GENERATION OF A COHERENT CHERENKOV RADIATION BY USING ELECTRON BUNCH TILTING

K. Sakaue†, WIAS, Waseda University, Tokyo, Japan
M. Nishida, M. Washio, RISE, Waseda University, Tokyo, Japan
R. Kuroda, Y. Taira, AIST, Ibaraki, Japan
J. Urakawa, KEK, Ibaraki, Japan

Abstract

We have been developing a compact accelerator based on a laser photocathode rf electron gun at Waseda University. Low emittance and short bunched electron beam can be generated from the gun. Also, the rf transverse deflecting cavity was developed for the bunch length measurement. We performed an experiment for generating a coherent Cherenkov radiation using bunch tilting. The rf transverse deflector can give a tilt for the electron bunch, and the tilt angle was set to the Cherenkov radiating angle which determined by the target refractive index. We successfully demonstrated a coherent Cherenkov radiation and the characterization of the radiation. The principle of coherent Cherenkov radiation generation, the experimental results and future prospective will be presented at the conference.

INTRODUCTION

Intensity of the coherent radiation increases with the square of the number of electron, which produce the radiation. This property leads advantages in the radiation, such as producing a high peak power radiation and oscillating a free electron laser. There are many types of radiation from the relativistic electron, for example, synchrotron radiation, transition radiation and bremsstrahlung radiation. In such radiations, Cherenkov radiation has advantage for producing high intensity radiation. Cherenkov radiation, which was firstly reported in 1944 [1], is produced when the velocity of electron is faster than the radiation in some medium. The interaction in the medium gives us large number of radiation. However, the radiation direction is not same with electron beam which determined by the electron velocity and the refractive index of the medium. This characteristic of Cherenkov radiation will disturb to achieve coherent radiation in whole part of the medium. We have developed the laser photocathode rf electron gun and the rf deflector for bunch length measurement at Waseda University. The rf deflector can tilt the electron bunch. We found that the tilt of the electron bunch can achieve the coherent Cherenkov radiation. This paper describes the principle of the coherent Cherenkov radiation by electron bunch tilting, experimental setup for observing the coherent Cherenkov radiation and results and discussions of the experiments.

COHERENT CHRENKOV RADIATION BY ELECTRON BUNCH TILTING

The schematic of Cherenkov radiation is shown in Fig. 1.

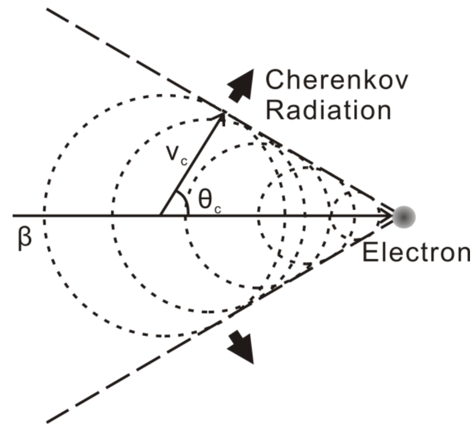

Figure 1: Schematic of Cherenkov radiation.

Cherenkov radiation radiates when the velocity of charged particle is faster than the radiation in the medium at an angle determined by the following:

$$\cos\theta_c = \frac{1}{n\beta} \quad (1)$$

where θ_c is radiation angle, n is the refractive index of the medium and β is the Lorentz factor. For achieving the coherent radiation, one will think how to produce the ultra-short electron bunch, which bunch length is much shorter than the radiation wavelength. Using such electron beam, the coherent Cherenkov radiation can be produced in the medium. However, if the medium is longer than the wavelength of the radiation, the radiations generated from the different position cannot be coherently overlapped. To solve this issue, electron bunch tilting can be used. The idea of the bunch tilting technique is originally tested in the laser terahertz generation by using wave front tilting. [2] We apply this idea to the electron bunch. Here we consider about the Cherenkov radiation from the tilted bunch. Figure 2 shows the Cherenkov radiation from the tilted bunch. The left side of the Fig. 2 shows the Cherenkov radiation from the single electron. Electron radiates the Cherenkov radiation at the different position of the medium. Radiation from the different position never overlapped each other. If the electron bunch is smaller and shorter than the radiation wavelength, the Cherenkov radiation from the one position is the coherent radiation. Then we think to achieve coherent Cherenkov radiation from all position of the medium by using electron bunch tilting. The right part of the Fig. 2 shows the Cherenkov radiation from the tilted electron bunch. The Cherenkov

† kazuyuki.sakaue@aoni.waseda.jp

radiation radiates at certain angle determined by the Eq. (1) from the head of the bunch. The radiation passes in the medium with the velocity of c/n.

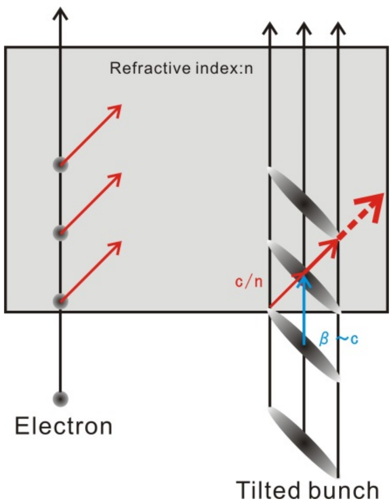

Figure 2: Cherenkov radiation from the tilted electron bunch.

On the other hand, the electrons pass with almost velocity of light. Radiation can keep overlapping with the latter electrons if electron bunch was correctly tilted. The point of this coherent Cherenkov radiation is small beam size before tilted. The beam size from the view of radiation angle is much smaller than the radiation wavelength, coherent Cherenkov radiation can be produced. The correct tilting angle of the bunch for the coherent radiation is the Cherenkov angle described in Eq. (1).

EXPERIMETAL SETUP

The experimental setup for coherent Cherenkov radiation is illustrated in Fig. 3.

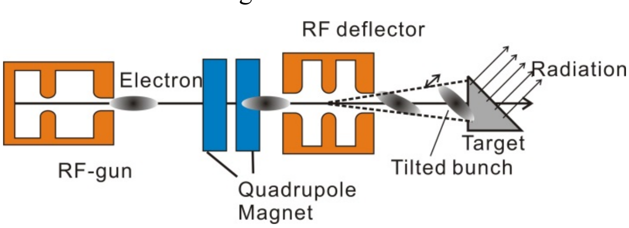

Figure 3: Experimental setup for coherent Cherenkov radiation by using tilted electron bunch.

Our accelerator system is based on laser photocathode rf gun. The gun is S-band, 1.6 cell type rf gun cavity. The photocathode is Cs-Te and the picosecond UV pulse produces phot- electron in the gun. The electron beam energy is up to 5 MeV with low emittance (2~3πmmmrad). The electron is pass the solenoid magnet right after the gun exit to compensate the emittance and focused by using quadrupole magnets. After the quadrupole, we placed rf deflecting cavity for bunch tilting. Our rf deflector cavity is also S-band 2 cell TM_{120} mode rf deflector specially designed for the ultra-short electron bunch measurement. [3][4] The rf power and phase of rf deflector can be adjusted using rf variable attenuator and phase shifter. The regulation of rf power can change the electron bunch tilt at the Cherenkov target. The rf power can change from 0 to 750 kW by the attenuator, which is enough for this experiment. At the target position, the profile monitor screen is also installed in order to measure the initial beam size and bunch tilting angle. First experiment of this technique, we decided to generate THz radiation. As a target, we used TOPAS [5], which is used as a THz lens due to its high transmission of THz radiation. Another remarkable property of TOPAS is uniformity of refractive index at the THz region. The refractive index of TOPAS is 1.52 in the whole THz region. The refractive index determines the radiation angle, so the refractive index difference will narrow the radiation spectrum bandwidth. After the target, the THz detectors are installed for measuring the THz pulses. We used quasi-optical detector (QOD), which has the sensitivity up to 2 THz frequency. [6] Depending on the experiments, the THz band-pass filter (BPF) is used to select the bandwidth of radiation.

RESULTS AND DISCUSSIONS

Firstly, we observed the THz radiation by electron tilting Cherenkov radiation. In Fig. 4, detected THz radiation is shown with the electron bunch signal detected by the fast current transformer (FCT) located before the rf deflector.

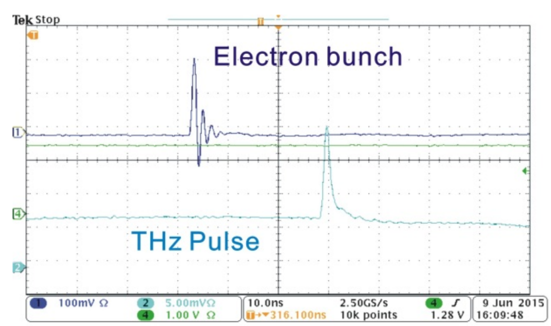

Figure 4: Electron beam signal detected by FCT (purple: top) and THz pulse signal by QOD detector (blue: bottom).

By changing THz BPF with center frequency of from 0.1 THz to 2 THz and observing the THz pulse, we found that the resulting THz pulse includes up to 2 THz frequency with correct electron bunch angle of 48.5 deg. Because of the uniformity of the refractive index of TOPAS, broad bandwidth THz pulse was produced by this technique. To confirm the coherent radiation using this bunch tilt technique, we measured the THz intensity as a function of the electron bunch charge as shown in Fig. 5. As shown in Fig. 5, the THz intensity increases with the square of the electron charge, i.e. the coherent radiation was produced.

ISBN 978-3-95450-147-2

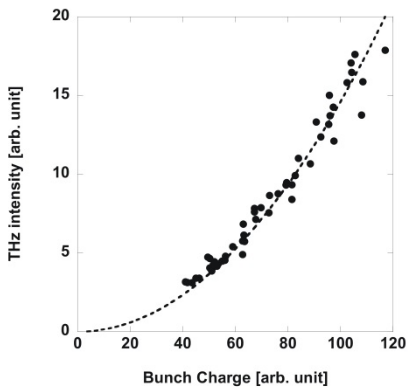

Figure 5: THz pulse intensity detected by QOD and 0.9 THz BPF as a function of the electron bunch charge.

In order to confirm that the technique of electron tilting was correctly worked, we measured the THz intensity with 1 THz BPF with changing the rf deflector phase and rf power of rf deflector. Figure 6 shows the result of measurement. The horizontal axis is the electron beam position on the target, which corresponds to the rf phase of the rf deflector and the vertical axis is the electron beam tilting angle, which corresponds to the rf power of the rf deflector. The measured angle of the bunch was also shown with the dotted line. The bunch angle was measured using beam profile screen. Measuring the center position of the bunch with changing the rf phase of the rf deflector leads the angle of the electron bunch. Using the π shift phase of the rf deflector cavity, the bunch angle of can change to inverse angle compared with the correct angle of the bunch.

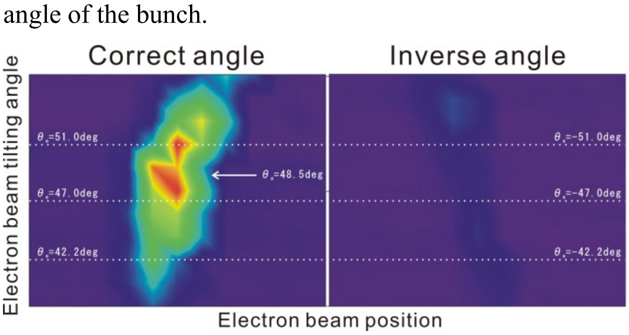

Figure 6: THz intensity as a function of the electron bunch position and electron bunch tilting angle.

As shown in Fig. 6, the maximum intensity of the THz pulse was observed at an angle of Cherenkov angle of 48.5 deg. Our TOPAS target is 1mm (width) and 1mm (thick) so only the 1mm position can produce the THz radiation. Comparing with the inverse angle, the THz pulse intensity is much larger in the correct angle. In the inverse angle situation, small intensity of the THz radiation was observed, which is correspond to the coherent radiation from the small area of the target as mentioned above. The THz pulse intensity was about ten times larger in the correct angle, thus the effect of the electron bunch tilting expected to be ten times increase in our experiment.

SUMMARY

We have firstly tested the coherent Cherenkov radiation with the electron bunch tilting. The electron bunch can be tilted by the rf deflecting cavity. Adjusting the bunch tilting angle to the Cherenkov radiation angle will produce the coherent Cherenkov radiation in the whole area in the target. As a result of the experiment, we have successfully observed the coherent THz Cherenkov radiation using TOPAS target. The THz pulse included from 0.1 THz to 2 THz so broadband THz radiation was achieved. The increase by the electron bunch tilting effect was about ten times compared with the inversely tilted bunch.

In near future, we have a plan to measure the spectrum of the THz pulse by the time-domain spectroscopy technique. Moreover, this THz pulse has enough energy to apply for the application researches such as THz imaging and/or THz spectroscopy so that the application research will be performed using the coherent Cherenkov radiation by electron bunch tilting.

ACKNOWLEDGMENT

This work was supported by a research granted from The Murata Science Foundation and JSPS KAKENHI 26286083.

REFERENCES

[1] P. A. Cherenkov, Trudy FIAN, 2, No. 4 (1944) pp. 3-62.
[2] H. Hirori et al., Appl. Phys. Lett. 98 (2011) 091106.
[3] Y. Nishimura et al., Nucl. Instrum. Meth. A764 (2014) pp. 291-298.
[4] K. Sakaue et al., Jap. J. Appl. Phys., 54 (2015) 026301-1-6.
[5] P. D. Cunningham et al., J. Appl. Phys., 109 (2011) 043505.
[6] Quasi-Optical Detector, Virginia Diodes, Inc., http://vadiodes.com/VDI/pdf/2009AugustNews.pdf