contains information on the micro structure, was observed under various laser conditions. In this paper, the THz CSR spectra obtained with various laser power conditions are reported and those are compared with the numerical calculations. The result of additional experiments was reported in Ref [5].

Table 1: Main Parameters of the UVSOR-II Storage Ring for the Experiments

Electron energy (MeV)	600
Circumference (m)	53.2
Natural emittance (nm rad)	17.4
Natural energy spread	3.4×10^{-4}
Revolution frequency (MHz)	5.6
Natural bunch length (ps)	90 (rms)
Momentum compaction factor	0.028
$R_{51,52,56}$ (Undulator to BL6B)	0.0396, -1.535, -0.268

Table 2: The Parameters of the Laser System

Wavelength (nm)	800
Pulse energy (mJ)	2.2
Reputation rate (kHz)	1
Pulse duration (ps)	0.2–1.2

EXPERIMENTAL SETUP

The schematic view of the experimental setup is shown in Fig. 1. At first the modulated laser pulse is injected to the undulator section of the ring. If a resonant condition is satisfied such that the laser wavelength is equal to the wavelength of the undulator radiation of the first harmonic, the injected laser and electrons exchange their energy. After this interaction, an energy modulation is created on the electron bunch. As a second step, the energy modulation is converted to a density modulation as the electron bunch pass through the following bending magnet. Then THz CSR is emitted and it's spectrum is measured at the IR/THz beamline installed at the second bending magnet.

The UVSOR-II storage ring was operated at the energy of 600 MeV since it was easy to achieve the resonant condition. The experiment was carried out at beam currents of 0.5–10 mA in the single-bunch mode to avoid the sponta-

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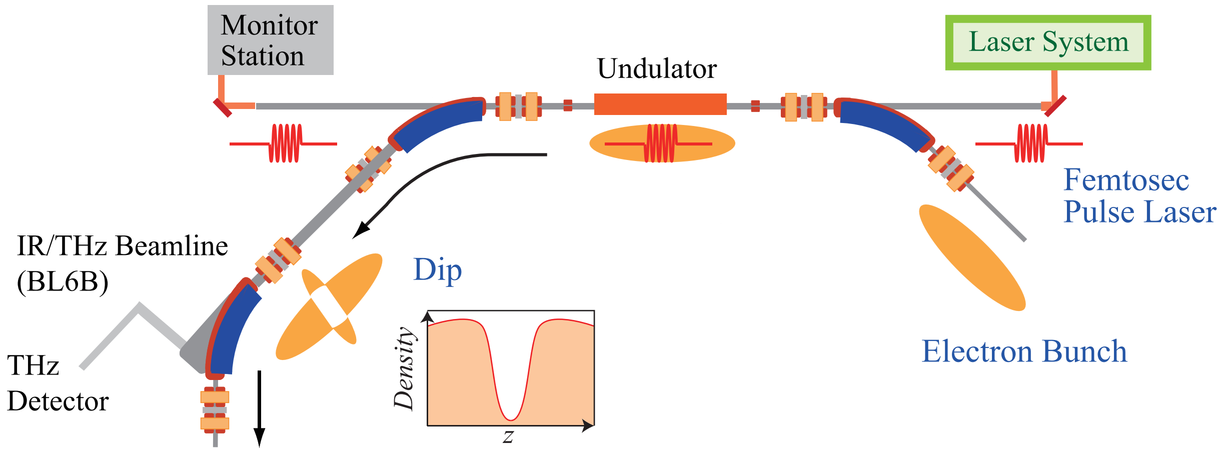

Figure 1: Schematic view of experimental setup and the calculated density on the modulated electron bunch.

neous bursts of THz CSR [7] and saturation of the detector. The main parameters of the UVSOR-II storage ring during the experiment are summarized in Table 1.

The laser pulses were produced by a commercial Ti:sapphire laser system (Coherent, Mira 900-F and Legend F-HE). An RF signal picked up from the RF cavity was delivered to the seed laser for synchronization between the laser pulse and the electron bunch. The pulse repetition rate was 1 kHz, and the output energy was typically 2 mJ/pulse. The pulse duration could be varied from 200 fs to 1 ps. The parameters of the laser system are listed in Table 2.

THz CSR was analyzed at the IR/THz beamline (BL6B) using an in-vacuum Martin-Puplett interferometer (JASCO, FARIS-1) [8], which was used to measure the spectra in the 2–50 cm^{-1} range with a resolution of 1 cm^{-1}. Pulse processing for the CSR measurement was done using a gated integrator (SRS, SR250) to reduce background from normal SR. The gated integrator was triggered by the 1 kHz repetition signal of the Ti:sapphire laser; a width of around 5 μs was chosen. In our measurements, the estimated intensity of the THz light was 10^4–10^5 times larger than that of normal SR.

RESULTS AND DISCUSSIONS

THz CSR spectra obtained under the various laser conditions are shown and compared with numerical calculations in this section. We performed numerical calculations of the CSR generation assuming that the laser pulse has a Gaussian distribution in the longitudinal direction. The measured spectra are divided by that of normal SR in order to exclude the sensitivity dependence of the bolometer.

CSR spectra shown in Fig. 2 were taken for four different laser energy conditions – 2.0, 1.5, 1.0 and 0.5 mJ – with a laser pulse duration of 322 fs. Each spectrum has two peaks in different frequency ranges. As the laser energy increases, especially for the peak in the higher frequency range, the intensity of lower-frequency component increases gradually.

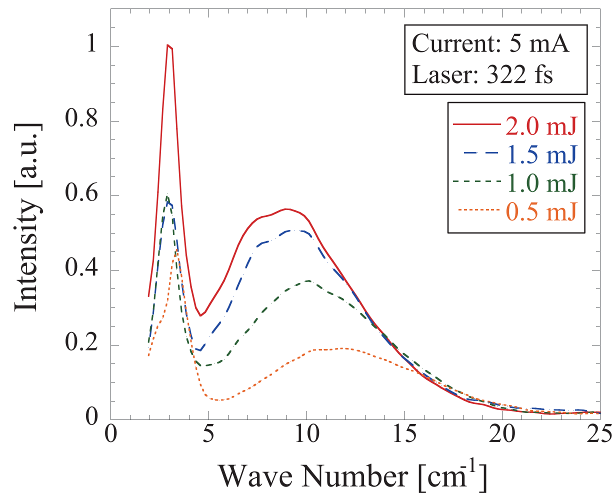

Figure 2: THz CSR spectra with different laser energies.

A calculation using the same laser conditions as those in the experiment was performed; the results are shown in Fig. 3. The peak in the higher frequency range corresponds to CSR emitted in the first turn of the storage ring, and that in the lower frequency range corresponds to CSR in the second turn. The contributions of the third and following turns are negligibly small. The wave number dependence has a similar tendency to that of the experimental data of Fig. 2. Since the temporal resolution of the detector is about 1 μs, it cannot resolve the emission from each turn. The measured double peak can be explained as a multi-turn effect. The peak frequencies of the experiments are slightly lower. This difference might be caused by the large acceptance angle of the beamline, which is 215 $\times$ 80 $mrad^2$ [8]. In this case, the R_{56} value changes from -0.20 to -0.31, however, the calculation was carried out only at a value of -0.268.

The peak intensity of the experimental and calculated results for the first-turn spectra as a function of relative laser pulse energy is shown in Fig. 4, where open circles and the solid line indicate the experimental and calculated re-

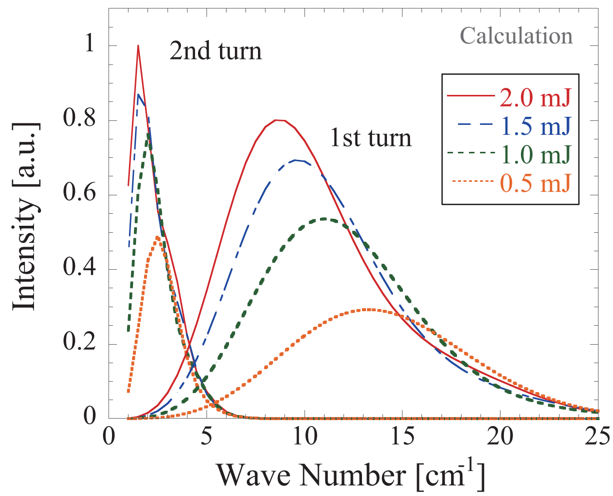

Figure 3: Calculated THz spectra with different laser energies.

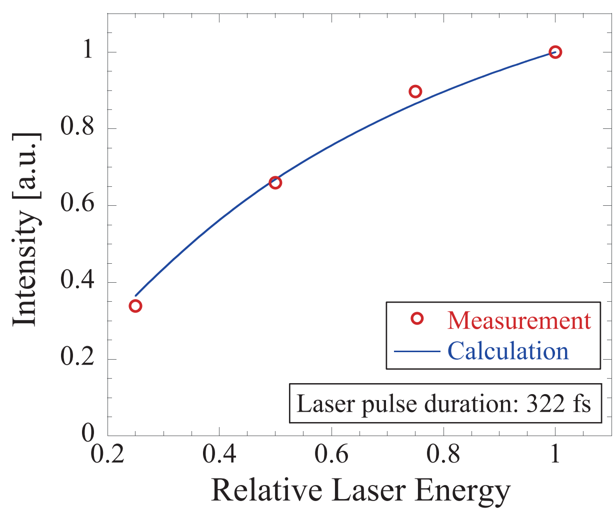

Figure 4: Intensity comparison of measured (open circles) and calculated (solid line) first-turn peaks.

sults, respectively. The calculation agrees well with the experimental result. The difference in spectral shape with different laser energies arises from the growth of the dip structure. The dip structure becomes larger and wider as the laser energy increases, and this leads to the increase in the lower-frequency components.

CONCLUSIONS

The formation of micro structure in electron bunches by the laser slicing technique was experimentally studied. THz CSR spectra were measured for various laser intensities. The measured spectra show double peaks, which can be attributed to the contributions of the first and second turns. The spectral shape depends strongly on the laser parameters and agrees qualitatively with the result of numerical calculations. Some discrepancies in the wave number were found, which are presumably due to the assumptions in the calculation that the CSR is emitted at a point in the bending magnet.

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