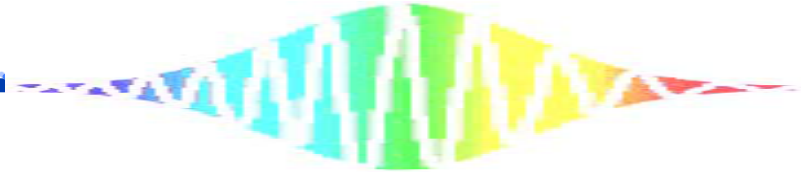
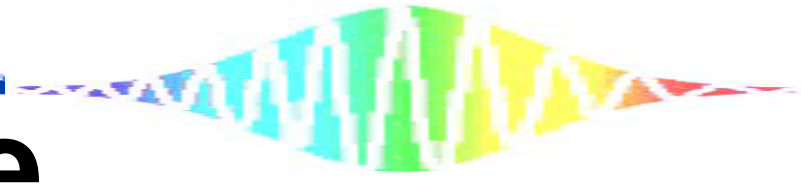


3430-IT-5

THz Color Scanner for Moving Object

Takeshi Yasui
Univ. Tokushima, Japan

IQEC/CLEO Pacific Rim 2011@Sydney (2011.8.30)



Outline

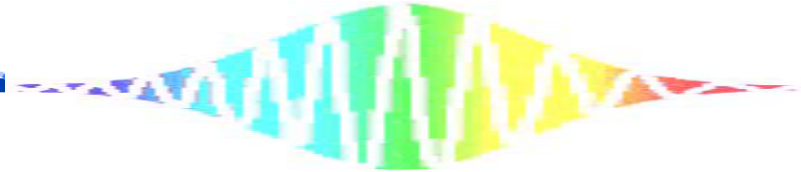
(1) Introduction

(2) Experimental setup and basic performance

(3) Increase of dynamic range for further speeding-up of moving object

(4) Application

(5) Summary



(1) Introduction

Color scanner

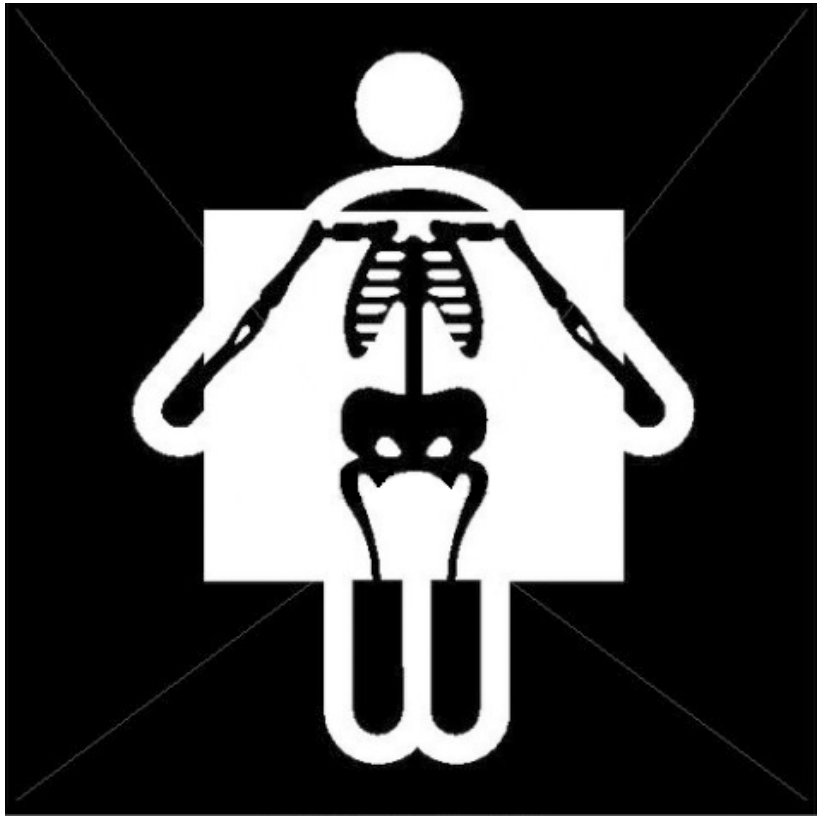
Utility:
scanning of documents and photographs

Spectral imaging apparatus using visible light

Visible-light color scanners can probe only in the vicinity of the object surface.

Color scanner to visualize internal structure of opaque object can be achieved if highly penetrative EM wave is used?

X-ray scanner (Radiography, CT)



Utility:
Nondestructive inspection
Medical imaging

Advantage:
High penetration

Disadvantages:
Hazardous ionizing effect
Too high penetration
Monochrome image
→Difficult to analyze chemical components

THz color (spectroscopic) imaging

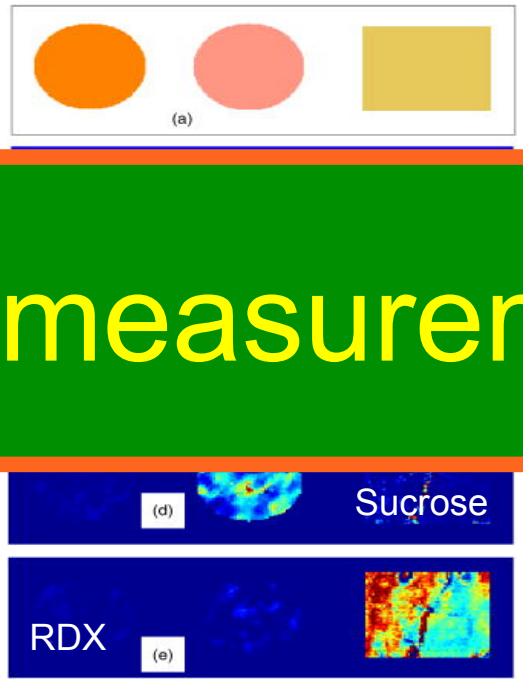
Nondestructive testing possible to analyze chemical components

Moderate penetration, insensitivity to optical scattering, low photon energy, and spectral fingerprint

Illegal drug

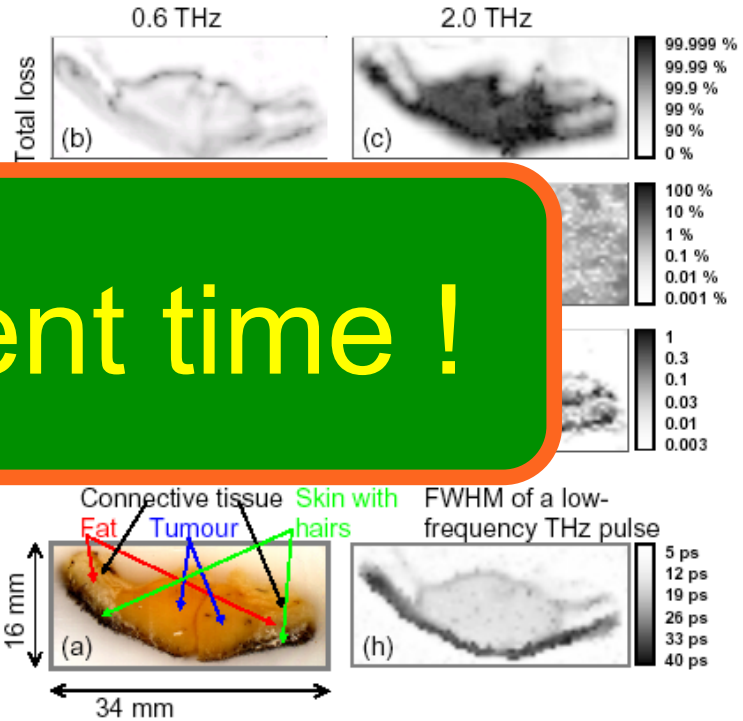
Kawase, OpEx, **11**, pp. 2549, 2003.

Explosive



Shen, APL, **86**, 24116,2005.

Cancer

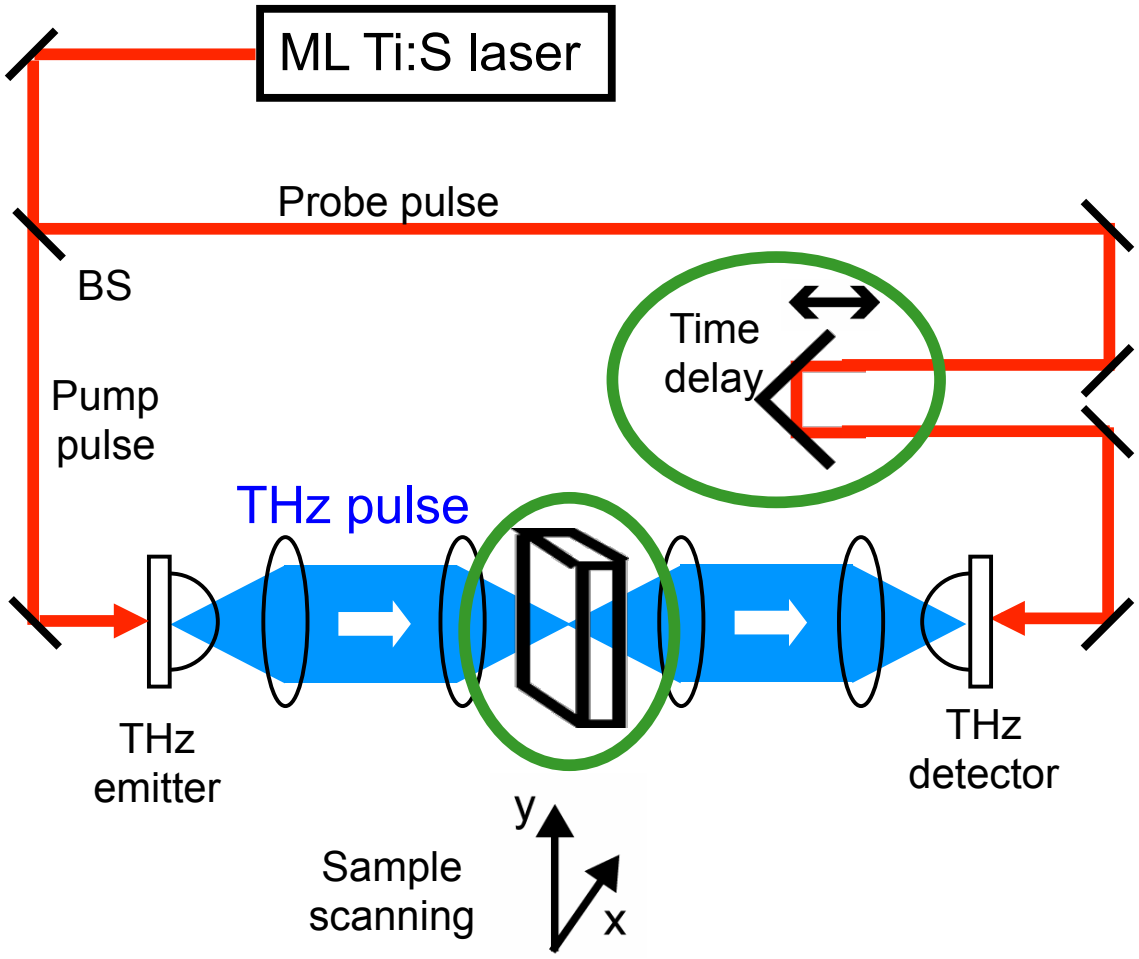


T. Loffler, OpEx, **9**, pp. 616, 2001.

Long measurement time !

Conventional THz-TDS imaging system

(Point-to-point measurement)



2D THz-TDS image

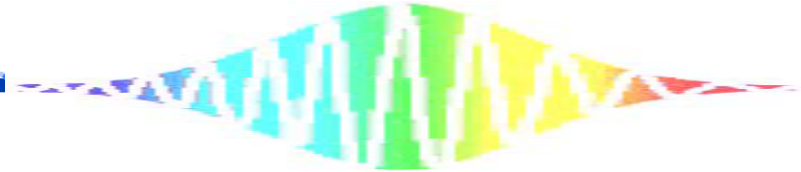
Mechanical scanning stages

- time delay
- sample position

Long acquisition time

- A few minutes @temporal waveform
- Several hours @2D image

Limited to stationary objects



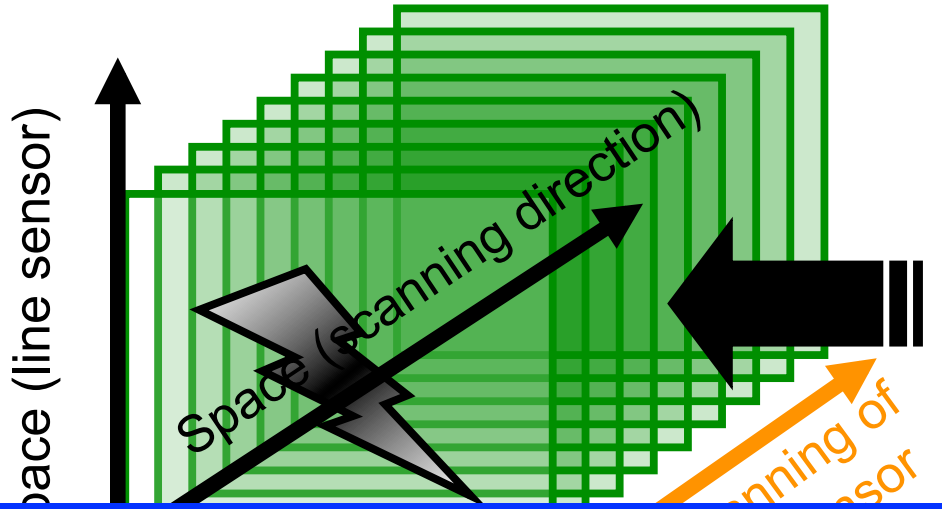
(2) Experimental setup and basic performance

Ref) T. Yasui, K. Sawanaka, A. Ihara, E. Abraham, M. Hashimoto, and T. Araki, "Real-time terahertz color scanner for moving objects," Opt. Express, Vol. 16(2), pp. 1208-1221 (2008).

Principle of visible-light color scanner

Color (spectroscopic)
line imaging in real time
(color CCD line-sensor)

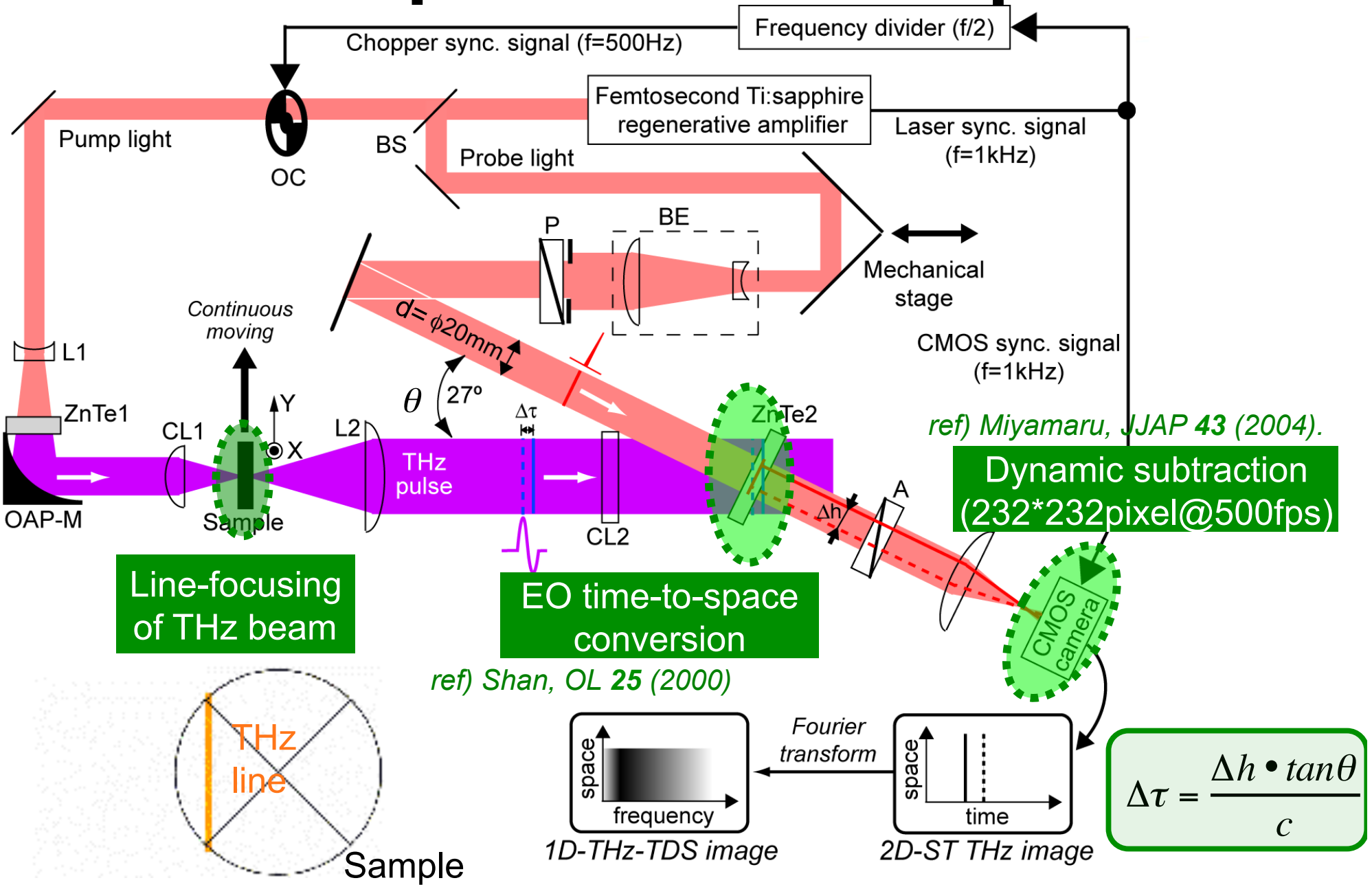
Key technique!



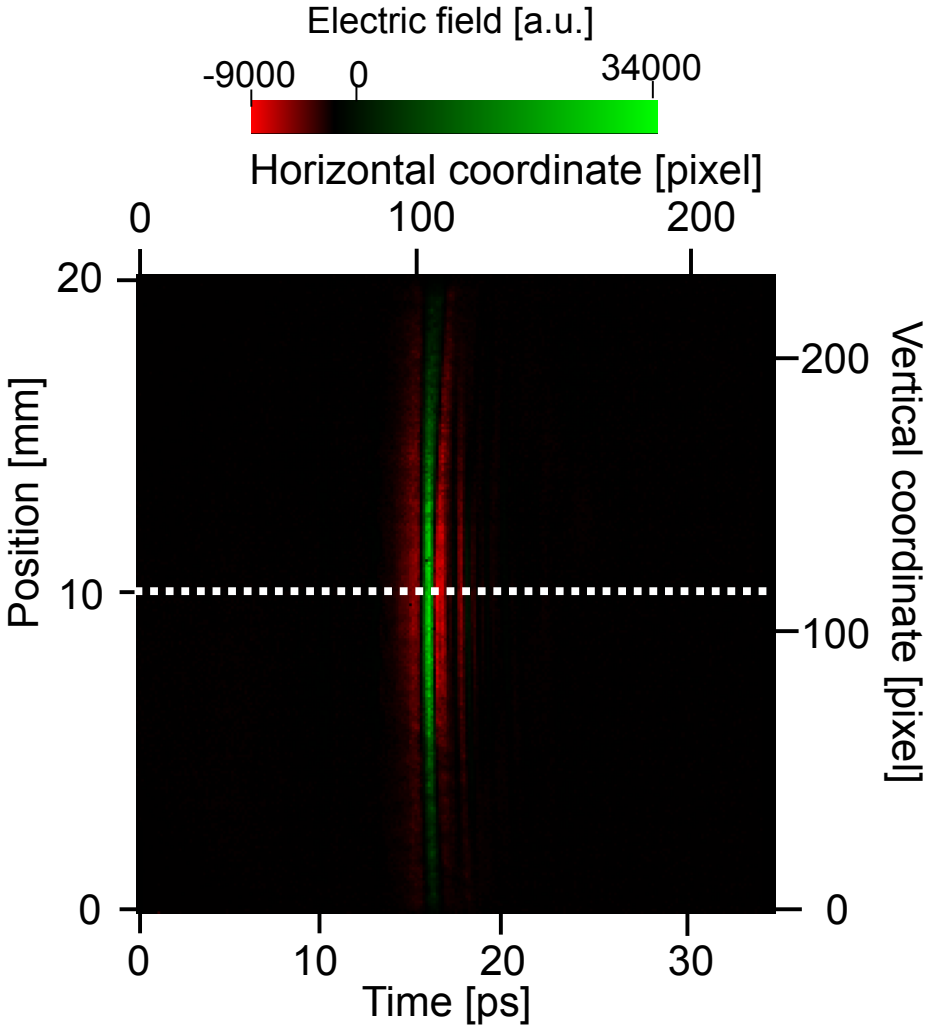
Two-dimensional spatio-temporal (2D-ST) THz imaging based on combination of line focusing of THz beam and time-to-space conversion in EO crystal

Ref) Yasuda, Opt. Comm. **267**, 128-136 (2006).

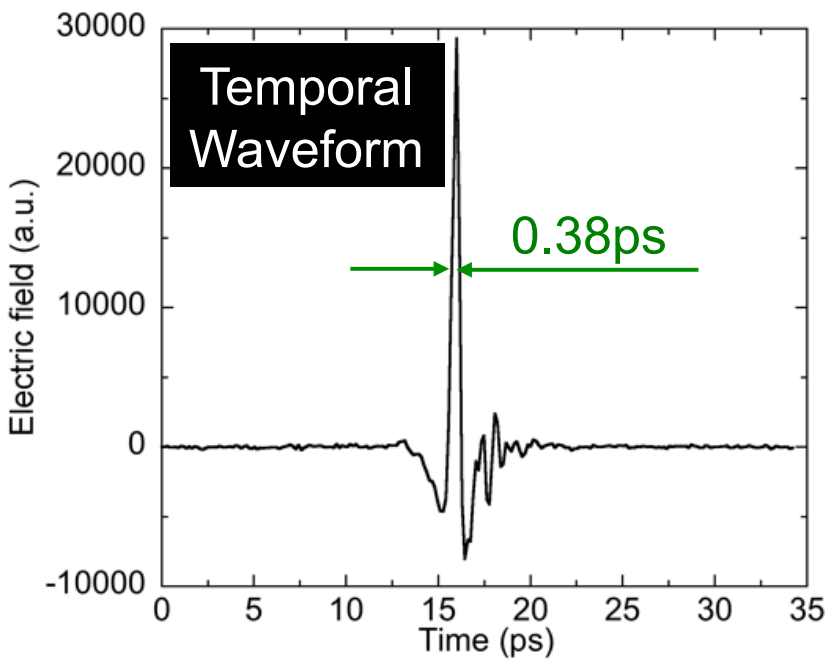
Experimental setup

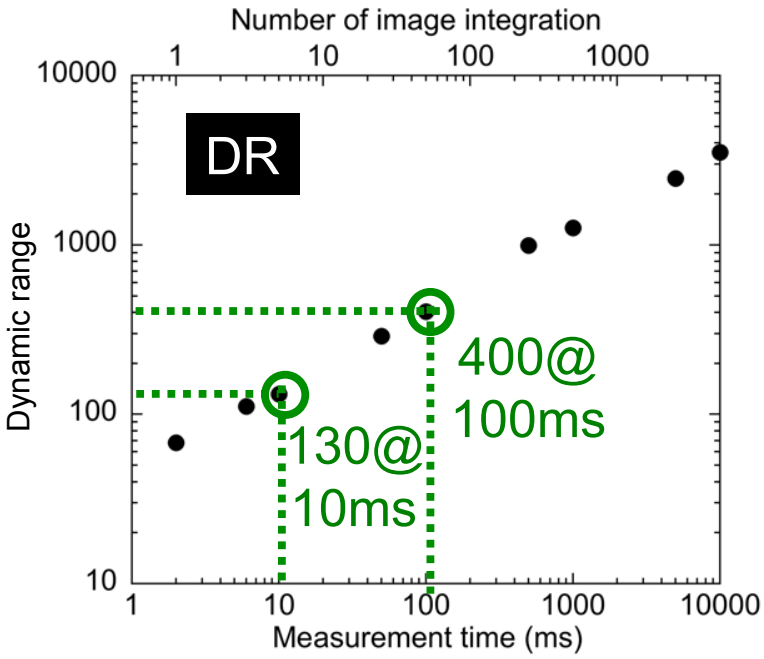


Time characteristics



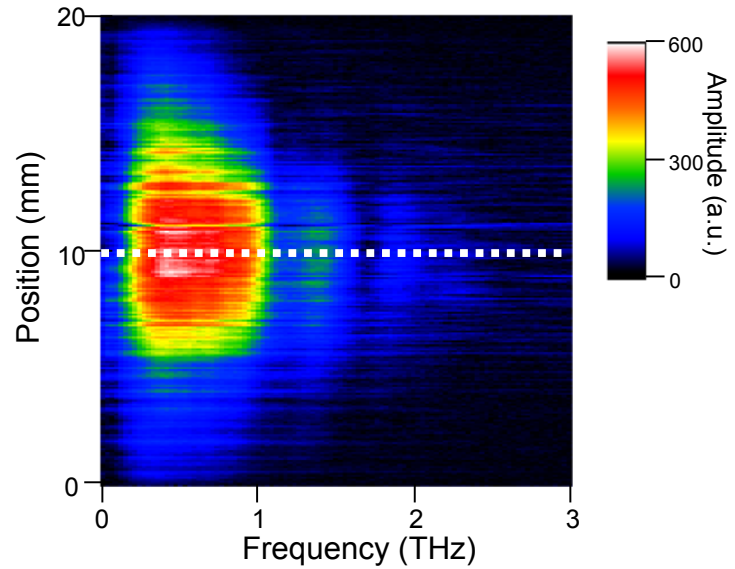
2D-ST THz image (without sample)
(measurement time = 100 ms)

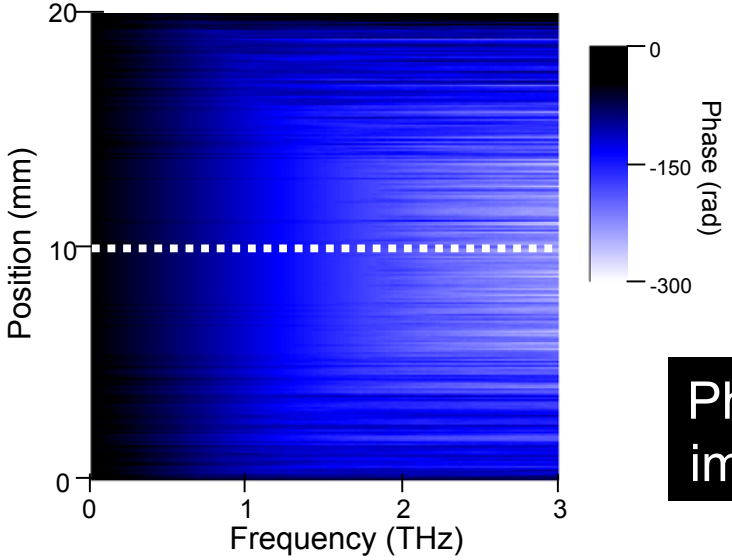




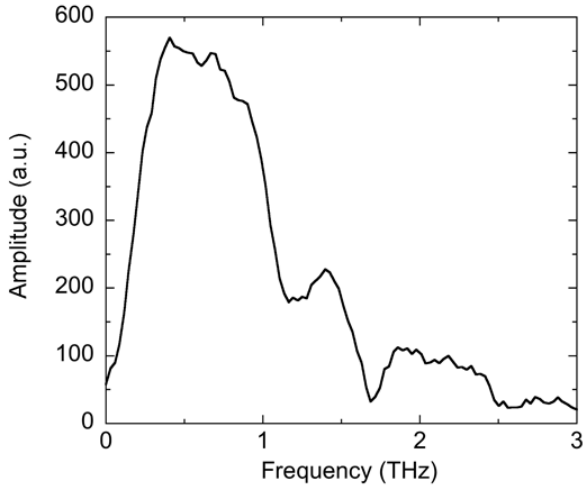
Spectral characteristics

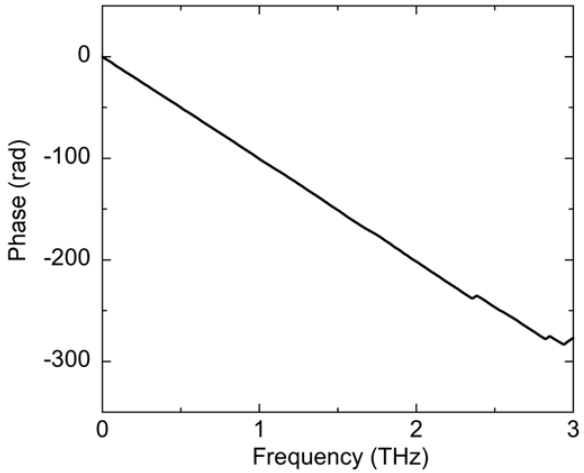
Amplitude image





Phase image

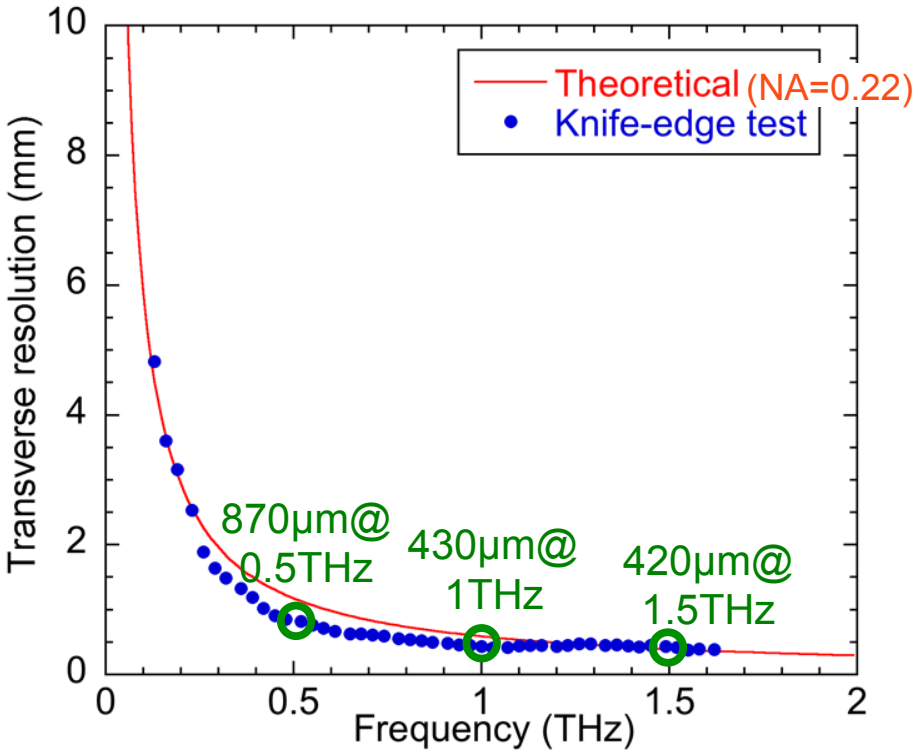




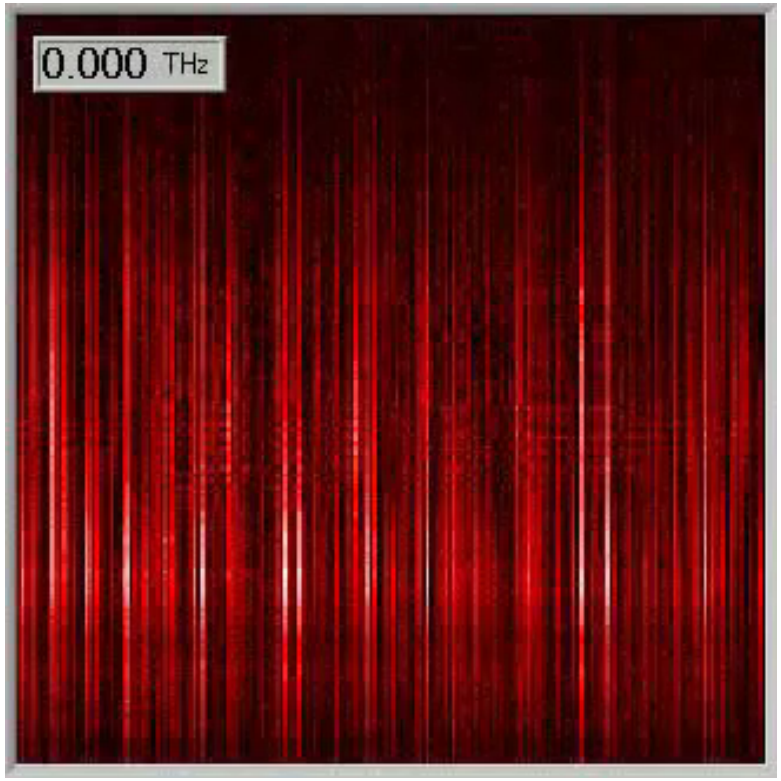
Spectral bandwidth = 3THz, Spectral resolution = 29GHz

Imaging performance

Spatial resolution



Consecutive spectral images of test chart (line space = 0.5 mm)

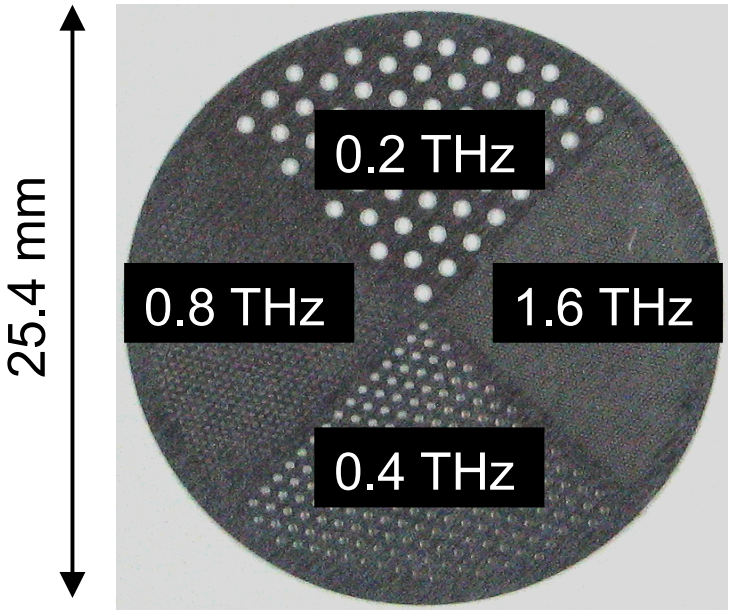


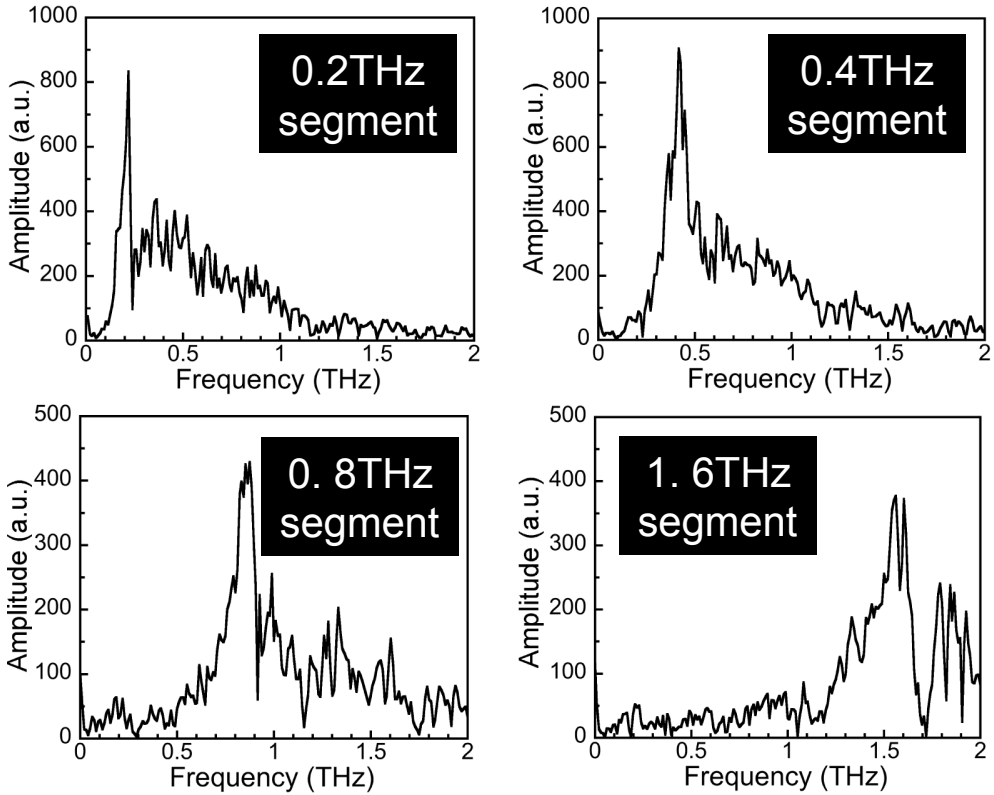
Spatial resolution of THz color scanner depends on THz frequency

4-segment metal hole array (4seg-MHA)

Metal hole array（MHA） *Bandpass filter in THz region*

Metal plate with periodic array of many holes
Passband is designed by size and interval of hole





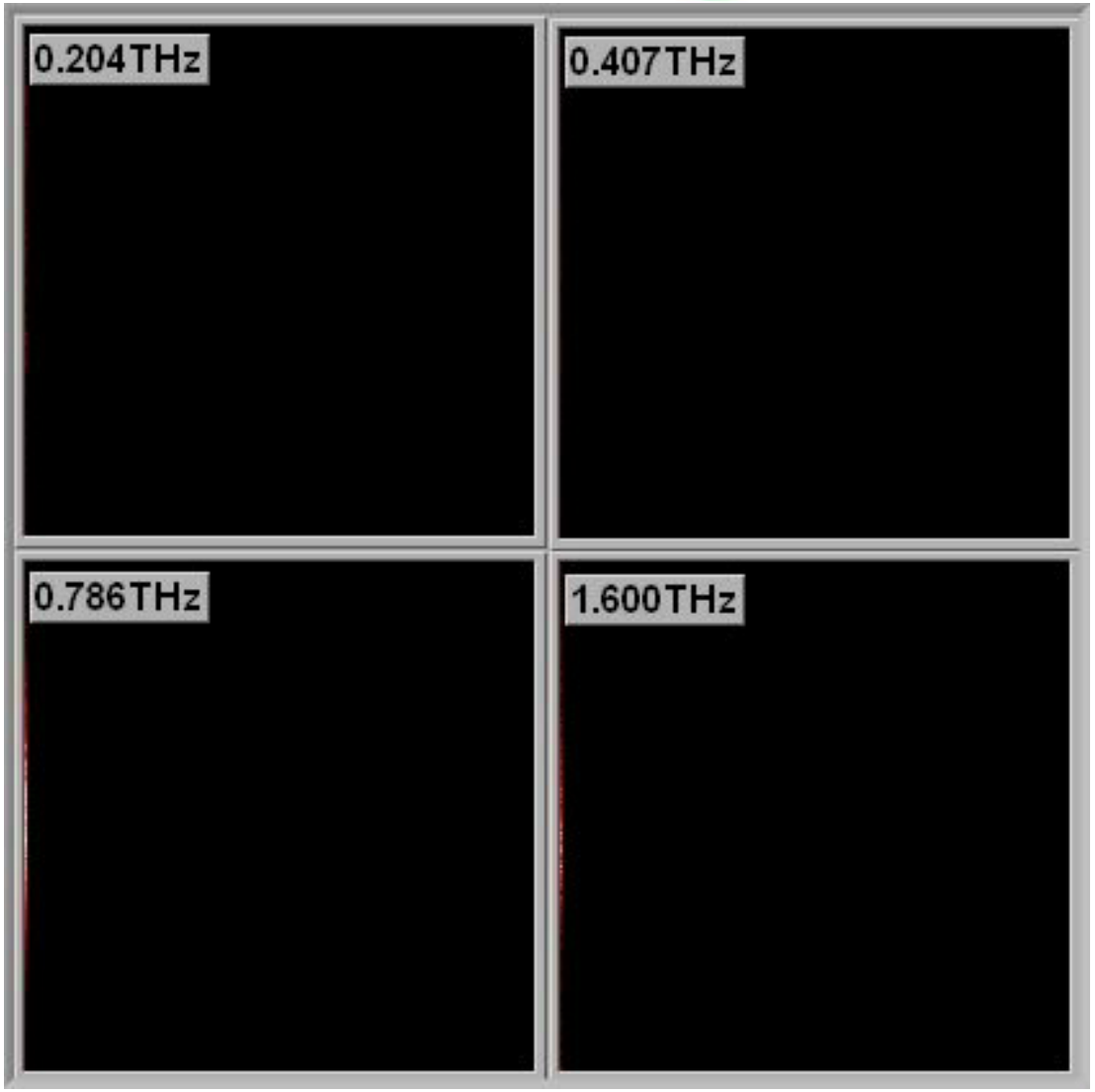
THz spectral imaging of moving 4seg-MHA

Sample moving

1mm/sec

THz line

image area
20 mm×20 mm

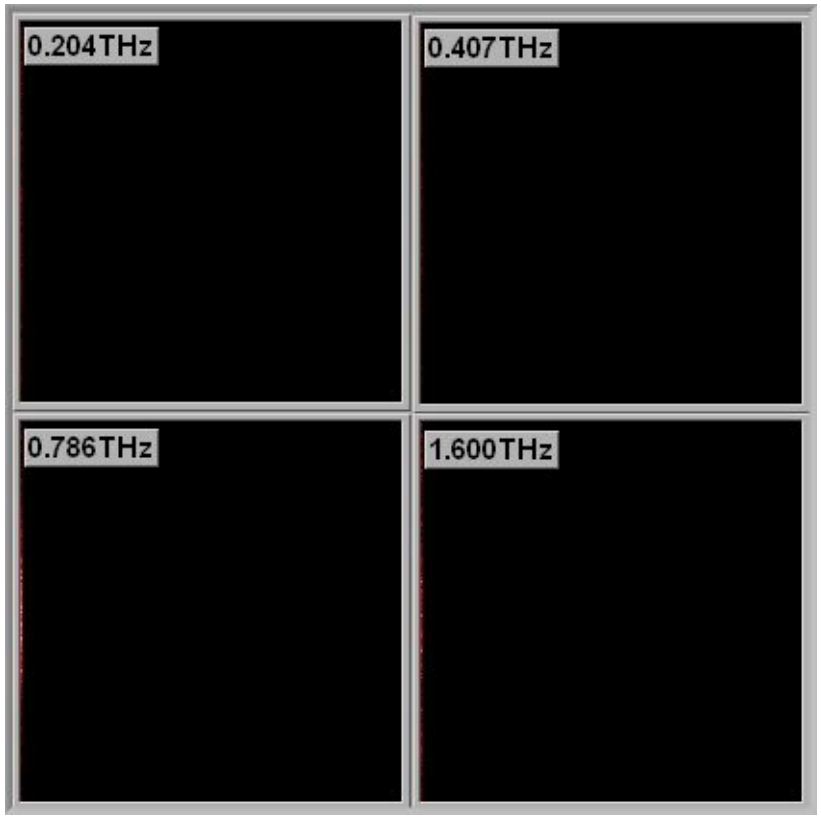


Monochromatic THz chart

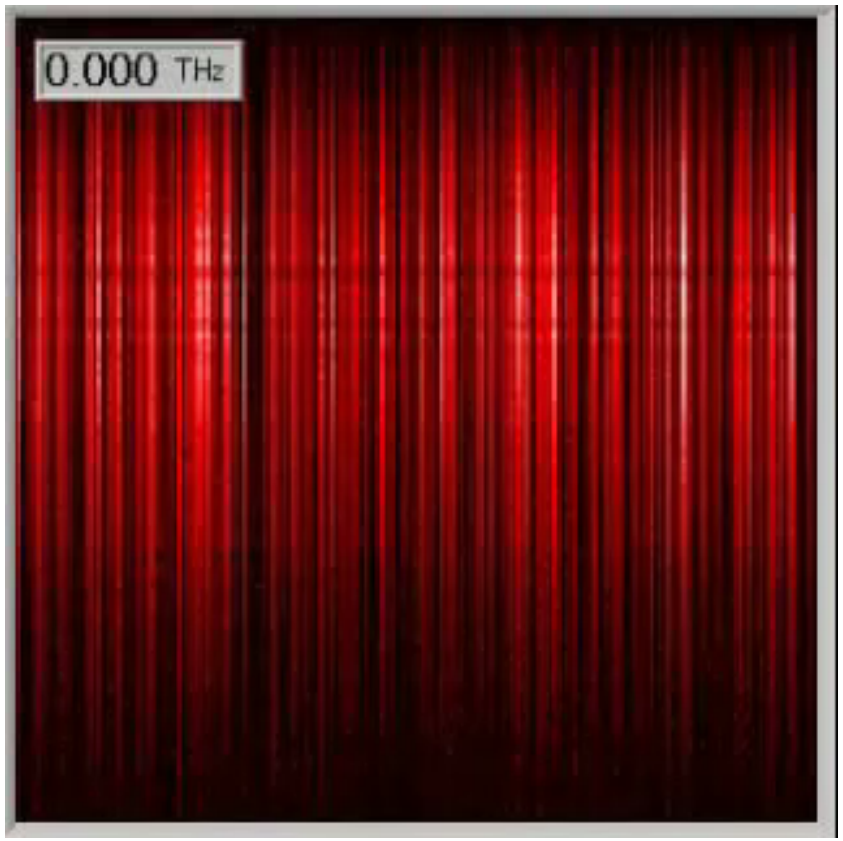
Speeding-up of moving 4seg-MHA

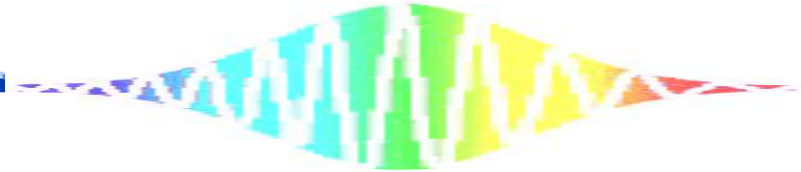
Sample speed = 10mm/sec (measurement time = 2sec)

Monochromatic THz chart

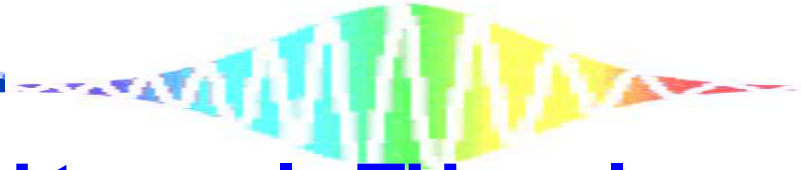


Consecutive THz-TDS image





(3) Increase of dynamic range for further speeding-up of moving object



DR should be further increased to apply THz color scanner for faster moving or more absorbable object!

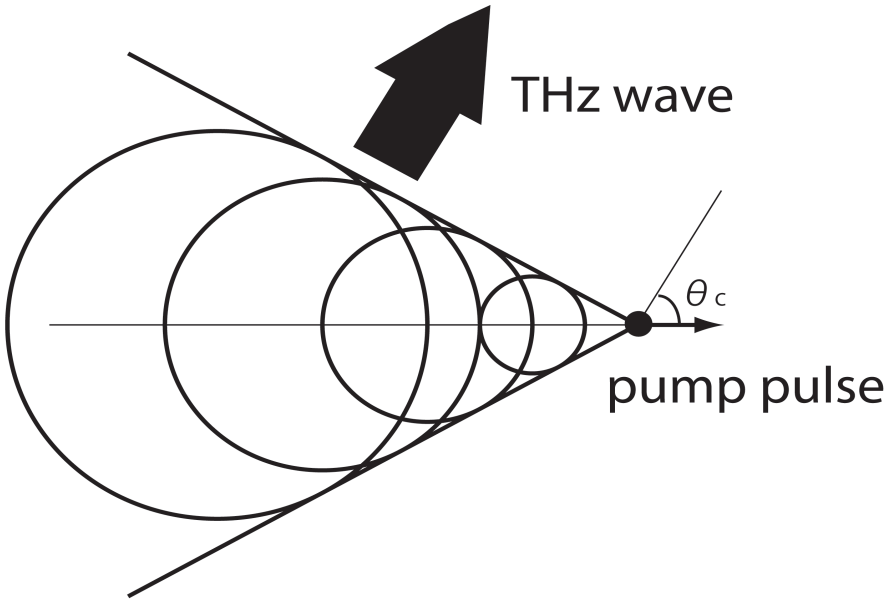
However, our THz detection system has already achieved the shot-noise limit.

Increase of THz power is a shorter way to increase DR!

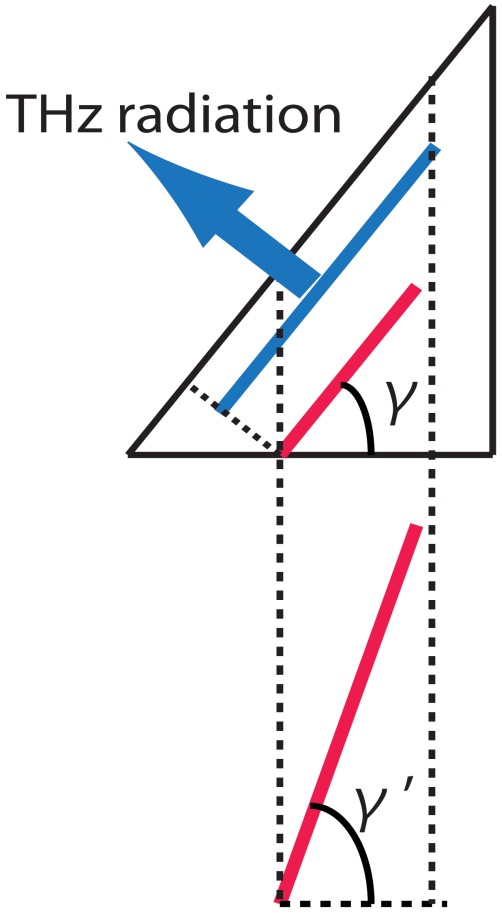
Generation of high power THz pulse using Cherenkov radiation by tilted pulse front excitation

High power THz pulse generation by pulse-front-tilting technique

$LiNbO_3$ has
- large nonlinear coefficient
- large difference of refractive index between optical and THz regions

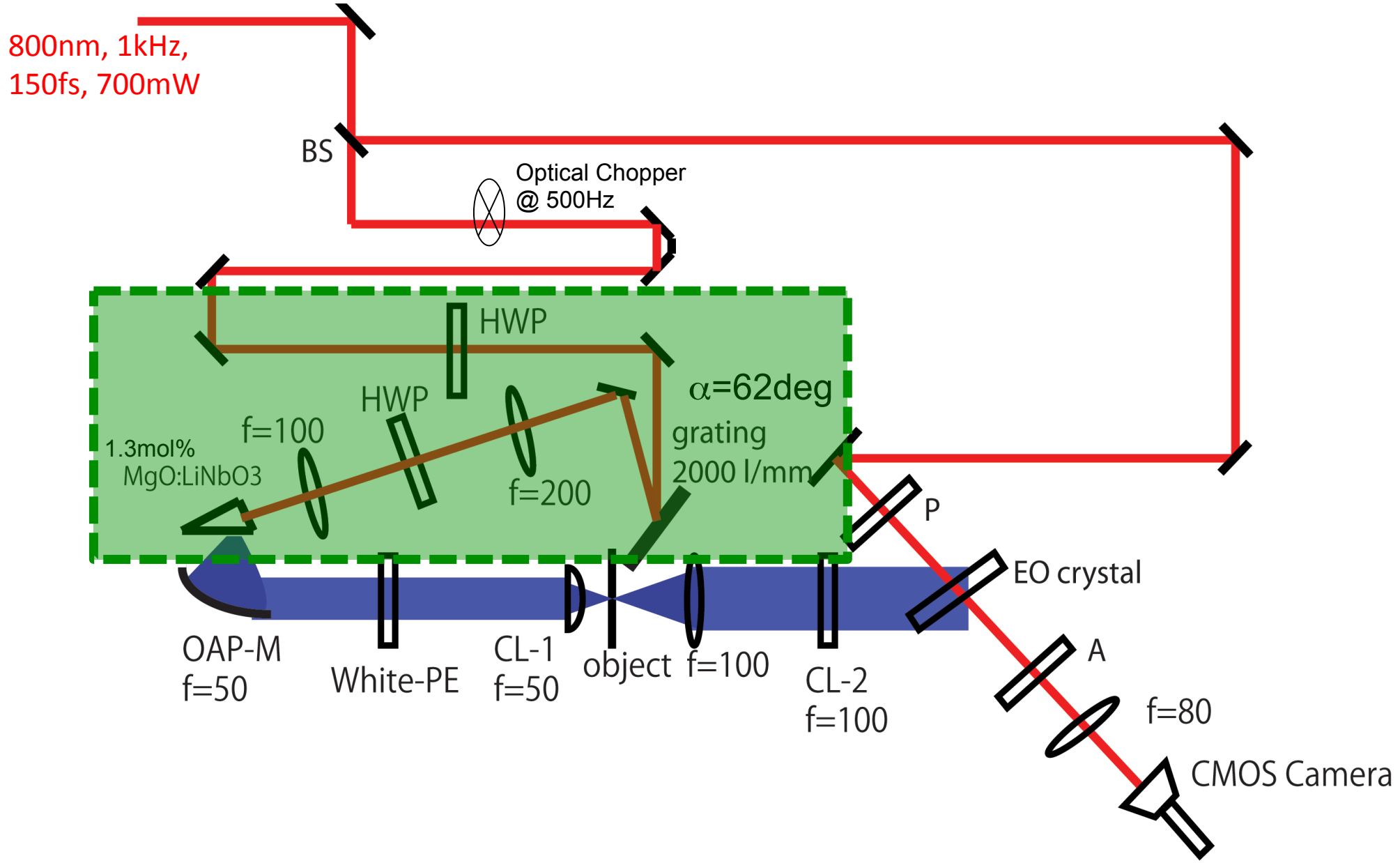


ref) J. Hebling, Opt. Express **10, 1161** (2002).



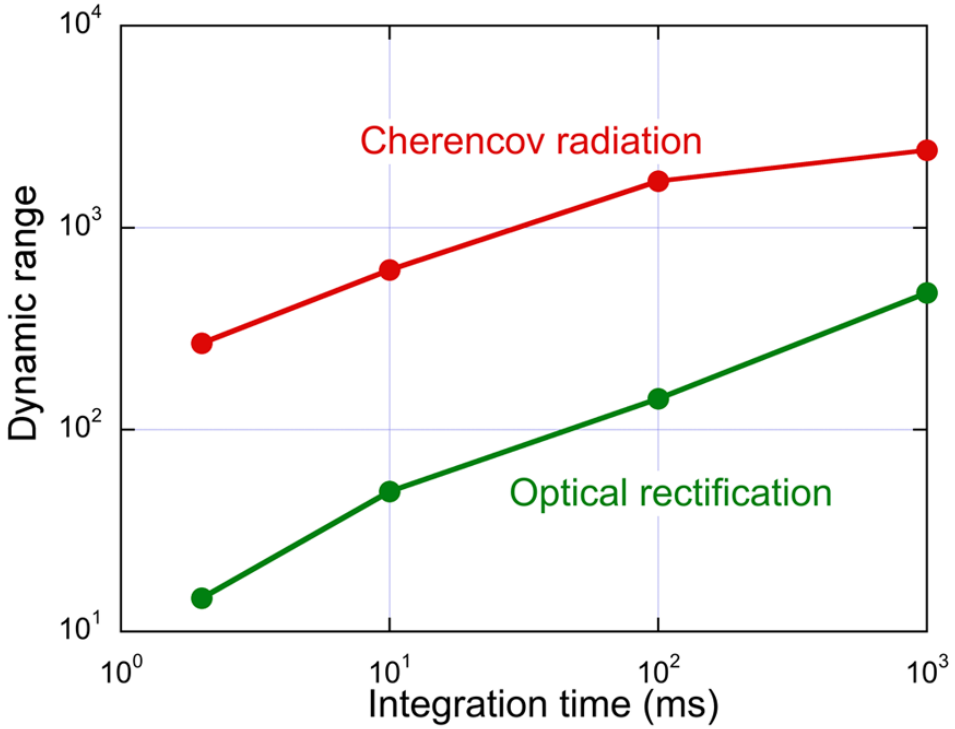
Effective phase matching

Modified experimental setup

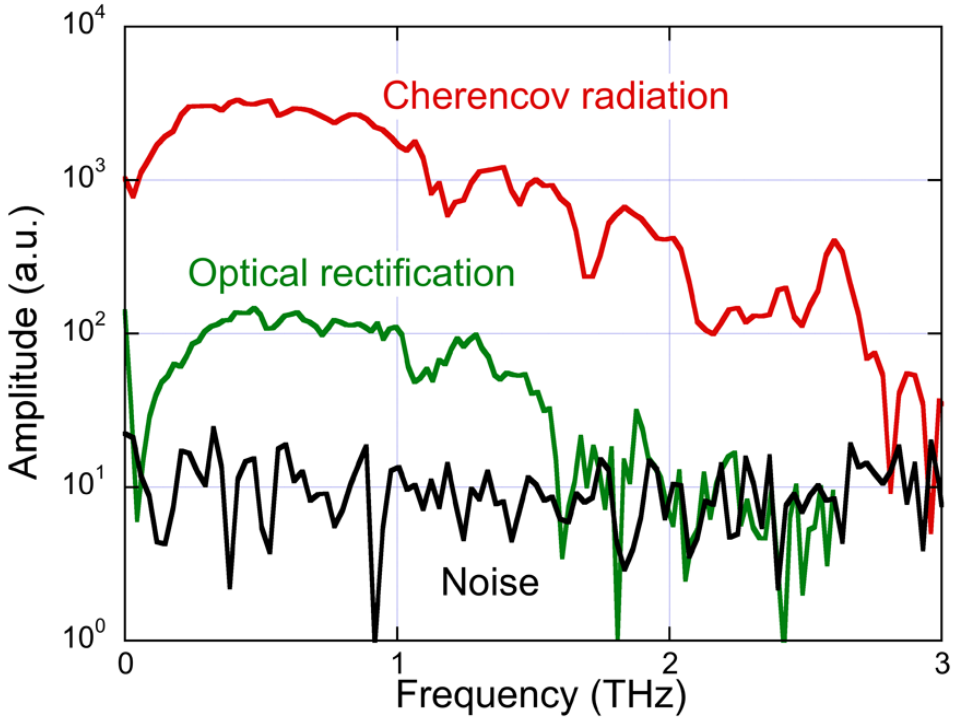


Comparison of DR between previous and modified THz color scanners

DR of temporal waveform



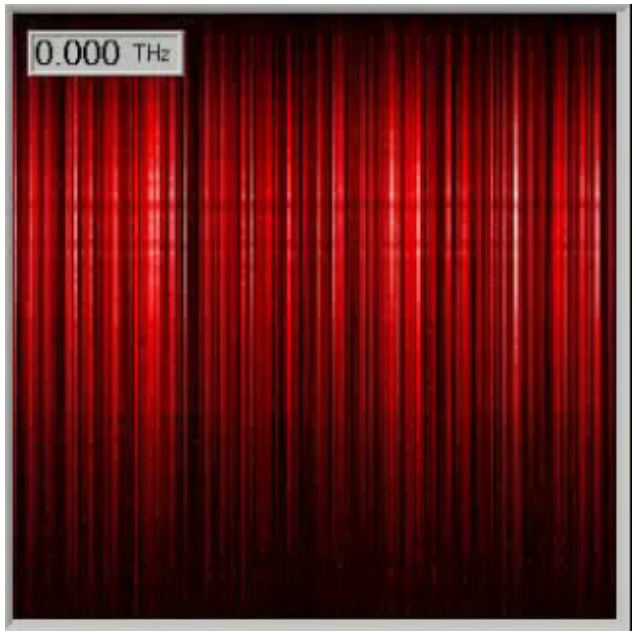
Amplitude spectra



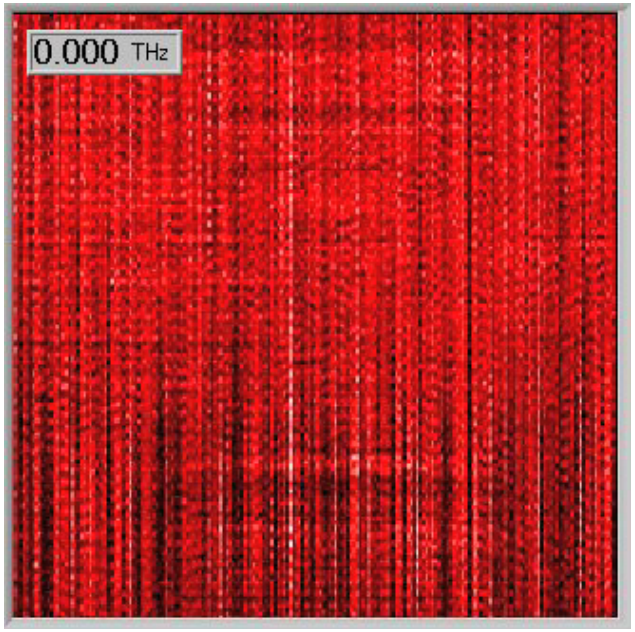
THz spectral imaging of moving 4seg-MHA

Optical rectification in ZnTe

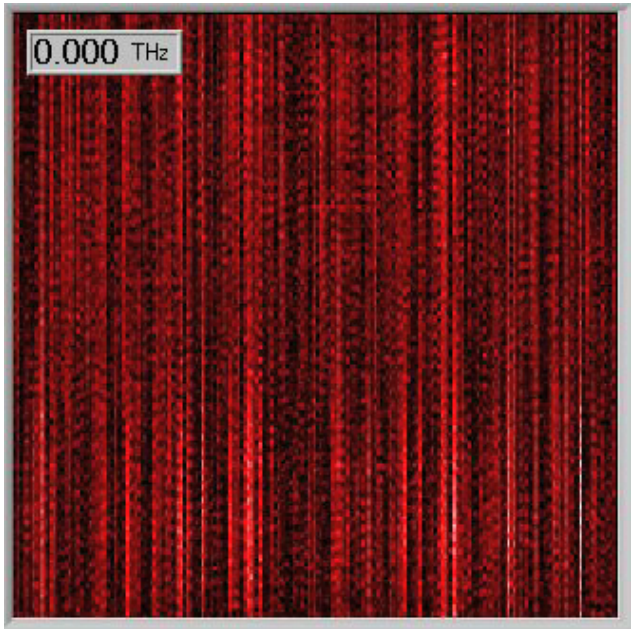
Pulse-front-tilted Cherenkov radiation in LN



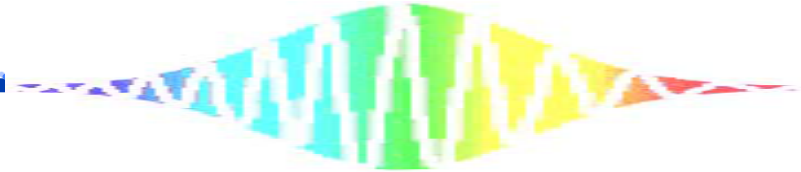
Sample speed=10mm/s
Image acquisition time=2sec



Sample speed=10mm/s
Image acquisition time=2sec



Sample speed=100mm/s
Image acquisition time=0.2sec



(4) Applications

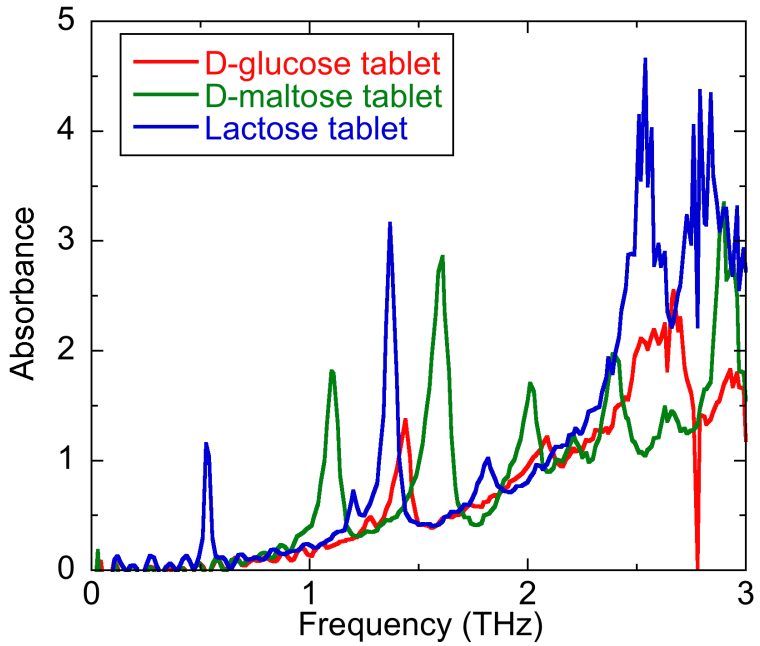
Ref) M. Schirmer, M. Fujio, M. Minami, J. Miura, T. Araki, and T. Yasui, "Biomedical applications of a real-time terahertz color scanner," Biomed. Optic. Express, Vol. 1(2), pp. 354-366 (2010) .

Pharmaceutical tablet (1)

Sugar tablets
(ϕ10mm@1mm-thick)

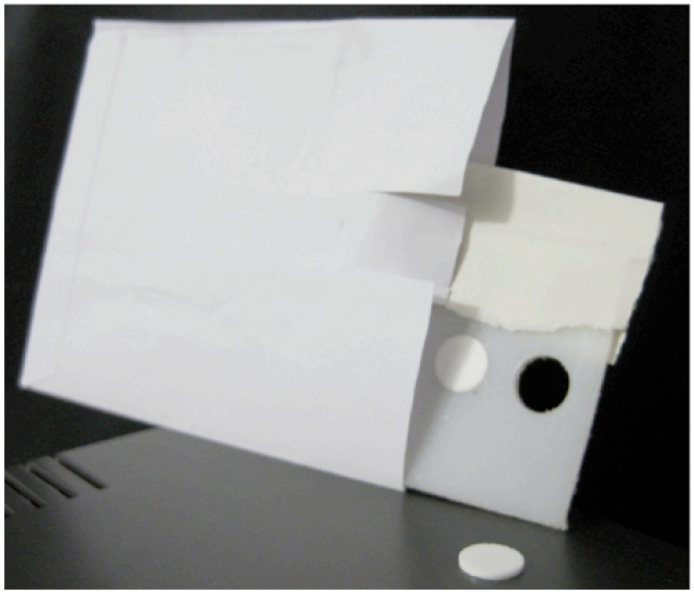
Tablet sample	Chemical composition (mg)				THz spectral fingerprint (THz)
	Polyethylene	D-glucose	D-maltose	Lactose	
D-glucose	75	25	0	0	1.44
D-maltose	75	0	25	0	1.10, 1.61
Lactose	50	0	0	50	0.525, 1.37
Reference	75	0	0	0	-

THz absorption spectra



Otsuka Electronics Co., Ltd., TR-1000

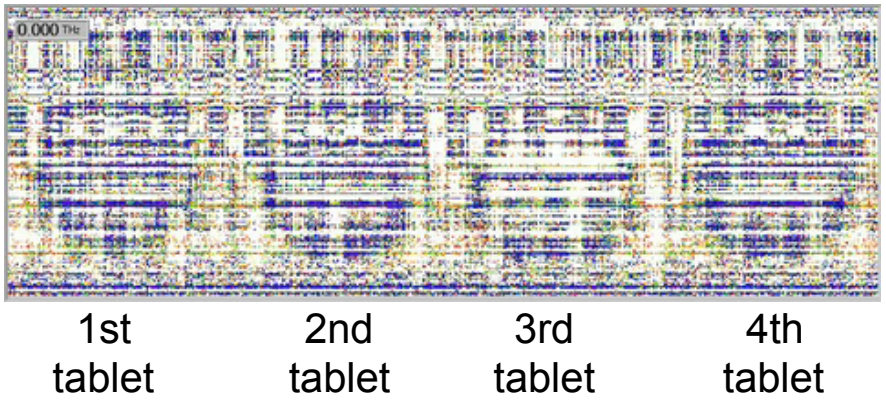
Photograph of sample and holder

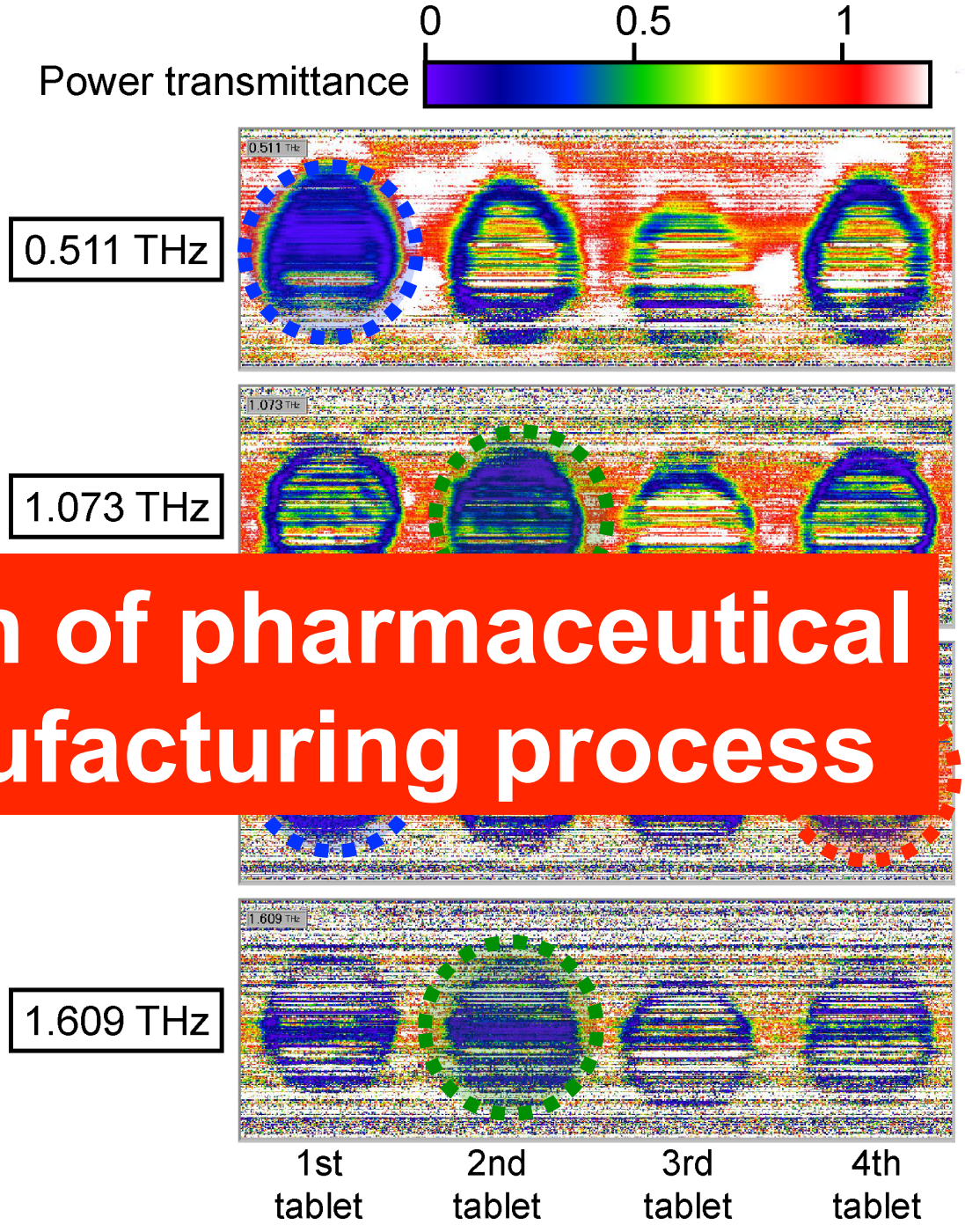


Pharmaceutical tablet (2)

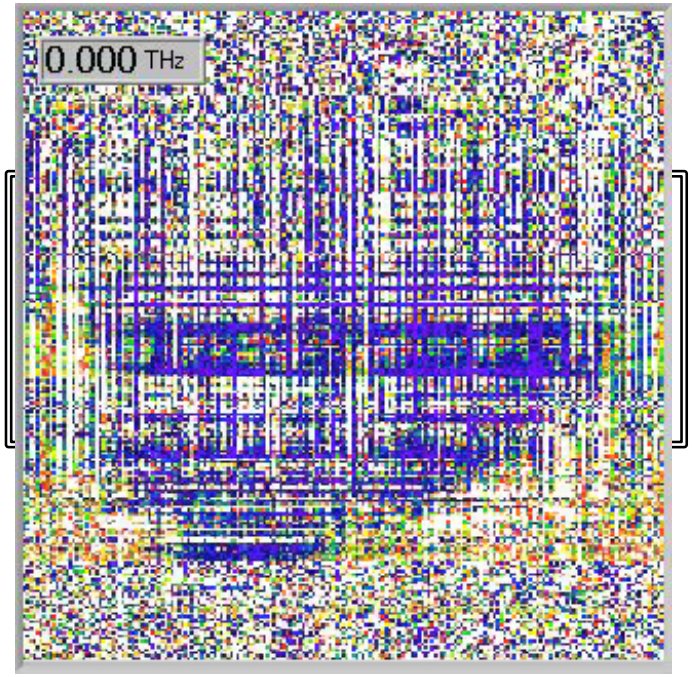
Sample	THz spectral fingerprint (THz)
D-glucose	1.44
D-maltose	1.10, 1.61
Lactose	0.525, 1.37

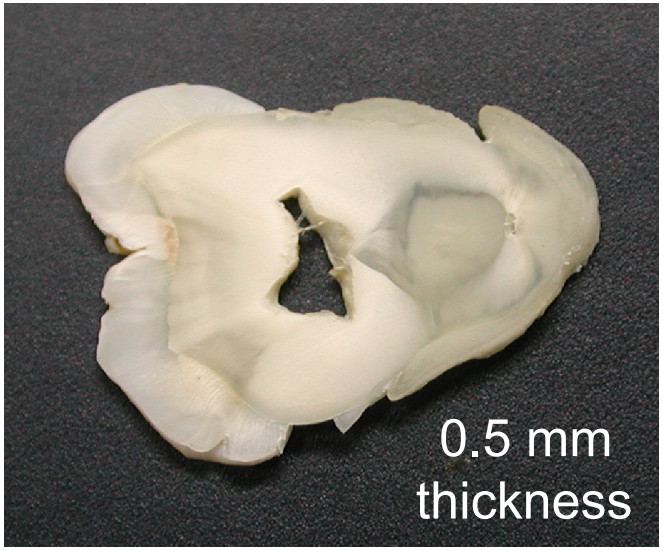
Total inspection of pharmaceutical tablets in manufacturing process

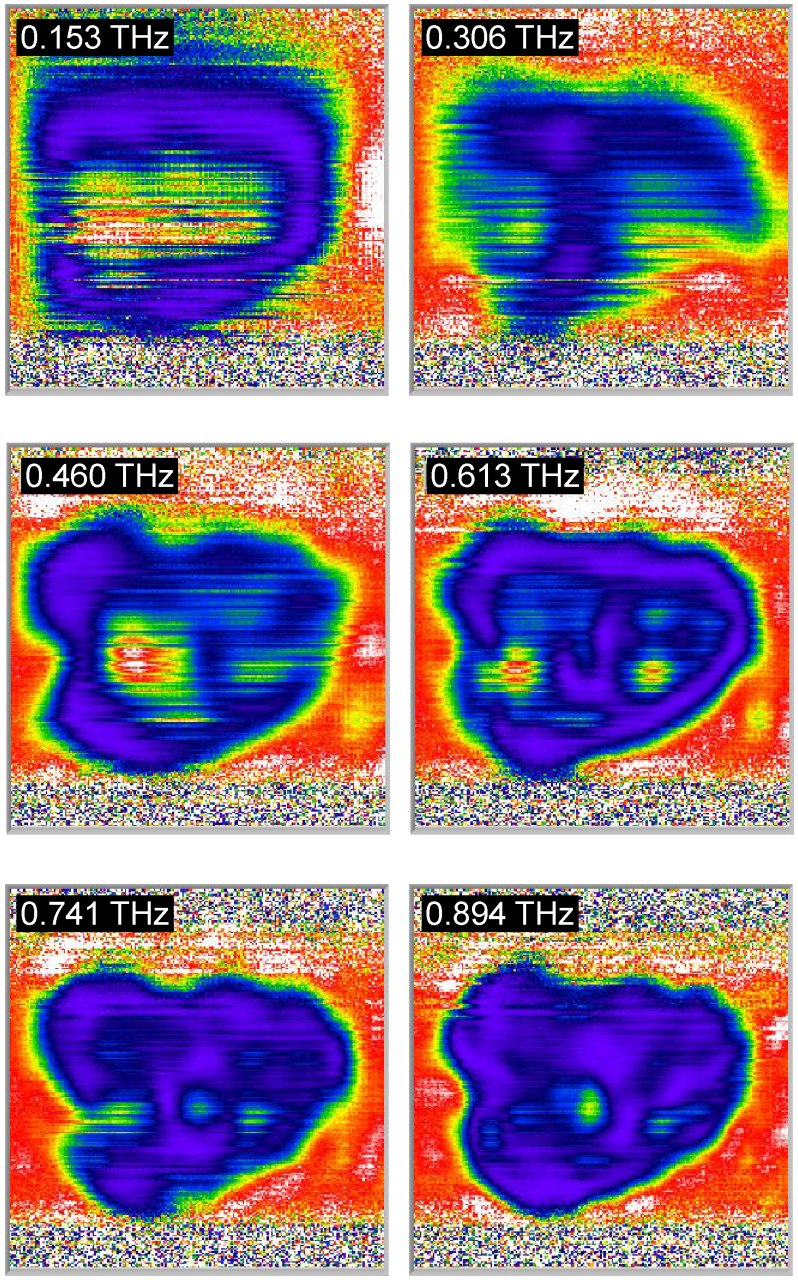




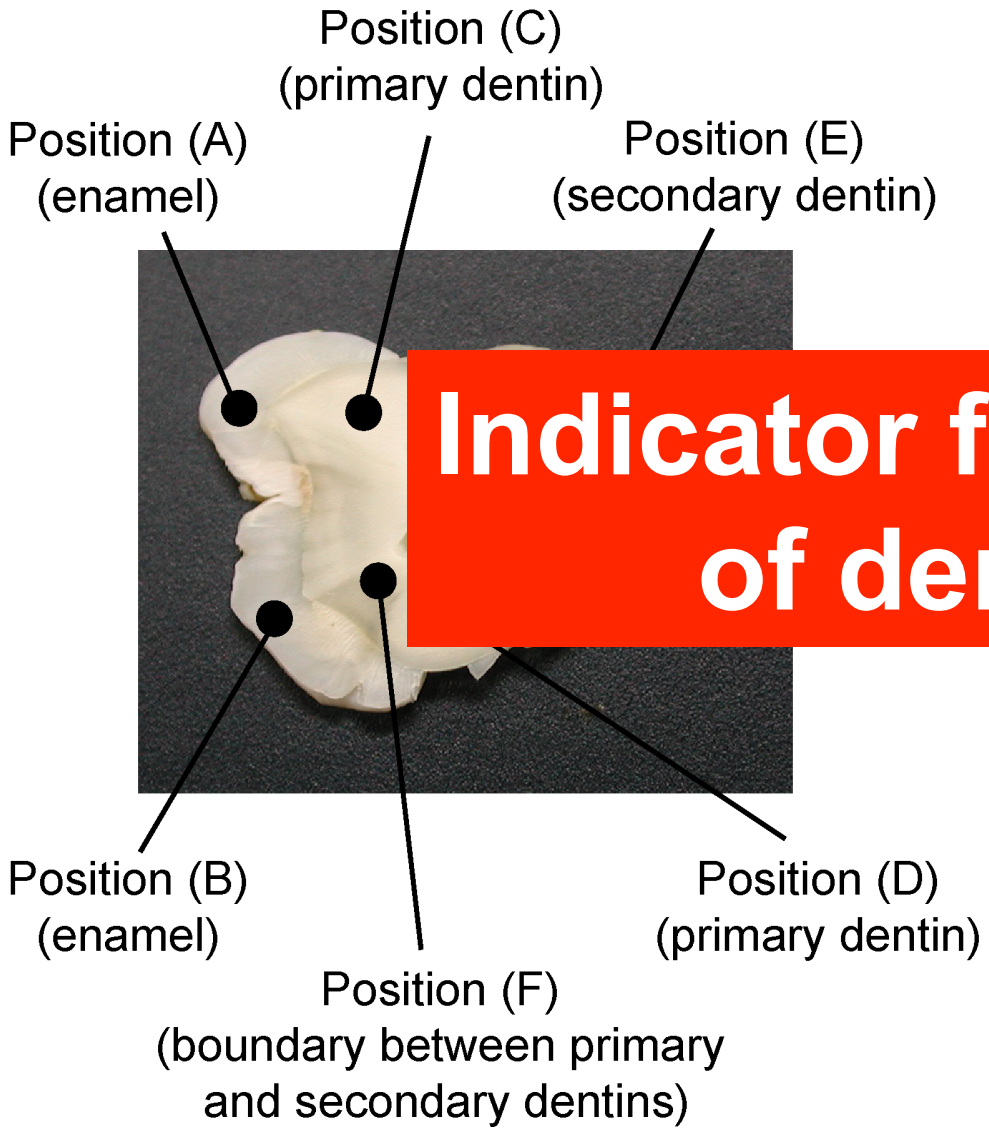
Sliced tooth (1)

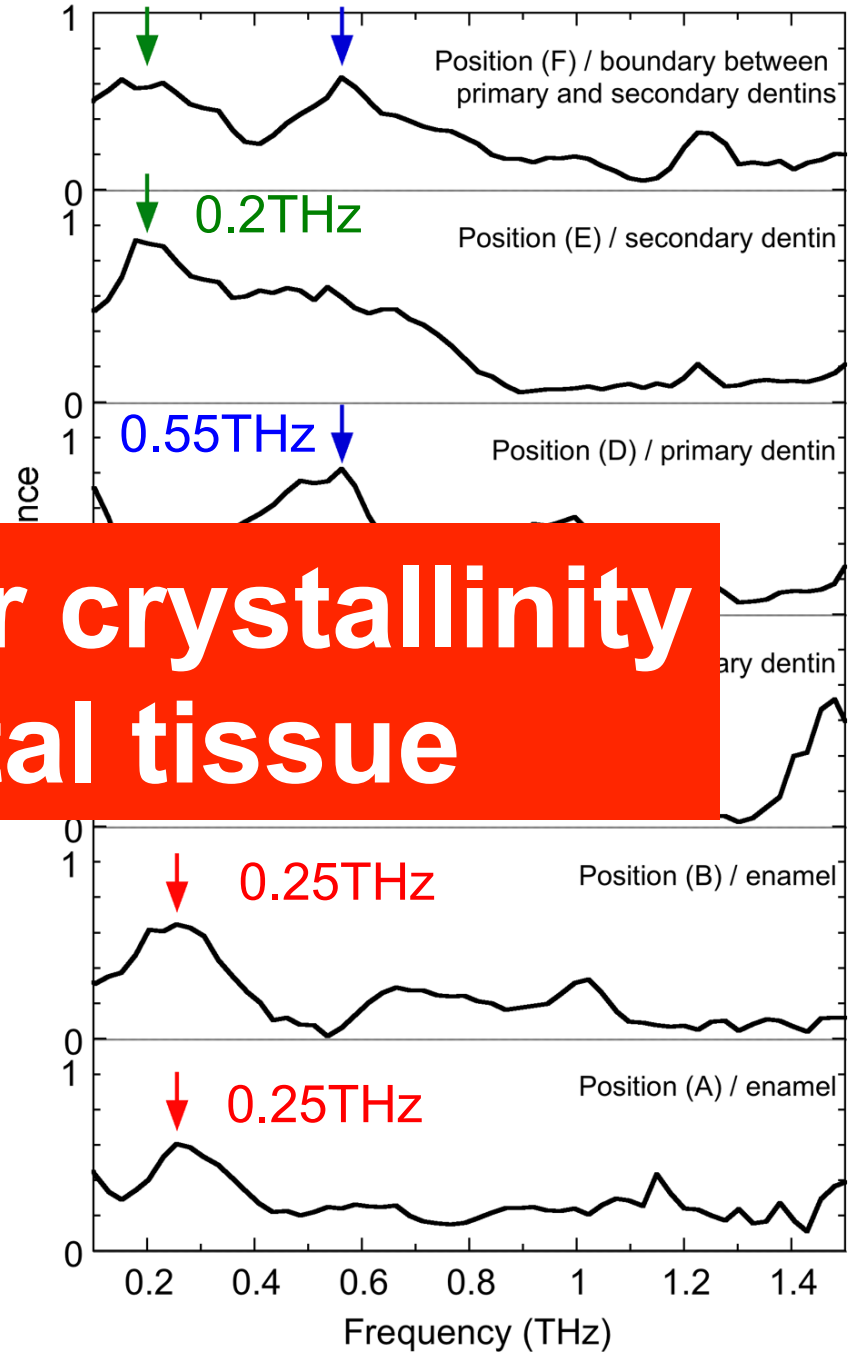






Sliced tooth (2)



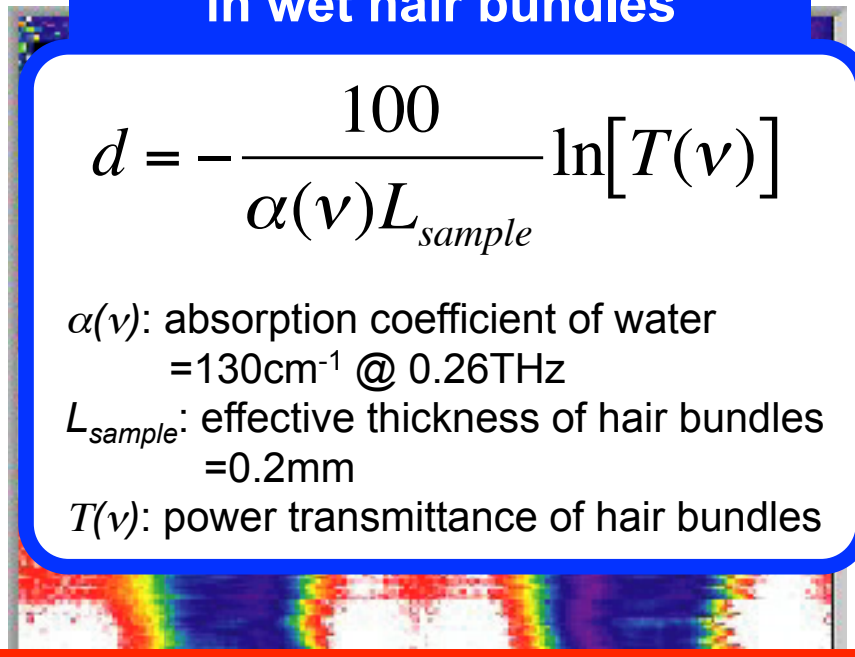


Indicator for crystallinity of dental tissue

Drying progress of wet hair bundle

0 0.5 1

Powe @0.26THz



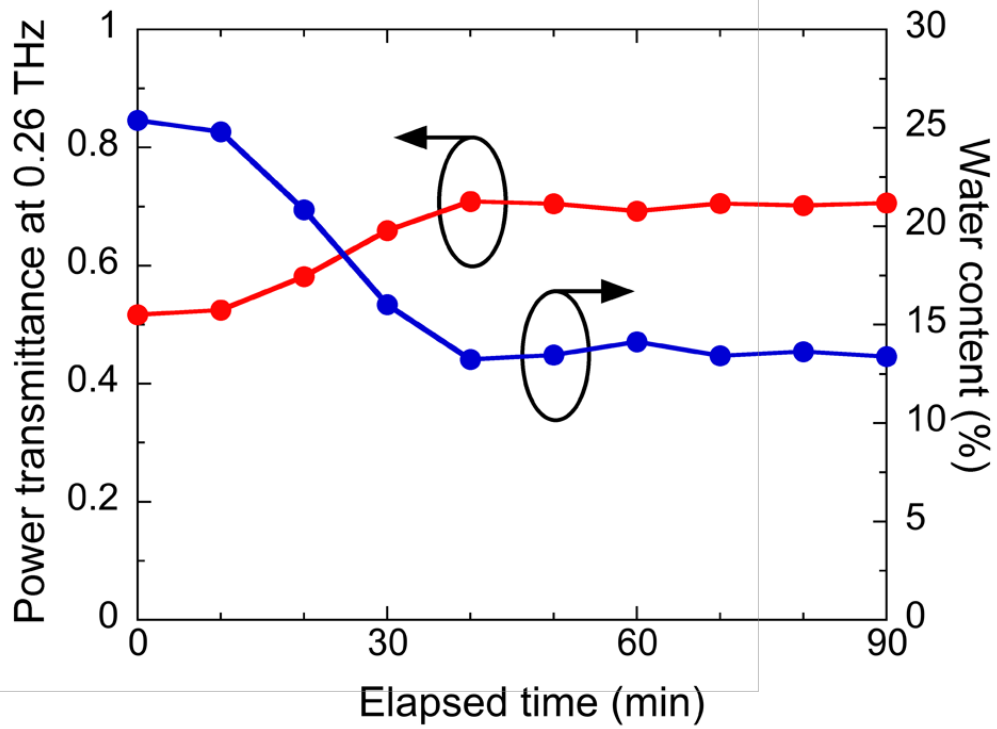
Percentage of water content in wet hair bundles

$$d = -\frac{100}{\alpha(\nu) L_{sample}} \ln[T(\nu)]$$

$\alpha(\nu)$: absorption coefficient of water
=130cm^{-1} @ 0.26THz

L_{sample}: effective thickness of hair bundles
=0.2mm

$T(\nu)$: power transmittance of hair bundles



Sensitive probe for water content

wet hairs

dry hairs

Summary

(1) THz color scanner equipped with real-time line-scanning

(2) Can be used for moving object at 100mm/s

(3) Applications

- Rapid inspection of pharmaceutical tablets
- Indicator for crystallinity of dental tissue
- Sensitive probe for water content

Acknowledgement

We thank Dr. M. Nagai (Kyoto Univ.) and Prof. J. Hebling (Univ. of Pécs) for useful discussion on Cherenkov radiation.