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Terahertz for Food Sensing

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Photonics 4 Food

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Terahertz TDS
Time Domain Spectroscopy

Motivation Terahertz and TDS

- **Extremely powerful for spectroscopy and imaging**

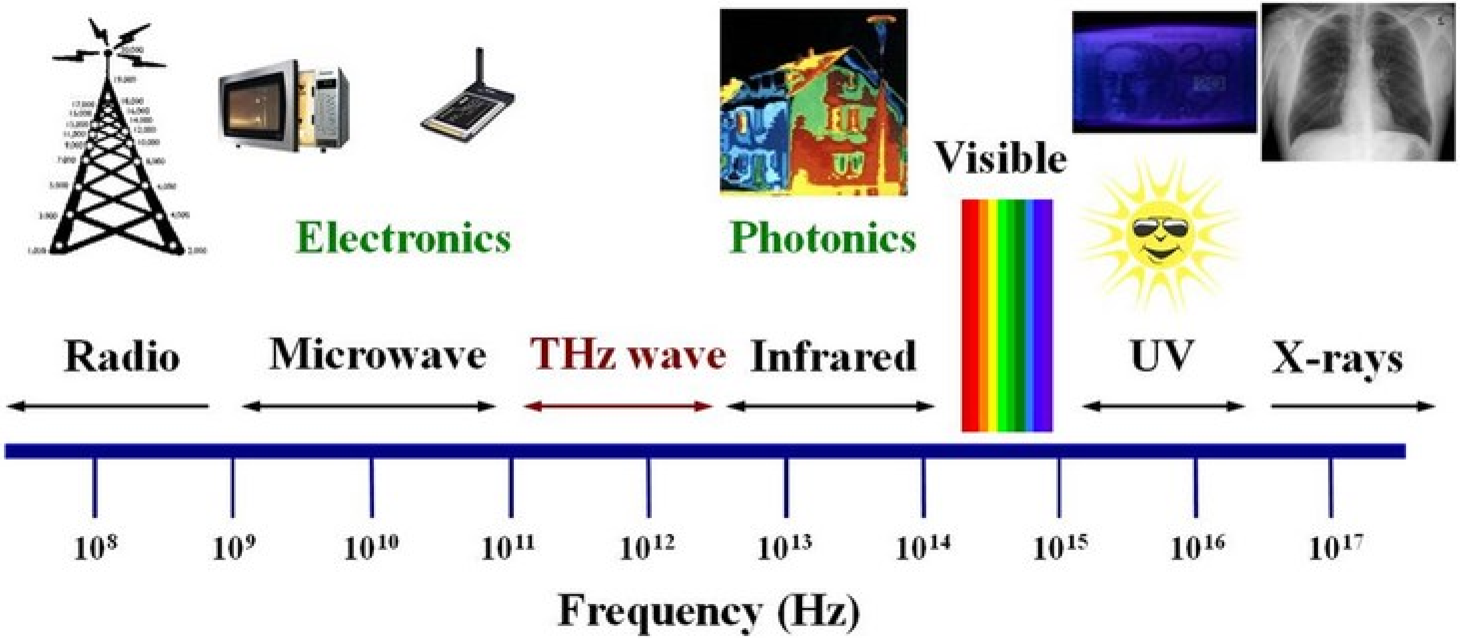
  body scanners, non-destructive testing, bio-Imaging, etc.

- **80% of publication on THz is on Time-Domain-Spectroscopy TDS today**
- Hamamatsu:
  - makes THz Photo conductive antenna (PCA)
  - Develops a THz spectrometer

→ What is good to know before starting digging into the subject

Terahertz: between optics and electronics

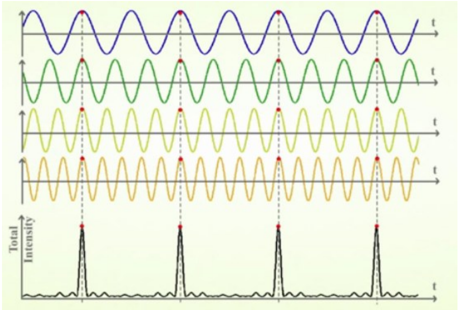
- Infrared: up to 15µm (long wavelength infrared)
- Far Infrared: 15µm to 1 mm 300 GHz to 20 THz ALSO TERAHERTZ
- **Terahertz: 30µm to 1mm 300 GHz to 10 THz**
- Microwave: 100cm to 1mm 300 MHz to 300 GHz



Titanium-Sapphire Femto Second Lasers

- 1972: Sub-ps passive mode locked dye laser
- 1986: Ti-Sa (solid state gain media) fs-laser
- 1990: Kerr Lens mode locking

- 1995: «Chirped Mirrors» phase correcting mirrors



Todays performance Ti:Sa Laser:

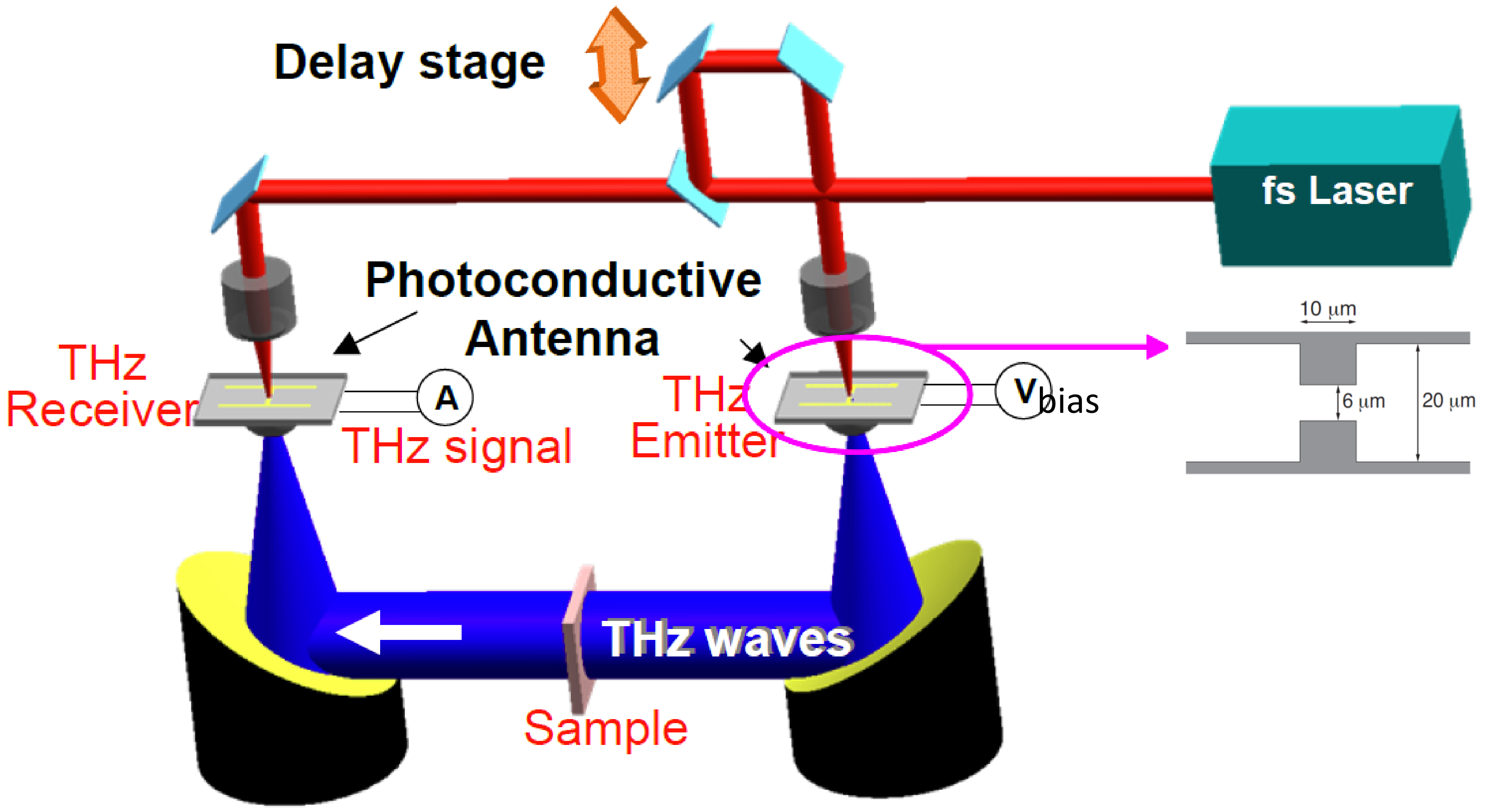
typ. repetition rate: **80 MHz – 100 MHz**

center wavelength : **780 nm (670 – 1070nm amplification band width)**

typical performance: **100 to 200 fs at 0.5 to 1.5 Watt average output**

best performance: approx . 4fs

Typcial Set-up for Terahertz Time Domain Spectroscopy



? Is THz TDS similar to Fourier Transform spectroscopy ?

! No - there are fundamental differences !

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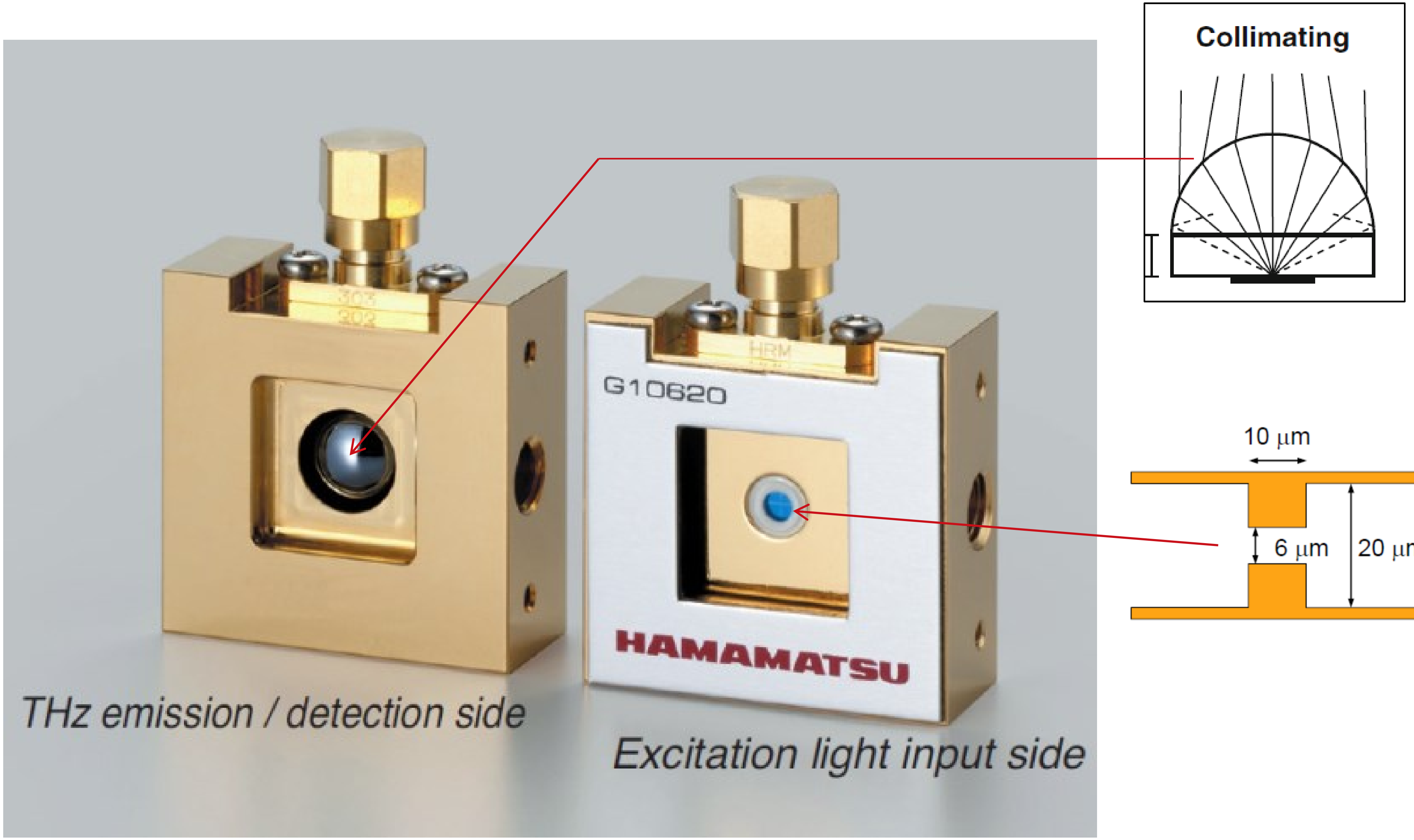
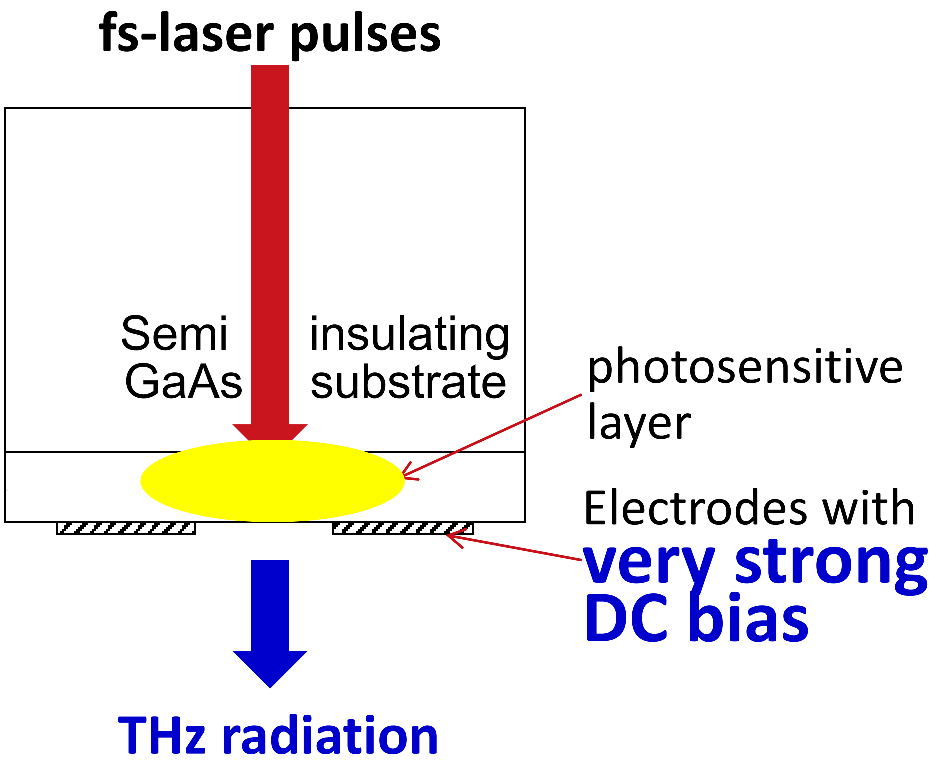
Emission or Detection of THz Radiation: same Photo Conductive Antenna - just used inverted



Generation of THz radiation from fs pulses

- Photo Conductive Antenna (Auston Switch)



THz generation chain:

fs laser pulses

↓

free carriers

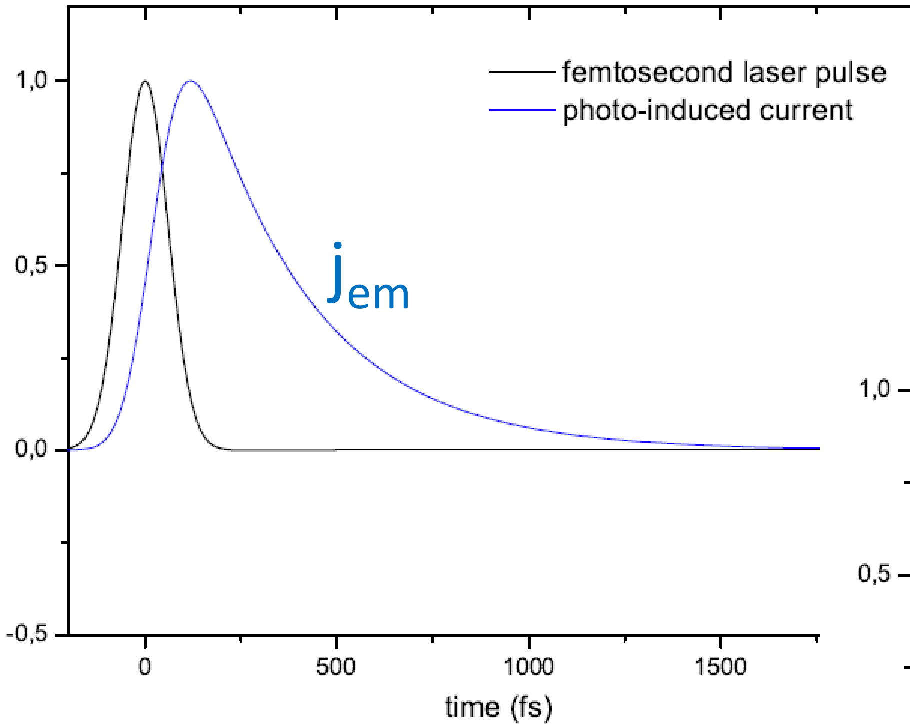
↓

current (t)

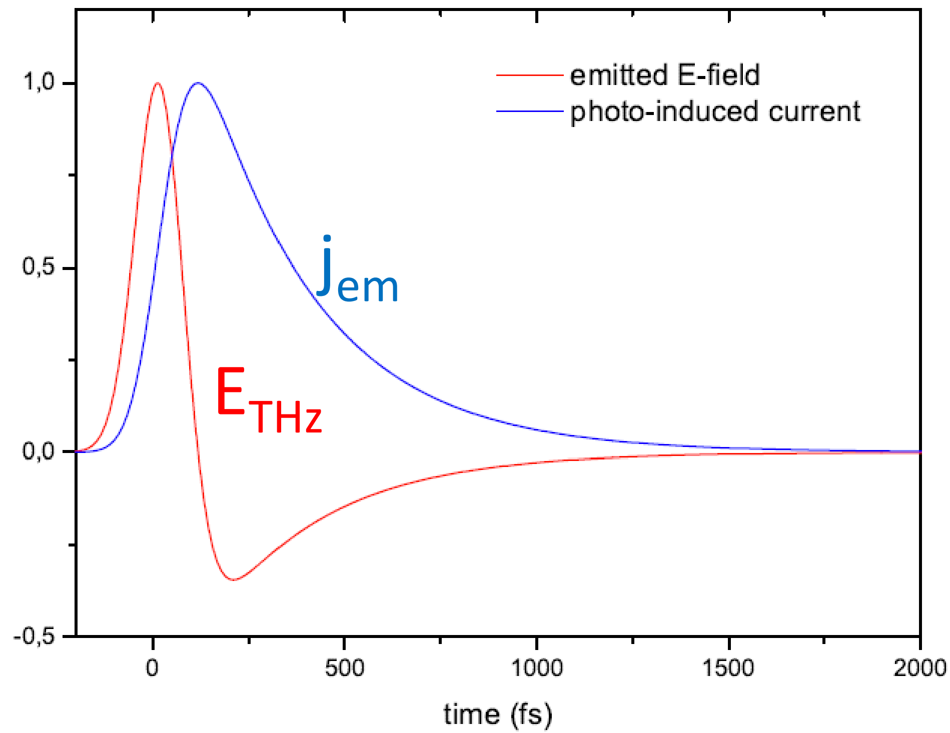
↓

THz radiation

Generation of THz radiation



Excitation of free charge carriers
$Nc = Nc \exp(-t^2/\Delta t^2)$
with carrier scattering time τs

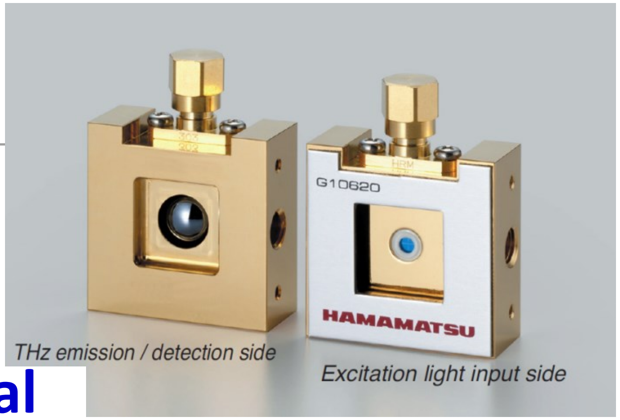


$$E_{THz} \propto dj_{em}/dt$$

Source: Novel Techniques in THz-Time-Domain-Spectroscopy, Matthias Hoffmann, Diss. 2006, Freiburg, D

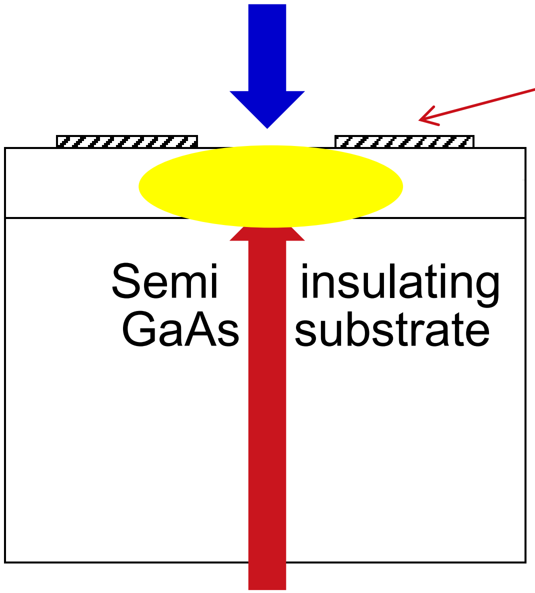
Detection of THz radiation

- Photo Conductive Antenna – reversed



THz radiation

Electrodes ->Current signal



fs-laser pulses
with adjustable delay Δt

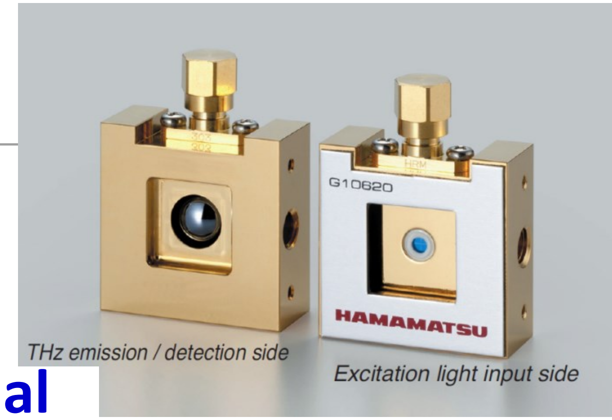
THz detection chain:

at time Δt:
fs laser pulse

THz radiation
'quasi-static E-field' + free carriers

Signal Current

Detection of THz radiation



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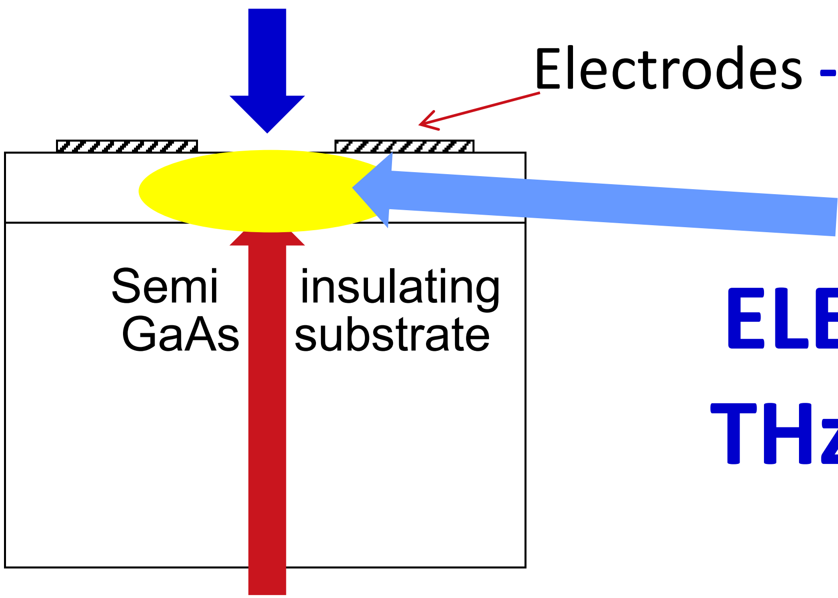


Measured here:

ELECTRICAL FIELD of the THz wave during fs pulse

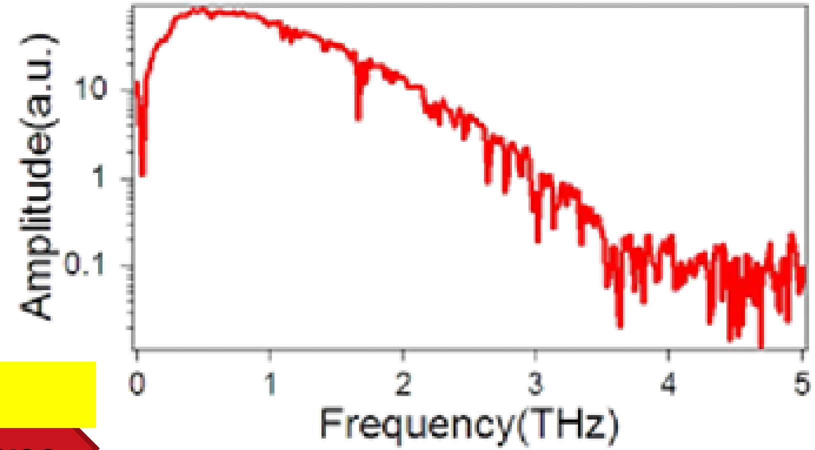
→ Signal E(Δt)

Difference between FTIR and THz TDS

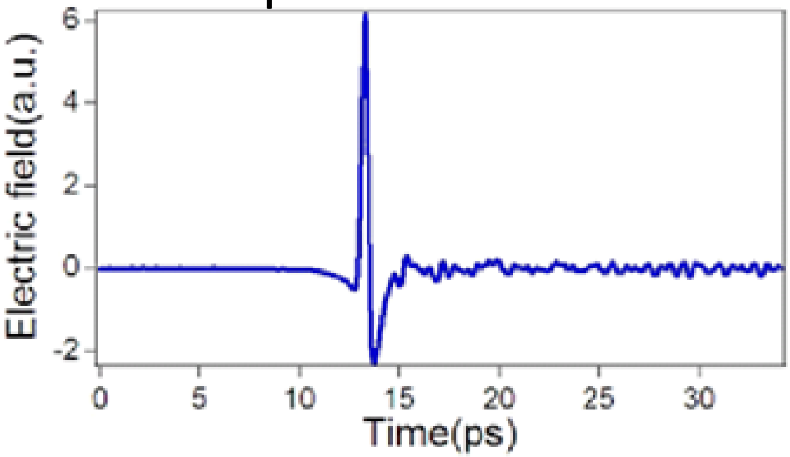
	FTIR	THz TDS
Classification:	Interferometry	Time measument
Measurand:	Intensity $\propto E \cdot E^*$	Electrical Field $E(\Delta t)$
	FOURIER TRANSFORM	
Result:	Spectrum	**Amplitudes and Phases**

Results of THz TDS Measurements

Amplitude Spectrum

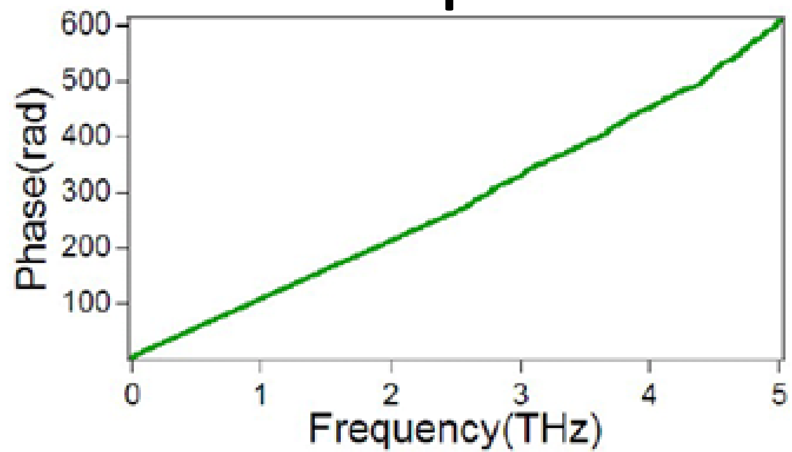


Temporal Waveform



Transform

Phase Spectrum



What makes THz TDS so powerful

- «Dielectric Spectroscopy»
- Measured property: «Permittivity $\varepsilon(\omega)$ »
- $\varepsilon(\omega)$ allows determines complex index of refraction **$n'(\lambda) = n(\lambda) + i\,k(\lambda)$**

- **THz TDS delivers**
  - **Absorption Spectra**

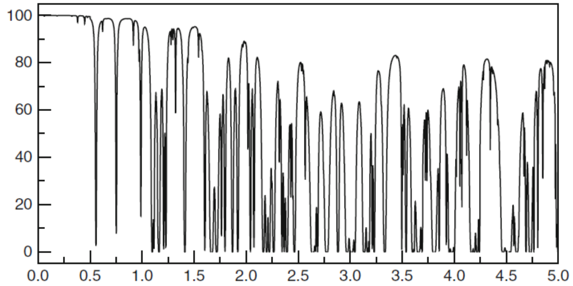
    and
  - **Refractive Index of sample***

* if sample thickness is known
with sufficient precision

Some Properties of THz Radiation

- Non-ionizing (→ regarded as biologically non-hazardous)
- Energy ($k_B T$): 300 GHz ~ 14 K; 10 THz ~ 210 K
- Gets absorbed by:
  - Polar substances
  - Water

example 1m 40%



- Does not get absorbed by plastics, paper, clothes, ...
- 'Sees'
  - vibration structure of heavy molecules
  - rotation lines of small polar molecules
- Progates like Gaussian optics → diffraction !

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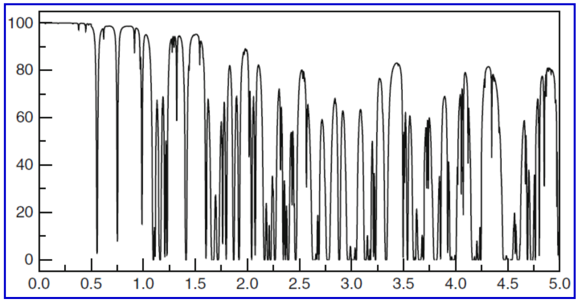

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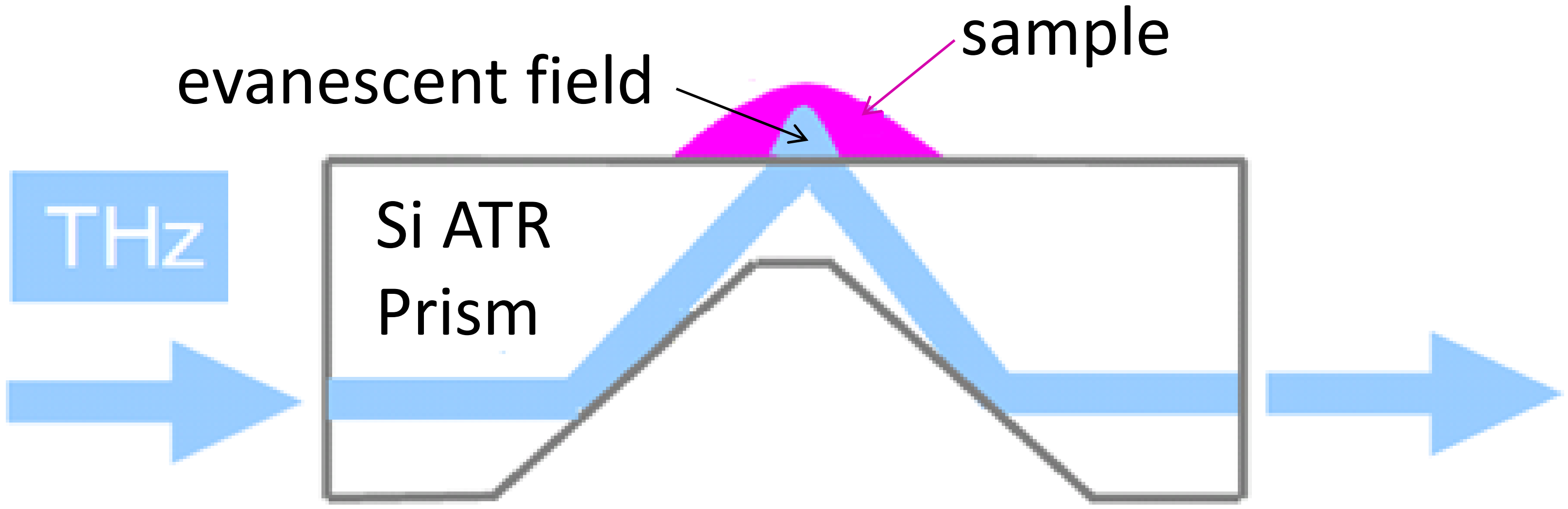
THz TDS with Attenuated Total Reflection (ATR)



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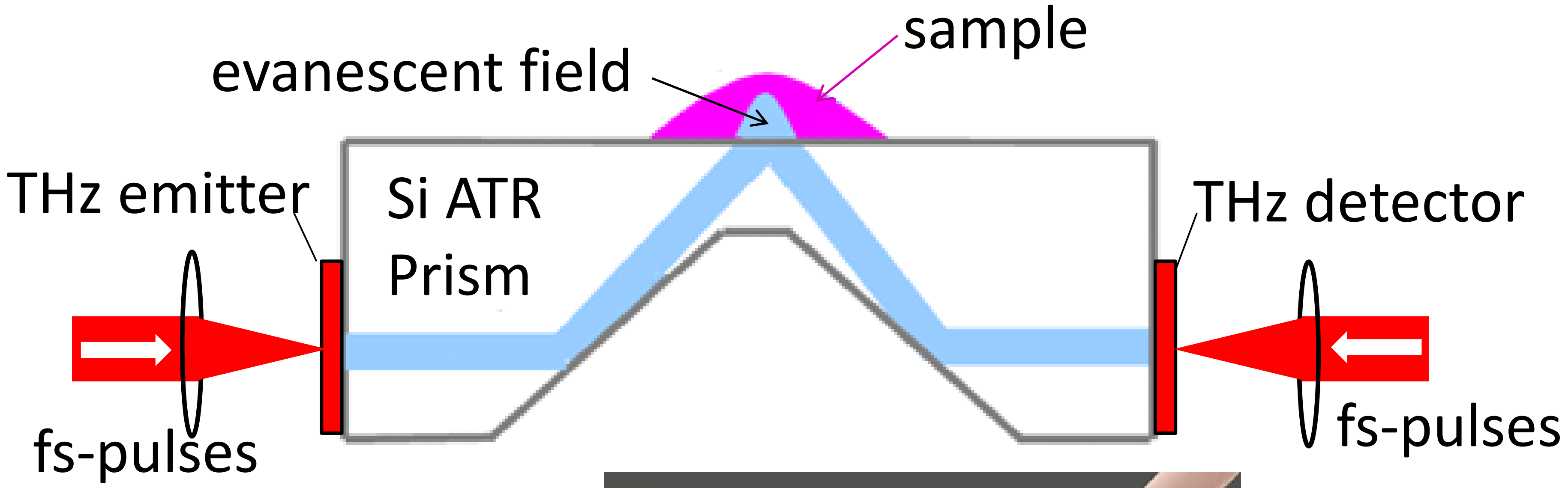
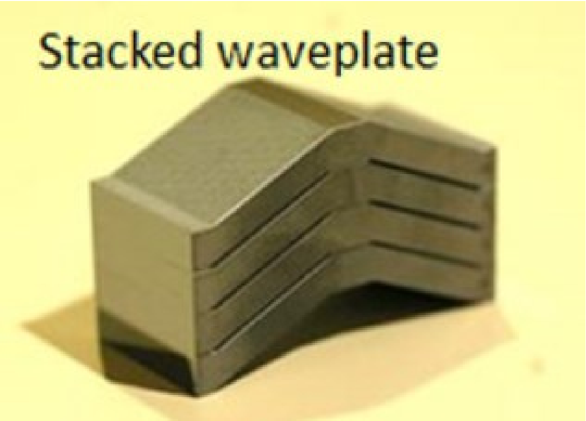
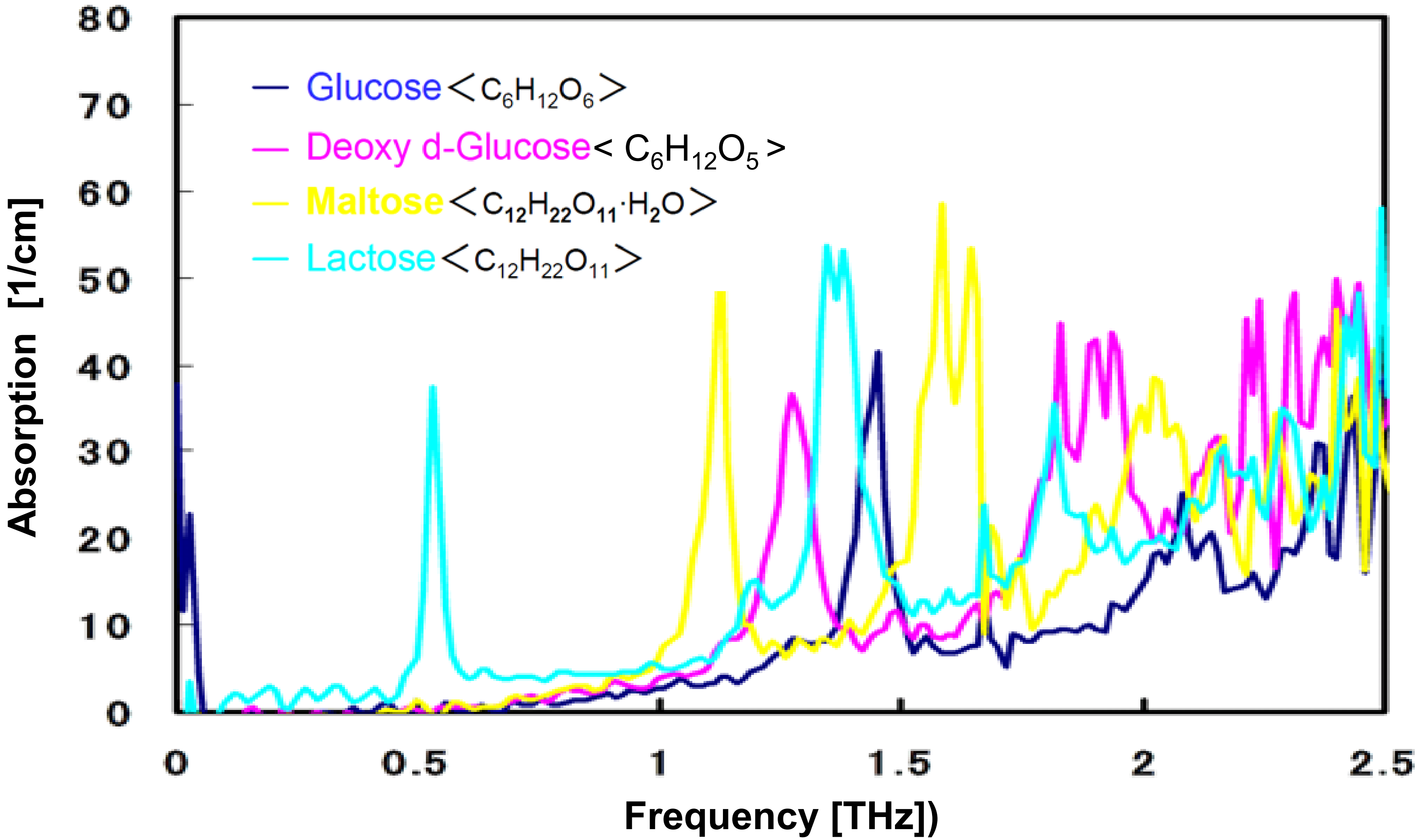




Example: Absorption of Different Sugars



Todays Status of Miniaturisation:
- one example of several on the market -

Mini-Z™

The Portable and Compact Terahertz Time-Domain Spectrometer

ZOMEGA

Size: 27.5 x 17 x 8.5 cm^3
Weight: 3 kg

Exchangable heads:
- Reflection
- Transmission
- ATR

http://www.zomega-terahertz.com

Thank you very much for your attention !