Development of THz TDS system on the basis of the S-band compact electron linac

Ryunosuke Kuroda

Senior Researcher,
National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan
(Visiting lecturer, Waseda University, Tokyo, Japan)

Colleagues of THz research

Y.Taira, M. Tanaka, H. Toyokawa, K. Yamada (AIST)
M. Kumaki[1], M. Tachibana[1], K.Sakaue[1], K. Kan[2], M. Yoshida[3], H. Tomizawa[4]

[1] *RISE, Waseda University, Japan,*
[2] *ISIR, Osaka University, Japan*
[3] *KEK, Japan*
[4] *RIKEN, SPring-8 Center, Japan*

Outline

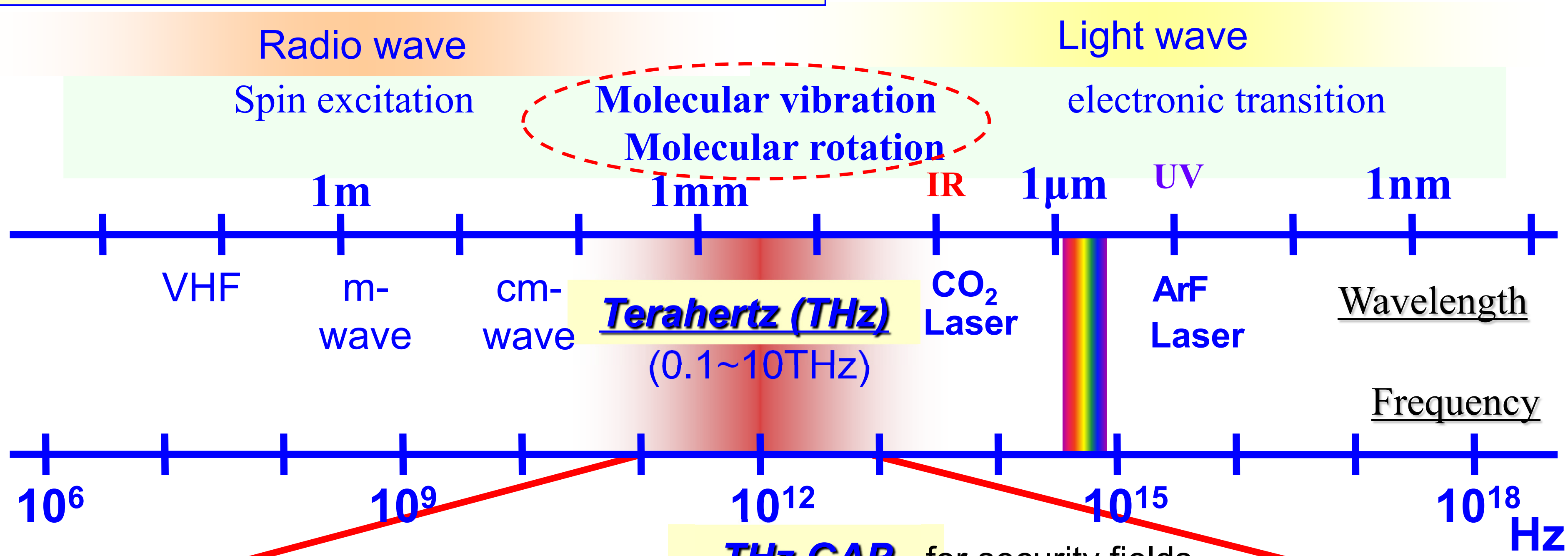
- Introduction
  - Instruction of THz region
  - Methods of THz generation
  - Coherent THz radiation (CSR, CTR in our case)
  - S-band compact electron linac and THz beam lines at AIST
- Measurement of THz-CTR characteristics

  THz-CTR Profile, Polarization, Frequency-range measurements
  with THz real-time camera, Polarizer and BPFs
- Present status of THz-CTR Time-domain spectroscopy (TDS)

  Setup of THz-CTR-TDS, Preliminary experiment results of THz-TDS with samples
- Summary

In collaborating with Central Custom Laboratory (Japan Custom) of Ministry of Finance Japan

THz region :(0.1 ~ 10 THz; 30μm ~ 3mm)

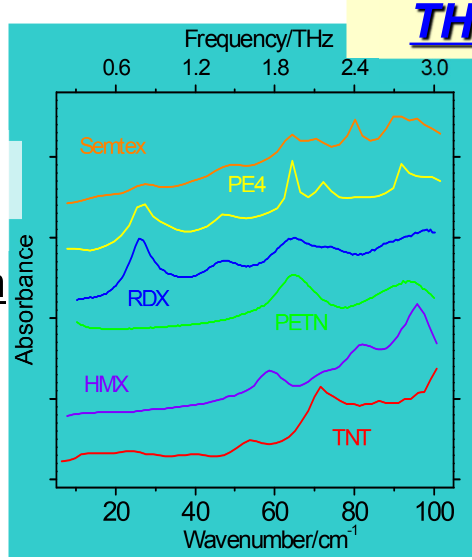


THz GAP for security fields

Inspection

Finger-print spectrum of explosives

Nature Photonics Vol. 2, 541 (2008)



Imaging

Science Vol. 297, 761 （2002）

Methods of THz generation

Type: Broadband (B), Monochromatic (M)

Peak power

Laser based

- Photoconductive antenna with fs-laser (B)
- Nonlinear crystal with fs-laser (B) or (M) — 100nw～10mW
- Parametric Oscillation（TPO, is-TPG）(M) — 10mW～1W

Accelerator based

High Peak Power

- Free electron laser（FEL）(M) — > 1 kW (up to MW)
- **Coherent radiation with ultra-short electron bunch (B)** — > 1 kW (up to MW)

Application Fields

Academic : Measurement of complex dielectric constant, reflective index (organic electroluminescence(EL), polymer…) …etc

Security : Inspection of explosives, illegal drug, handgun, knives …etc

Medical : Diagnostics of skin/ breast cancer …etc

However, THz radiation is strongly absorbed by the atmosphere (water)!
Low peak power THz source can not be applied to industrial uses.

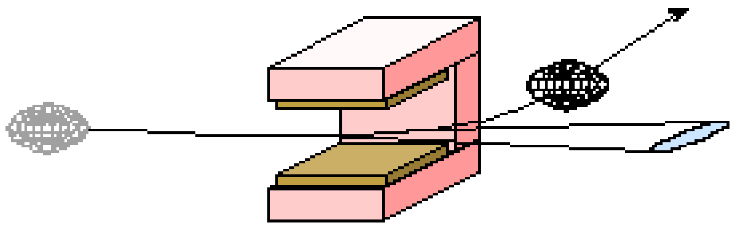
Therefore

For the in-situ measurement and the solvation sample measurement, High peak-power THz source is strongly required.

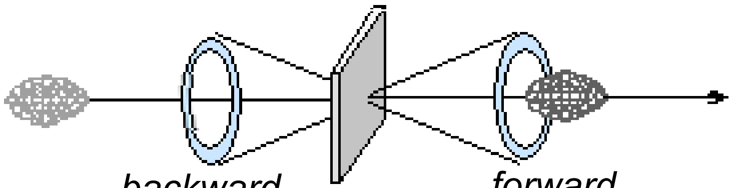
Coherent THz radiation

Coherent radiation methods

Coherent Synchrotron radiation (CSR)



Coherent Transition radiation (CTR)

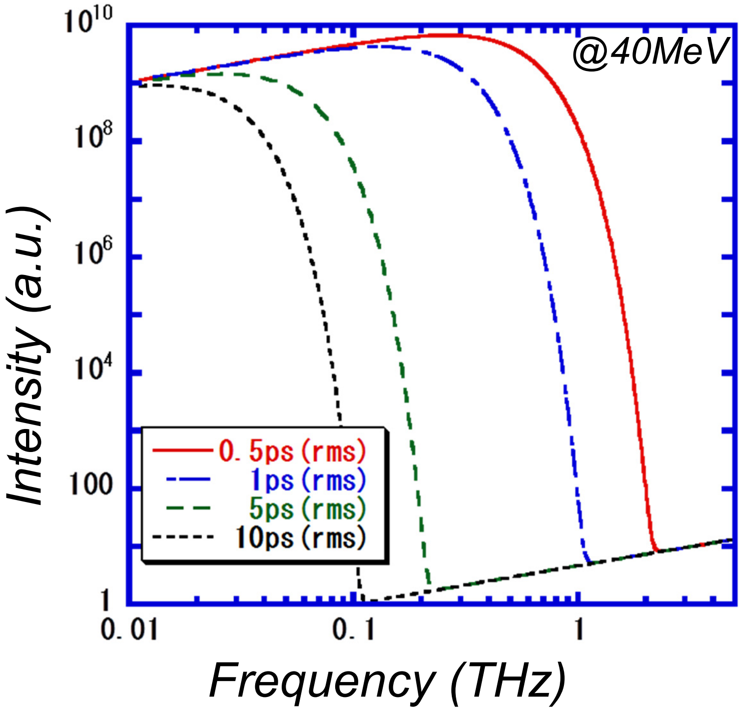


Critical frequency ω_c

$$\omega_c = \pi c / \sigma_l$$

Intensity of Coherent radiation

$$I_{tot} = I_{inc}(1+(N-1)f(\omega))$$



In our case

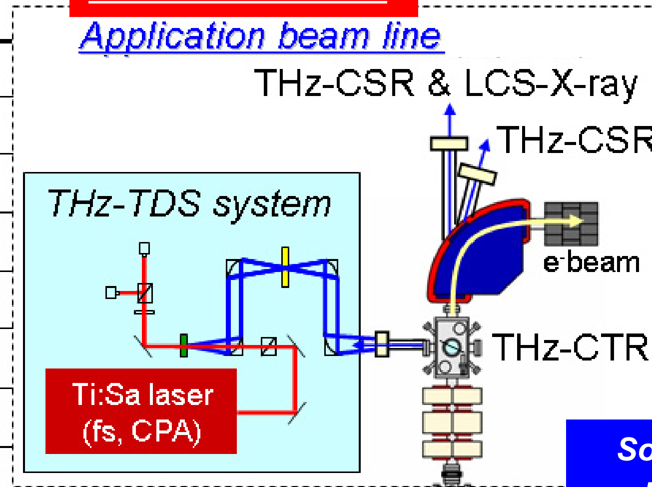
*THz **CSR** has been developed for*
THz imaging (only measure intensity deference
*THz **CTR** has been developed for*
THz time domain spectroscopy (TDS) .
(Fourier limited pulse, small spot size)

To generate the coherent THz radiation,
the electron bunch should be compressed to less than 0.5 ps.

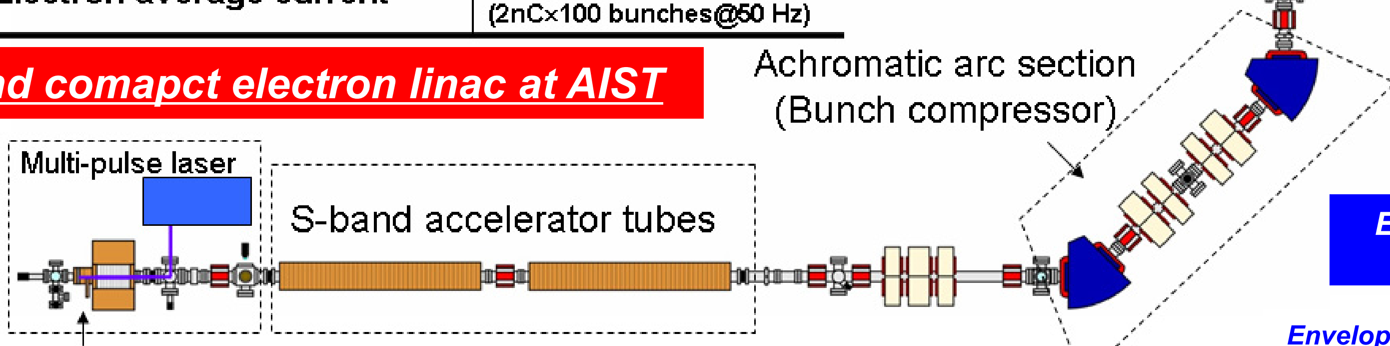
Electron beam specification

Electron energy (tunable)	10 – 42 MeV
Energy spread (rms)	0.2 – few %
Electron charge	0.5 – 5 nC
Electron bunch length	300 fs – 3 ps
Bunch number /macro pulse	1 – 100
Macro pulse rep. rate	1 – 50 Hz
Electron peak current	>1kA (@1nC, 1ps)
Electron average current	>10 μA (2nC×100 bunches@50 Hz)

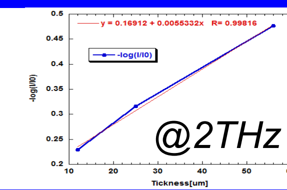
THz beamlines



S-band comapct electron linac at AIST

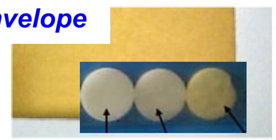


Solvation sample measurement



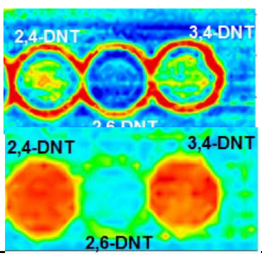
Explosive inspection Inside of Envelope

Envelope



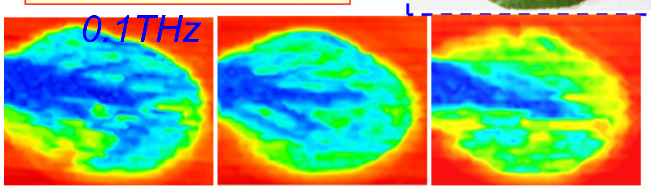
Isomers

2,4 2,6 3,4 DNT



Freshness measurement

In-situ water distribution imaging



0 hour 10 hours 14 hours

THz specification

THz freq.: 0.1 ~ 2 THz (up to 5 THz)
Pulse energy: >100 nJ
Peak power: >10 kW
Source: CSR for imaging
CTR for spectroscopy

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Measurement of THz-CTR characteristics

THz-CTR Profile measurement
with THz Camera *(made by NEC corp.)*

Ultra-short electron beam

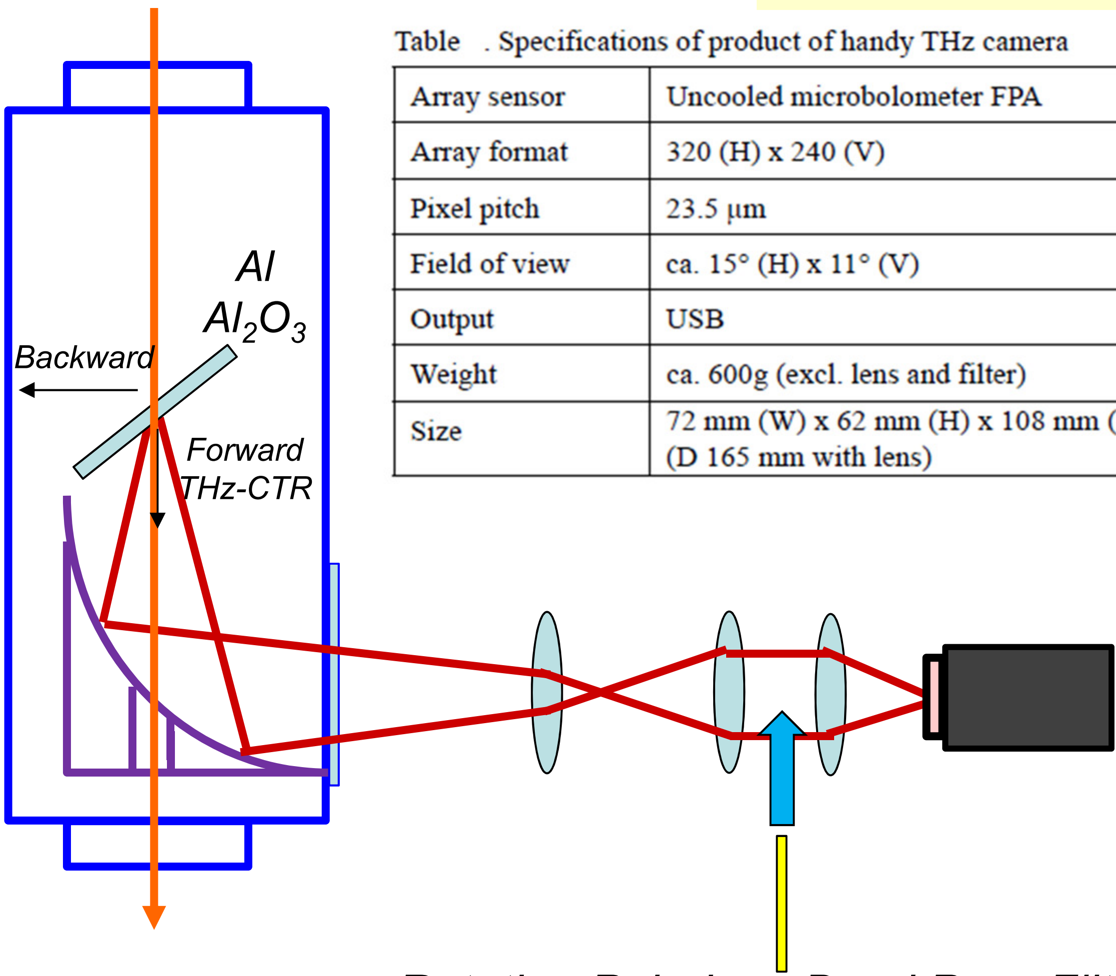
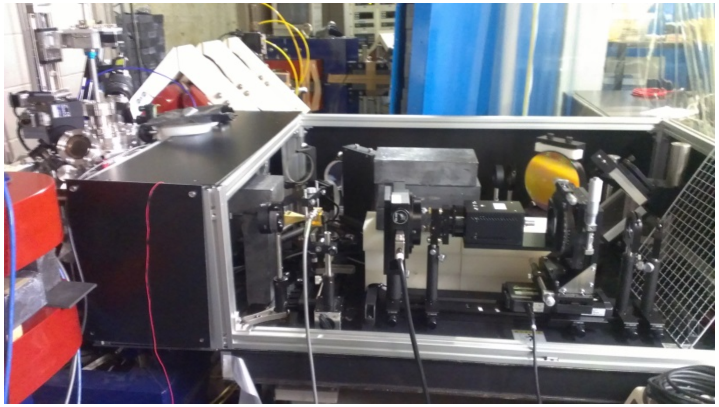


Table . Specifications of product of handy THz camera

Array sensor	Uncooled microbolometer FPA
Array format	320 (H) x 240 (V)
Pixel pitch	23.5 μm
Field of view	ca. 15° (H) x 11° (V)
Output	USB
Weight	ca. 600g (excl. lens and filter)
Size	72 mm (W) x 62 mm (H) x 108 mm (D) (D 165 mm with lens)

View area :7.5mm ×5.6mm
Frame rate: 30Hz

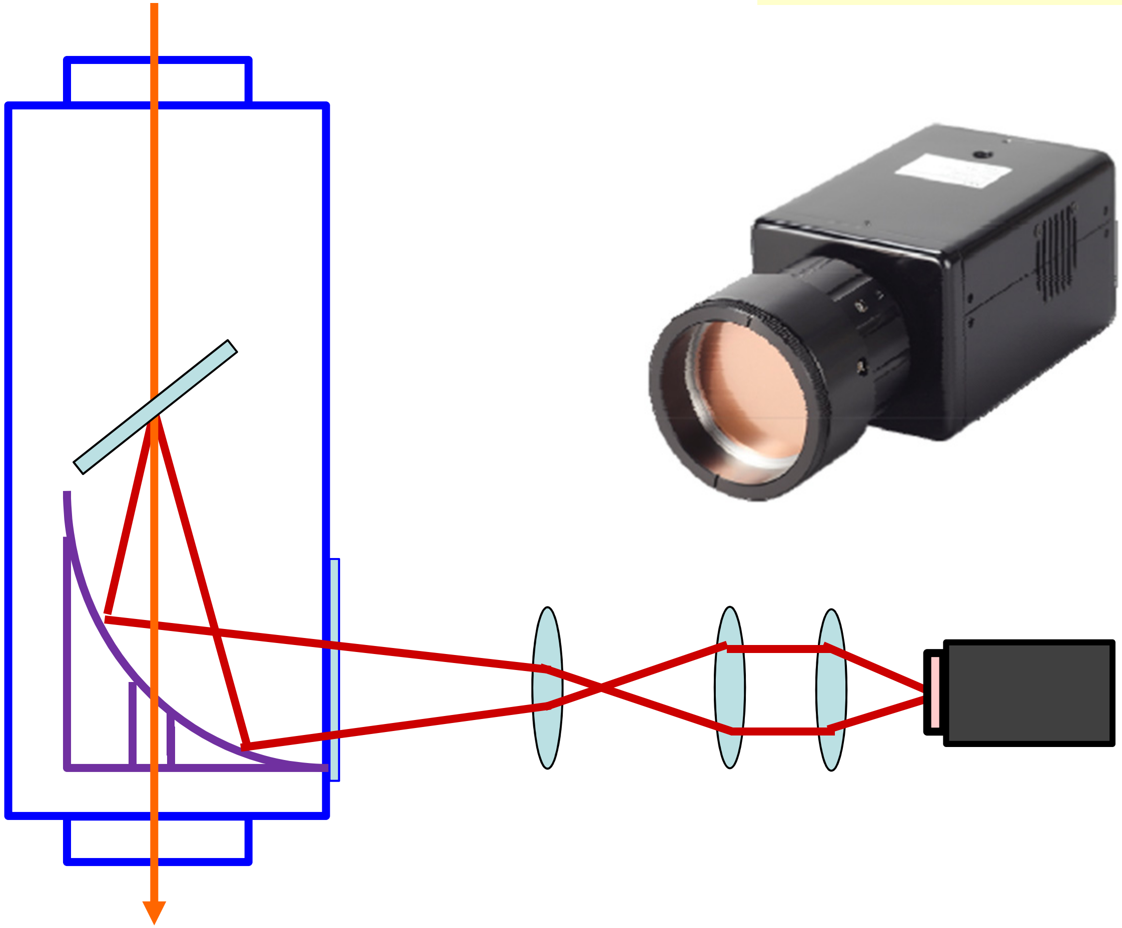


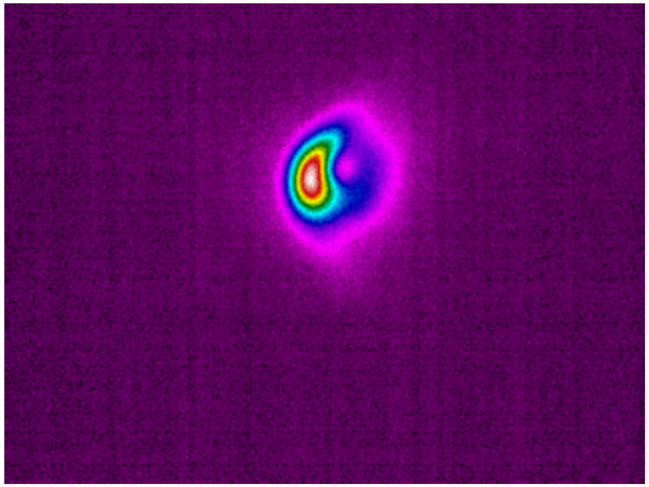
Rotating Polarizer, Band Pass Filter(BPF) etc

THz-CTR Profile measurement

THz-CTR Polarization measurement with THz Camera *(made by NEC corp.)*

Ultra-short electron beam





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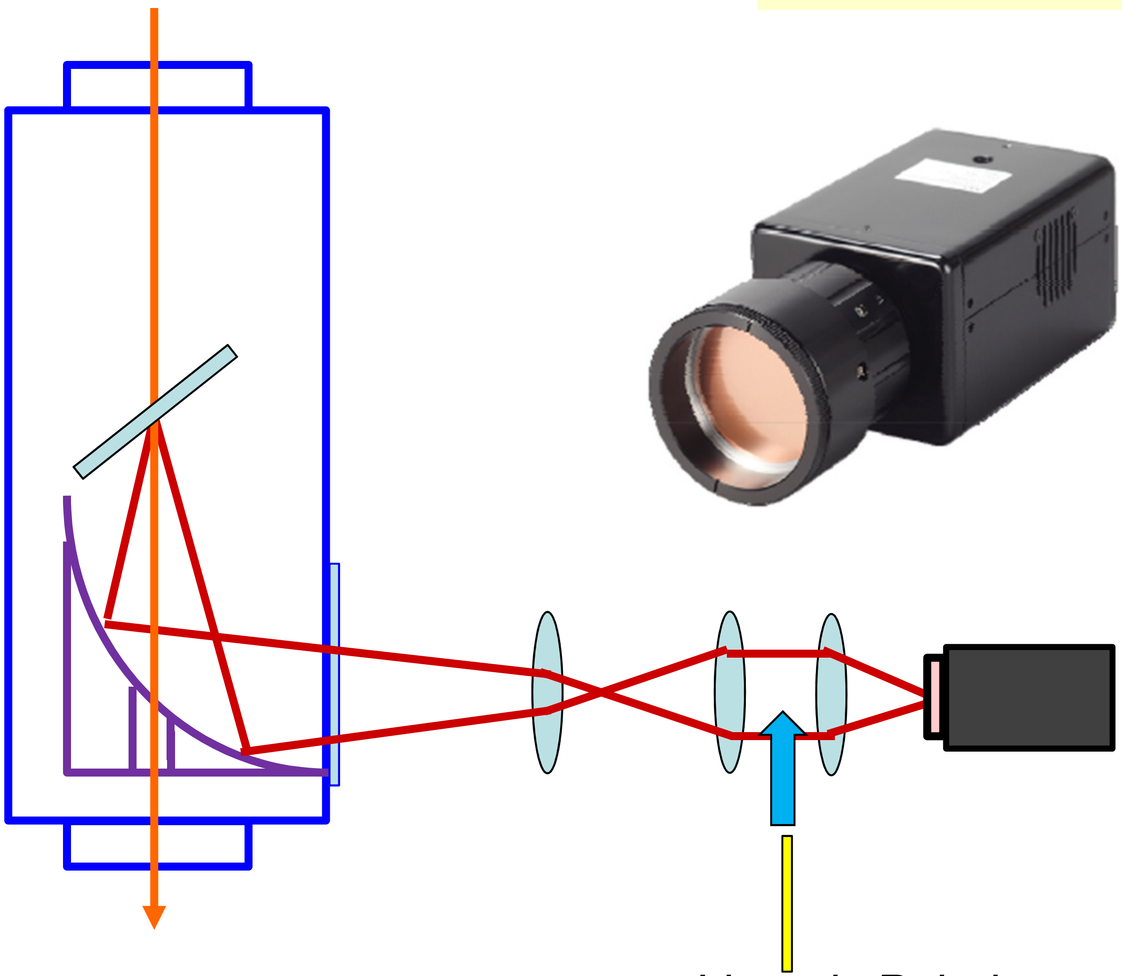
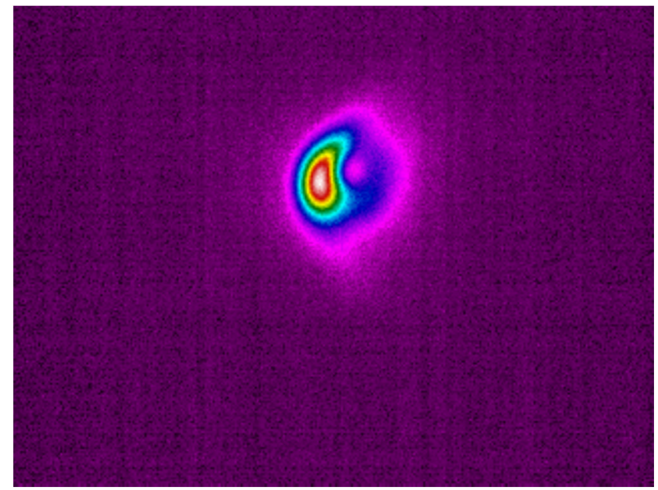
Ultra-short electron beam

THz-CTR Polarization measurement with THz Camera *(made by NEC corp.)*





Linearly Polarizer

THz-CTR Profile measurement

THz-CTR Polarization measurement
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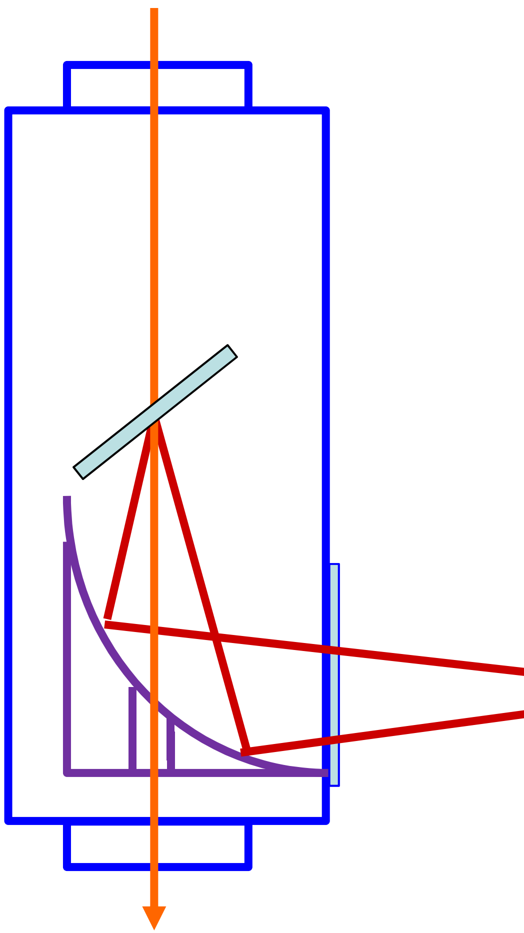
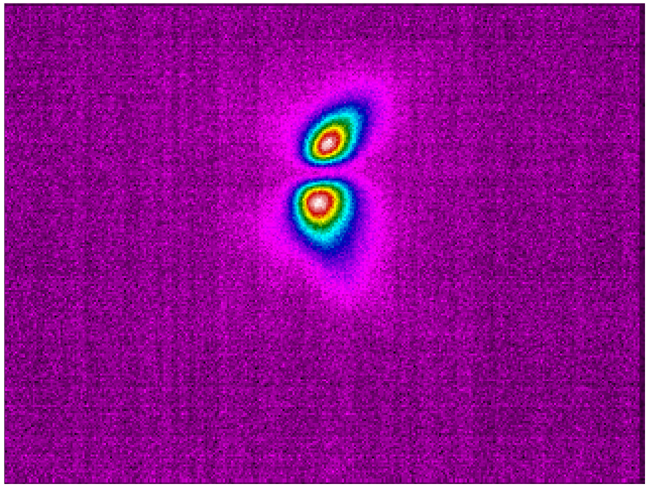
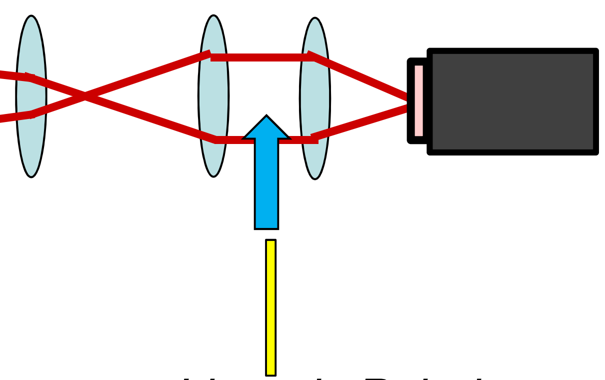
Ultra-short electron beam







Linearly Polarizer

THz-CTR Profile measurement

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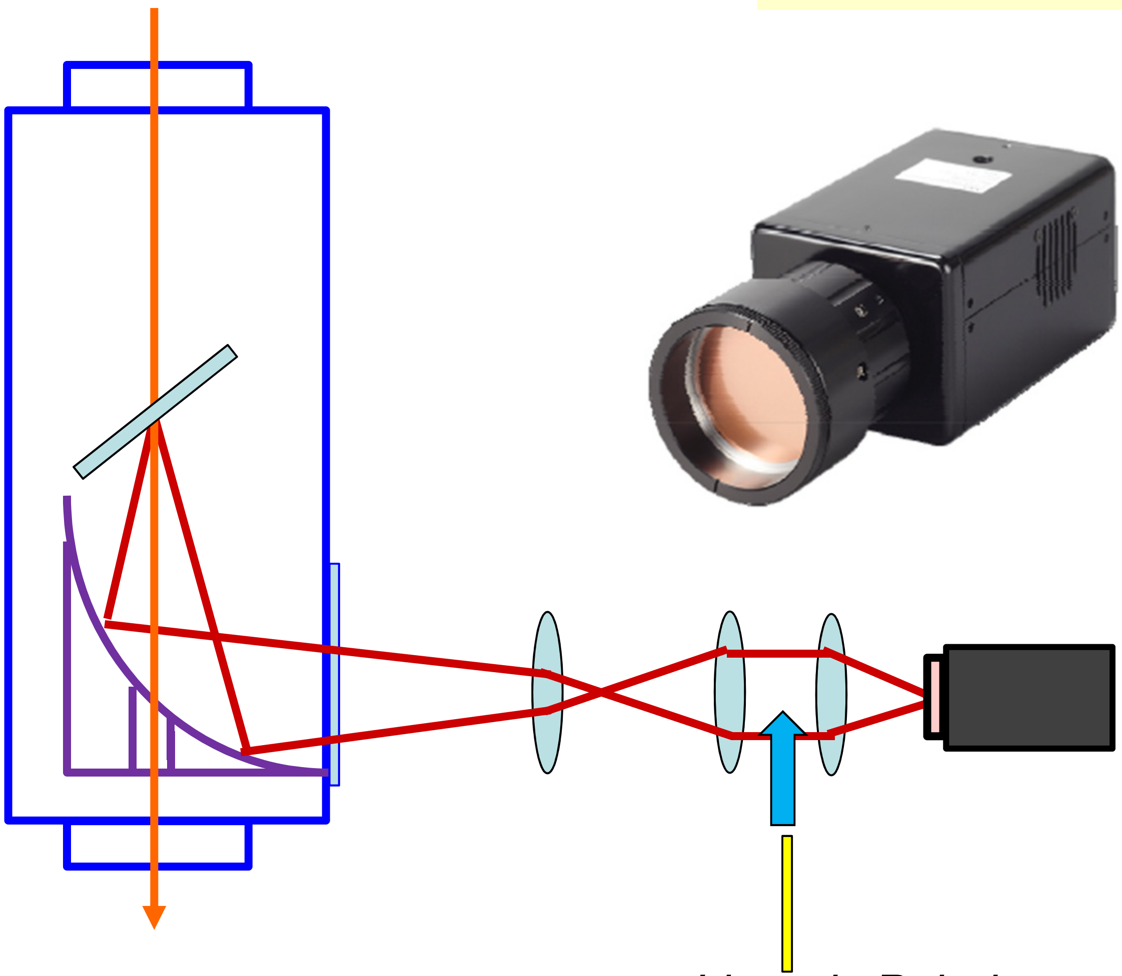

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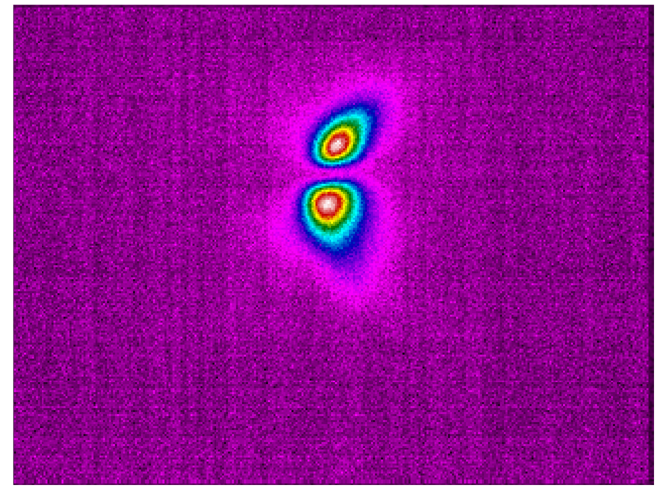

with Linearly Polarizer

THz-CTR Profile measurement

THz-CTR Polarization measurement
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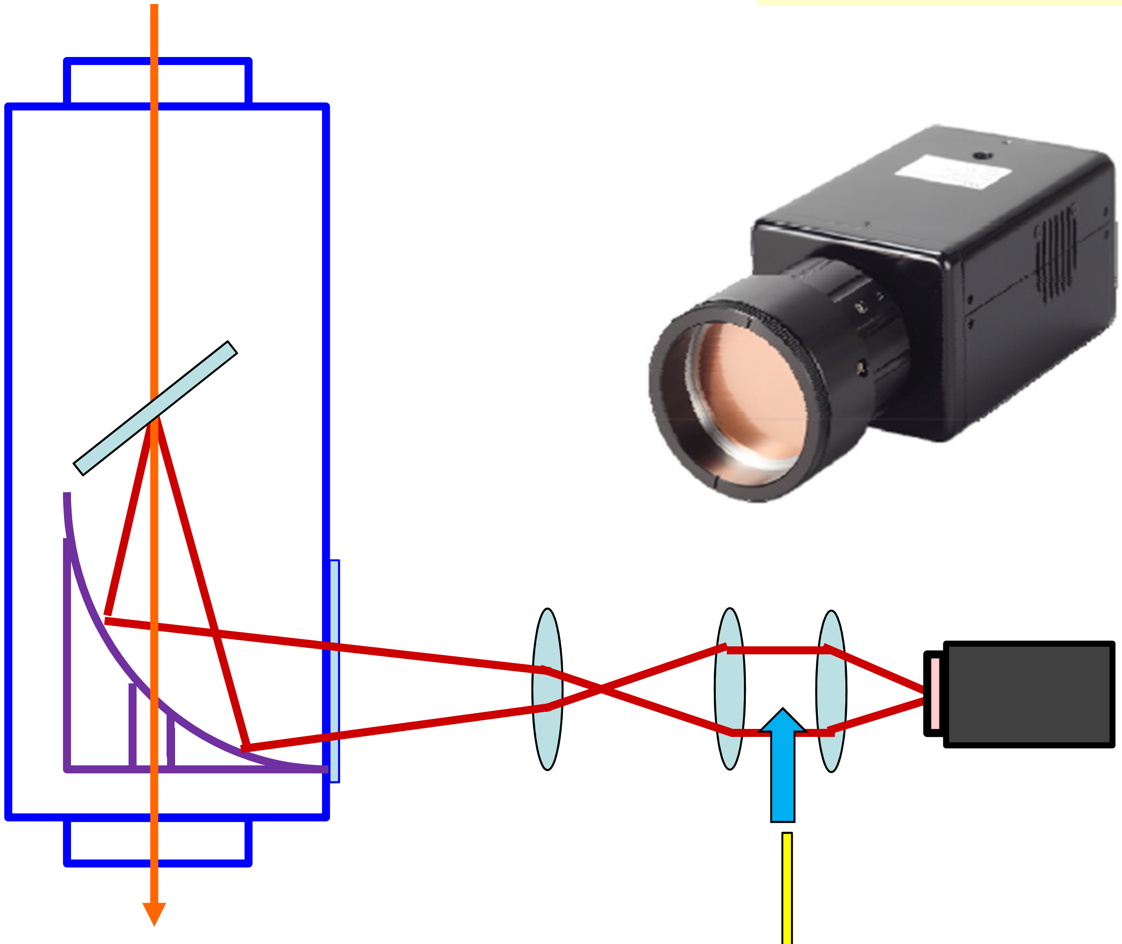
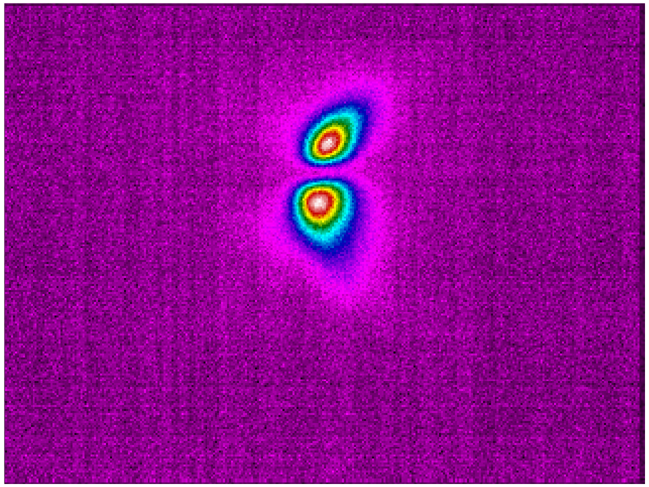
Ultra-short electron beam

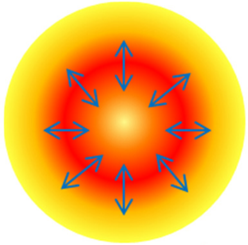


Linearly Polarizer



with Linearly Polarizer

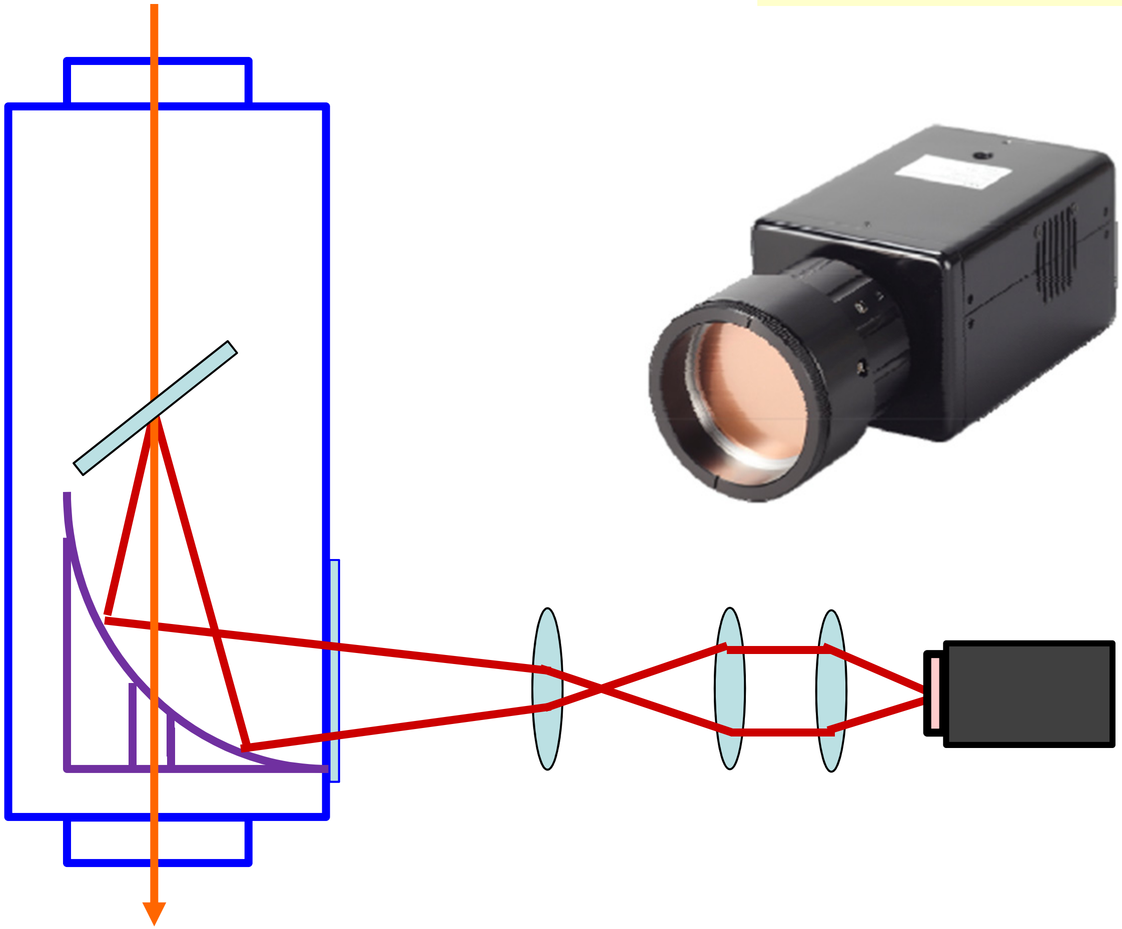
Radial polarization

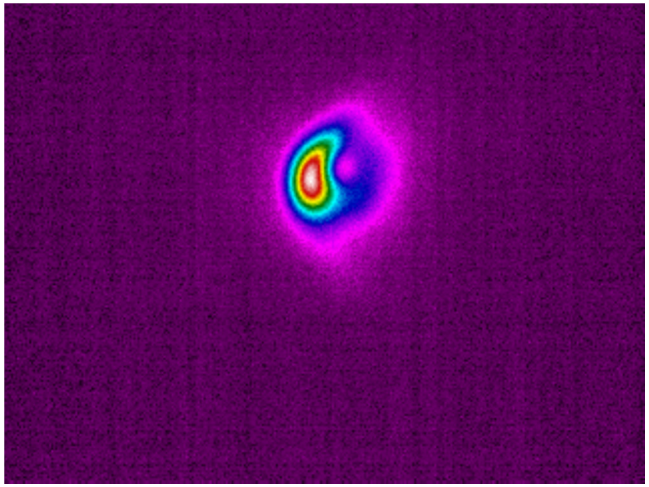


THz-CTR Profile measurement with BPF

THz-CTR measurement
with THz Camera *(made by NEC corp.)*

Ultra-short electron beam





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THz-CTR measurement
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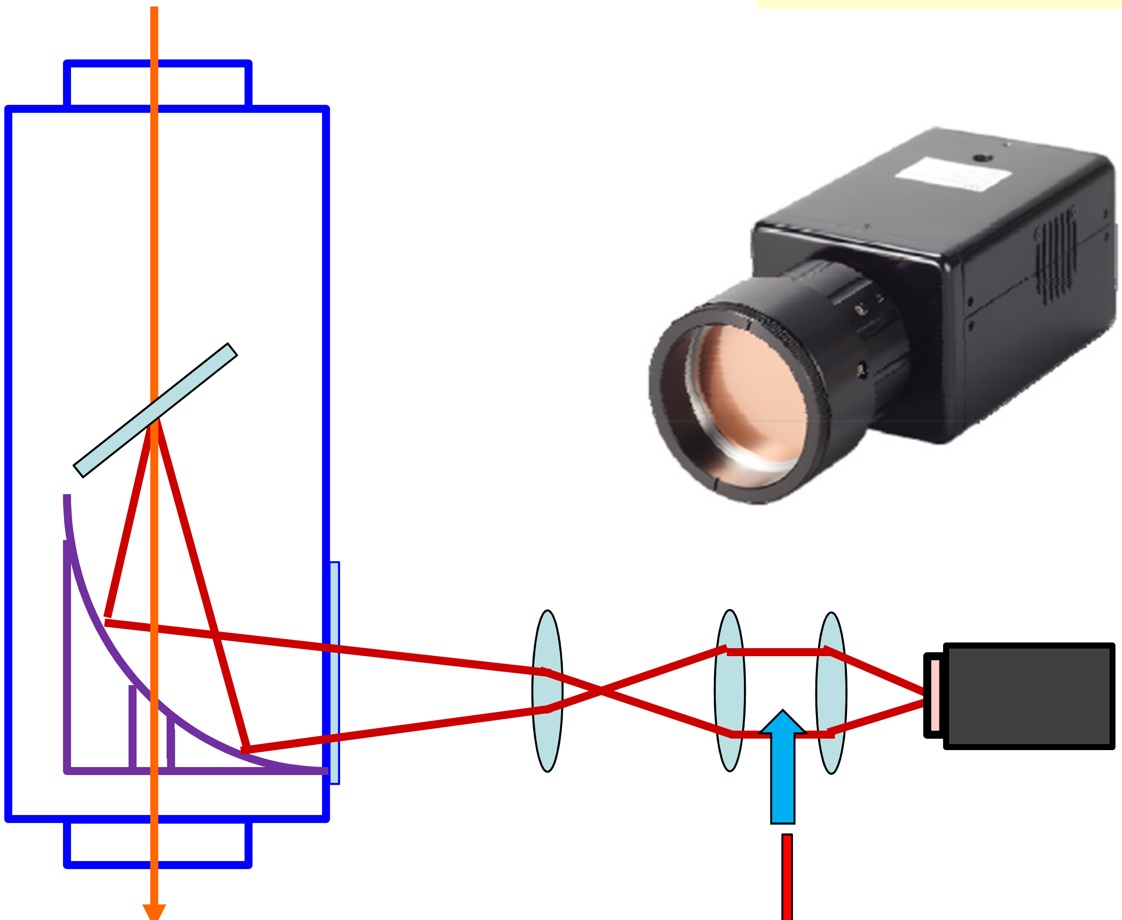

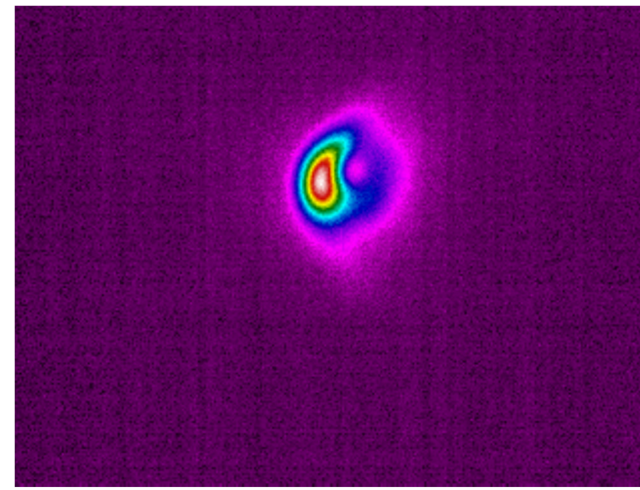

BPF

TYDEX® J.S.Co.

THz-CTR Profile measurement with BPF

THz-CTR measurement
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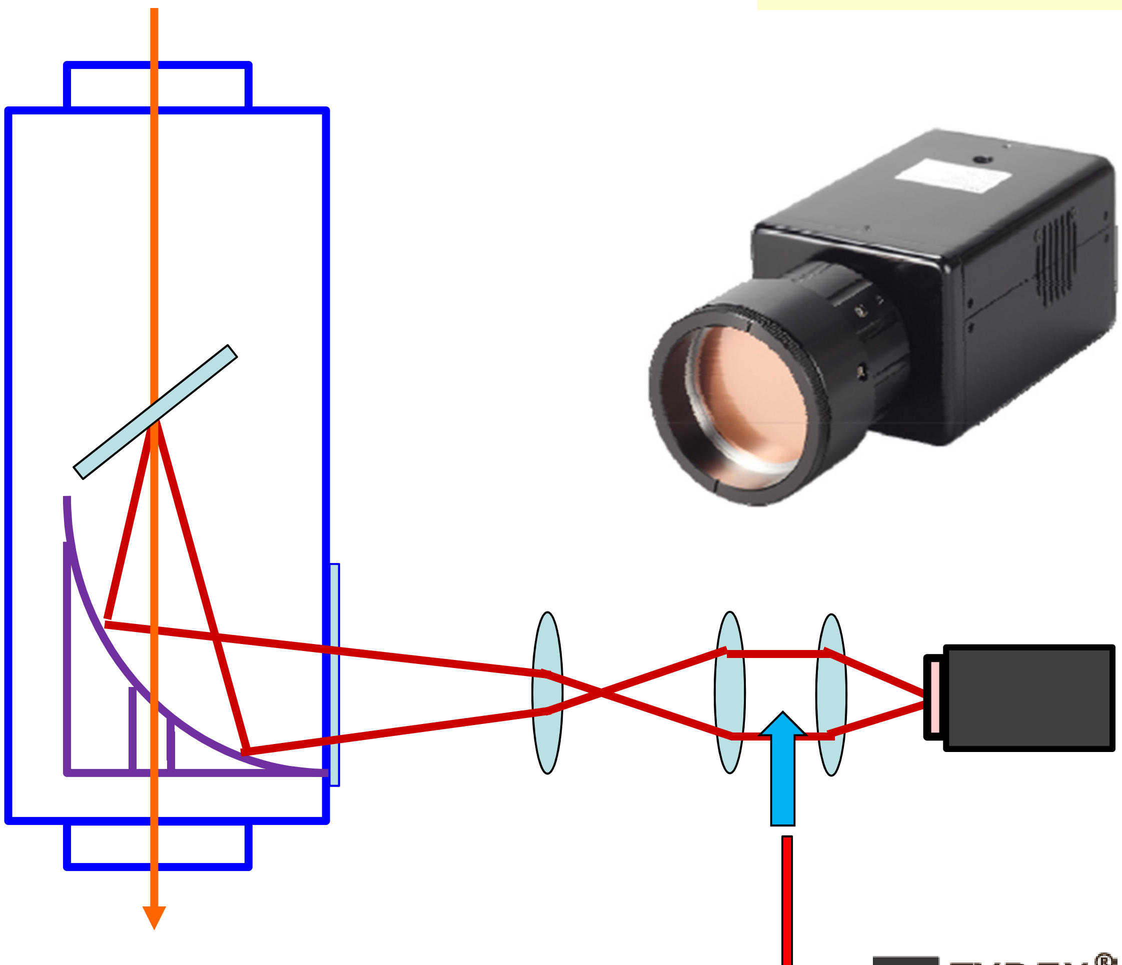
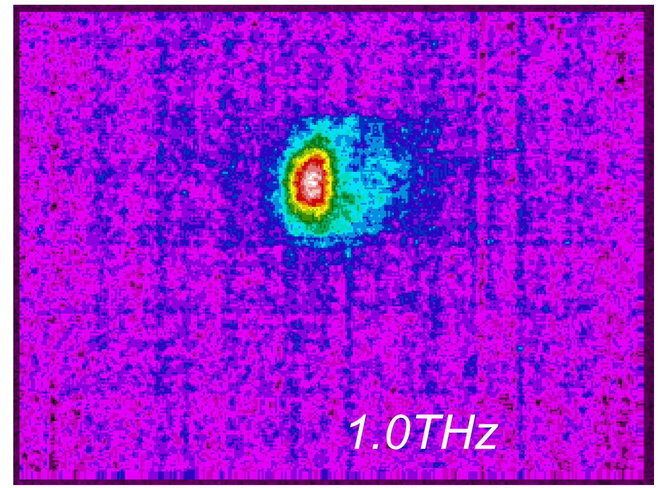
Ultra-short electron beam





BPF

THz-CTR Profile measurement with BPF

THz-CTR measurement
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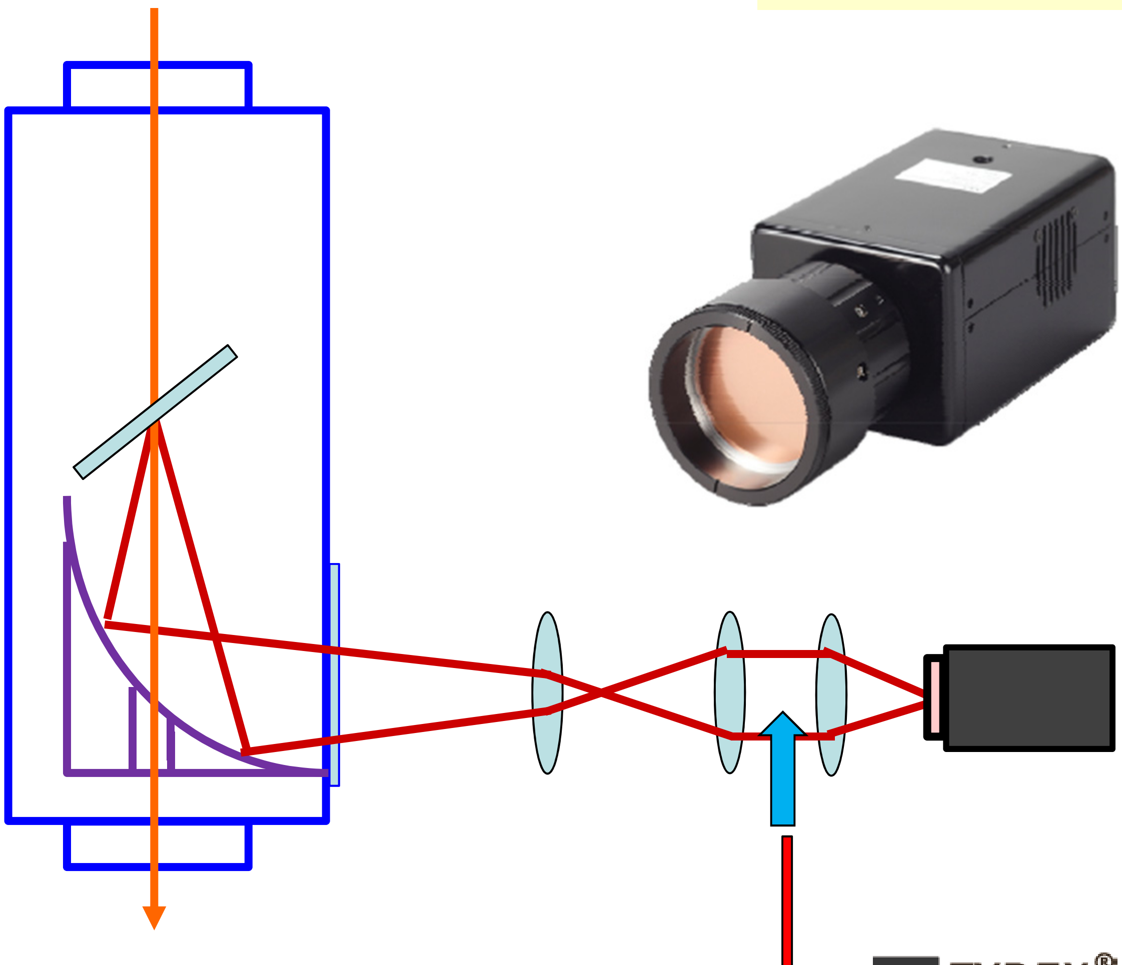
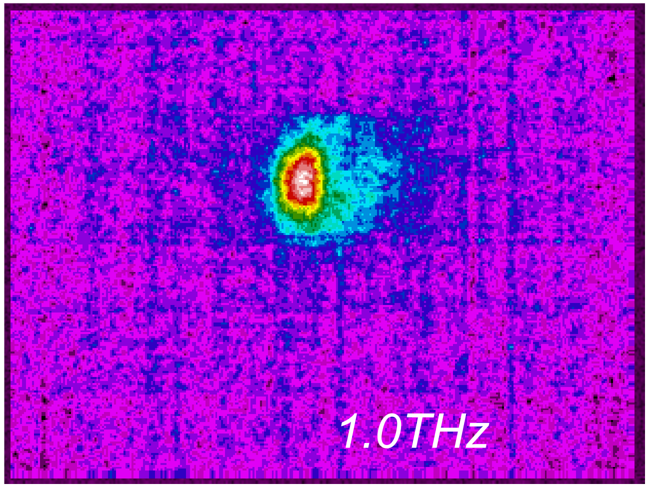
Ultra-short electron beam





BPF TYDEX J.S.Co. *(1.0 – 5.0 THz)*

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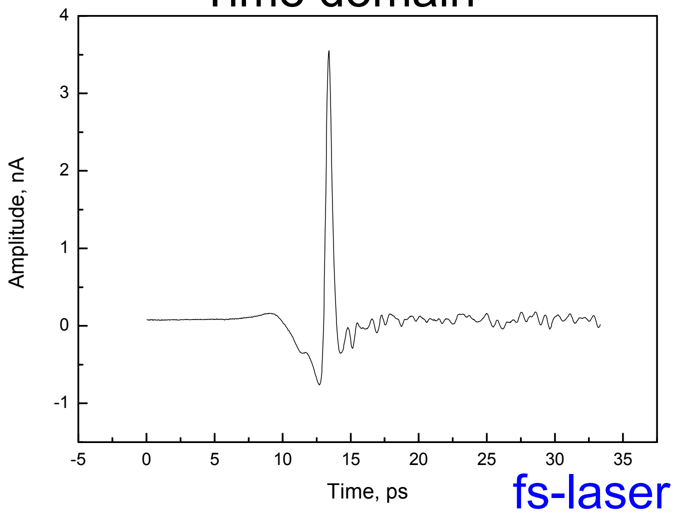
THz-CTR Time Domain Spectroscopy(TDS) with EO sampling method

THz time-domain spectroscopy (THz-TDS) has recently emerged as a useful probe for the investigation of illegal materials such as explosives and drugs.

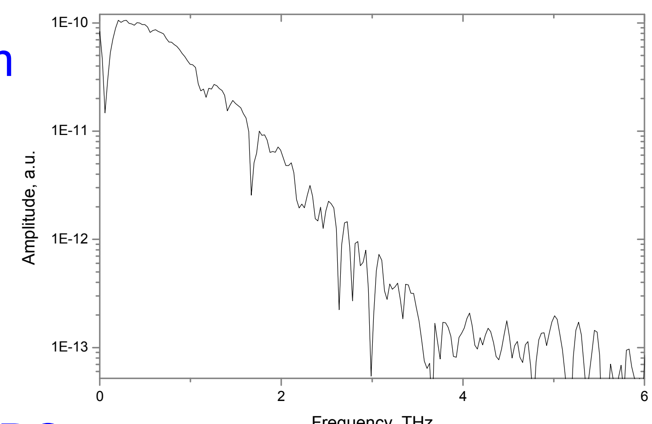
(Temporal decoding)

Time domain



Fourier transform

Frequency domain



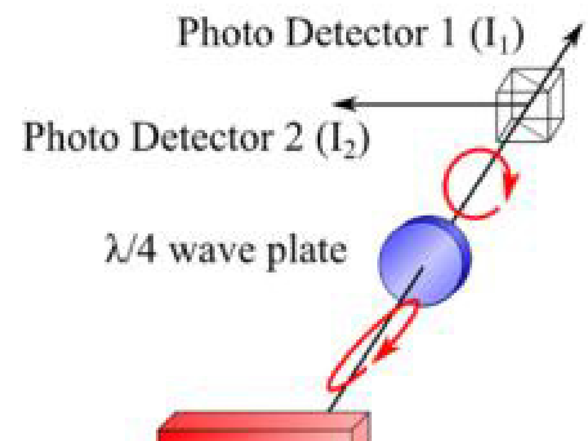
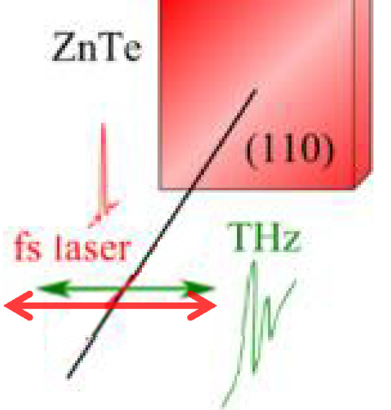
fs-laser based THz-TDS system

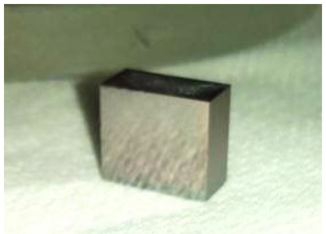
Principle of EO sampling method for THz-TDS

Irradiated THz can make Pockels effect in EO crystal

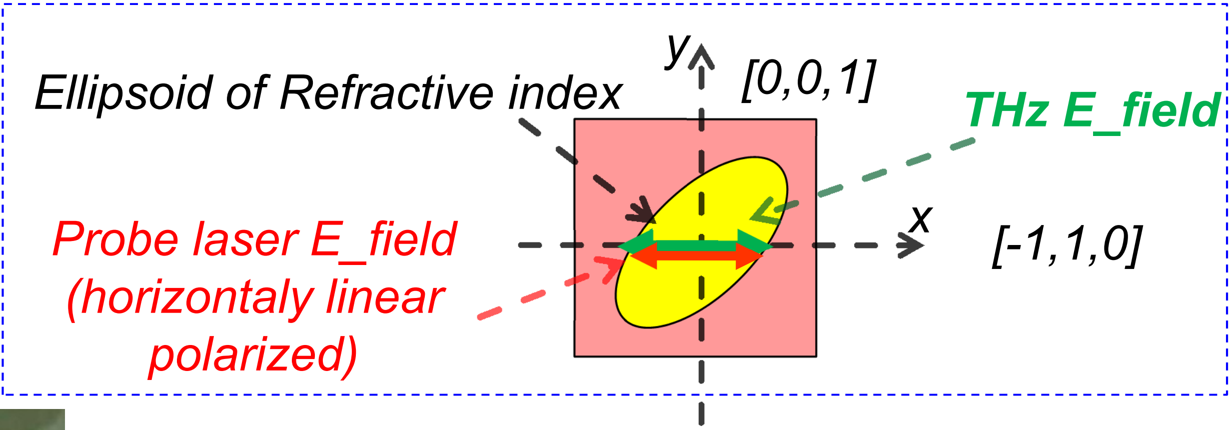
⇨ *Measurement of the phase difference Γ*

$$\Gamma = \frac{2\pi d}{\lambda} n_0^3 r_{41} E_{THz}$$



< 1 1 0 > oriented
ZnTe crystal



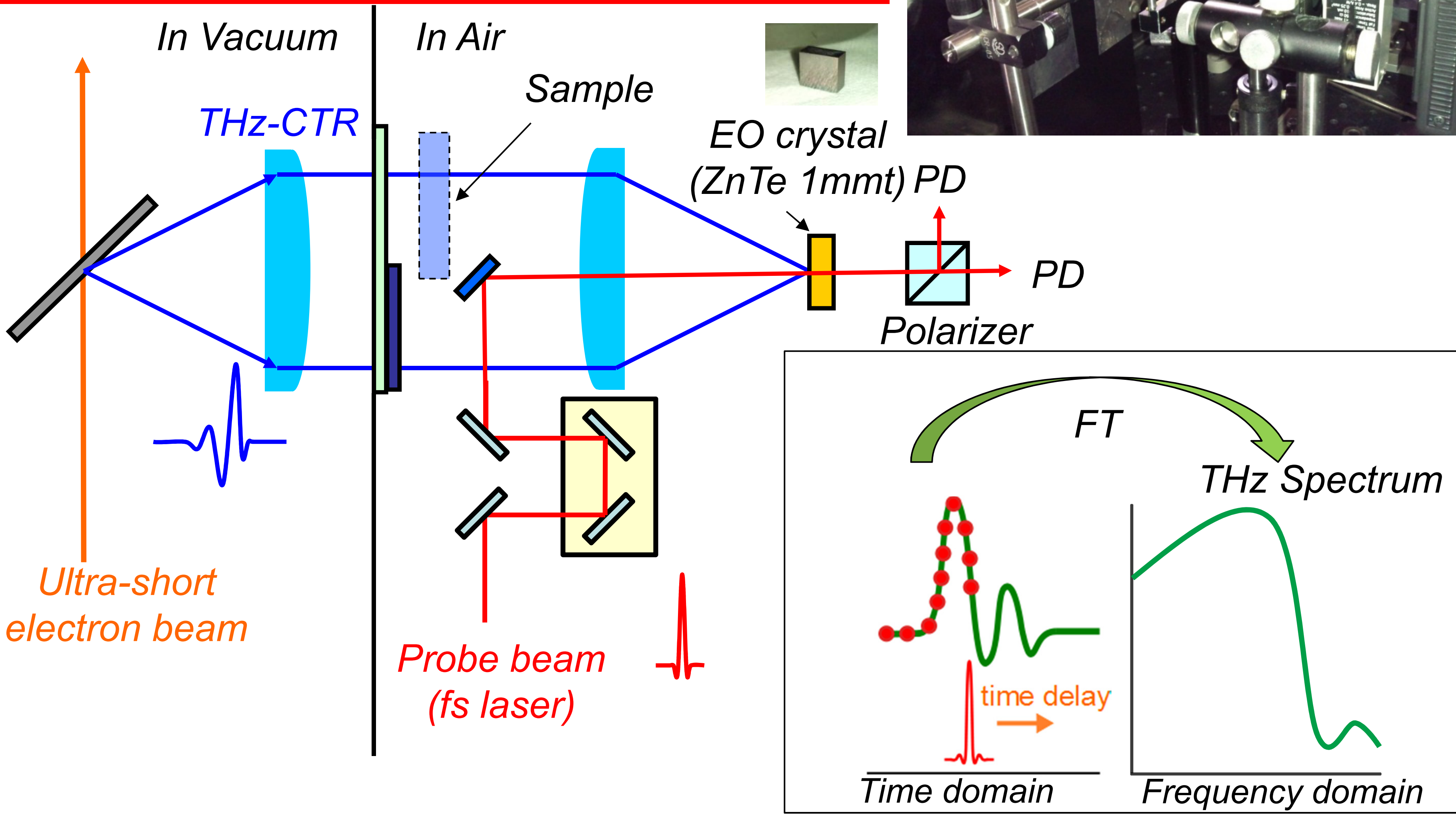
- *Initial E_field of probe laser*

$$\boldsymbol{E_{in}} = E_0 \begin{bmatrix} 1 \\ 0 \end{bmatrix} \begin{array}{l} \leftarrow \text{horizontal} \\ \leftarrow \text{vertical} \end{array}$$

- *Output E_field of probe laser*

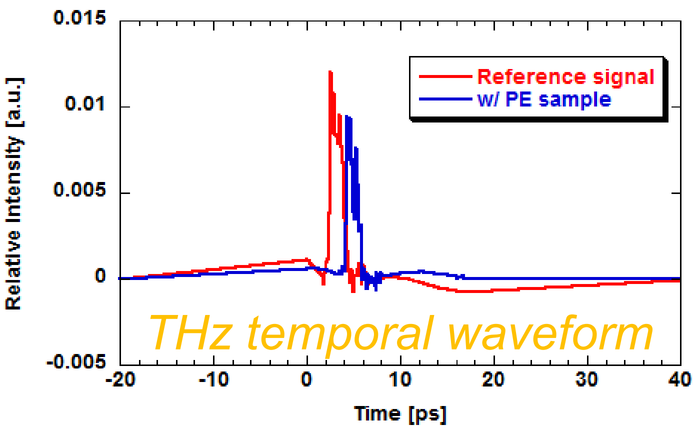
$$\boldsymbol{E_{out}} = E_0 \begin{bmatrix} \cos\frac{\Gamma}{2} \\ i\sin\frac{\Gamma}{2} \end{bmatrix} \begin{array}{l} \leftarrow \text{horizontal} \\ \leftarrow \text{vertical} \end{array}$$

Setup of THz-CTR Time-domain spectroscopy (TDS) with EO sampling method (pump-probe technique)

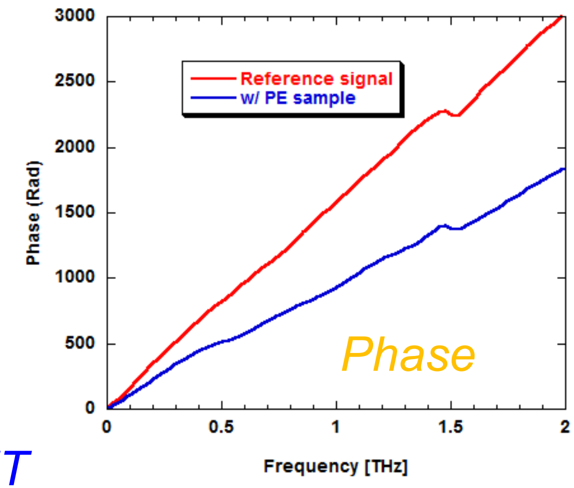


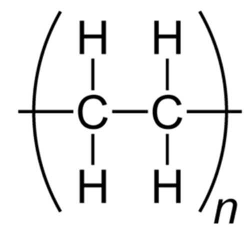
THz-TDS Result with Polyethylene(PE) sample

To demonstrate the THz-TDS system,
the refractive index measurement has been done using the well-known sample (PE)
It is well-known that PE has about 1.5 refractive index from optical to THz region.

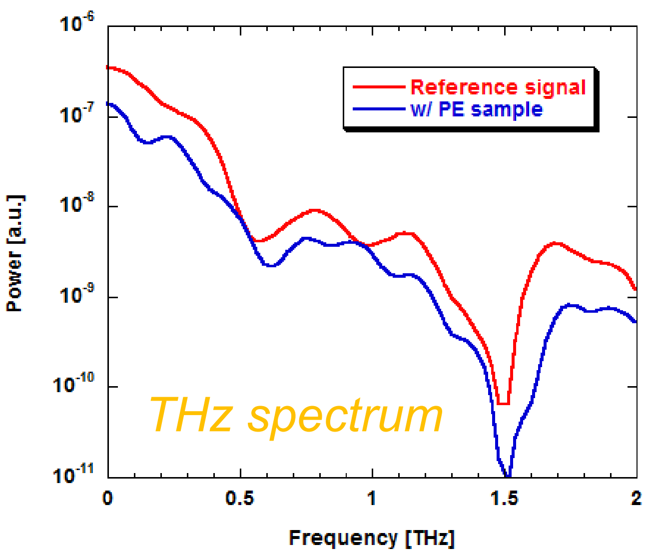


FT





Sample:
Polyethylene(PE) plate
(1 mmt)



Calculated

Refractive index

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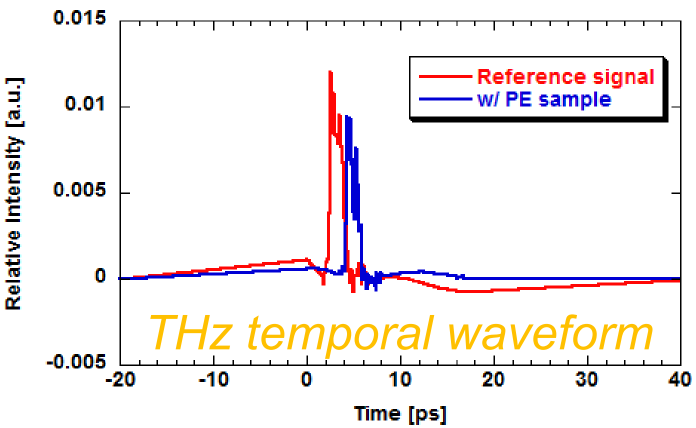

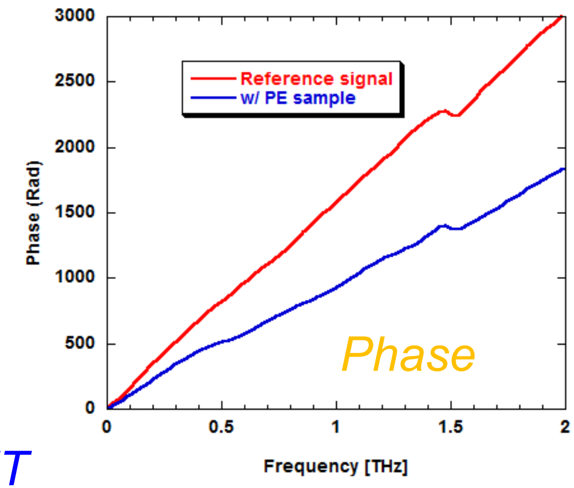

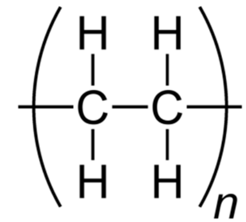

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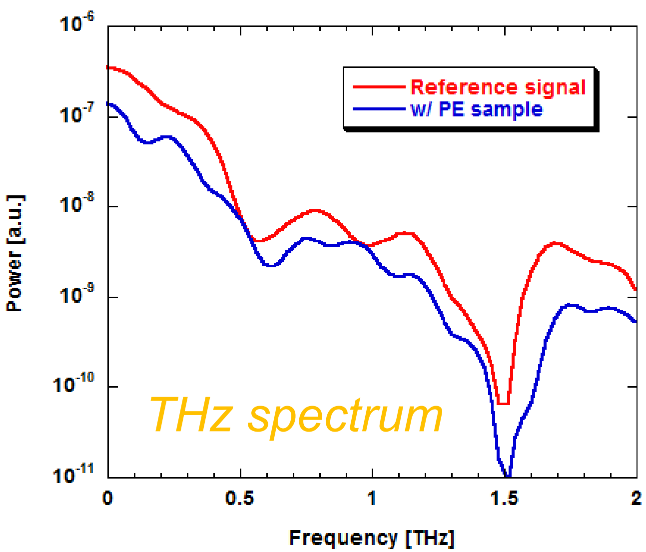

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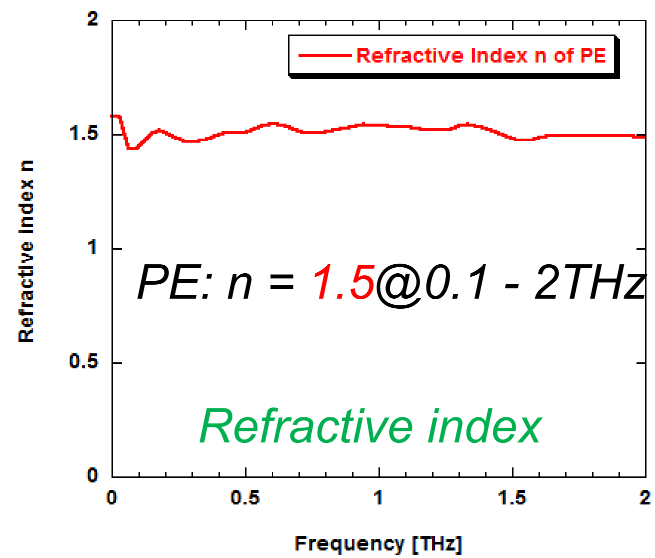

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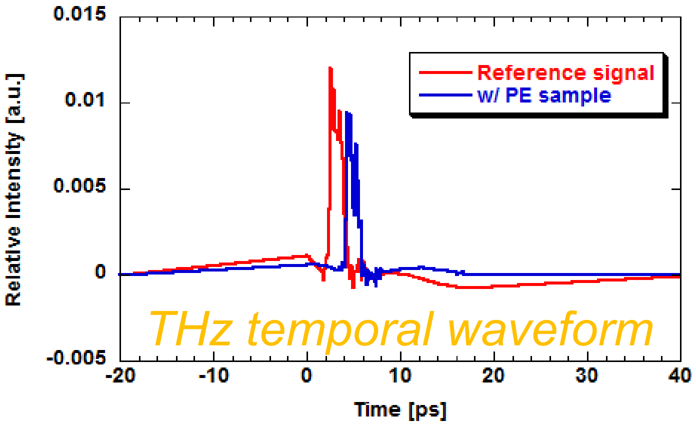

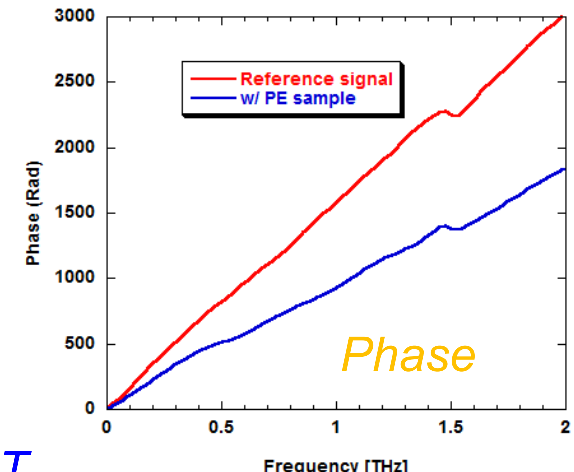

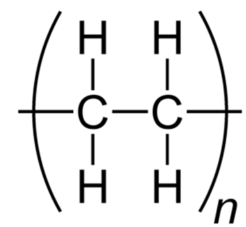

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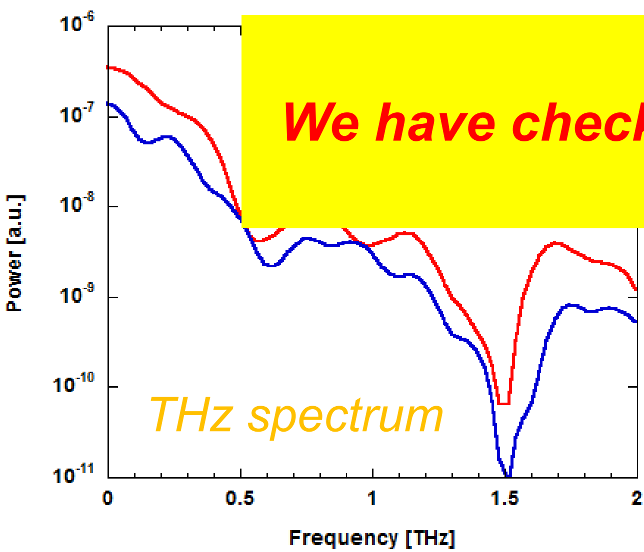
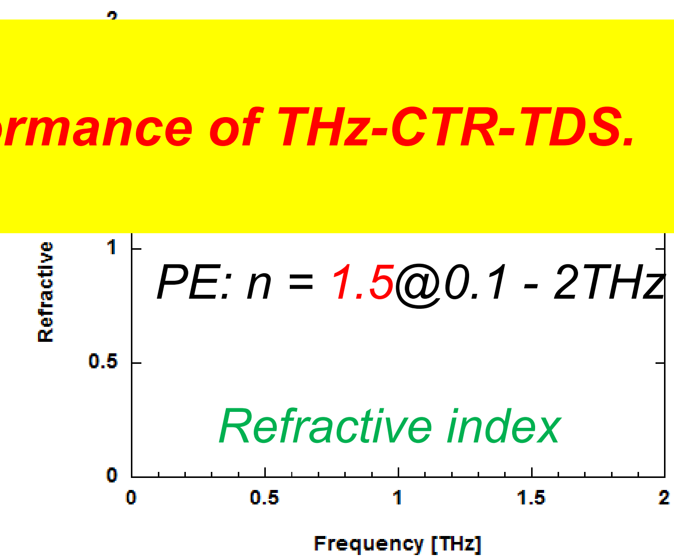
(1 mmt)

FT

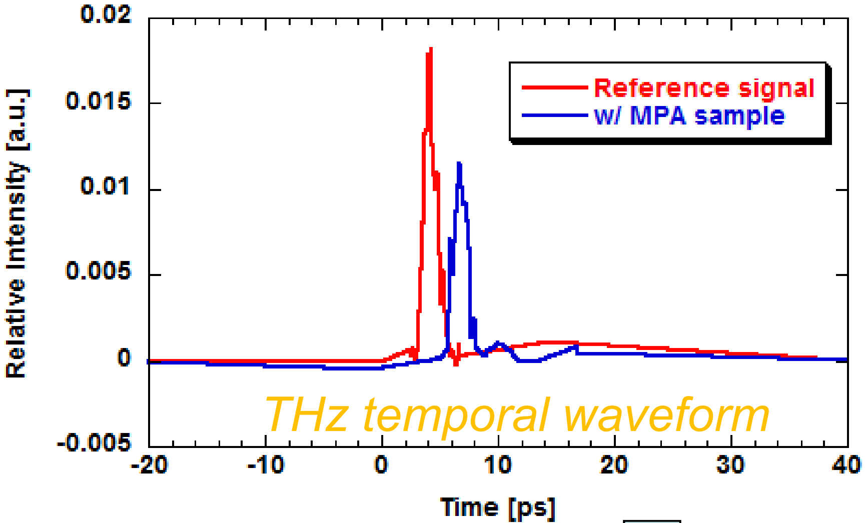


We have checked the performance of THz-CTR-TDS.

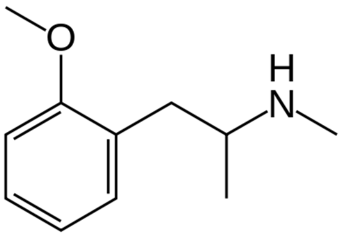
Calculated



THz-TDS Result with drug sample (MPA)

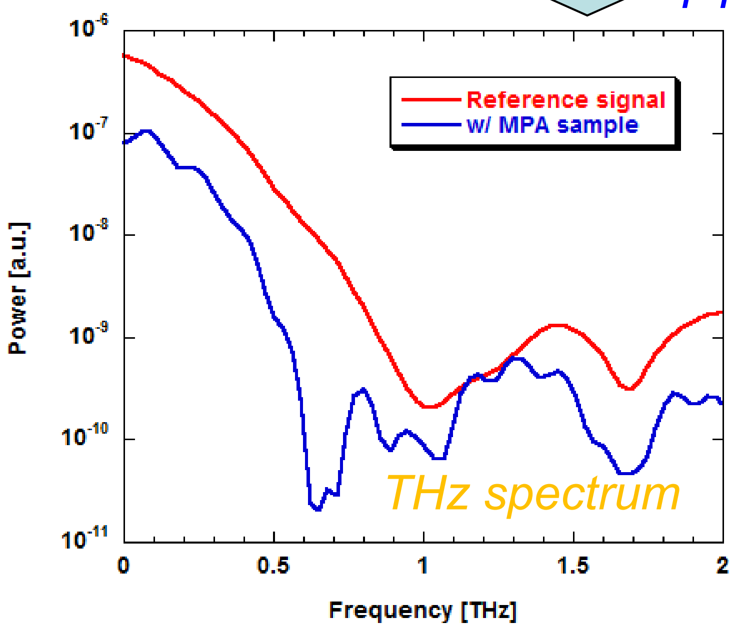


(Imitation Drug of Methamphetamine)



Pellet (1 mmt) of
Methoxyphenamine hydrochloride (MPA)

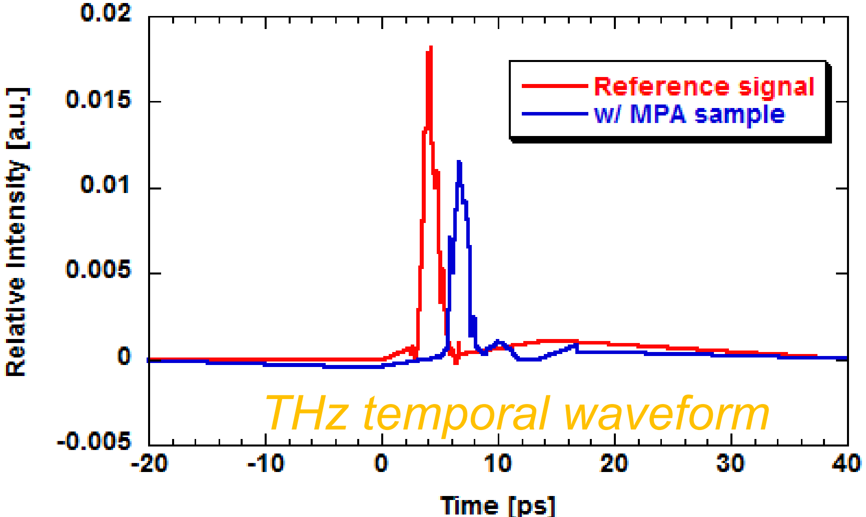
FT



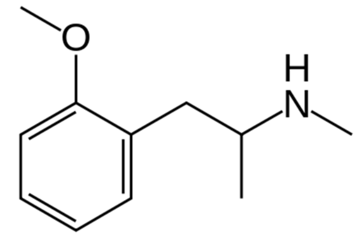
Calculated

Absorption spectrum

THz-TDS Result with drug sample (MPA)

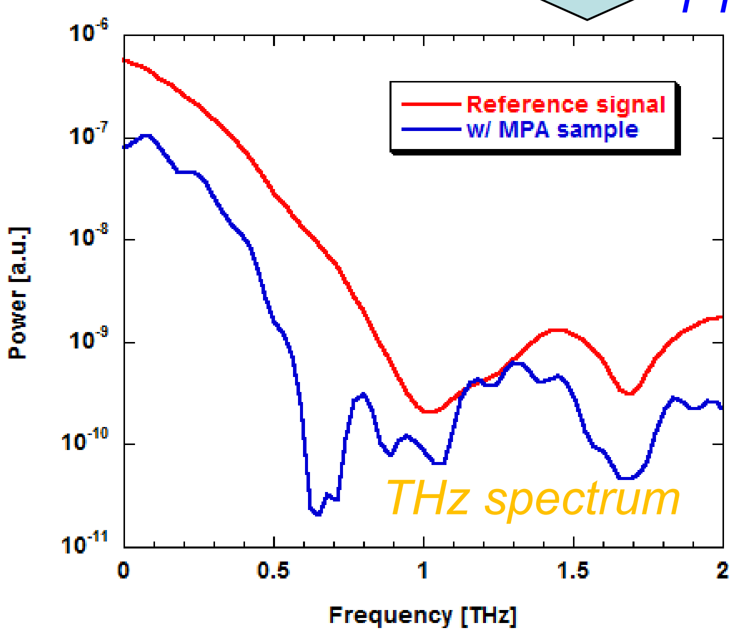


(Imitation Drug of Methamphetamine)

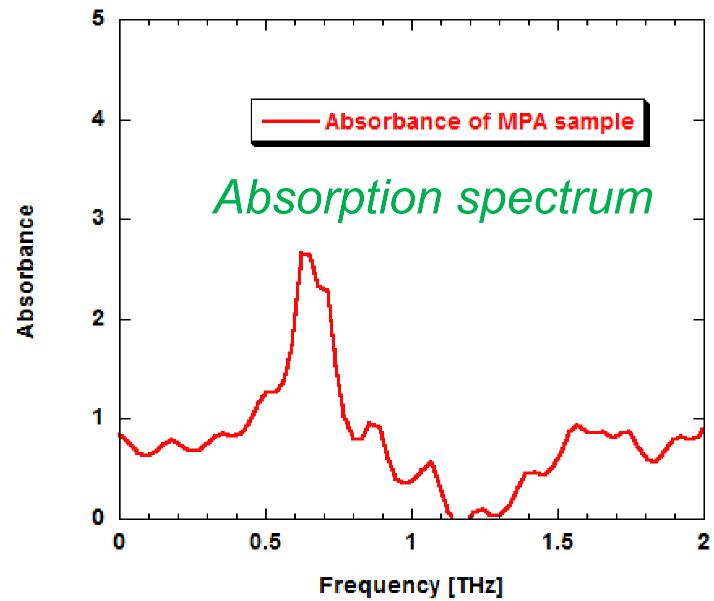


Pellet (1 mmt) of
Methoxyphenamine hydrochloride (MPA)

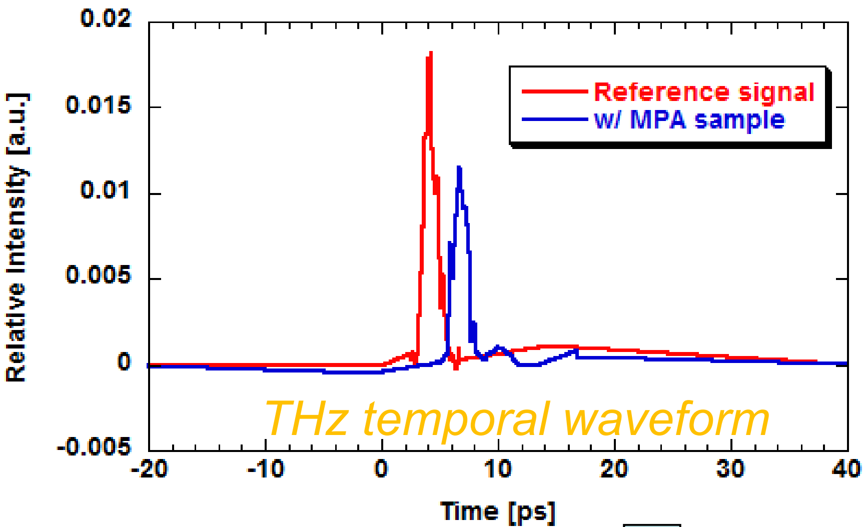
FT



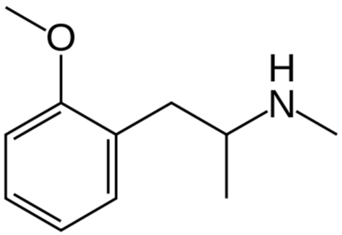
Calculated



THz-TDS Result with drug sample (MPA)



(Imitation Drug of Methamphetamine)



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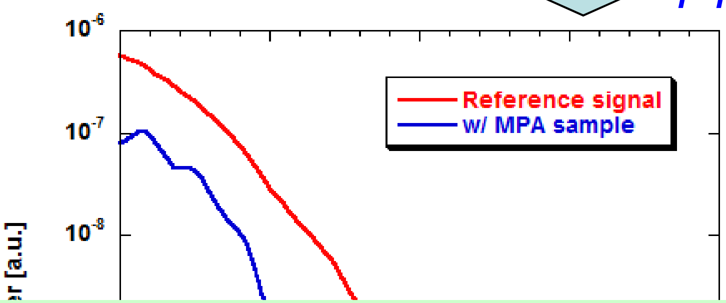

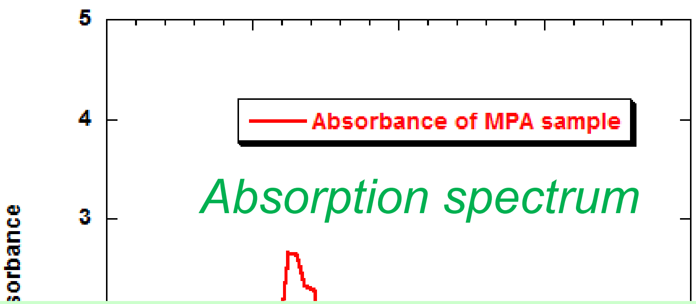

The sample absorption has been successfully measured in atmosphere.
However, the accuracy of the THz-TDS system should be improved.
One of the solutions is the single-shot measurement
with the chirped pulse laser (spectral decoding).
Now, we are preparing the single-shot scheme.

Summary

1. *High peak power THz source has been developed with CSR, CTR techniques on the basis of the S-band compact electron linac at AIST.*
2. *THz-CTR characteristics (Profiles, Polarization, Frequency range) have been measured with the real-time THz camera, Polarizer and BPFs*

   THz frequency range: 0.1 – 5.0 THz
3. *THz-CTR Time-domain spectroscopy (TDS) has been demonstrated in freq. range between 0.1 – 2 THz. The refractive index (PE) and the absorption (MPA) measurements have also successfully performed in atmosphere.*

In near future, single-shot measurement (Spectral decoding) will be performed.

In-situ Security Inspection (Investigation of explosives and illegal drugs)

Colleagues of THz research

Y.Taira, M. Tanaka, H. Toyokawa, K. Yamada (AIST)
M. Kumaki[1], M. Tachibana[1], K.Sakaue[1], K. Kan[2], M. Yoshida[3], H. Tomizawa[4]

[1] RISE, Waseda University, Japan,
[2] ISIR, Osaka University, Japan
[3] KEK, Japan
[4] RIKEN, SPring-8 Center, Japan

Summary

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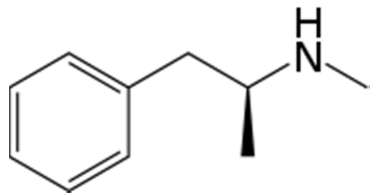
gal drugs)

. Tomizawa[4]

Thank you
for your attention !

REFERENCES

Methamphetamine



Methoxyphenamine