OBSERVATION OF THz SYNCHROTRON RADIATION BURST IN UVSOR-II ELECTRON STORAGE RING

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Abstract

Very intense THz synchrotron radiation bursts have been observed in single-bunch operation in UVSOR-II electron storage ring. The observation was performed in an infrared beam line by using a liquid-He-cooled In-Sb hot-electron bolometer that has good response time of several microseconds. Thanks both to the beam line and the detector, temporal structure of the terahertz bursts could be clearly observed. The peak intensity of the bursts was about 10000 times larger than that of usual synchrotron radiation in the same wavelength region. The extremely high intensity strongly suggests that the bursts are coherent synchrotron radiation, although the radiation wavelength was much shorter than the electron bunch length.

INTRODUCTION

The UVSOR electron storage ring, which is dedicated to a synchrotron radiation (SR) light source especially for VUV and soft X-ray, has been improved at the beginning of 2003, and transverse emittance in the improved ring (UVSOR-II) has been decreased drastically[1]. Because of the improvement including both the storage ring and the injector, a bunch current of larger than 200mA that is twice larger than before improvement can be stored in single-bunch operation. Moreover, a beam line for infrared SR has been upgraded to the world most powerful beam line in the terahertz region[2]. Consequently, UVSOR-II becomes suitable to investigate the coherent synchrotron radiation (CSR) in terahertz region. We have started the CSR experiment in 2004, and soon we have detected very intense terahertz bursts with good temporal resolution[3], thanks to the beam line and the detector. In the CSR experiments, UVSOR-II ring has been operated in the energy of 600MeV that is the injection beam energy from the booster synchrotron to the storage ring; in usual users runs the beam is accelerated from 600MeV to 750MeV in the storage ring. The operation under the injection energy has been adopted because of intense electron beam as much as possible especially in the CSR experiment. The basic parameters in UVSOR-II for the CSR experiments (600MeV operation) are summarized in Table 1.

Table 1: Basic parameters in UVSOR-II in CSR experiment.

Electron Energy	600 MeV
Circumference	53.2 m
Natural Emittance	17.4 nm-rad
Natural Energy Spread	3.4×10^{-4}
Momentum Compaction Factor	0.028
RF Accelerating Voltage	55 kV
RF Frequency	90.1 MHz
Natural Bunch Length	3.1 cm
Synchrotron Frequency	14.4 kHz
Longitudinal Radiation Damping Time	19 ms
Bending Radius	2.2 m

OBSERVATION

The observation of the CSR was performed in an infrared beamline (BL6B) in the UVSOR-II. The beam line has been constructed and used for infrared and terahertz spectroscopy of solids[2]. The beam line has a special mirror (magic mirror) that is settled inside a beam duct of a bending magnet and can collect the infrared SR with very wide solid angle (215×80mrad^2). The infrared SR is collected with the magic mirror and transported to the experimental port. In the experiments, In-Sb hot-electron bolometer that has detecting sensitivity in the wavelength region of $0.2 \sim 3$ mm and temporal resolution of several μ sec was used for detecting the terahertz SR.

Figure 1 shows dependence of averaged SR intensity measured by the bolometer on the beam current[3]. In the experiment a lock-in amplifier with a mechanical chopper was used for measuring the terahertz SR intensity. In the figure, the intensity both in single-bunch and in multibunch (12 bunches) condition were shown. As seen in the figure, the intensity was proportional to the beam current in multibunch condition, however, in the single-bunch condition, the intensity had very large fluctuation around 80mA and above 140mA. The averaged intensity in the anomalous fluctuation is much larger compared to the intensity in multibunch condition despite the large fluctuation. Figure 2(a)-(c) and Figure 3 show temporal structure of the terahertz signal in the beam current region at the fluctuating intensity[3]; Fig. 2(a)-(c) correspond to the results above 140mA and Fig. 3 corresponds to that around 80mA. As seen in the figures, there are a lot of negative burst signals (the detector has negative output). In the figures, intensity of usual terahertz SR is almost equal to the background level; that indicates generation of coherent synchrotron radiation burst in the terahertz region. At larger beam current

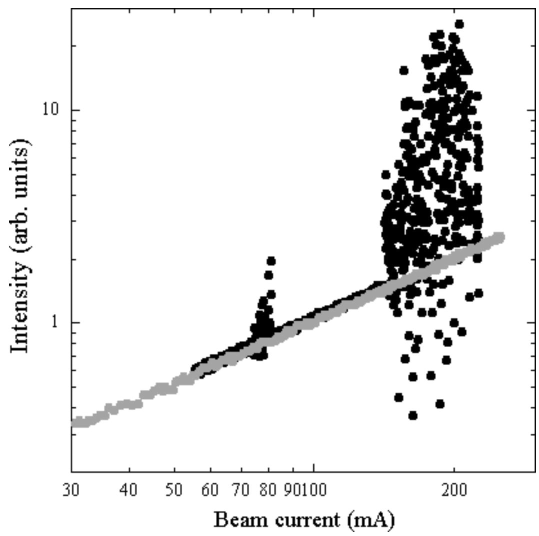

Figure 1: Averaged intensity of terahertz radiation measured by In-Sb bolometer. Gray and black circles correspond to the intensity in multibunch and in single-bunch condition.

(Fig. 2(a)) the burst signal is chaotic temporal structure, however, at smaller current (Fig.2(b),(c)) the bursts have quasi-periodic structure and the period tends to change with the beam current; in these cases the periods are 14 and 11ms for Fig. 2(b) and (c). One should notice that these periods are close to the longitudinal radiation damping time. On the other hand, as seen in Fig. 3, the bursts in 80mA has also periodic structure, however, the period (95ms) is much longer than that in larger beam current region.

Figure 4(a,b) show typical microscopic temporal structure of burst signal[3]. In the larger beam current region (Fig. 4(a)), a burst signal has several peaks that have also quasi-periodic structure; time period of the peaks is about 30μ sec and the time duration of one burst is about 200 μ sec. The intensity of the burst signal has about 10000 times larger than the usual terahertz SR in multibunch condition in the same electron beam current. On the other hand, in the smaller beam current (Fig. 4(b)) there also seem several quasi-periodic peaks in one burst signal; the period time is also about 30 μ sec but the time duration becomes larger (500μsec) compared to that in the large current. The period of the microscopic structure is close to the half value of synchrotron oscillation period of 69/2μsec=35μsec; that suggests some relation between the microscopic structure and longitudinal motion of the electron beam. Figure. 5 shows a microscopic structure of terahertz burst in the same beam current as in Fig. 4(a) but in different RF accelerating voltage of 28kV[3]. Under the lower RF voltage, the natural bunch length and the synchrotron frequency changed to 4.3cm and 10.3kHz; as seen in Fig. 5 the burst has also quasi-periodic structure but the period becomes larger than that in Fig. 4(a). The period changed to 45μ sec that is also close to the half value of synchrotron oscillation period of 97/2μsec=49μsec in this case.

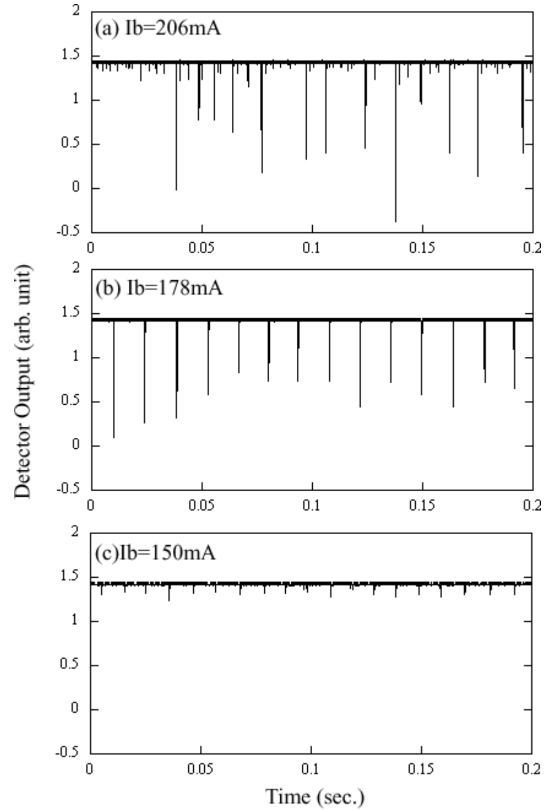

Figure 2: Temporal structure of terahertz radiation signal observed by InSb bolometer at the beam current of (upper)(a)206mA, (middle)(b)178mA and (bottom)(c)150mA.

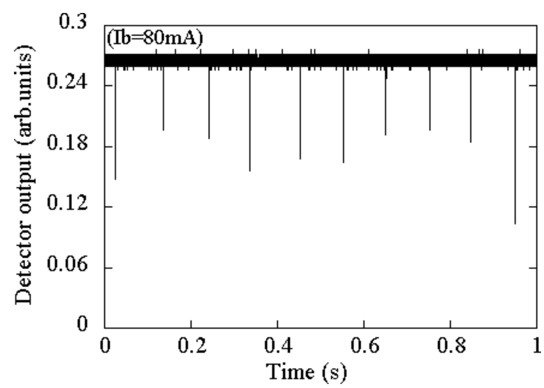

Figure 3: Temporal structure of terahertz radiation signal observed by InSb bolometer at the beam current of 80mA.

In quest of understanding of the relation between the terahertz burst and the longitudinal motion of the electron beam, we have observed both bunch length and the terahertz burst simultaneously. By using the same trigger signal for a streak camera that can observe longitudinal bunch shape with sufficient temporal resolution and for an oscilloscope by which the burst signal was observed, we observed temporal relation between the longitudinal motion of the bunch and the burst signal. Figure. 6 shows an example of the observation. As seen in the figure, the bunch

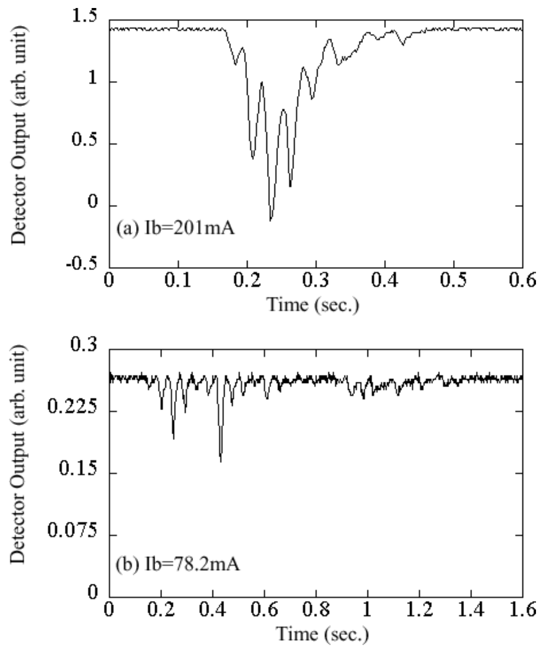

Figure 4: Microscopic temporal structure of the intense terahertz burst in (upper)(a) beam current of 201mA and (bottom)(b) 78.2mA.

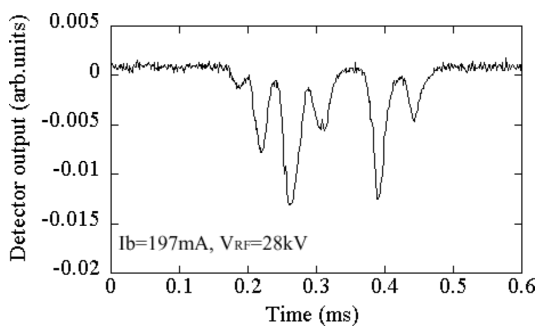

Figure 5: Microscopic temporal structure of the intense terahertz burst in RF voltage of 28kV and in 197mA.

length tends to oscillate quasi-periodically, and the terahertz bursts seem to synchronize with the oscillation of the bunch length. The bunch length increase suddenly, and at the same time the terahertz burst is also observed. After the longitudinal blowup of the bunch, the bunch length gradually shrinks again in the time period that is close to the longitudinal radiation damping time, and after the shrinking the bunch blows up again with the burst.

DISCUSSION

Cut-off wavelength λ_c of the coherent synchrotron radiation[4, 5, 6] is written as $\lambda_c \approx 2\sqrt{h^3/\pi\rho}$, where h and ρ are full width of vertical aperture of the beam duct and bending radius. In case of UVSOR-II where the bending radius is 2.2m and the full width of the vertical aperture is 38mm, the cut-off wavelength is 6mm that is smaller

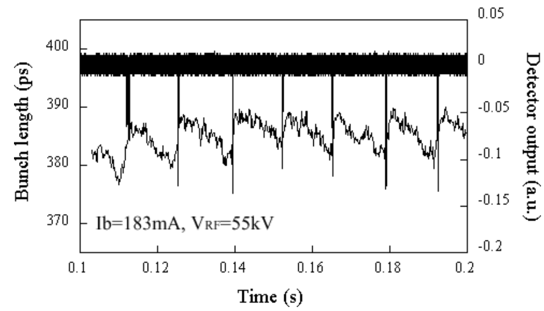

Figure 6: Typical time structure of terahertz burst signals and bunch length when the beam current was 183mA and the RF voltage of 55kV.

than the natural bunch length of UVSOR-II. Therefore, it is supposed that the terahertz bursts come from some modulation on the longitudinal density of the electron bunch, such as a density modulation caused by microbunching instability[7, 8, 9, 10]. The threshold N_{MBI} of the beam intensity of the microbunching instability induced by SR is gives by[9, 11, 12]

$$N_{MBI} = D(B/E)^{1/3} f_{rf} V_{rf} \sigma_{z0} \lambda^{-2/3}, \qquad (1)$$

where $D = 4.523 \times 10^{-3}$ in SI units, B and E are bending magnet field and total beam energy, f_{rf} and V_{rf} are RF frequency and RF voltage, σ_{z0} and λ are the bunch length and wavelength of the radiation. In case of UVSOR-II, the threshold current from Eq. (1) for λ =1mm that is typical wavelength in the experiments is estimated to be about 130mA; that is close value to the beam current that is the threshold for the terahertz burst in larger beam current region in Fig. 1.

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