Coherent Terahertz Radiation at UVSOR-II

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Abstract. Development of intense terahertz radiation source is progressing at UVSOR-II, based on the mechanism of coherent synchrotron radiation (CSR). The terahertz CSR has successfully been produced by two methods. When the storage ring is operated in the single bunch mode with a sufficiently high beam current, intense bursts of terahertz radiation are emitted. Micro-structures in the longitudinal density distribution of the electron bunches created by a beam instability may be the origin of the radiation. The duration of the bursts is typically 100 micro-seconds. The peak intensity is 10000 times higher than that of the normal synchrotron radiation. The bursts appear chaotically or quasi-periodically depending on the beam current with a typical interval of 10 milli-seconds. It has been also demonstrated that the terahertz CSR could be produced by the laser-bunch slicing method. The density modulation produced on the electron bunch by the laser is the origin of CSR. The repetition rate of the terahertz pulses is 1 kHz, which is same as the laser repetition rate. The intensity per pulse is 10^5 times higher than that of the normal SR.

Keywords: coherent synchrotron radiation, terahertz, laser, storage ring, instability
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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 pulses provided by a linear accelerator [1]. Since then, terahertz CSR has been produced on many linear accelerators. On the other hand, because the length of the electron bunches circulating in the electron storage ring is typically a few cm or longer, it had been believed until recently that the coherent synchrotron radiation could not be observed at storage rings in the terahertz region. However, in these years, terahertz CSR has been observed in many storage rings [2]. In some cases, the rings are operated under special condition called low momentum compaction mode, to make the electron pulse length as short as the radiation wavelength. In other cases, CSR is emitted from the electron pulses 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 pulse which is produced either artificially or spontaneously.

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 [3]. 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 the single bunch operation with very high beam current [4]. In 2005, we installed an ultra-short pulse laser which could be synchronized with the electron pulses. By using this laser, we tried a laser bunch slicing experiment and have successfully detected terahertz CSR produced as a result of the interaction between the laser and the electron beam [5]. In this paper, we report the recent progress in the coherent terahertz source development at UVSOR-II.

TERAHERTZ BURSTS IN SINGLE BUNCH OPERATION

When the UVSOR-II storage ring is operated in the single bunch mode with a high beam current above a certain threshold value, which is typically 100 mA, intense bursts of terahertz radiation are emitted [4]. Terahertz radiation

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is observed at an infrared beam line BL6B by using a liquid-helium cooled InSb bolometer, which is sensitive to the wave length range from 0.2 to 3mm. The response time of the detector is several micro-second. Thanks to this fast response, we can observe the terahertz bursts with fine temporal resolution. During this experiment, the storage ring is operated with the electron energy of 600 MeV, which is the injection energy. This is to accumulate electrons as many as possible. The parameters of the UVSOR-II in this operating condition are summarized in Table 1.

In Fig. 2, a few examples of the terahertz bursts are shown. The duration of the bursts is typically 100 micro-seconds. The peak intensity is 10000 times higher than the normal synchrotron radiation observed in the same wavelength region. This extremely high intensity strongly suggests that the bursts are CSR, although the electron pulse length is much longer than the radiation wavelength. Micro-structure created on the electron pulse is considered to be the origin of the bursts. The existence of the threshold current suggests that such structure is created by a beam instability. The bursts appear chaotically or quasi-periodically, depending on the beam current with a typical interval of 10 milli-seconds. In Fig. 2, temporal structure of individual burst is shown. There can be seen another periodicity of a few tens of micro-seconds, which may be related to the longitudinal bunch motion [4].

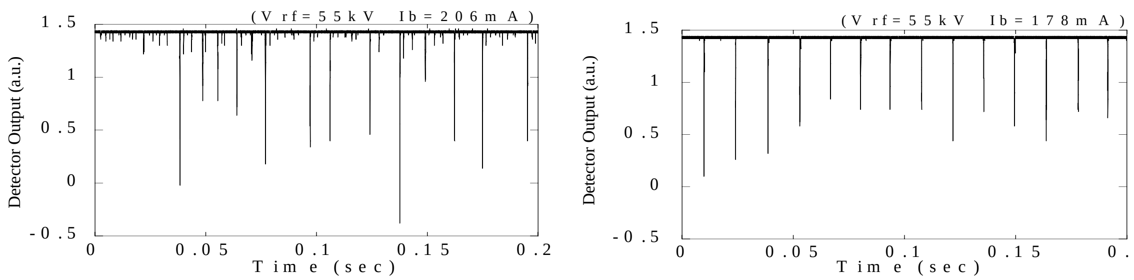

FIGURE 1. Typical temporal structure of the terahertz bursts observed at higher beam current (left) and lower (right). Terahertz component of the normal synchrotron radiation is continuously emitted between the bursts but in the background level.

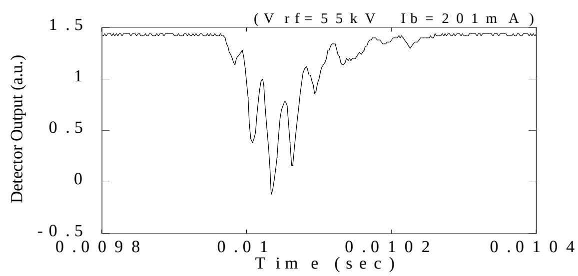

FIGURE 2. Typical fine temporal structure of a burst.

TABLE 1. Main Parameters of UVSOR-II during CSR experiments

Parameters	**Values**
Electron Energy	600 MeV
Circumference	53.2 m
Natural Emittance	17.4 nm-rad
Natural Energy Spread	3.4×10^{-4}
RF Frequency	90 MHz
Natural Bunch Length	3.1 cm
Synchrotron Frequency	14.4 kHz
Longitudinal Damping Time	19 msec
Bending Radius	2.2 m

TERAHERTZ RADIATION BY LASER BUNCH SLICING

The very high intensity of the bursts described above is very attractive for some applications. However, the occurrence of the bursts can not be predicted even when they appear quasi-periodically. To control the terahertz radiation, we have tried the laser bunch-slicing technique [6], in which a part of electron bunch is sliced out as a result of the interaction between the laser and the electron beam. If we use a sub-pico-second laser pulses, we can create micro density structure of sub-millimeter scale on the electron pulse. This structure would be the origin of the coherent terahertz radiation.

This technology can be realized by using an undulator whose fundamental wavelength can be tuned to the laser wavelength and an external short pulse laser synchronized with the RF acceleration of the storage ring. In 2005, a TiSa laser, which can be synchronized with the RF acceleration of UVSOR-II, was installed. The UVSOR-II storage ring is equipped with a free electron laser (FEL) [7]. The undulator used for FEL can be tuned to 800 nm, the wavelength of the TiSa laser. Basic parameters of the laser and the undulator are summarized in Table 2 and 3. It is estimated that the laser intensity is sufficiently high to produce energy modulation whose amplitude is comparable to the momentum acceptance of the ring [5].

The experimental setup is schematically shown in Fig. 3. The light ports for the optical cavity of FEL can be used to introduce the TiSa laser pulses to the ring. The laser pulses interact with electron bunches in the undulator. As the result of the energy exchange between laser field and electrons, a part of the electron bunch suffers a large energy modulation. As the bunch is proceeding in the ring, a dip, which is as short as the laser pulse width, is created on the bunch. This micro-structure is the origin of CSR, which is observed at an infrared beam-line located downstream of the undulator section.

TABLE 2. Main Parameters of TiSa Laser

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

TABLE 3. Main Parameters of Undulator during the CSR experiment

Parameters	Values
Number of Periods	21
Period Length	110 mm
Pole Length	2.35 m
Polarization	Linear
Deflection Parameter	6.18

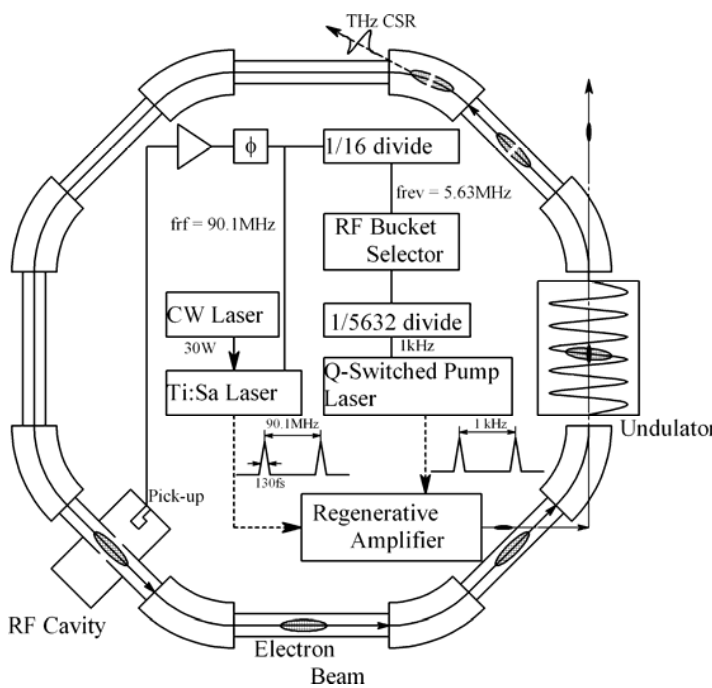

FIGURE 3. Schematic drawing of the laser bunch slicing experiment at UVSOR-II

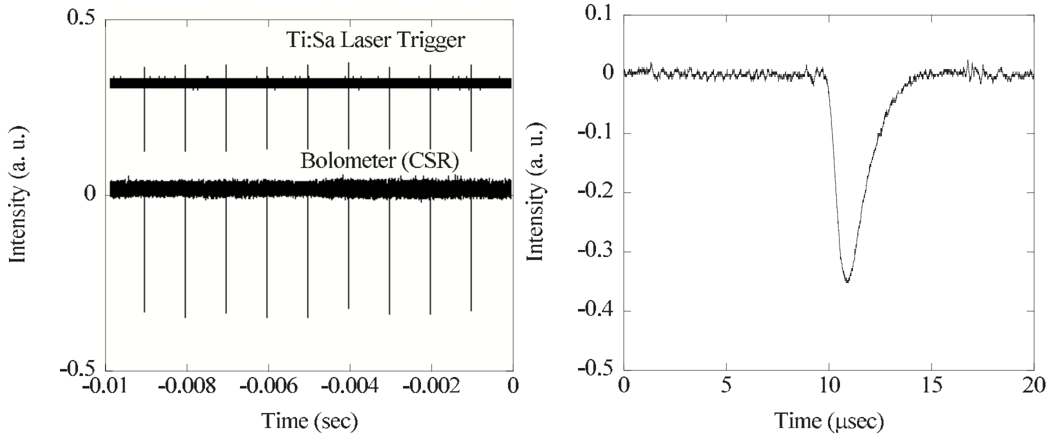

FIGURE 4. Terahertz pulses produced by the laser bunch slicing (left) and the temporal structure of individual pulse.

We have observed intense terahertz pulses which were synchronized with the laser injection as shown in Fig. 4. The measurements were done for a beam current much lower than the threshold beam current of the spontaneous terahertz bursts described in the previous section. The intensity per pulse is 10^5 times higher than that of the normal synchrotron radiation. The time response of the detector is not fast enough to resolve the temporal structure of individual pulse. The intensity of the terahertz radiation was measured versus beam current. The result showed that the intensity is proportional to square of the peak current of the electron beam. This clearly indicates that the observed radiation is CSR. More details of the experimental results will be described in a separated paper [5].

SUMMARY AND CONCLUSION

Intense terahertz radiation source based on the coherent synchrotron radiation mechanism is successfully progressing at UVSOR-II. We have succeeded in producing intense terahertz radiation by two methods. Intense bursts of the terahertz radiation can be produced just by operating the ring in single bunch mode with a high beam current above a certain threshold value. Intense terahertz pulses could also be produced by the laser bunch slicing method. In both cases, coherent synchrotron radiation is produced by electron bunches much longer than the radiation wavelength. Micro structures on the longitudinal density distribution are the origin of coherent radiation. The peak intensity is extremely high as compared with that of normal synchrotron radiation. Next step is to increase average intensity, which is currently limited by the bursting interval or the laser repetition rate.

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REFERENCES

1. T. Nakazato et al., *Phys. Rev. Lett.* **63 (12)**, 1245 (1989)
2. e. g. C. Biscari (ed.), “Coherent Synchrotron Radiation in Storage Rings” in *ICFA Beam Dynamics News Letter* No. 35, 2004, 20
3. S. Kimura et al., in *Synchrotron Radiation Instrumentation*, edited by T. Warwick et al., AIP Conference Proceedings 705, American Institute of Physics, Melville, NY, 2004, pp.416-419
4. Y. Takashima et al., *Jpn. J. Appl. Phys.*, Vol.44, No.35, 2005, pp L1131-1133
5. M. Hosaka et al., to be submitted to *Jpn. J. Appl. Phys.*
6. A. Zholents and M. Zolotorev, *Phys.Rev.Lett.* **76**, 912 (1996)
7. M. Hosaka et al., *Nucl. Instr. Meth. Phys. Res. A* **528**, 291-295 (2004)