Advanced THz Measurement Technology and High-Value applications

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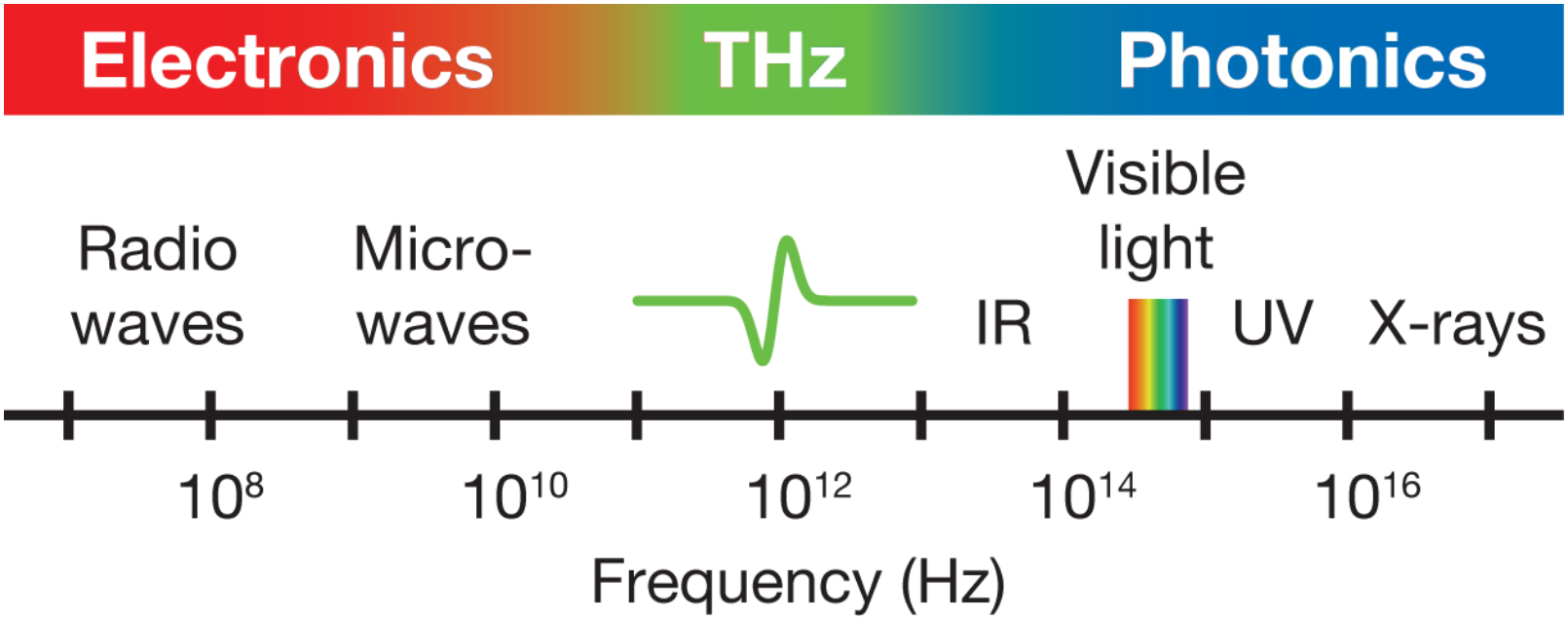
Rainbow Photonics AG

- Generation and Detection of THz Radiation
- Organic THz Generators: DSTMS and OH1
- THz Radiation for Materials Testing and Materials Identification
- THz Instruments for Imaging and Spectroscopy
- Examples of Technological Applications
- Outlook

Terahertz (THz) Radiation

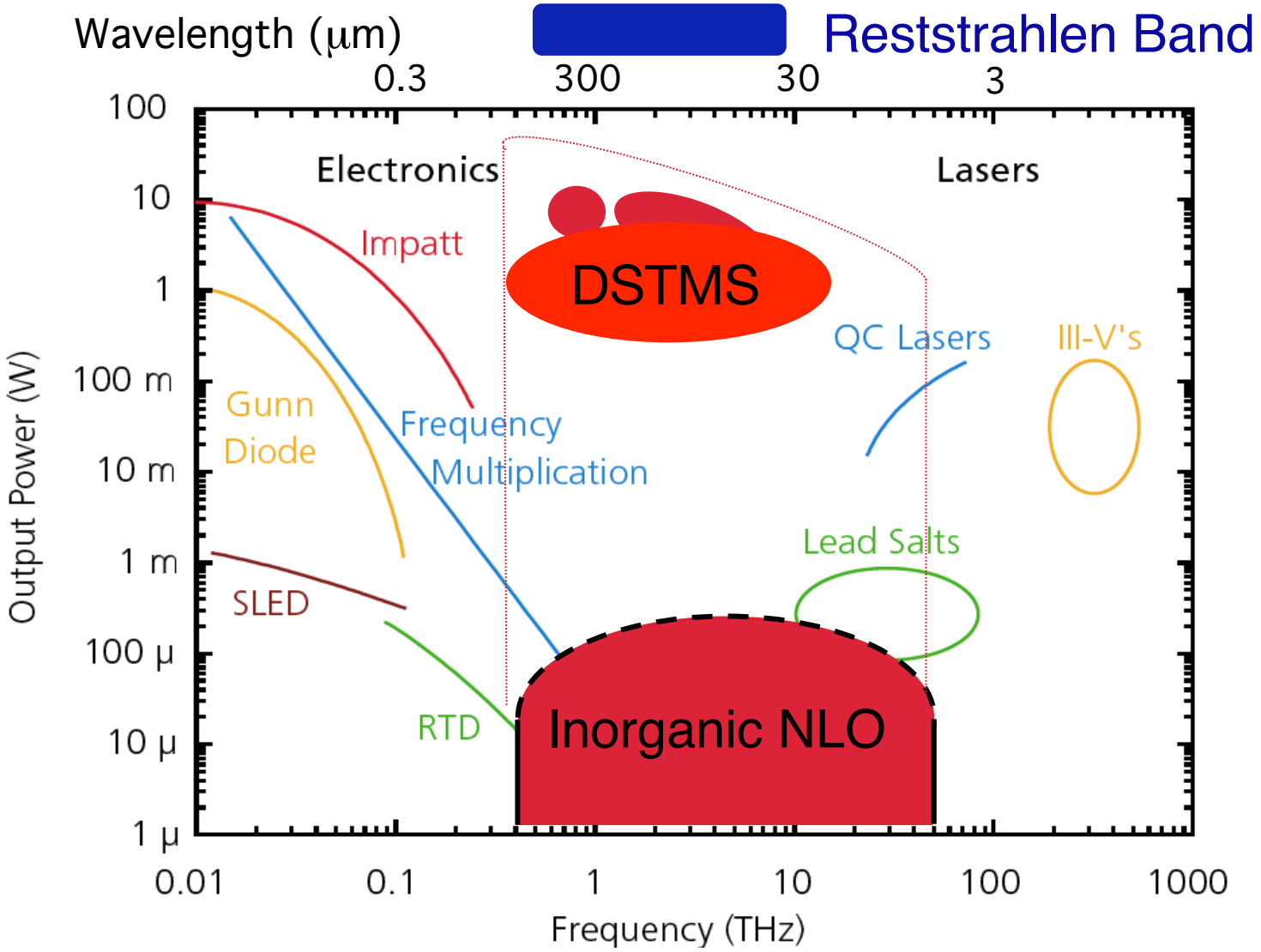


- Specific transmission characteristics in the THz range (**fingerprints**)
- **Non-ionizing** (no harm to people)
- Ideal for **materials testing, security**
- **Radiation goes through most packing materials and cloth**

Applications of THz Radiation

- Basic Research
- Materials Spectroscopy
- Non destructive Materials Defect Inspection
- Explosives Detection
- Chemical and Biological Agents
- Bio-medical
- Inspection (cargo, postal)
- Food safety

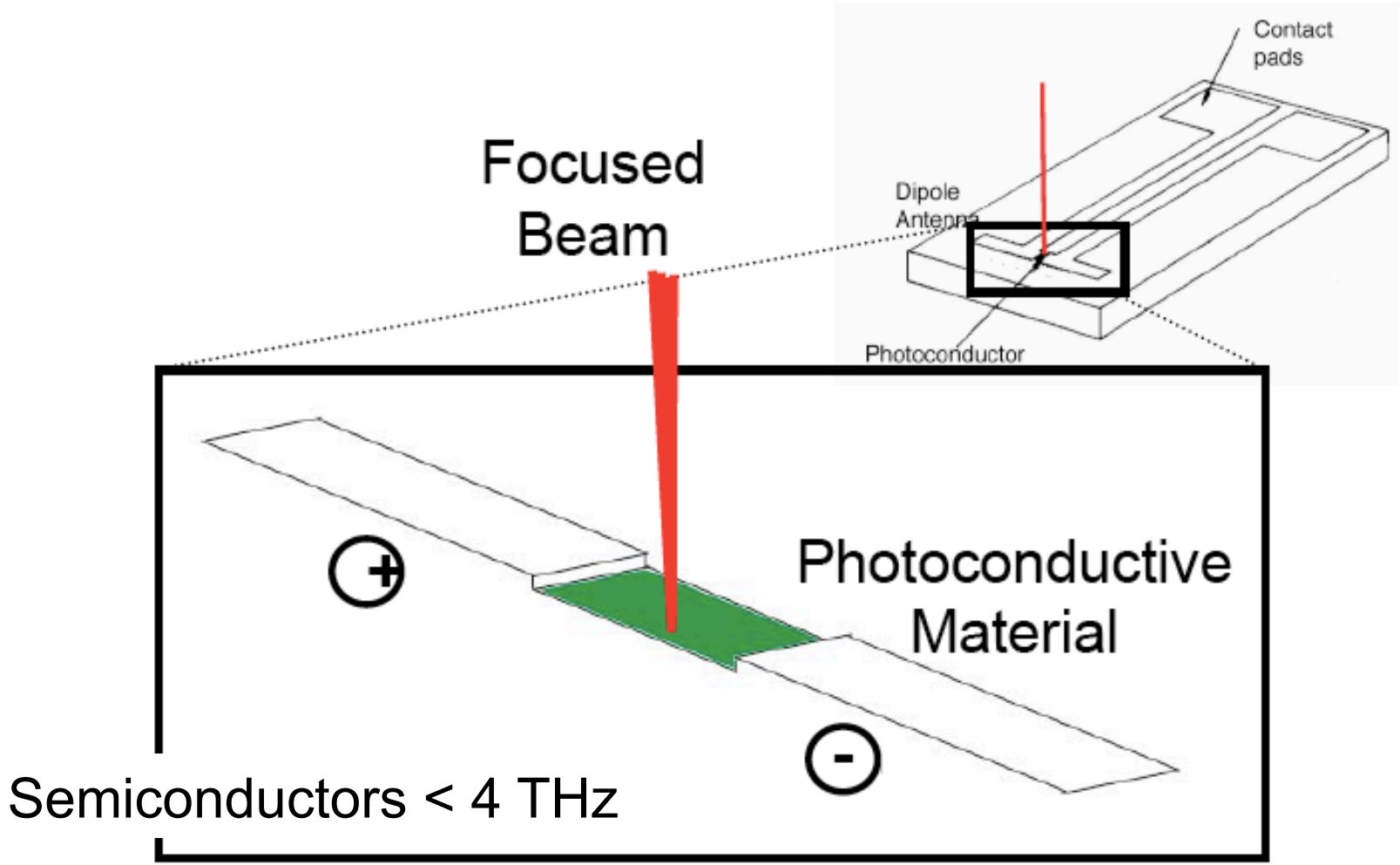
Electronics, THz Waves and Lasers



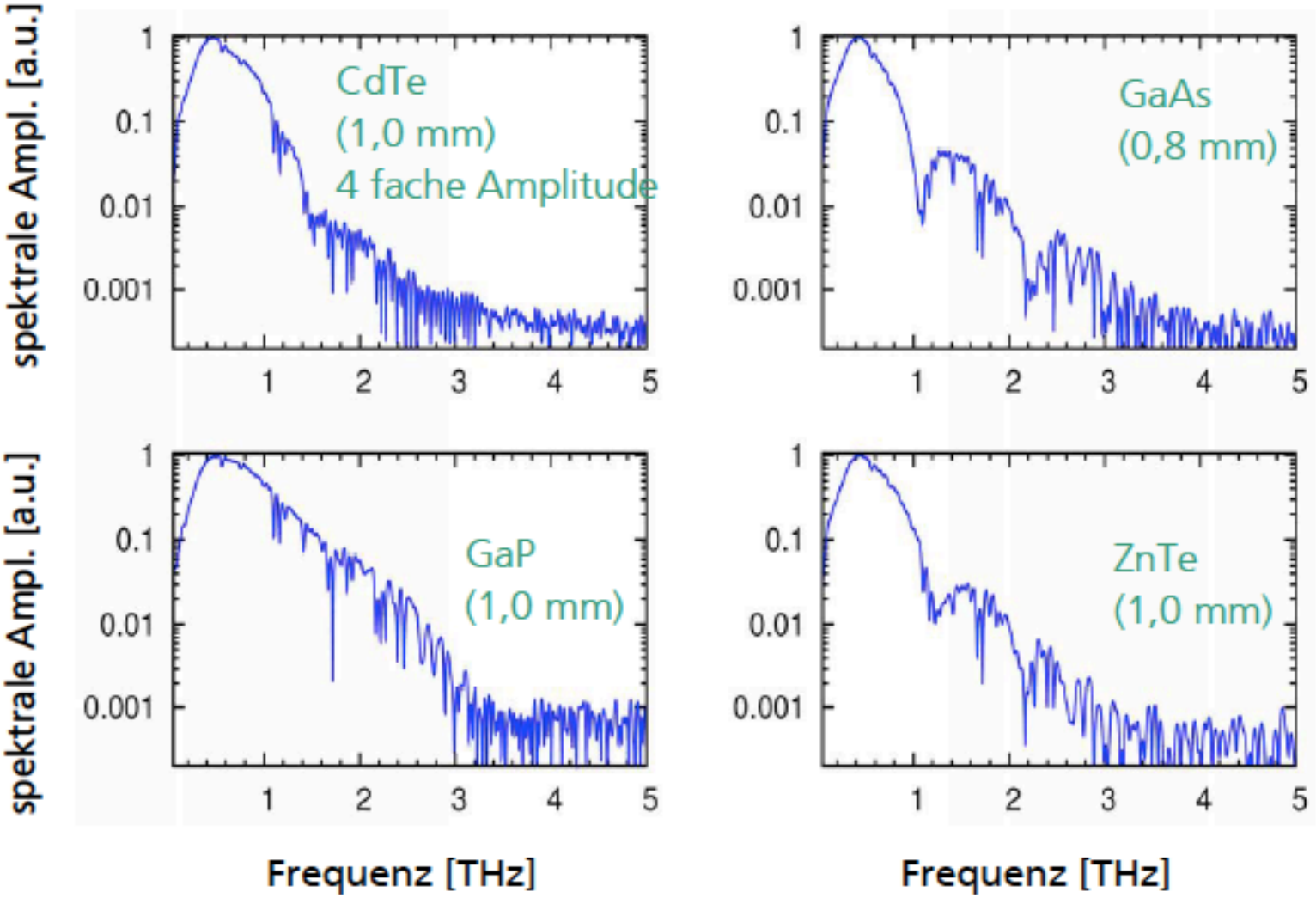
Terahertz Sources

- Auston Switch (Semiconductors < 4 THz)
- Quantum Cascade Lasers
- Optical Rectification up to 20 THz with organic materials
- Difference Frequency Generation 1 – 100 THz
- UTC-PD (< 1 THz)
- BackWOscillators

Auston Switch



THz Spectra from Auston Switches



Nonlinear Optical Techniques

difference-frequency generation

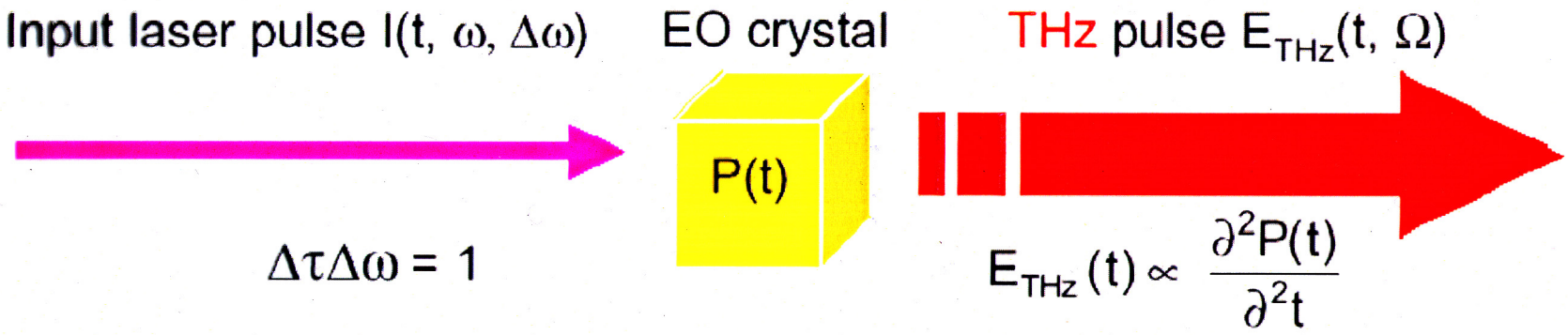
$$\omega_3 - \omega_1 \rightarrow \omega_2$$

special case: optical rectification

$$\omega - \omega \rightarrow \Omega \approx 0$$

$$\left.\begin{aligned} \omega_1 &= \omega + \Omega/2 \\ \omega_2 &= \omega - \Omega/2 \end{aligned}\right\} \Rightarrow \omega_1 - \omega_2 = \Omega \qquad (\ \omega \gg \Omega\ )$$

THz Optical Rectification



Beating frequency $\Omega < \Delta\omega$ (laser bandwidth)

Dielectric polarization: $P(\Omega) = \chi^{(2)}(\Omega, \omega+\Omega, -\omega)\, E(\omega+\Omega)E^*(\omega)$

$$E_{THz}(t) \propto \frac{\partial J(t)}{\partial t} = \frac{\partial^2 P(t)}{\partial^2 t} = \chi^{(2)} \frac{\partial^2 I(t)}{\partial^2 t}$$

NLO fs pulses

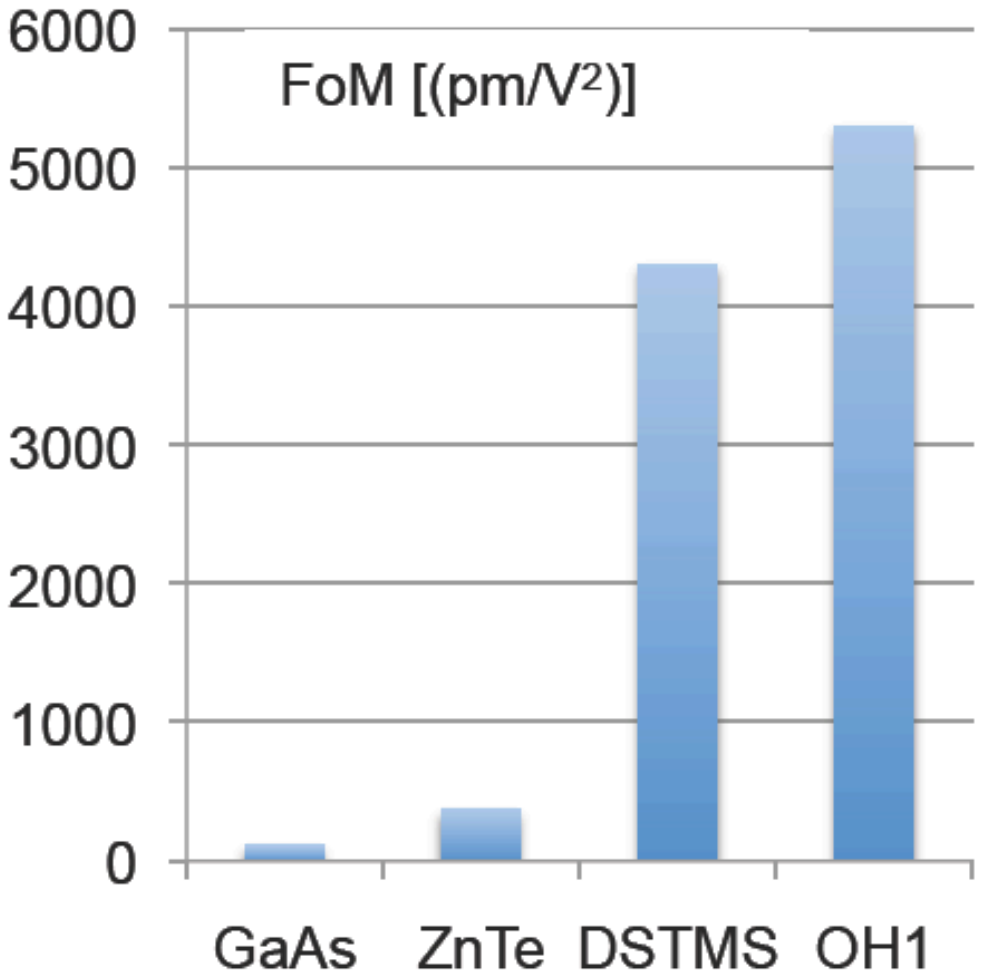
E_{THz} = 83 MV/cm (Shalaby & Hauri. Nat. Commun. **6**, 8439 (2015))

Requirements for Efficient THz Generation

- Large nonlinear susceptibility: $\chi^{(2)}$
- Low absorption: α
- Velocity-matching between the optical and the THz pulse: $\Delta k=0$

Organic crystals satisfy all these conditions particularly well!

Figure of Merit



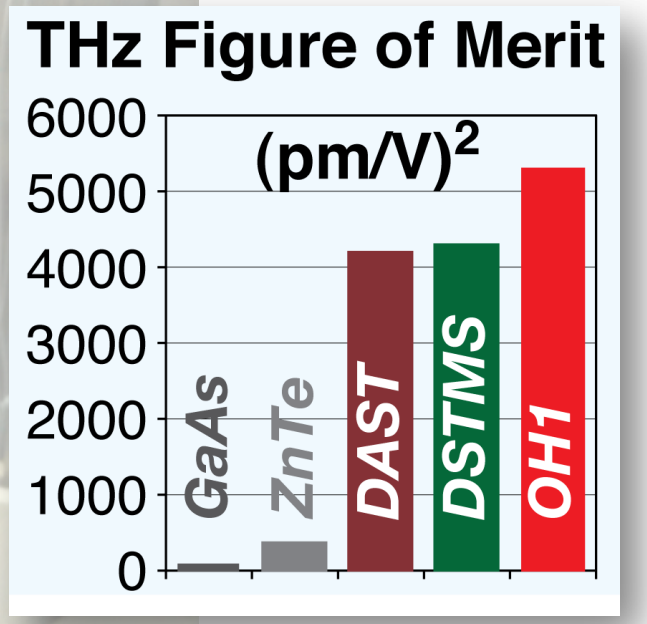
$$\mathrm{FoM} = b \cdot 4n_{\mathrm{IR}}^{7} r^{2} / ((1+n_{\mathrm{IR}})^{2}(1+n_{\mathrm{THz}})^{2})$$

Core product: THz Generation Materials

- **Organic materials:**
  DAST, DSTMS, OH1
  Worldwide only producer

- **Core product from**
  Rainbow Photonics AG
  protected with patents

- **Production line at the premises of**
  Rainbow Photonics AG
  since 2007



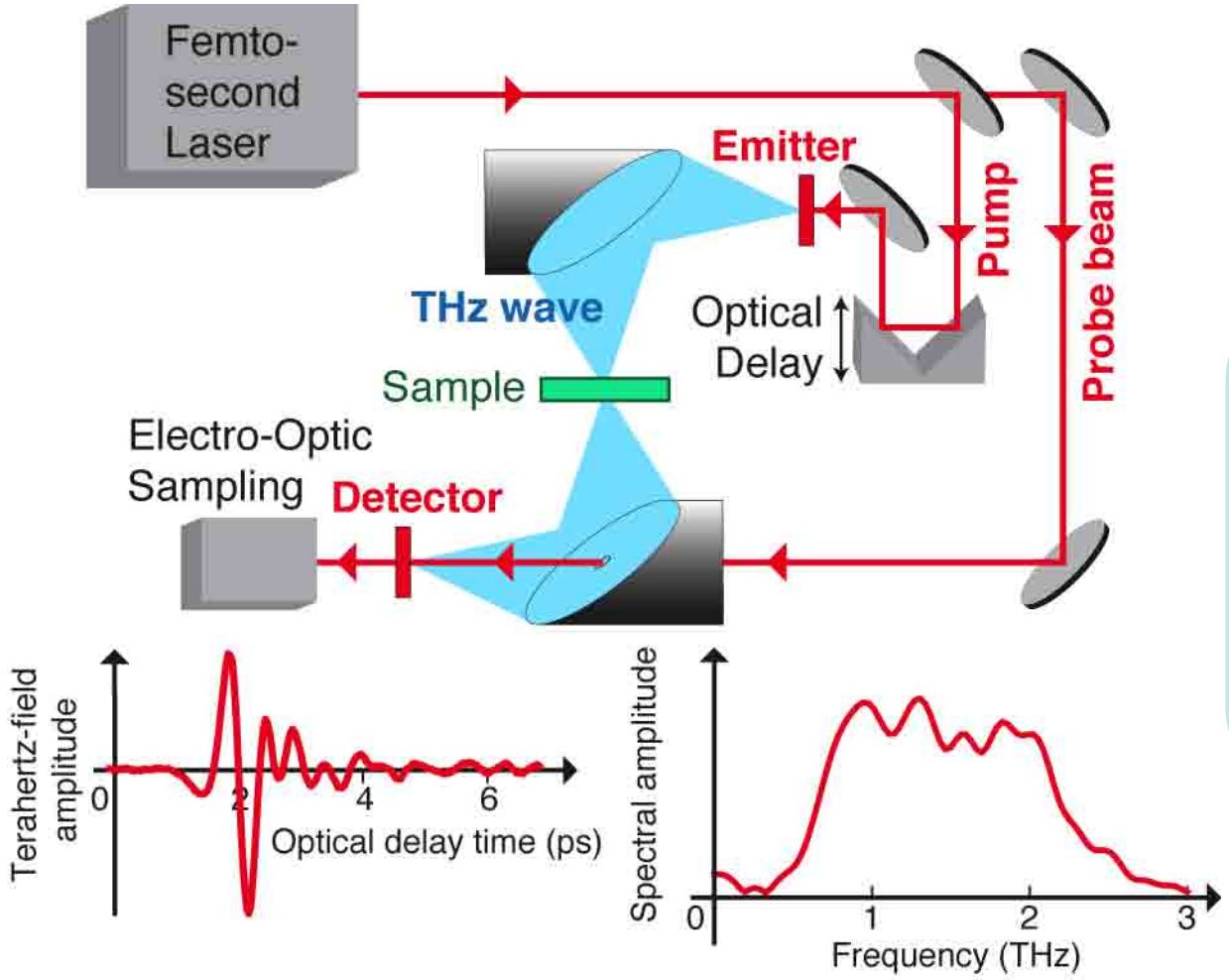
Requirements for Commercial Sources

- Compact
- Turn key operation
- Fast measuring time (high laser pump power, high nonlinear optical susceptibility)
- Reliable and maintenance free (all-solid state)

TeraSys® - AiO (1-14 THz)

Transmission-Reflection-Imaging
All in One

THz Wave Generation by OR - Setup



THz time-domain system

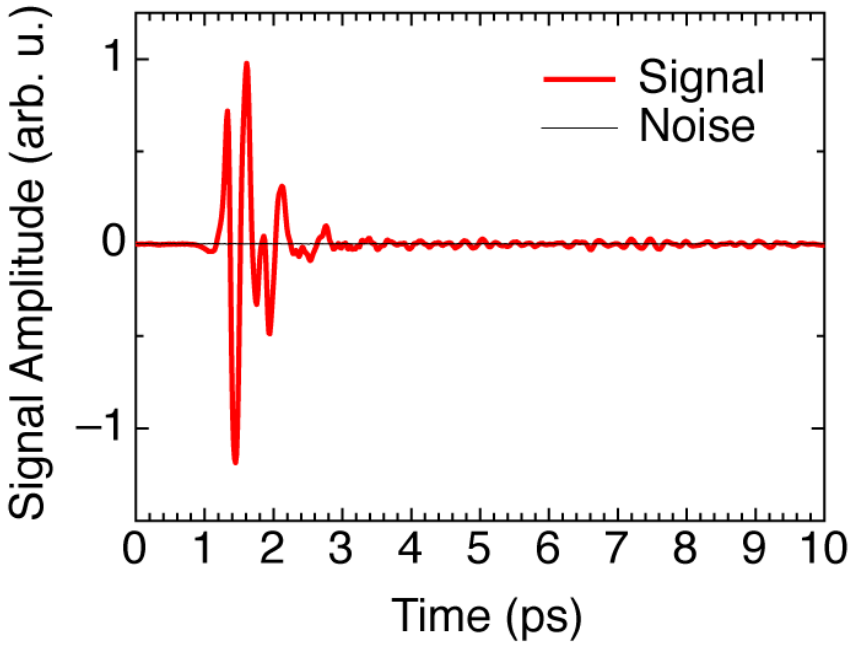
Detection: THz induced lensing in org. crystals

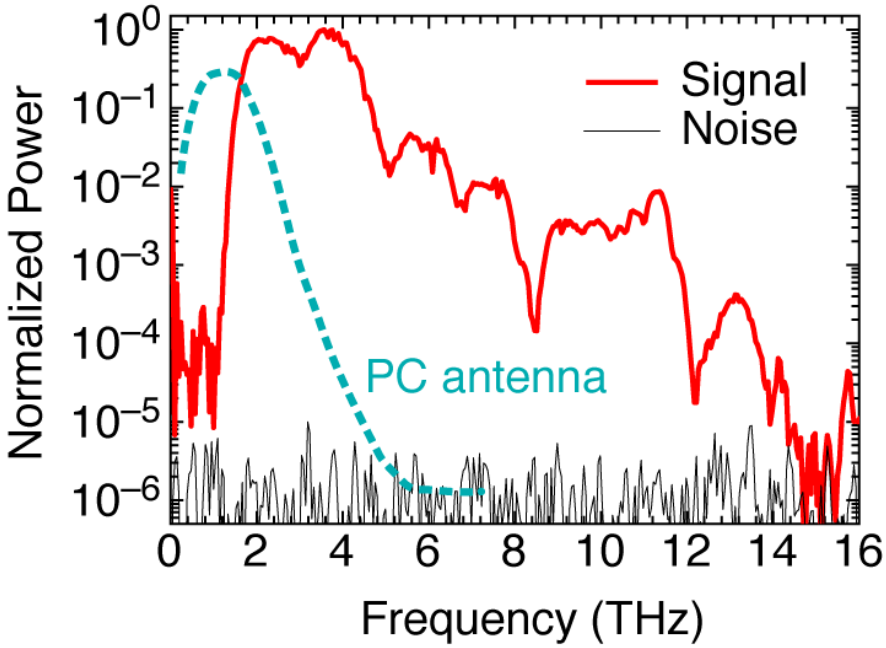
(Schneider et al, Appl. Phys. Lett. 84)

TD-THz system

- THz wave generated and detected in with **DSTMS** crystals (Pump laser: 1560 nm, 43 fs, 120 mW average power, 1.2 nJ energy/pulse)

— Rainbow Photonics





- The spectrum extends up to 14 THz

Applications of THz Radiation

- Basic Research
- Materials Spectroscopy
- Non destructive Materials Defect Inspection
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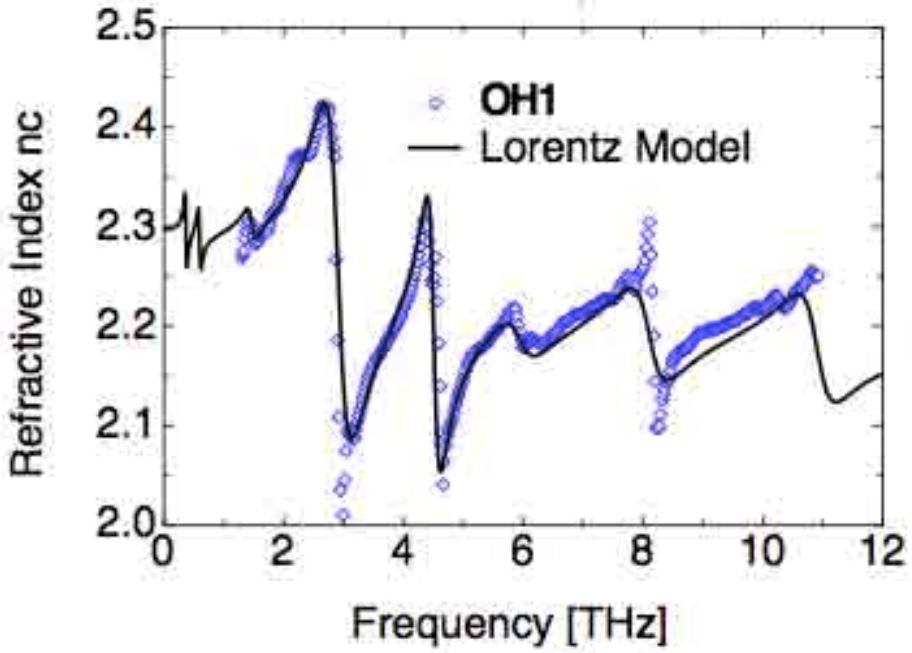
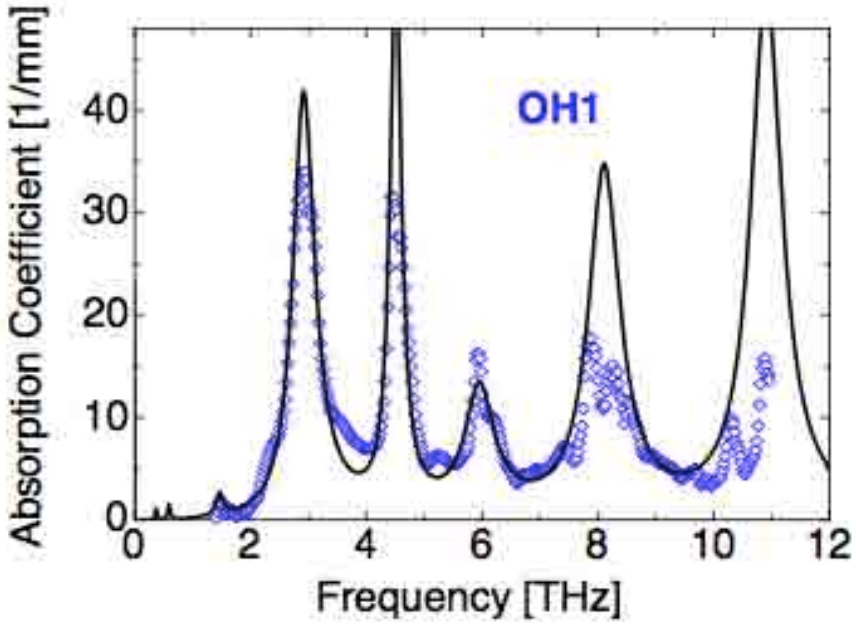
OH1: THz Refractive Indices & Absorption



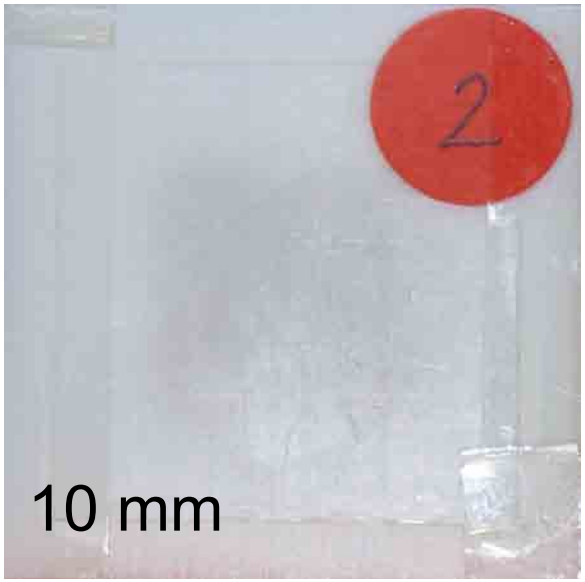


THz Absorption of Explosives

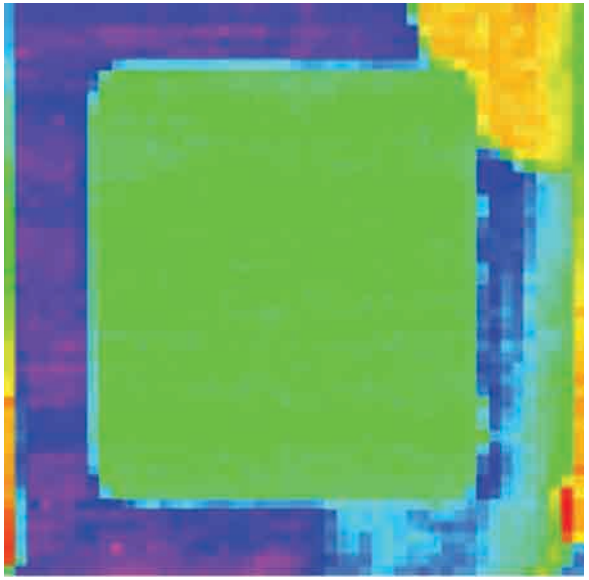
Explosive		Measured Absorption Peak Position (THz)
TNT		1.66, 2.20, 3.69, **4.71, 5.52, 8.28, 9.12, 10.65, 11.01**
RDX	Semtex	0.82, 1.05, 1.5, 1.96, 2.20, 3.08, **6.73, 10.35, 11.34, 12.33**
HMX		1.78, 2.51, 2.82, **5.31, 6.06, 11.28, 12.0, 12.54**
Tetryl		**5.97, 10.11, 11.28, 14.67**
2-amino-4,6-DNT		**0.96, 1.43, 1.87, 3.96, 5.07, 6.27, 8.49, 9.87, 10.77, 12.15**

THz-Image of Semtex

(a)



(b)

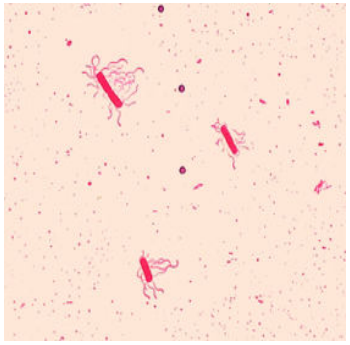


Semtex (RDX, HMX) hidden in Teflon

Size: 25 x 25 mm

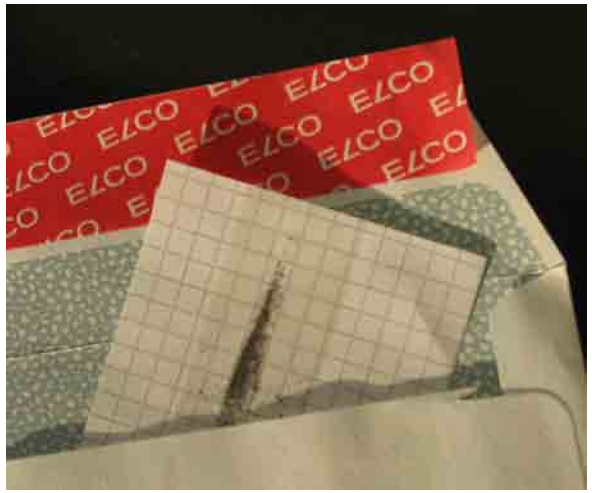
- No explosive
- Explosive
- Red paper sticker in upper right corner.

THz imaging: Bacillus cereus spores

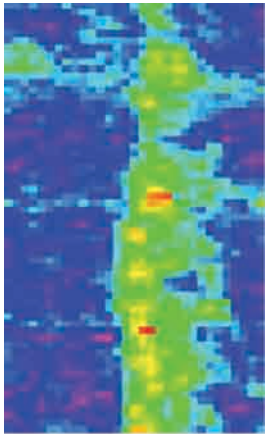


Bacillary, anaerobic and spore forming bacteria
→Food poisoning
→Closely related to B. anthracis!

THz-Image



10 mm



- **Particle size ~1 micron**
- **~ Monolayer**
- **Scanned area: 7.5 x 15 mm**
- **0.25 x 0.25 mm/pixel**

Ultra-High Density Polymers

- Biomedical industry (knee/shoulder/hip implants)
- Automotive industry/ aerospace

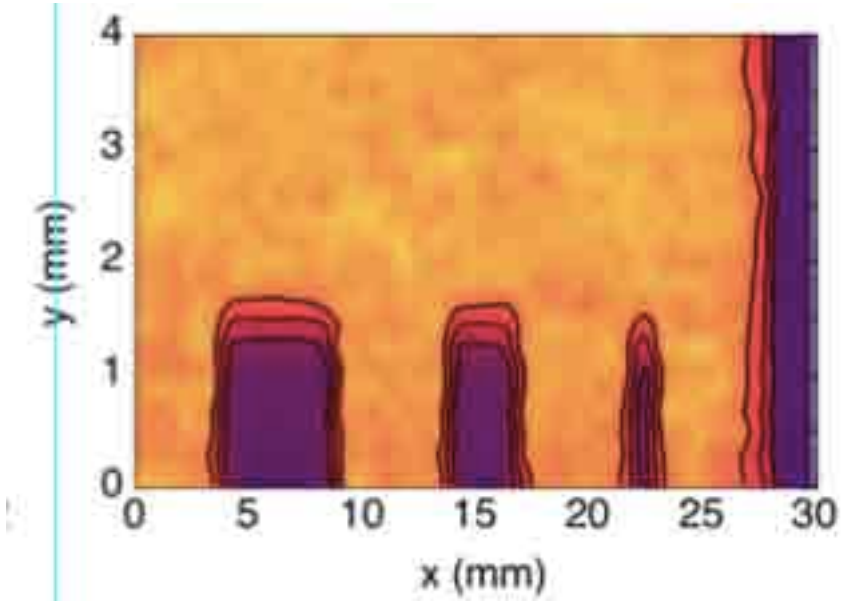
The problem: Quality testing

Not satisfactory results with present technologies:

- visual inspection
- ultrasound
- UV light
- X-ray

THz imaging: Biomedical and Polymers

Optical image:



THz image:

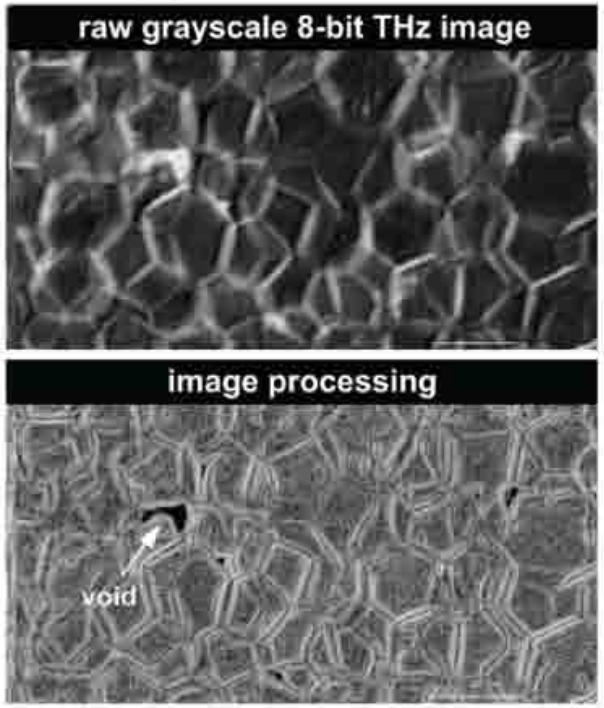
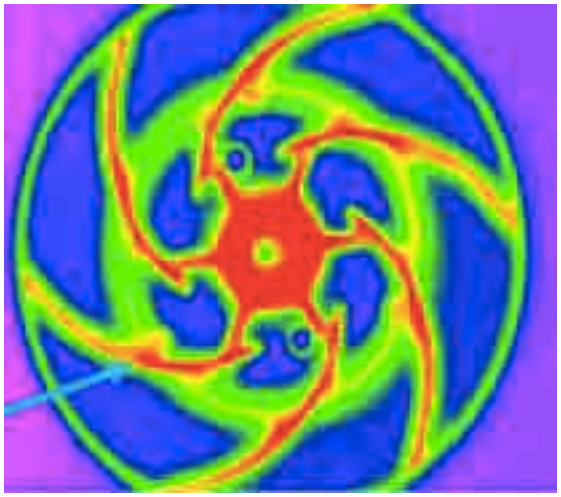
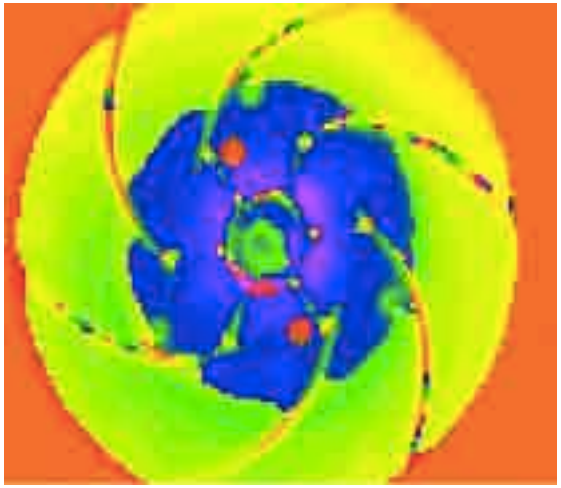


Image from: A. Abina et al, "Structural analysis of insulating polymer foams with THz spectroscopy and imaging", Polymer Testing 32, 739 (2013)

THz Imaging in Materials Testing





Materials Testing (Resolution)

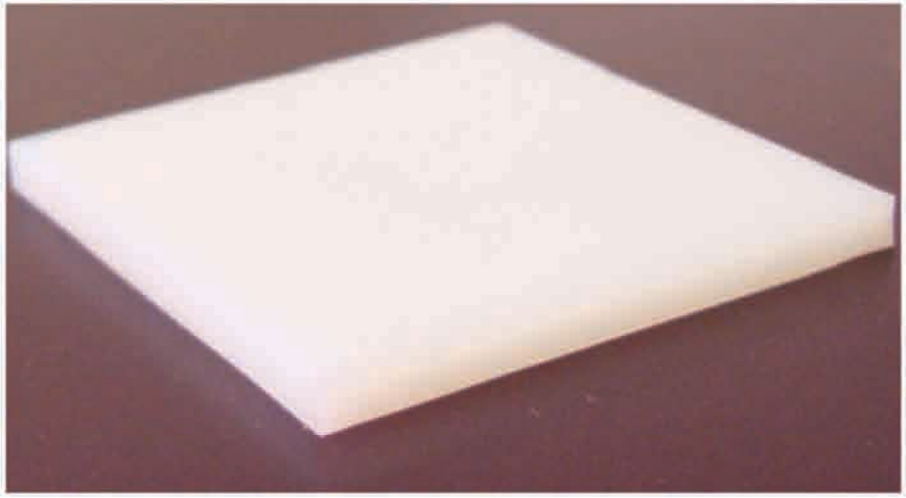


Figure 2(a) Optical image of an UHMWPE (Ultra high molecular weight polyethylene) sample

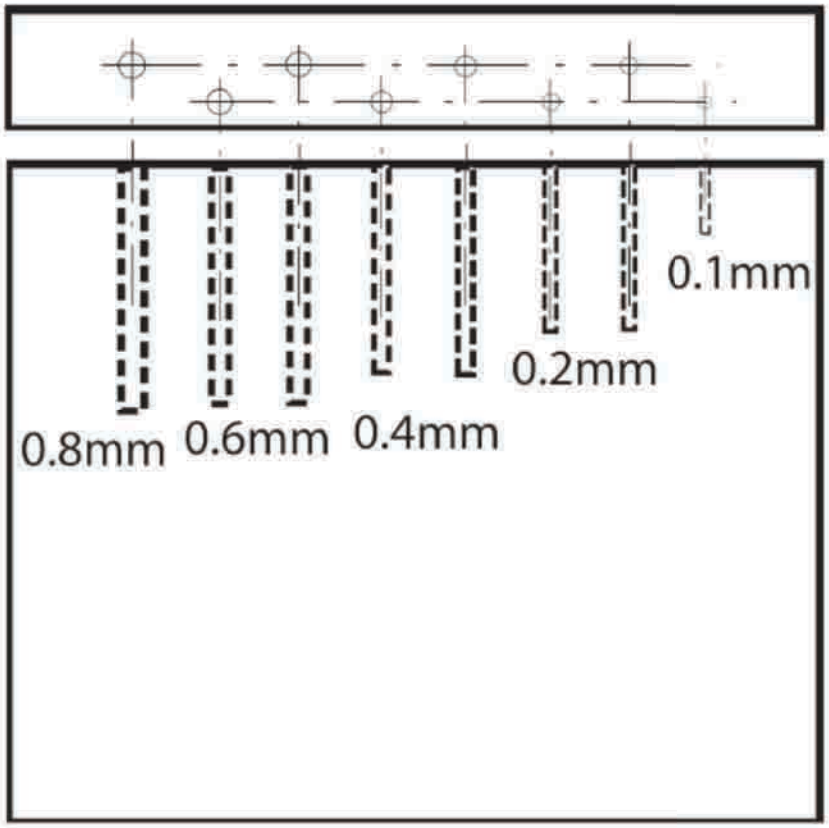
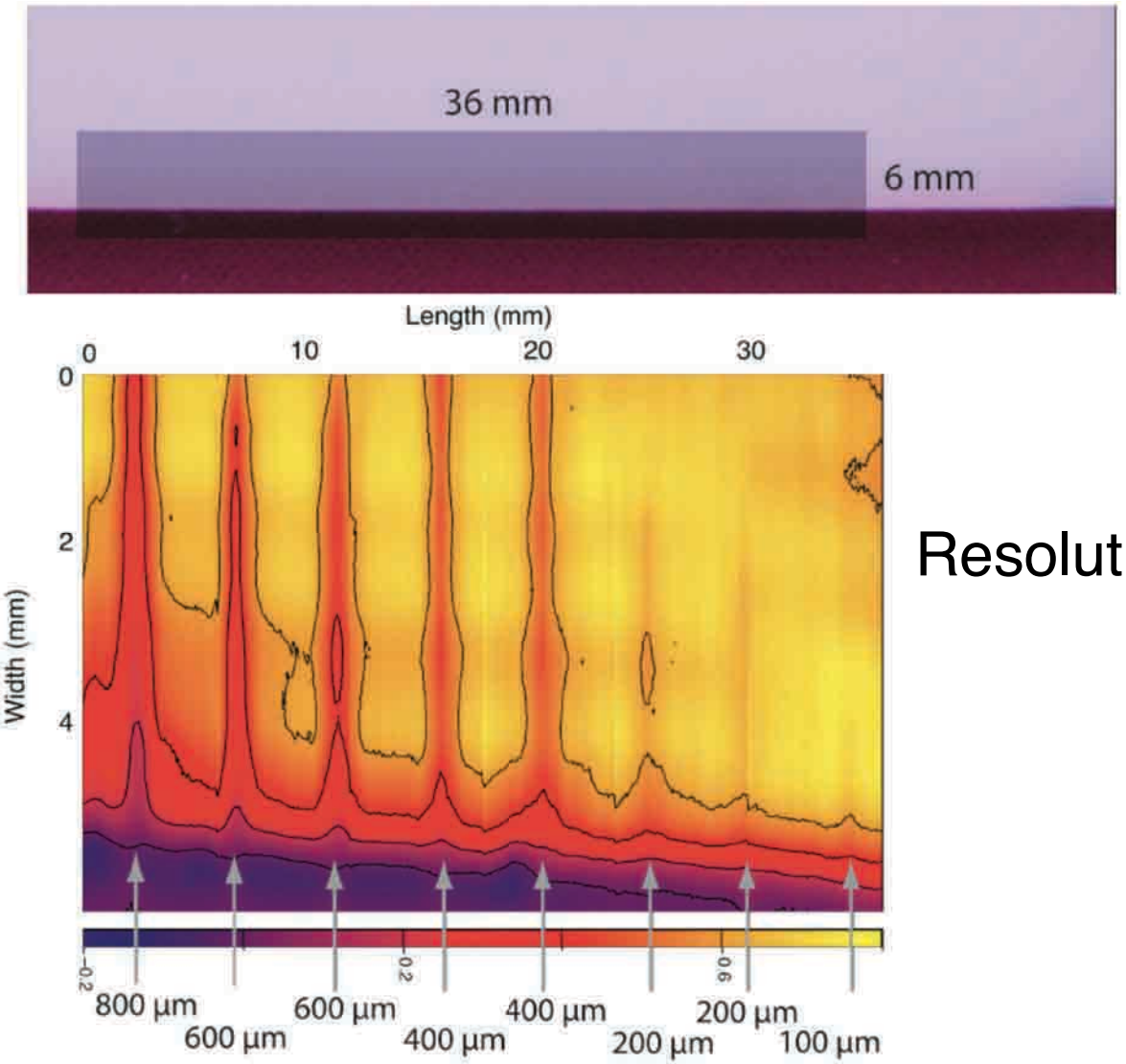


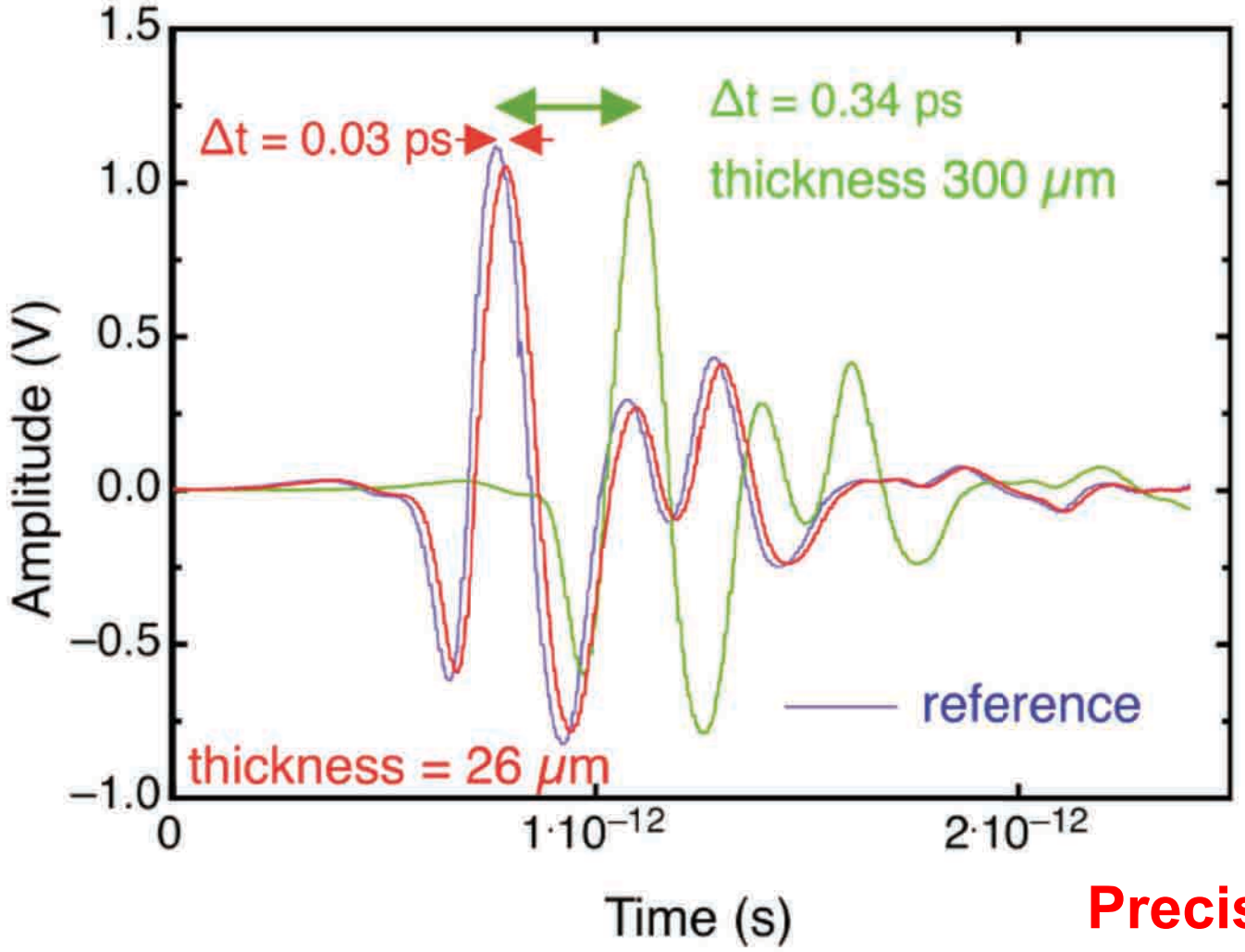
Figure 2(b). Location of the intentionally made holes in the UHMWPE

THz image of hidden holes in UHMWPE



Resolution Limit: 50 μm

Thickness of Plastic Foils



Reference

Slide-foil

Wrapping foil

Precision: 5…10 µm

Outlook

THz technology is ideally suited for :

- Detection of special chemicals, drugs,
- Industrial materials testing of defects in polymers, ceramics, etc..
- Gas sensing

Future:

- Food safety
- Industrial systems for non destructive testing (biomedical, automotive, ceramics)
- Thickness monitoring of industrial plastic foils, paper production etc…