[WEPAB052]

Development of an EO sampling system for the analysis of THz waves generated by Coherent Cherenkov Radiation

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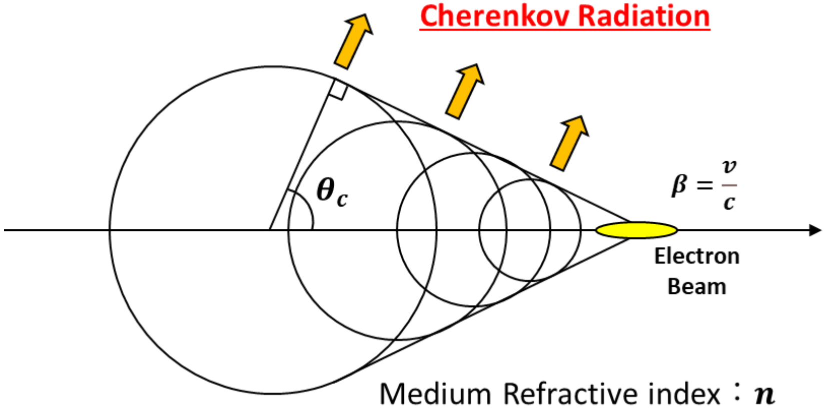
Abstract

THz waves, located between microwaves and light waves, have transparency, directionality and fingerprint spectrum of specific materials. Therefore, they are expected to be useful for various applications.
We have been studying THz waves generation via Cherenkov radiation with electron beams from a photocathode rf-gun. In our early studies, we have succeeded in the generation of coherent Cherenkov radiation by tilted electron beams using an rf-deflector.
Furthermore, we have generated quasi-monochromatic THz waves by spatially modulated electron beams and have succeeded in its measurement by bandpass filters.
This study aims to obtain the THz wave form in time domain by electro-optic (EO) sampling, which is an useful detection system for obtaining the information of the electric field and the phase simultaneously with high S/N.
In this conference, we report about our probe laser system, results of the time-domain spectroscopy measurement of THz waves by EO sampling, and future prospects.

➢ Cherenkov Radiation



Condition :

Cherenkov radiation occurs when an electron travels faster than the phase velocity of light in a medium.

➡ $v > c/n$

Characteristic :

An electron generates the radiation to the angle, called the Cherenkov angle, that depends on the velocity of it and the refractive index of the medium.[1]

➡ **Cherenkov angle: $\theta_c = \cos^{-1}(1/n\beta)$**

➢ Coherent Radiation

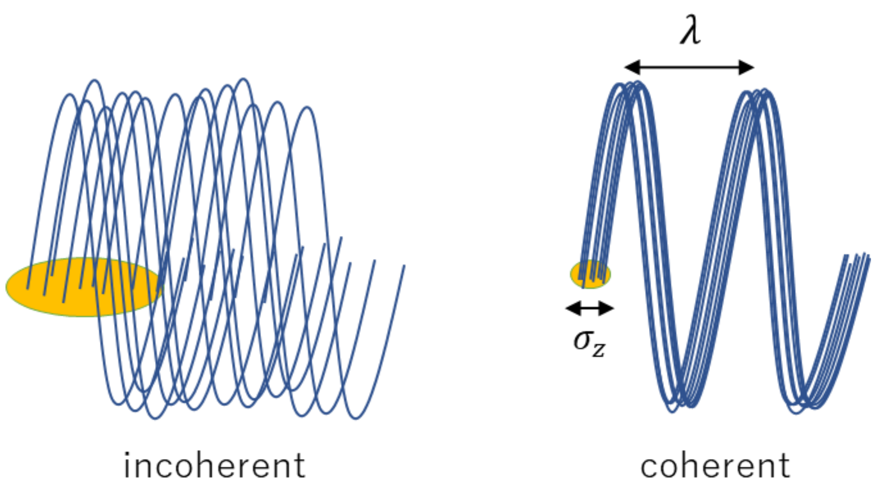
Coherence:

Relationship between the phases of radiations at a single frequency[2]

$$P(\lambda) = P_0(\lambda)N\{1 + (N-1)f(\lambda)\}$$

$$= \begin{cases} P_0(\lambda)N \text{ (incoherent)} \\ P_0(\lambda)N^2 \text{ (coherent)} \end{cases}$$

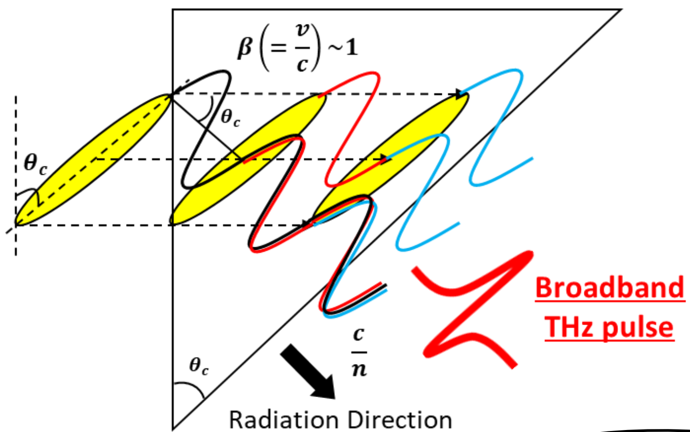
※ P : Radiation intensity from an electron bunch
P_0 : Radiation intensity from an electron
N : Number of electrons
(in our experiment : $\sim 10^{10}$)
$f(\lambda)$: form factor($0 \leq f(\lambda) \leq 1$)



$\sigma_z \gg \lambda$ **Condition** $\sigma_z \ll \lambda$

※σ_z : bunch length, λ : wavelength

THz pulse generation



- **Coherent Cherenkov radiation**

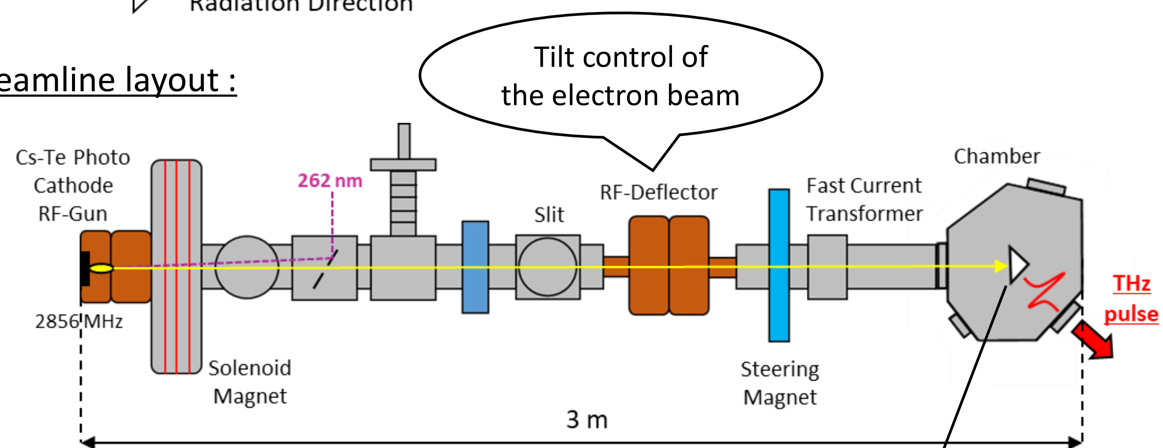
  Cherenkov radiation from each electron overlaps each other if the electron beam is tilted to the Cherenkov angle.

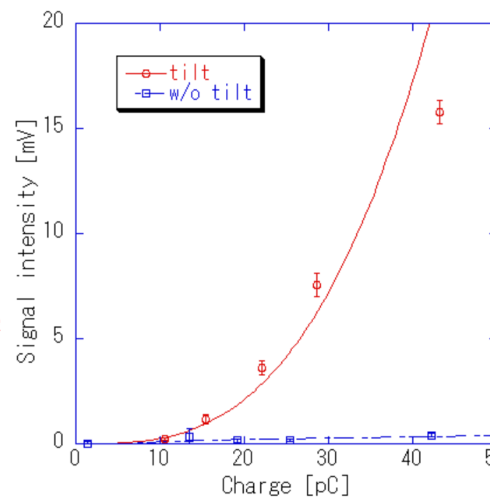
- **The spectrum** of the generated electromagnetic waves depends on **the electron beam size.**

  Our electron beam size : ~395 µm

  → THz pulse has broadband spectrum below 0.3 THz.

Beamline layout :





Beam parameters

Max charge	380 pC
Energy	4.8 MeV
Repetition frequency	5 Hz
Beam size(rms)	395 µm
Bunch length(rms)	1.1 ps

Target medium : TOPAS®

Characteristics across the THz band[3]

- Low absorption(< 3 cm^{-1})
- Constant refractive index

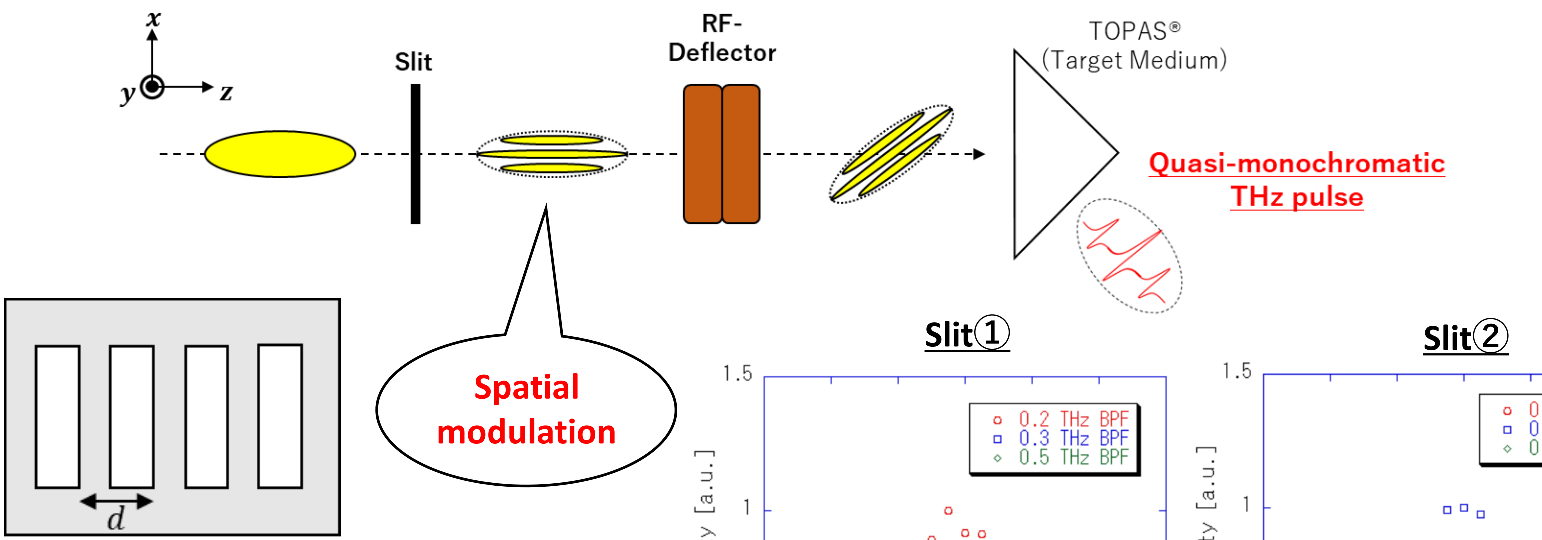
  $n = 1.53$

  → $\theta_c = 48.9$ deg

➢ Quasi-monochromatic THz pulse

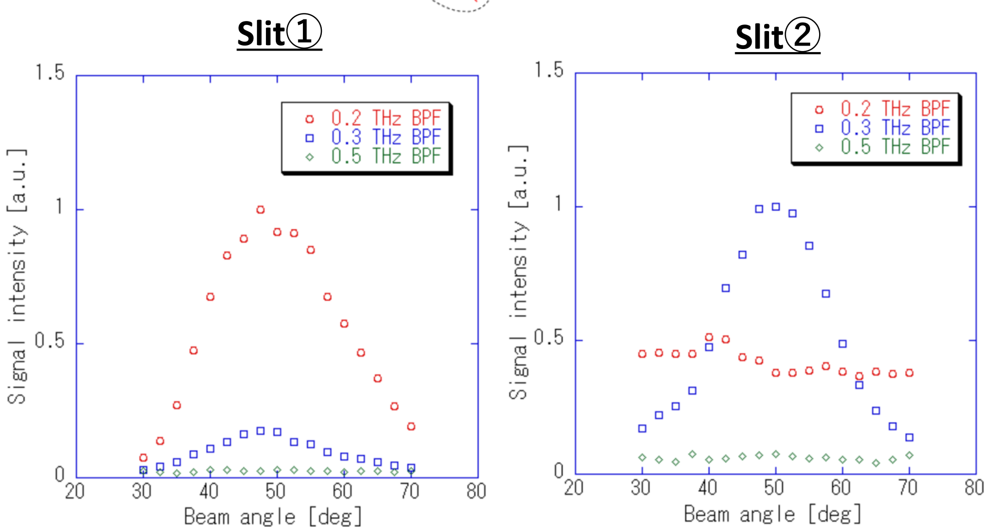
The slit in front of the RF-Deflector gives the spatial modulation to the electron beam.

→ **The radiation of a specific frequency corresponding to the slit period becomes coherent.**



The slit designs

	Slit①	Slit②
Slit period d	1.3 mm	0.8 mm
Corresponding frequency f	0.2 THz	0.33 THz



The frequency corresponding to the period of each slit is enhanced respectively.

➢ Electro-Optic(EO) sampling

EO sampling is a detection method that can acquire the waveform of the THz pulse in time domain.

Method[4]:

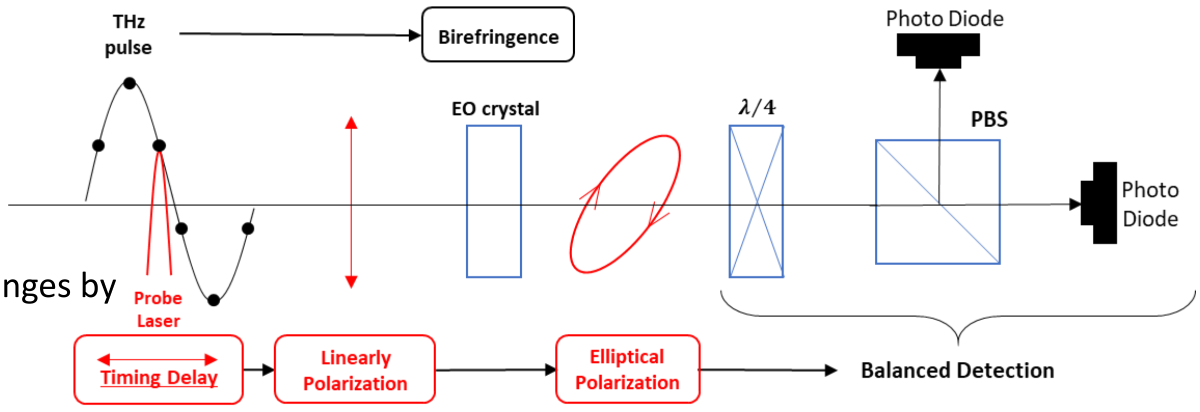
The THz pulse induces birefringence in the EO crystal depending on its electric field strength.

↓

The polarization of the probe laser changes by the magnitude of the birefringence.

↓

The waveform of THz pulse in time domain can be reproduced by scanning the timing of the probe laser.



The following graphs show the results of the broadband THz pulse by EO sampling.

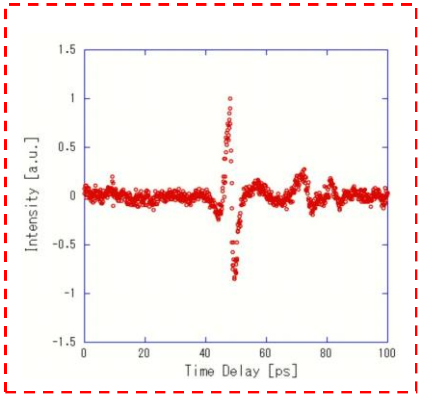
Characteristics[4] :

The electric field strength and the phase of THz pulse can be obtained simultaneously with high S/N.

Aim :

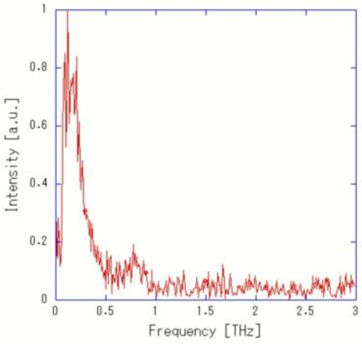
To obtain waveform of quasi-monochromatic THz pulse in time domain by EO sampling.

Time domain F



Fourier Transform →

Spectrum ω

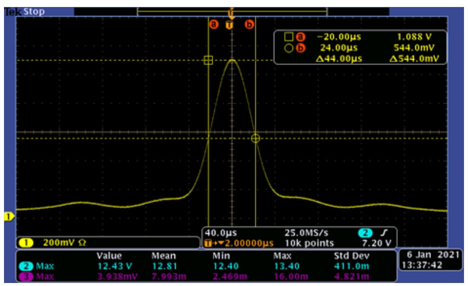


➢ Probe Laser System

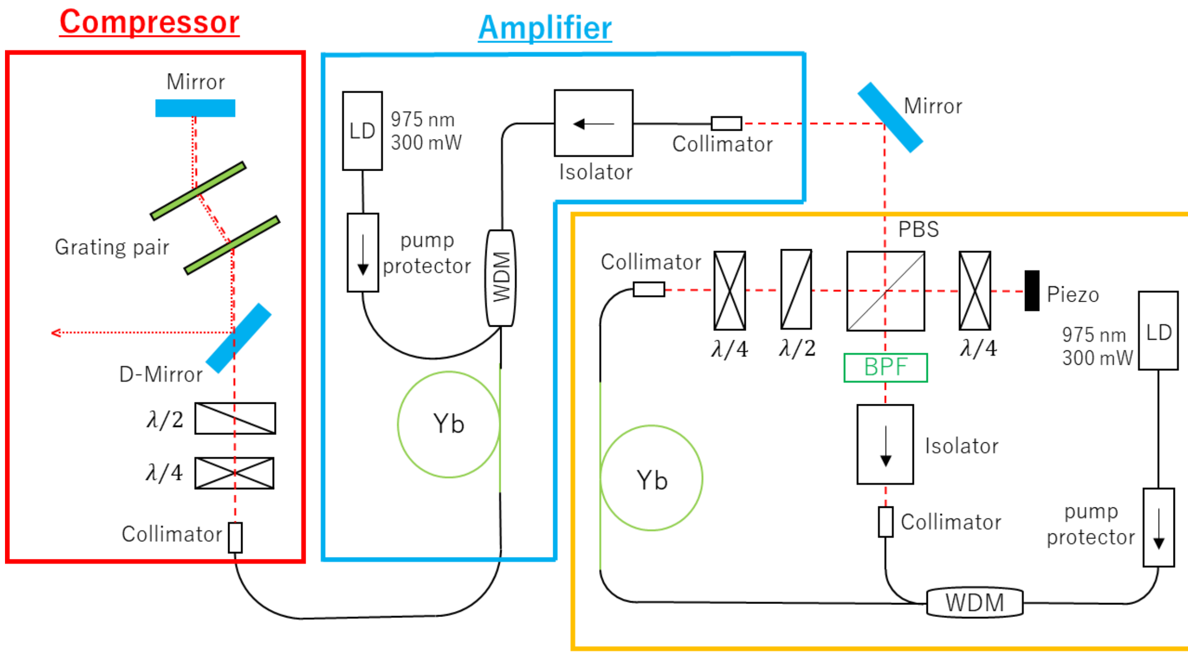
Probe Laser System consists three component,

Oscillator, **Amplifier**, and **Compressor**.

Autocorrelation waveform



※measured by autocorrelator



Oscillator (ANDi)

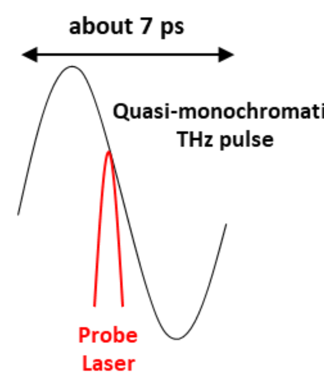
Laser parameters

Center wavelength	1030.4 nm
Repetition frequency	39.66 MHz
Pulse energy	**3.73 nJ**
Spectrum width(FWHM)	21.5 nm
Transform limited pulse(FWHM)	72.4 fs
Pulse duration(FWHM)	**180 fs**

- Expected micro pulse in the THz pulse duration(FWHM) : 2~3 ps

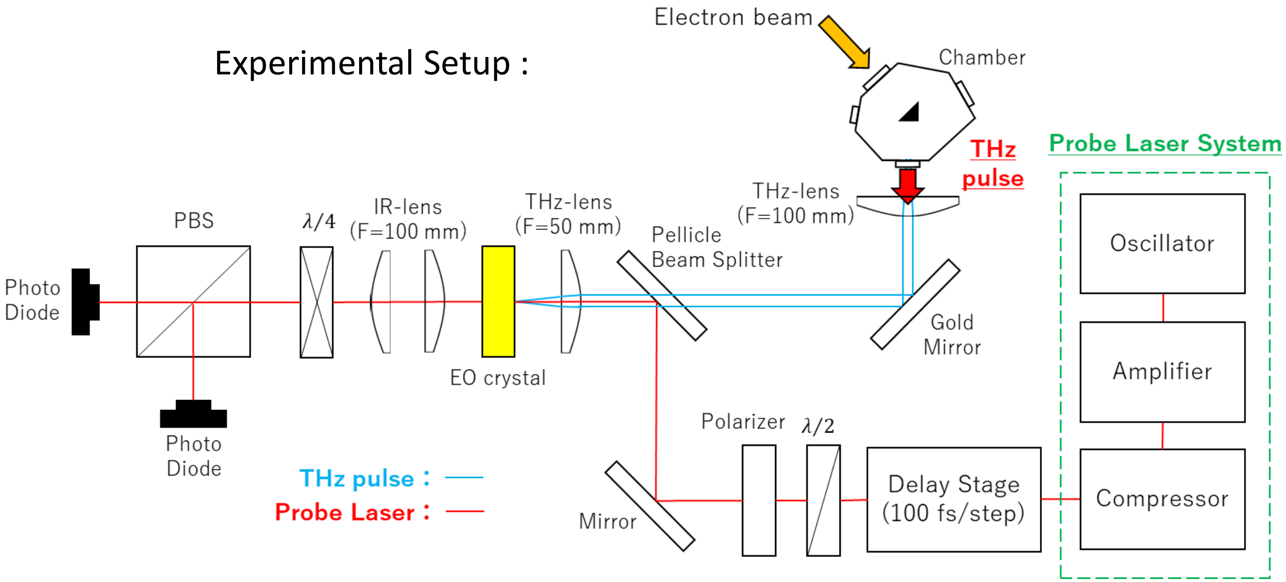
→ **Required probe pulse duration(FWHM) : Sub-ps**

- our probe pulse (FWHM) = **180 fs**

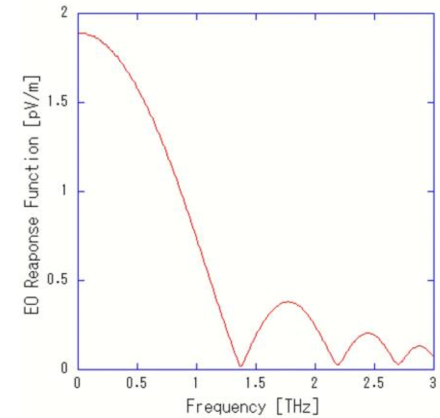


➢ EO sampling measurement

Experimental Setup :



EO crystal : 1 mm ZnTe



Sensitivity to THz pulse[4]
(Yb(1030 nm) and 1 mm ZnTe)

Result : **The waveform of the quasi-monochromatic THz pulse could not be obtained by EO sampling.**

The following causes and solutions can be considered:

①The intensity of the quasi-monochromatic THz pulse was too weak.

⟶ Amplification of the THz pulse intensity using an optical enhancing cavity.

②The accuracy of the timing synchronization was not good enough(=1 ps).

⟶ Optimization of the timing synchronization system to improve the accuracy and the stability.

Conclusion

- We have succeeded in the generation of THz pulse by coherent Cherenkov radiation.
- Quasi-monochromatic THz pulse generation using spatially modulated electron beams and its measurement with bandpass filters have been successfully done.
- We have succeeded in the development of a probe laser system with the pulse duration as short as 180 fs.
- **The waveform of quasi-monochromatic THz pulse in time domain could not be detected by EO sampling**.
- We aim to obtain the waveform of quasi-monochromatic THz pulse in time domain by the following solutions.
  - Developing an optical enhancing cavity for the THz pulse ➡ Refer to WEPAB048 (P.Wang, *et al.*)
  - Optimizing the timing synchronization system

Reference

[1] J.V.Jelley, *et al.*, Br. J. Appl. Phys. 6, 227 (1955)

[2] Toshiharu Takahashi, *et al.*, Phys. Rev. E 62, 8606 (2000)

[3] Paul D. Cunningham, *et al.*, J. Appl. Phys. 109, 043505 (2011)

[4] S.Casalbuoni, *et al.*, Phys. Rev. ST Accel. Beams 11, 072802 (2008)