STUDY ON THz IMAGING BY USING THE COHERENT CHERENKOV RADIATION

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Abstract

THz frequency is a special electromagnetic wave which is categorized between a radio wave and a light wave. It can pass through the various materials like a radio wave and can be transported with optical components like a light wave. Thus, it is suitable for imaging application of materials. At Waseda University, we have a high-quality electron beam by Cs-Te photocathode RF-gun and generate the coherent Cherenkov radiation using the tilted electron beam by RF-deflector. We successfully observed a high peak power coherent THz light. Our target is to obtain the three-dimensional THz images. So, we performed the cross-section images as a pre-stage of three-dimensional imaging.

INTRODUCTION

Recent technological innovation brought about the applied study using the THz light. The THz light is applied to various fields including industry, medical care, agriculture, and the security. As an imaging tool, the X-ray is well known for the baggage check at the airport and X-ray examination at the hospital. The THz light has the same property as the X-ray at a point to obtain transparent images in non-destruction. But the advantage of the THz light is safety to the human body because energy is extremely low in comparison with the X-ray [1]. So, we can detect the weapons such as a knife or the handgun which a person hides in irradiating the THz light to the human body. Furthermore, as well as transmission imaging, we can obtain reflection imaging by using the property of the light wave. So, we can detect the crack of the concrete, the rust of the vehicle body under the painting.

We generated the coherent Cherenkov radiation, and succeeded in observing a high power THz light using Cs-Te photocathode RF-gun that we own. In this paper, we report the outline of generating the THz Cherenkov radiation, results of the three-dimensional THz imaging of materials and future prospects.

GENERATION OF THE THz LIGHT

Coherent Cherenkov Radiation

Cherenkov radiation that appears while the electron beam travels in a media with a velocity that exceeds the speed of light in the media is investigated and widely used in particle detectors for nuclear physics. The radiation cone in transparent medium is defined by following condition:

$$\cos\theta_c = \frac{1}{\beta n} \tag{1}$$

where θ_c is the radiation angle, β is the electron velocity in the speed of light units, n is the refractive index [2]. Moreover, the degree of the coherent effect depends not only on the longitudinal size of the electron beam but also on the emittance, or transverse size and the angular divergence of the electron beam. The total radiation intensity is defined by following:

$$P = \begin{cases} NP_0 & \text{(incoherent limit)} \\ N^2P_0 & \text{(coherent limit)} \end{cases} \tag{2}$$

where P is the total radiation intensity, P_0 is the intensity emitted by a single electron, N is the number of the electron. In the case of coherent radiation, the total radiation intensity is known to be proportional to square of the number of the electron [3]. In this way, the intensity of the coherent radiation is much higher.

Observation of the THz Light

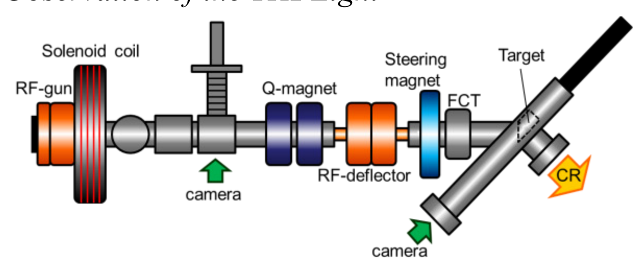

Figure 1: Schematic of the electron beam line layout.

Figure 1 shows the beam line layout at Waseda University. Our accelerator system is very compact which is approximately 3m in total. In this experiment, the accelerated electron beam is tilted by RF-deflector [4] and passed TOPAS [5] as a target. TOPAS is one of the polymer and has characteristic that the refractive index hardly changes in the THz region (n=1.52). Therefore, the Cherenkov radiation angle in the THz region is approximately 48.9deg from Eq.1. Also, Fig.2 shows the principle of generating the coherent Cherenkov radiation. When the electron beam is tilted the same angle as the Cherenkov radiation angle by RF-deflector, the beam size from the view of radiation angle is much smaller. Furthermore, phase matched THz light is generated to overlap the phase of the wave with each point. So, we can generate high peak power coherent THz light [6].

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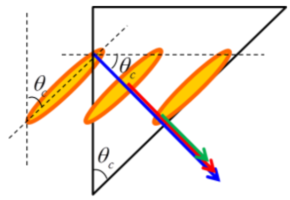

Figure 2: Principle of generating the coherent Cherenkov radiation.

We observed the generated THz light using a broadband wave detector of a Quasi-Optical schottky Diode detector (QOD) [7]. We confirmed that the THz light, which we observed, was coherent. Figure 3 shows that the intensity of the THz light when we changed the charge of the electron beam. The graph of the measurement result can fit by square. Therefore, it is concluded that observed THz light is coherent.

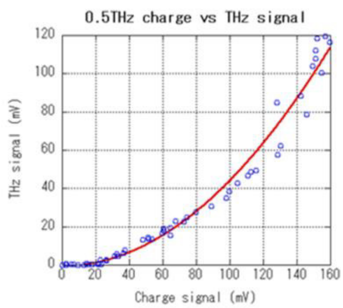

Figure 3: The relation between the intensity and the beam current.

THz IMAGING

Cross-section Imaging

We tried to obtain cross-section images using the THz light generated from the coherent Cherenkov radiation. Figure 4 shows the measurement principle of cross-section imaging. We applied the principle of the microscope: we adjust the focus point of the light to the part of the observation material. Measurement method is the same: we adjust the focus point of the THz light to the position of the specific cross-section of the sample where we want to observe. We scanned a sample in two dimensions like transmission imaging using this measurement method, then measured the intensity of THz light that transmitted in the QOD. So, the cross-section image that specialized in the section of the focal position of the THz light should be obtained.

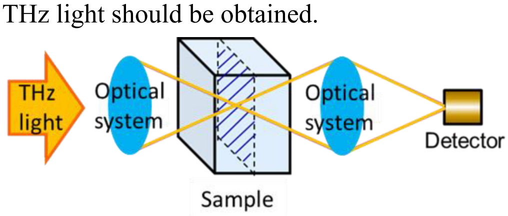

Figure 4: Measurement principle of cross-section imaging.

Figure 5 shows a schematic top view of the cross-section imaging and the shape of the sample. In this experiment, we installed a band pass filter (BPF) of 0.5THz just before the QOD. The THz light was irradiated for a section of the sample perpendicularly. And the dimensional of the sample is 40mm (length), 40mm (width), 40mm (height). We marked a circle and a cross in front and back each of the sample using a tape made by aluminium (width: 4-5mm). Then we measured a focus point of the THz light by knife-edge method. The x-y scanning step was 1mm. In the results (Fig.6), we observed a circle when we focused on the front side of the sample. On the other hand, we observed a cross when we focused on the back side of the sample. But these images are not so clear because the influence of other side of the mark has been given to each image. So we have to improve the clarity of the cross-section images for the three-dimensional imaging.

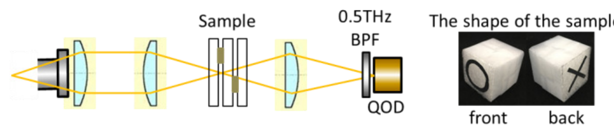

Figure 5: Measurement setup and the shape of the sample.

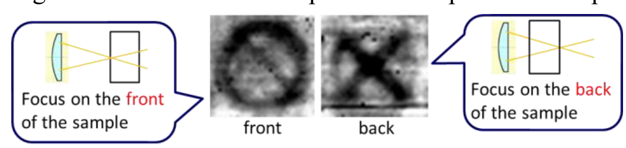

Figure 6: Measurement results of the cross-section imaging.

THz-CT [8]

In order to obtain the clear cross-section images, we introduced the CT technique. The method for measurement of THz-CT is the same as X-ray CT. We scanned one-dimension for a certain section and measured transmission intensity of the THz light in QOD. Then we scanned one-dimension equally while turning the sample little by little. Finally, we reconstructed the section image.

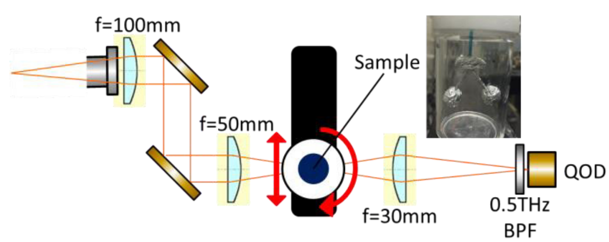

Figure 7: Measurement setup of THz-CT.

Figure 7 shows a schematic top view of the THz-CT. This time, we also installed a BPF of 0.5THz. Unlike cross-section imaging, we irradiated the THz light parallel to a section of the sample. The sample was placed on a rotating table mounted on a line scanning stage. We measured a focus point of the THz light by knife-edge method and installed the sample so that the focus position accorded with the central location on the sample. As a sample, we used the model of a cherry made by aluminium which was in the plastic case. The THz-CT images obtained at the red dash lines in Figure.8. In this experiment, we scanned one-dimension by 0.5mm steps while turning it from 0deg to 180deg in 5deg steps. The resulting reconstruct images are also shown in Figure.8. To reconstruct the cross-section images, we used the technique of the filtered back projection [9] that we programed in MATLAB. This sample varies in structure at the upper part, the intermediate part, the lower part. These reconstructed images (Fig.8) clearly demonstrated the sample characteristics of each position, distance, and diameter. Moreover, we confirmed that not only the cherry of the inside but also the plastic case of the circumference clearly visualized in these images. However, it takes much time to obtain a cross-section image. So it is necessary to take measures to reduce the influence of the fluctuation of the quantity of electron charge of the electron beam. We think that we may compose the three-dimensional images by obtaining such a cross-sectional slice image as much as possible, and piling up them.

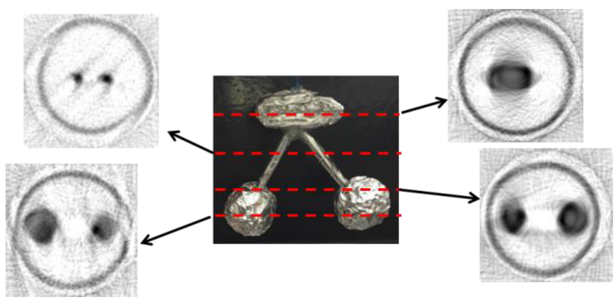

Figure 8: Measurement results of THz-CT.

CONCLUSION

As a result of this experiment, we succeeded in observing a high power THz light from the coherent Cherenkov radiation. The intensity of the THz light when we tilted the electron beam was about six times higher than that of un-tilted.

About THz imaging, we tried the obtainment of the cross-section images by two methods. As a result, we succeeded to analyse both cross-section imaging and THz-CT. As for the obtained cross-section images, THz-CT was clearer for the three-dimensional imaging.

As the future prospects, we will compose the three-dimensional images by obtaining such a cross-sectional slice image by THz-CT method as much as possible, and piling up them. Furthermore, we will think about an efficient imaging method in a short time by considering the fluctuation of the quantity of electric charge.

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