DEVELOPMENT OF THE HIGH POWER TERAHERTZ LIGHT SOURCES AT LEBRA LINAC IN NIHON UNIVERSITY*

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Abstract

Development of THz light source has been underway at Laboratory for Electron Beam Research and Application (LEBRA) at Nihon University in collaboration with National Institute of Advanced Industrial Science and Technology (AIST) since 2011. Basic research on coherent transition radiation (CTR) in the THz region has been carried out using the Parametric X-ray Radiation (PXR)-beam line of LEBRA. Since fiscal year 2016, the THz transport line has been constructed on the same axis as the PXR beam line taking the construction cost and simultaneous use of the two beams into account. Basic measurement and intensity upgrading test have been carried out for the THz lights generated on the PXR-generating electron beam line. The average intensity of the THz lights obtained at the output port in the accelerator room has been 5 mW. In 2016, the superposition transport system of the THz lights to the PXR beam-line was installed in a multi-purpose vacuum chamber. The fundamental experiment of THz lights was performed at the PXR output port. Construction of the THz transport beam-line and the property of the THz lights is discussed in the report.

INTRODUCTION

Research of a high performance electron linac for the generation of Free Electron Laser (FEL), Parametric X-ray Radiation (PXR) and THz lights has been continued at the Laboratory for Electron Beam Research and Application (LEBRA) of Nihon University as a joint research with the High Energy Accelerator Research Organization (KEK) and National Institute of Advanced Industrial Science and Technology (AIST) [1], [2], [3].

The LEBRA linac consists mainly of the 100 kV DC electron gun, the buncher section and the three 4 m long accelerating tubes. The RF power sources have been powered by two S-band klystrons (Mitsubishi Electric Corporation: PV-3030A1, the peak output power of 20 MW, the repetition rate of 12.5 Hz and the pulse duration of 5 ~ 20 μs). Specifications of the LEBRA electron linac are listed in table 1. The saturated FEL lasing has been achieved in the wavelength region of 0.4~6 μm [1], [4]. The PXR generator covers the X-ray energies from 4 to 34 keV by using Si(111) and Si(220) planes as the target [2]. THz light source development in the FEL beam-line has been carried out since 2011[3].

This THz light of FEL line has been used for non-destructive testing of concealed metals and biological imaging [5], [6]. Based on the results of the THz light source development in the FEL line, higher power THz light source line has been constructed in the PXR line since 2016.

Table 1: Specifications of the LEBRA 125 MeV Electron Linac and Light Sources

Maximum Energy	125	MeV
DC gun voltage	-100	kV
Accelerating RF frequency	2856	MHz
Klystron peak RF power	30	MW
Number of klystrons	2	
Macropulse duration	5~20	μs
Repetition rate	2~12.5	Hz
Macropulse beam current	200	mA
Energy spread (FWHM)	0.5~1	%
FEL wavelength	0.4~6000	μm
PXR energy	4~34	keV
THz wavelength	0.1~2	THz

THz LIGHT SOURCES OF PXR BEAM LINE

For the development of high-intensity terahertz light source, the basic measurement of THz light source (coherent transition radiation: CTR) at PXR line has been performed. A titanium plate seat with a thickness of 50 μm and measures 80 mm by 60 mm was installed in an up/down drive mechanism for the profile monitor in the vacuum of PXR beam line. The CTR source target is set at an angle of 45 degrees to the electron beam axis and the CTR light is extracted through to the upper atmosphere side through the vacuum viewport. The quartz crystal with a thickness of 5.5 mm in diameter φ 100 mm is used for the vacuum window material (Fuji Ideck, Inc. [7]). The energy measurement of CTR was carried out using a power sensor (Ophir 3A-P-THz) with calibration for terahertz wavelengths. The average power of the CTR was measured approximately 1 mJ (macro pulse 4.5 μs, a micro pulse charge of 23 pC) near the light source point in the frequency range of 0.1 ~ 2.0 THz [8], [9]. Based on this measurement result, optical mirrors were installed to transport THz light to a constantly accessible laboratory.

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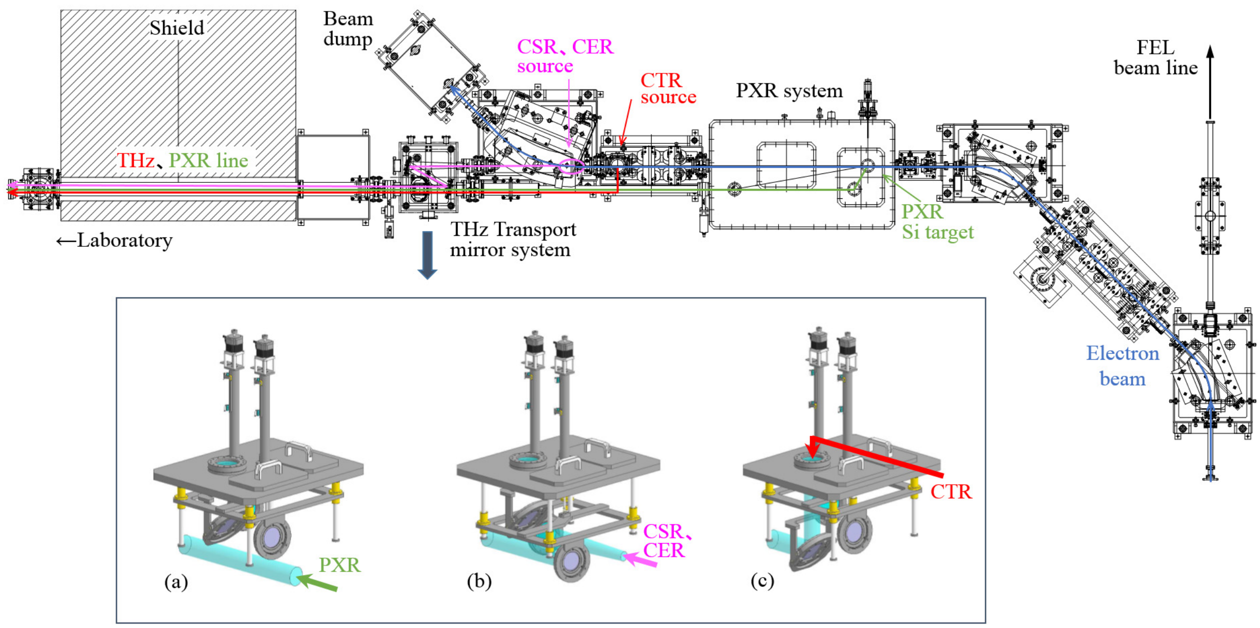


Figure 1: Top view of the LEBRA-PXR beam-line and the THz transport optical system. In addition to the PXR beam, in order to transport the CER and the CSR lights generated in the bending magnet section of the PXR beam-line, this the transport system can be switched according to the purpose. (a): PXR transport mode. (b): Forward CER-THz and CSR transport mode. (c): Backward THz-CTR transport mode.

THz TRANSPORT OPTICAL SYSTEM IN PXR BEAM LINE

Figure 1 shows the external view of the LEBRA-PXR beam-line and the THz transport optical system. The PXR generating system is connected to the linac through two 45 degrees bending sections. PXR is generated by irradiating the Si single crystal with an electron beam.

The transport optical system of the THz was installed in the multipurpose vacuum chamber on the downstream side of the PXR beam-line. In addition to the PXR beam, in order to transport the CER and the CSR lights generated in the bending magnet section of the PXR beam-line, this the transport system can be switched according to the purpose.

In the future, simultaneous transportation of THz and X-rays will be planned by using the thin plate Beryllium in the mirror in the transport system.

TEST AND PROBLEM OF THz TRANSPORT SYSTEM

As a result of the intensity and the spectrum measurement of the THz light after transportation, it was confirmed that there is not any problem in the transport line of CER and CSR although it is lower than the power of near the CTR light source point. The THz-CER transported to the laboratory was measured at an output power of 1 mW (Macropulse beam current: 94 mA, macropulse duration: 5 μs and repetition rate: 5 pps) and a spectrum at a peak of 0.3 THz up to around 1 THz. The THz energy was measured by a calibrated THz energy meter (Ophir 3A-P-THz) [10]. The spectrum of THz-CER was measured using a Martin-Puplett type interferometer and the result is shown in figure 2 [9], [11]. The output power was slightly fluctuating due to the influence of the electron beam, but the transport to the laboratory of THz-CER light was successful.

On the other hand, even if it was taken into consideration the unnecessary attenuation due to the water vapor absorption in the CTR transport line, the power of

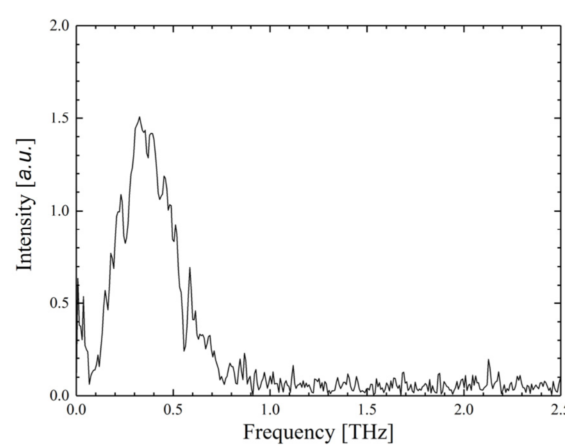
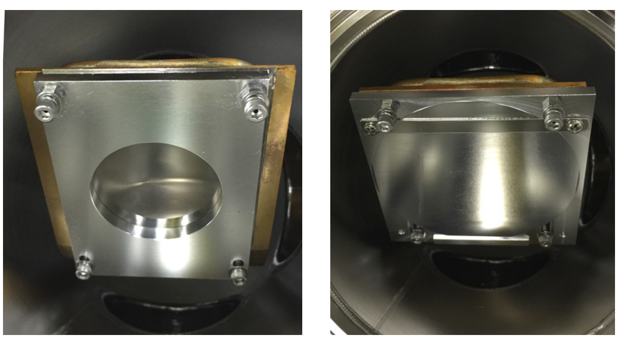


Figure 2: The spectrum of THz-CER measured using a Martin-Puplett type interferometer. The output power of 1 mW (Macropulse beam current: 94 mA, macropulse duration: 5 μs, repetition rate: 5 pps) and a spectrum at a peak of 0.3 THz up to around 1 THz.

the CER light compared to the vicinity of the light source point was attenuated significantly to less than one-tenth. From these results, it was shown that there is a problem in the CTR transport system. The condition of the CER target used for the light source was seen as the cause of the decrease in the transport rate. It appears that the transport efficiency of the CTR THz light has decreased due to the disturbance of the generated wavefront because the target of titanium in the rough surface state was utilized.

To solve the problem that the titanium target was replaced with a Si single crystal plate (diameter: φ76 mm, thickness: t0.2 mm) with high surface accuracy used for generation of PXR. This silicon wafer has been coated with a thickness of 10 μm aluminium. Figure 3 shows the appearance of the target before and after the replacement. The new target is only slightly pressed and fixed with a thin plate. However, the increase in the transport rate of the CTR light has not been achieved in the measurement performed after the exchange. Additionally, the absorbing rate in the THz band of the vacuum window installed in the transportation line has been only about 10% difference from the other windows, and therefore it turned out that there has been a cause in other parts of the THz-CTR transport line.



(a) (b)

Figure 3: The appearance of the target before and after the replacement. (a) The target of titanium in the rough surface state, (b) The new target of a silicon wafer has been coated with a thickness of 10 μm aluminum. This target is only slightly pressed and fixed with a thin plate.

SUMMARY

The THz transport line has been constructed on the same axis as the PXR beam line taking the construction cost and simultaneous use of the two beams into account. The transport optical system of the THz was installed in the multipurpose vacuum chamber on the downstream side of the PXR beam line.

As a result of the intensity and the spectrum measurement of the THz light after transportation, it was confirmed that there is no problem in the transport line of CER-THz and CSR-THz. The CER-THz transported to the laboratory was measured at an output power of 1 mW and a spectrum at a peak of 0.3 THz up to around 1 THz. The transport to the laboratory of THz-CER light was successful.

On the other hand, the power of the THz-CTR light compared to the vicinity of the light source point was attenuated significantly to less than one-tenth, from these results, it was shown that there is a problem in the CTR transport system. To solve the problem that the titanium target was replaced with a Si single crystal plate with high surface accuracy used for generation of PXR. However, the increase in the transport rate of the CTR light has not been achieved in the measurement performed after the exchange. The cause of the low transport efficiency of the CTR THz still remains unresolved, and further improvement of this THz transport system has been underway.

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