

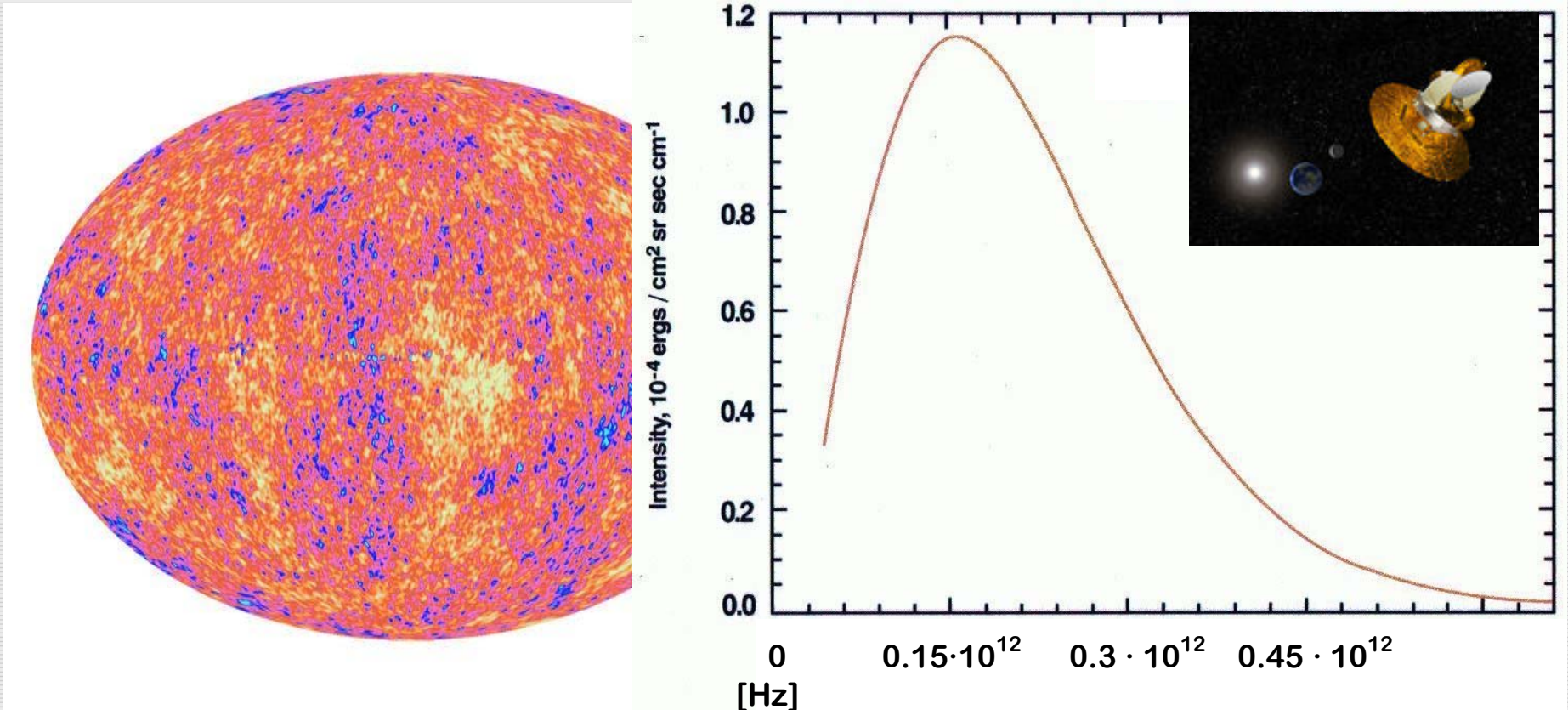
THz based Imaging for Inspection and spectroscopic Analysis



Outline

- **Introduction**
- Basic principles
- Imaging THz-systems
- Applications
- Potentials for metrology in production
- Summary

Cosmological radiation



courtesy of: Prof. Wagner, FhG-IPMT

Characteristics of THz-radiation

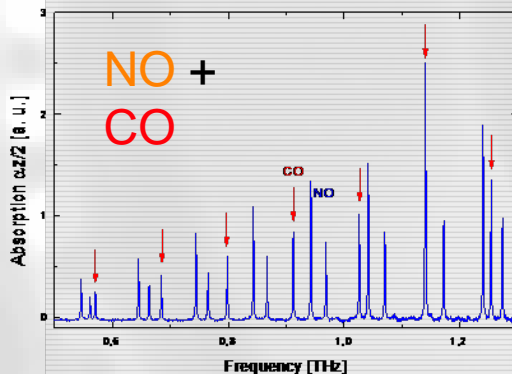
Overview

■ THz-radiation is non-ionizing

- ▶ No modification of chemical properties of organic substrates
- ▶ No danger for living cells

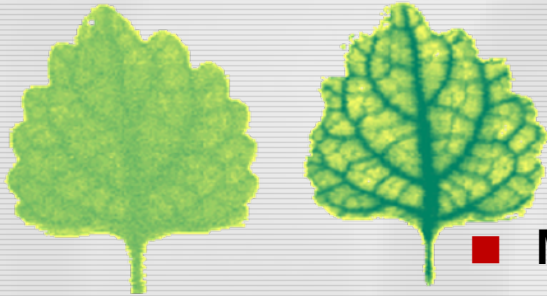
■ Characteristically absorption of nearly all polar molecules

- ▶ Exact determination of complex molecules
- ▶ e. g. pharmaceuticals, drugs, explosives
- ▶ e. g. analysis of chemical reactions



Characteristics of THz-radiation

Overview



- **Strong absorption of polar fluids (water)**

- ▶ Little penetration depth in hydrous substrates
- ▶ Low range in humid air
- ▶ Possibility of quantification of specific humidity

- **Metals are non-transparent for THz-radiation**

- ▶ Possibility to detect metals

- **Dielectrics are transparent to THz-radiation (paper, plastics, textiles, etc.)**

- ▶ Possibility to radiograph for instance packages

THz-Technologies in focus of the media

Press release

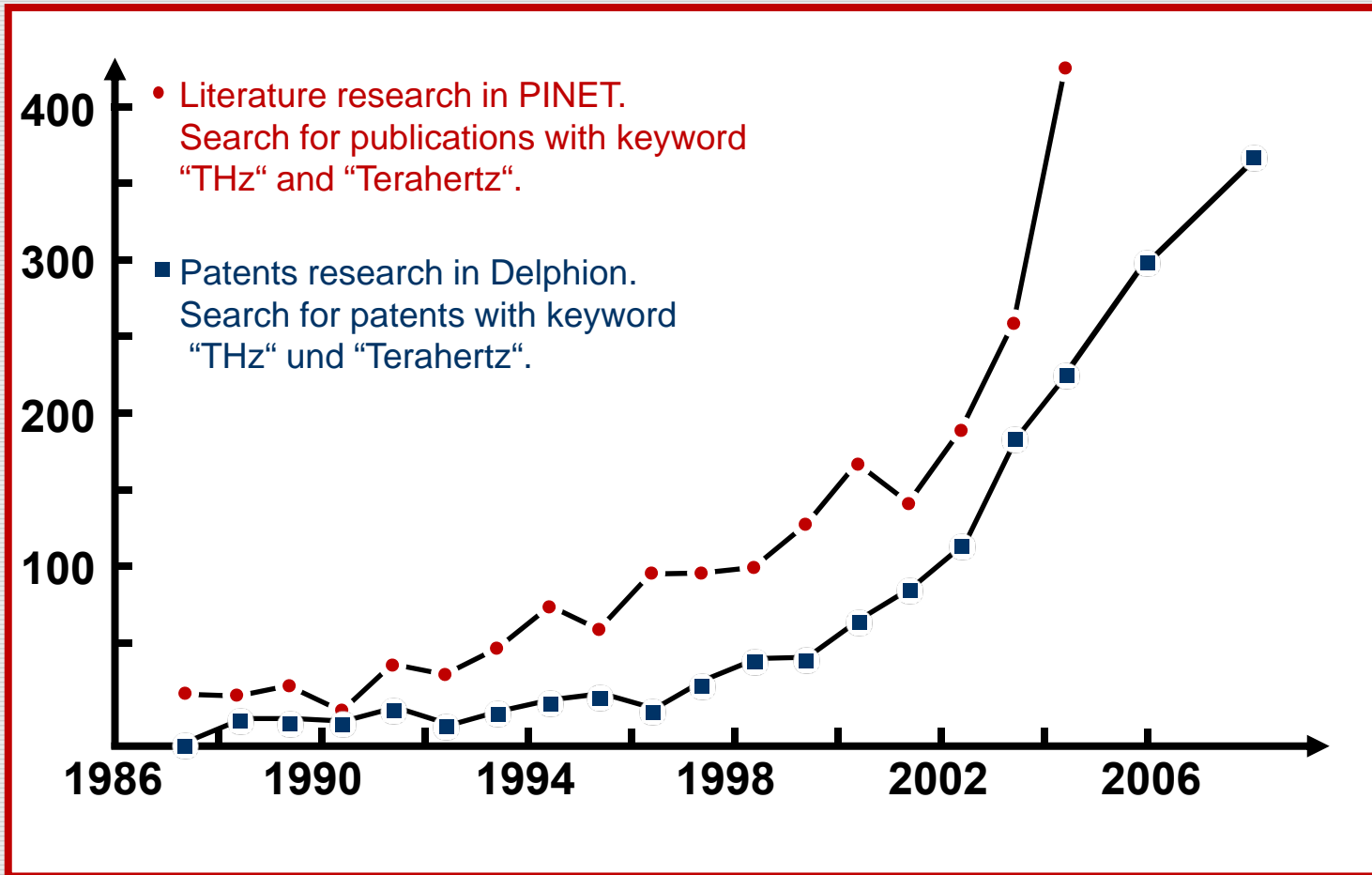


Mysterious waves: Naked on the monitor

A mysterious radiation fascinates physicians: Ubiquitous, but nearly non-detectable radiate terahertz-waves in the frequency domain between infrared and microwaves. Now they should improve precaution of cancer and strengthen security at airports. (Spiegel 11/2002)

- **Passengers virtually stripped naked by 3-D airport scanner (CBC-News 06/2008)**
- **A camera that can "see" explosives, drugs and weapons hidden under clothing from 25 metres has been invented . (BBC 03/2008)**

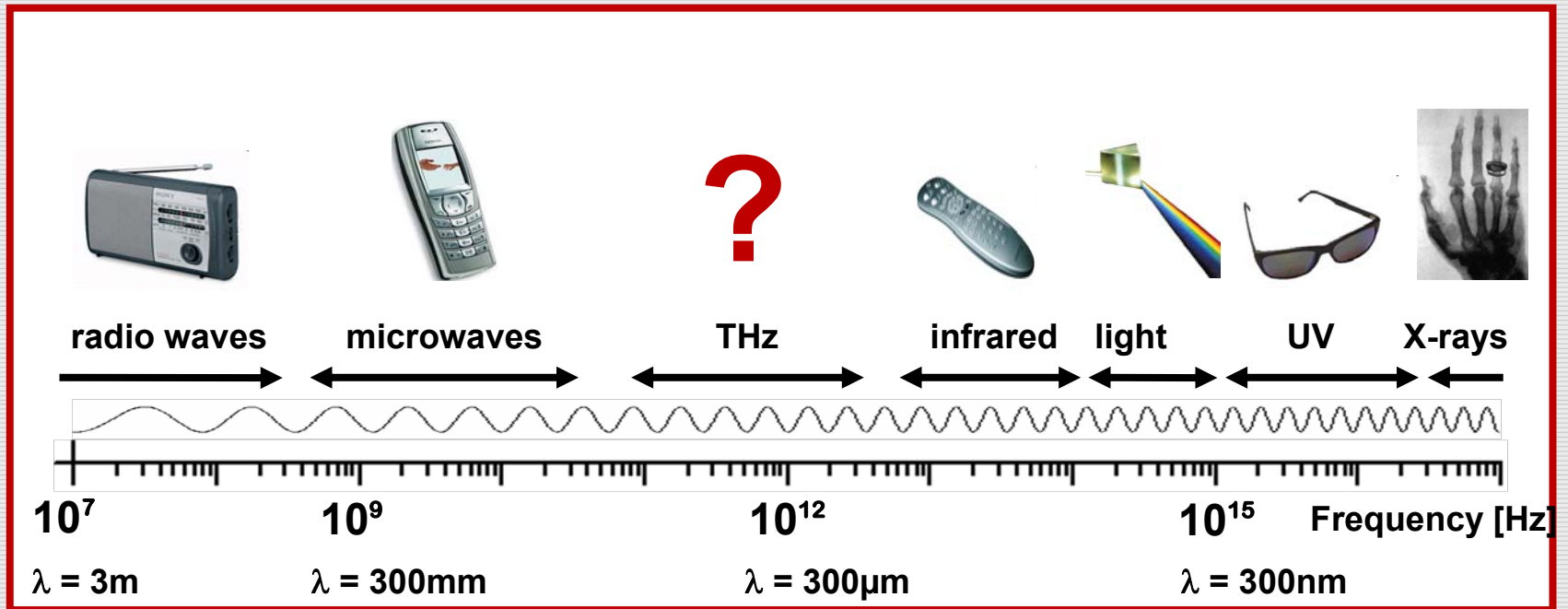
Publications and patents for THz



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The spectrum of electromagnetic radiation



Terahertz-range: $f = 0,1 \text{ THz} - 10 \text{ THz}$
 $\lambda = 30 \mu\text{m} - 3 \text{ mm}$

THz-Systems: variable sources between 50GHz – 10 THz

pulsed

cw

pulswidth ≤ 1 ps

pulswidth >10 ps

frequency mixer

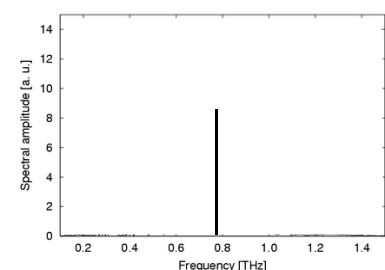
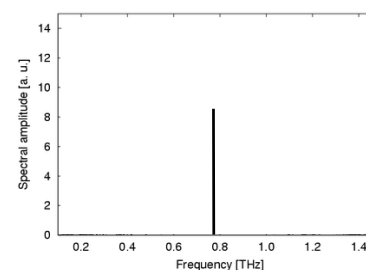
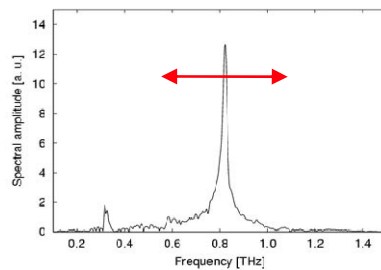
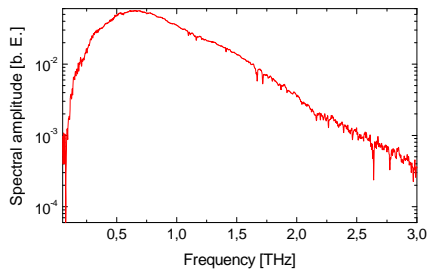
direct generation

broad band
THz- radiation

narrow band
THz-radiation

discrete
THz-wavelength

discrete
THz-wavelength



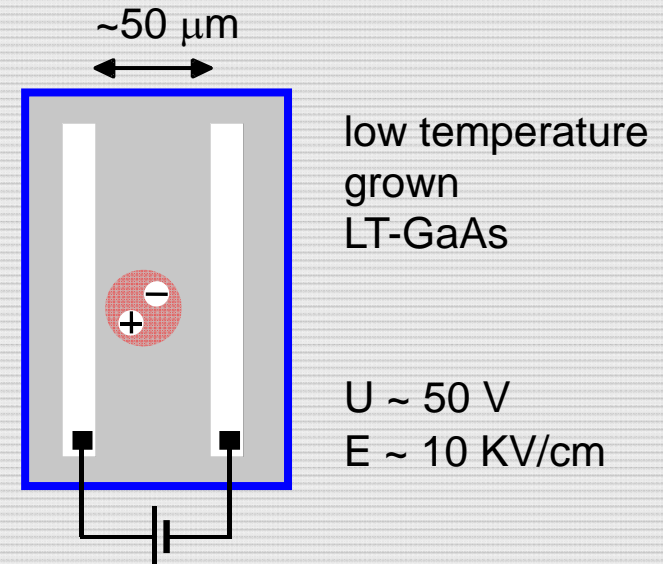
Technical generation of THz-radiation

Photoconductive switch

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

Transient Photoconductivity:

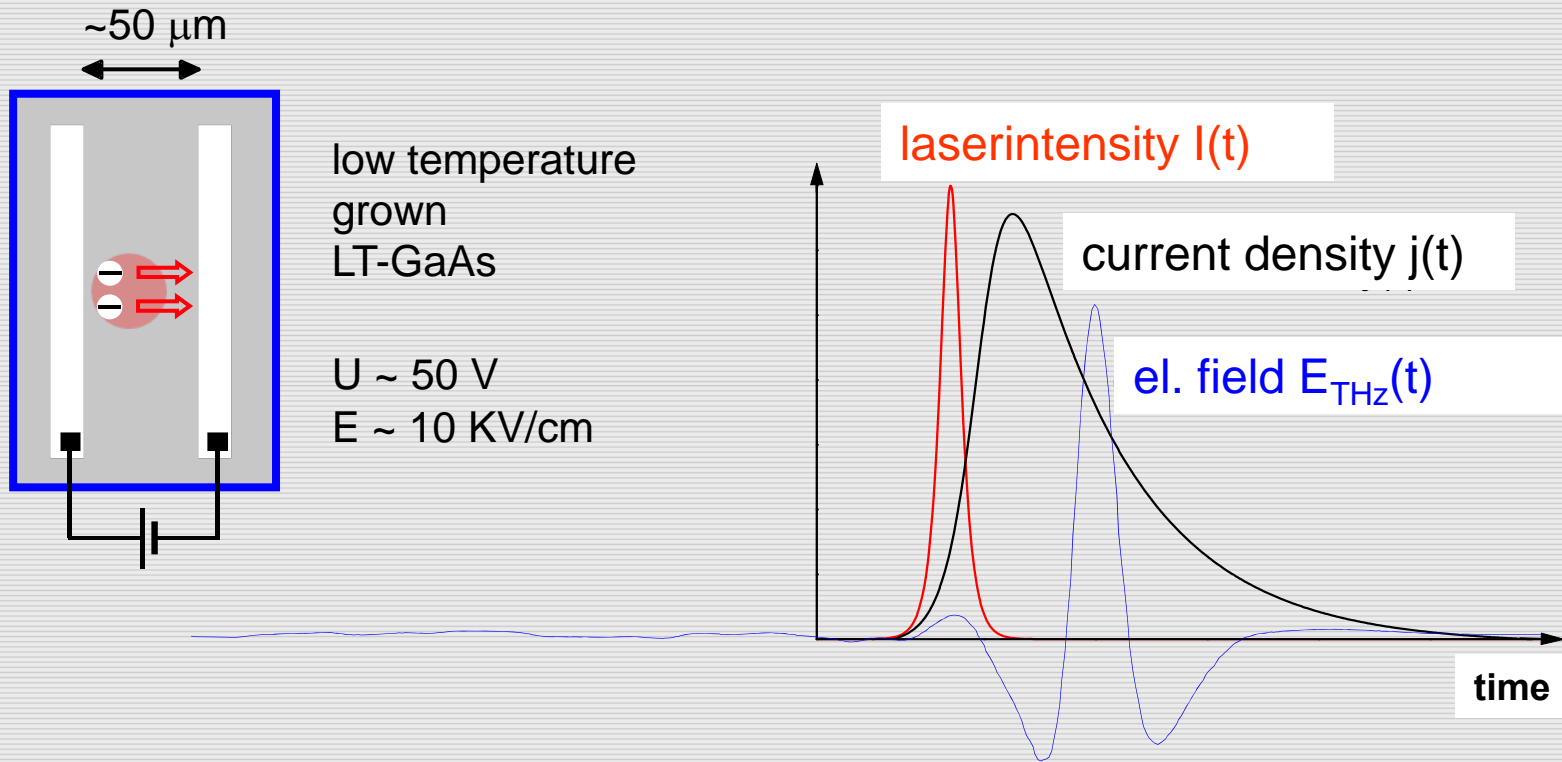
- Ultra fast (<100 fs) IR/vis pulse of Ti:Sa or fibre-Laser (Er, Nd)
- Generation of free charge carriers in semiconductor (e.g. LT grown GaAs: $\tau_e \sim 0,1$ ps, $\tau_h \sim 0,5$ ps, $\mu \sim 10^3$ cm²/Vs; $E \sim 10$ KV/cm)



courtesy of: Prof. Wagner, FhG-IPMT

Technical generation of THz-radiation

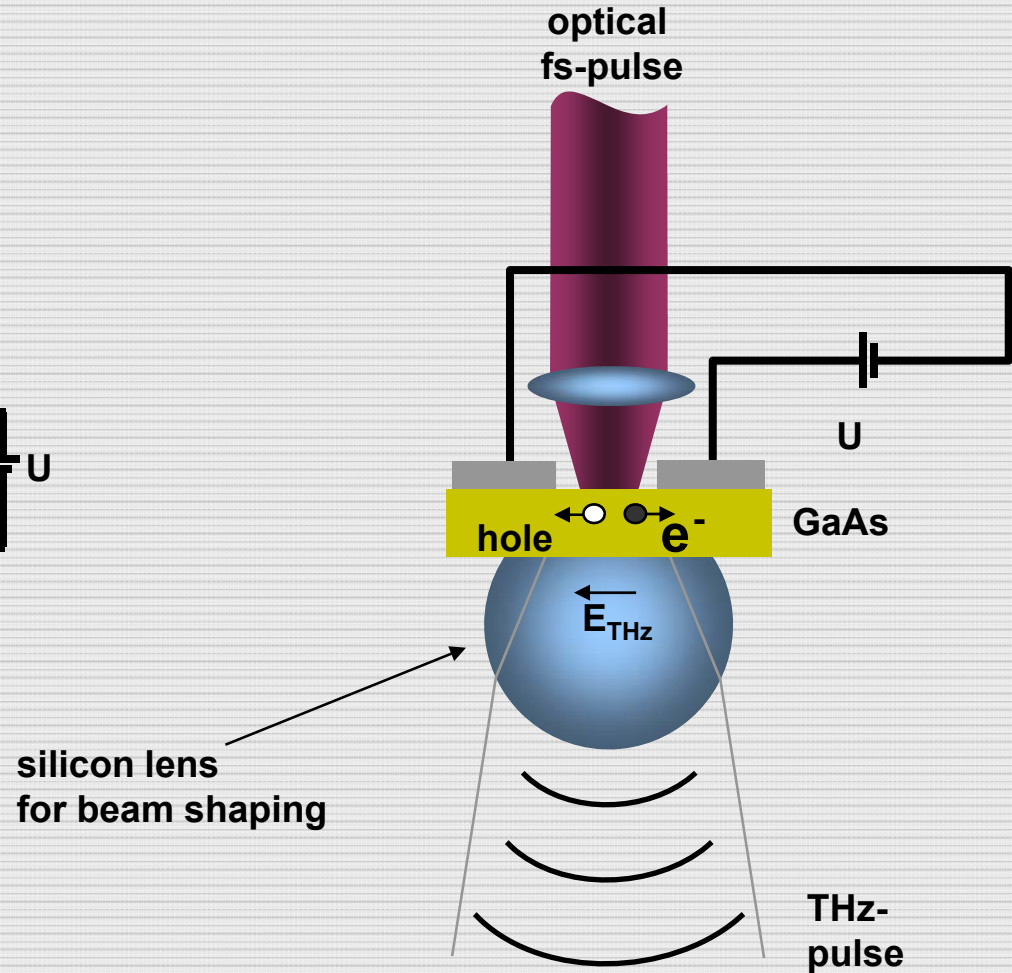
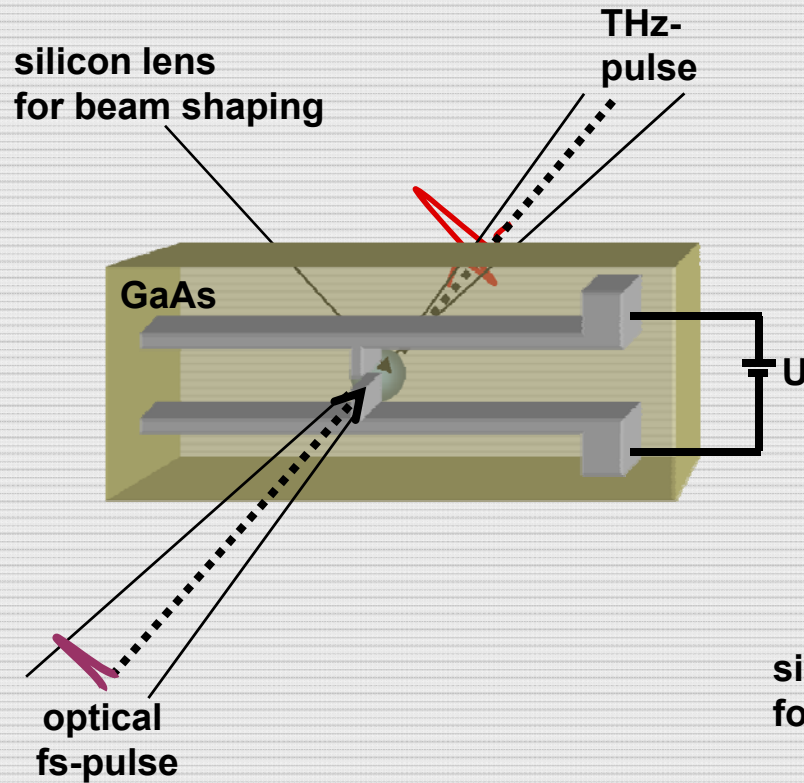
Photoconductive switch



courtesy of: Prof. Wagner, FhG-IPMT

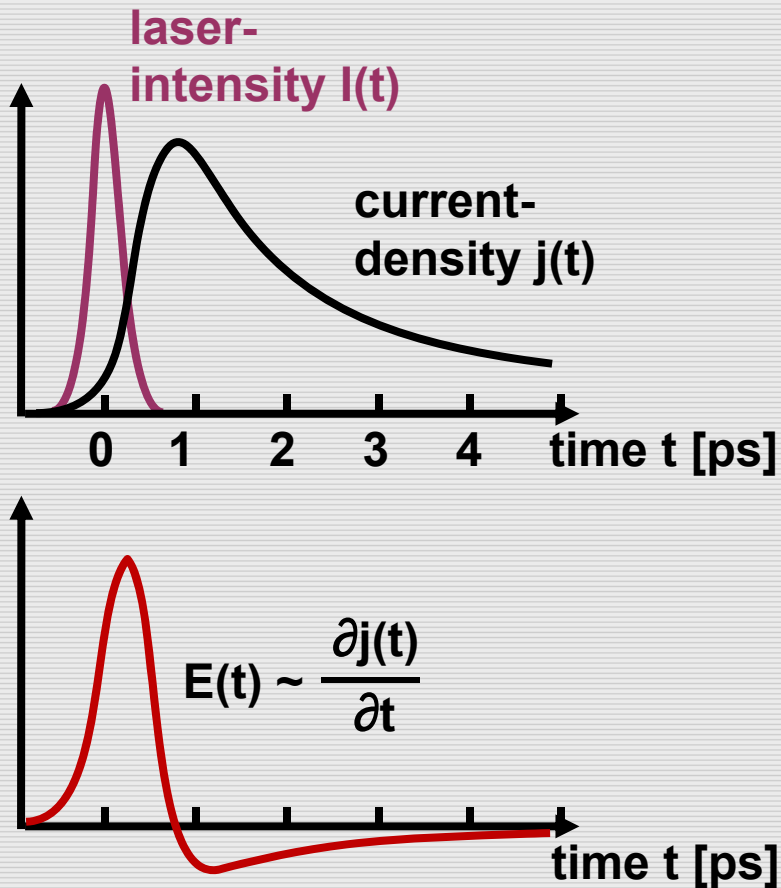
Generation of THz-Pulses

THz-antenna (emitter)

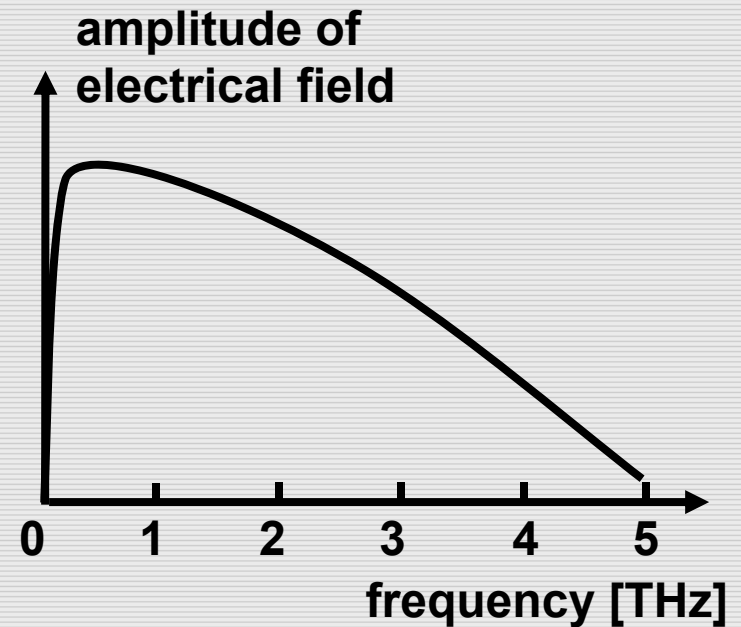


THz-pulse in time and frequency domain

Time domain

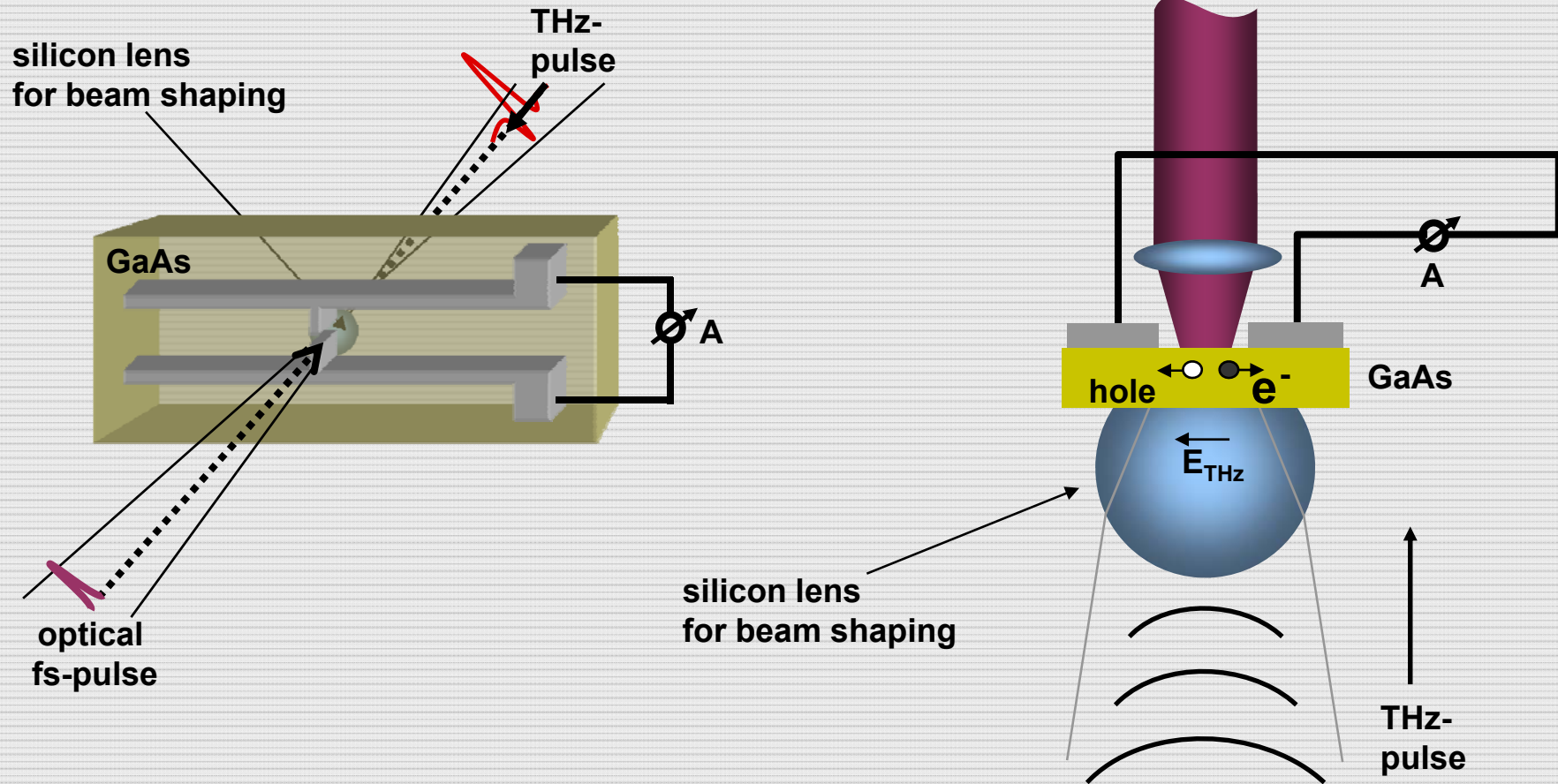


Frequency domain



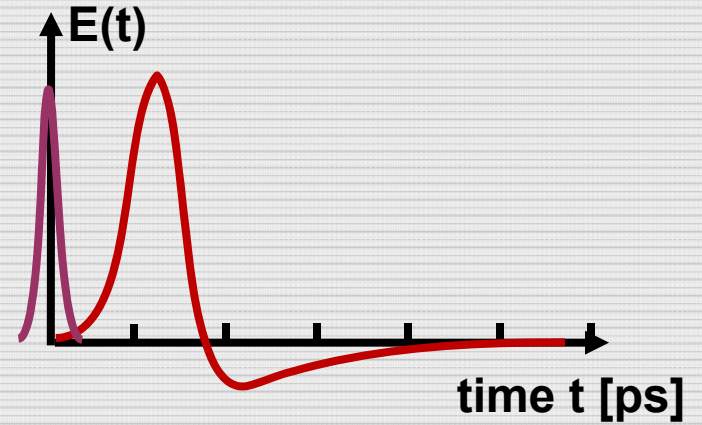
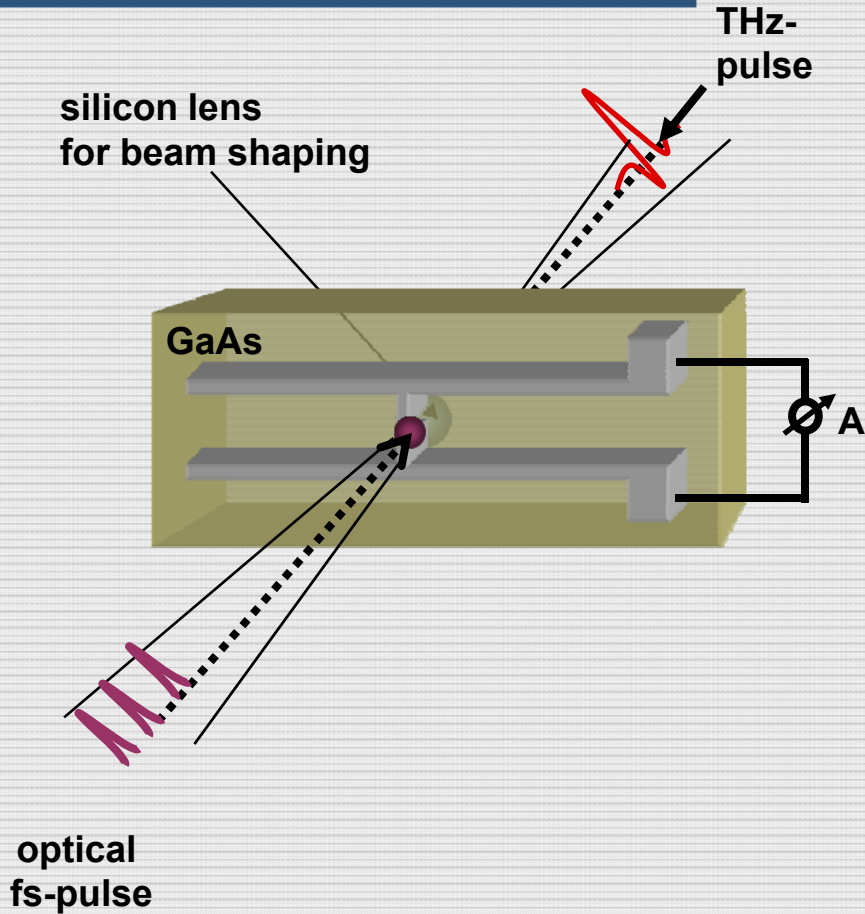
Detection of THz-pulses

THz-antenna (detector)



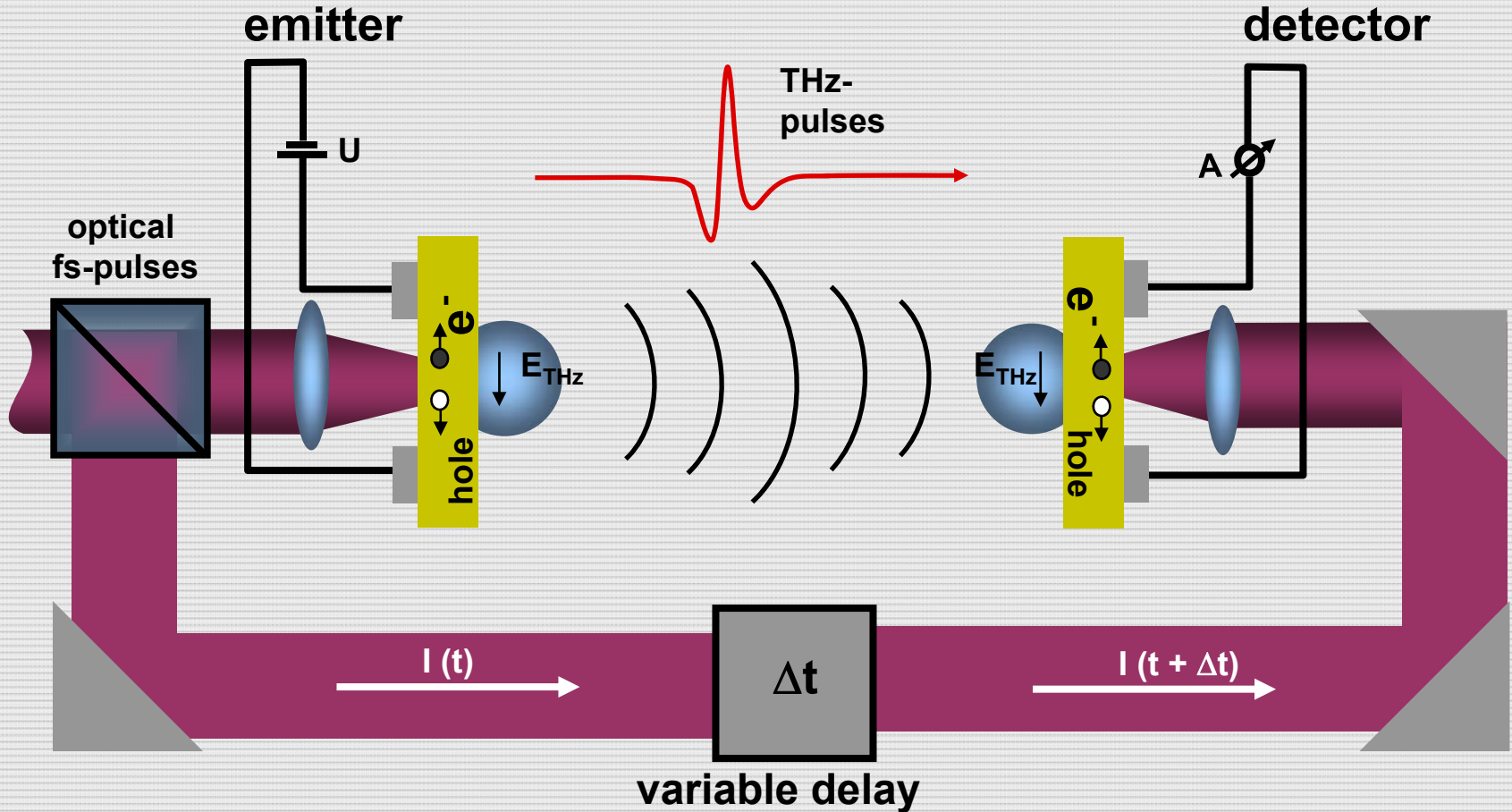
Detection of THz-pulses

THz-antenna (detector)



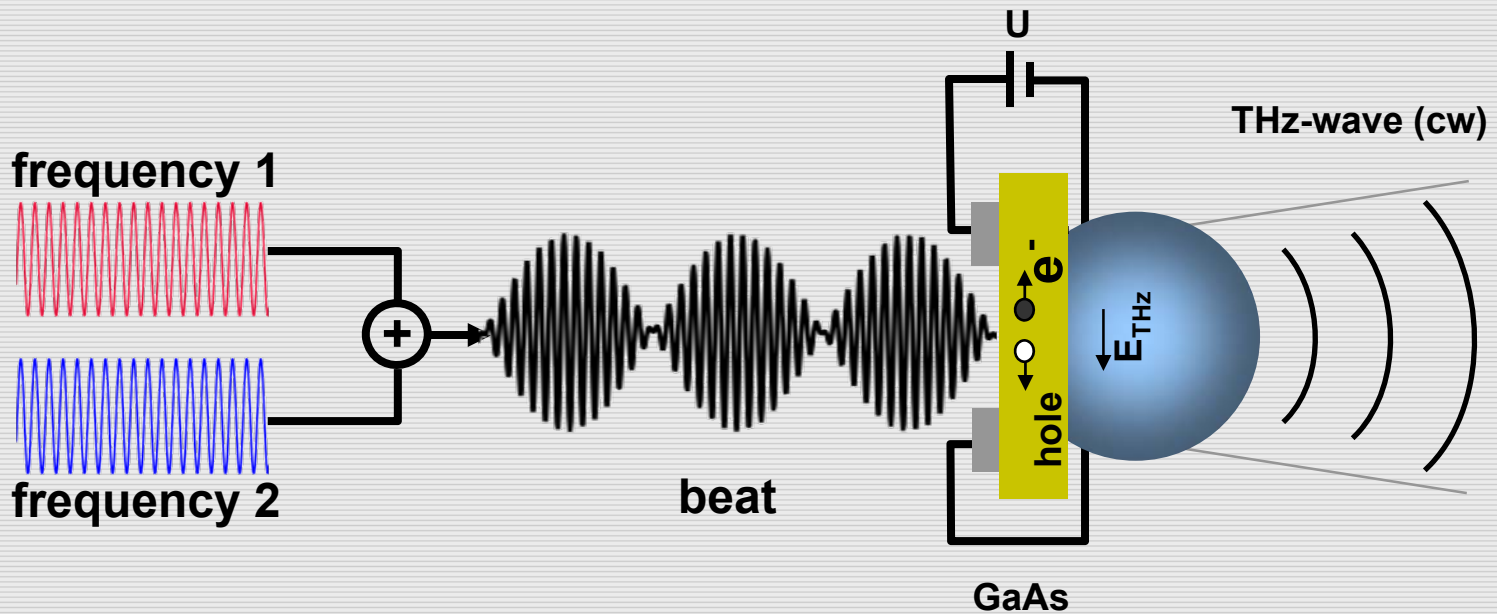
Transmission range of THz-pulses

THz-Transmission



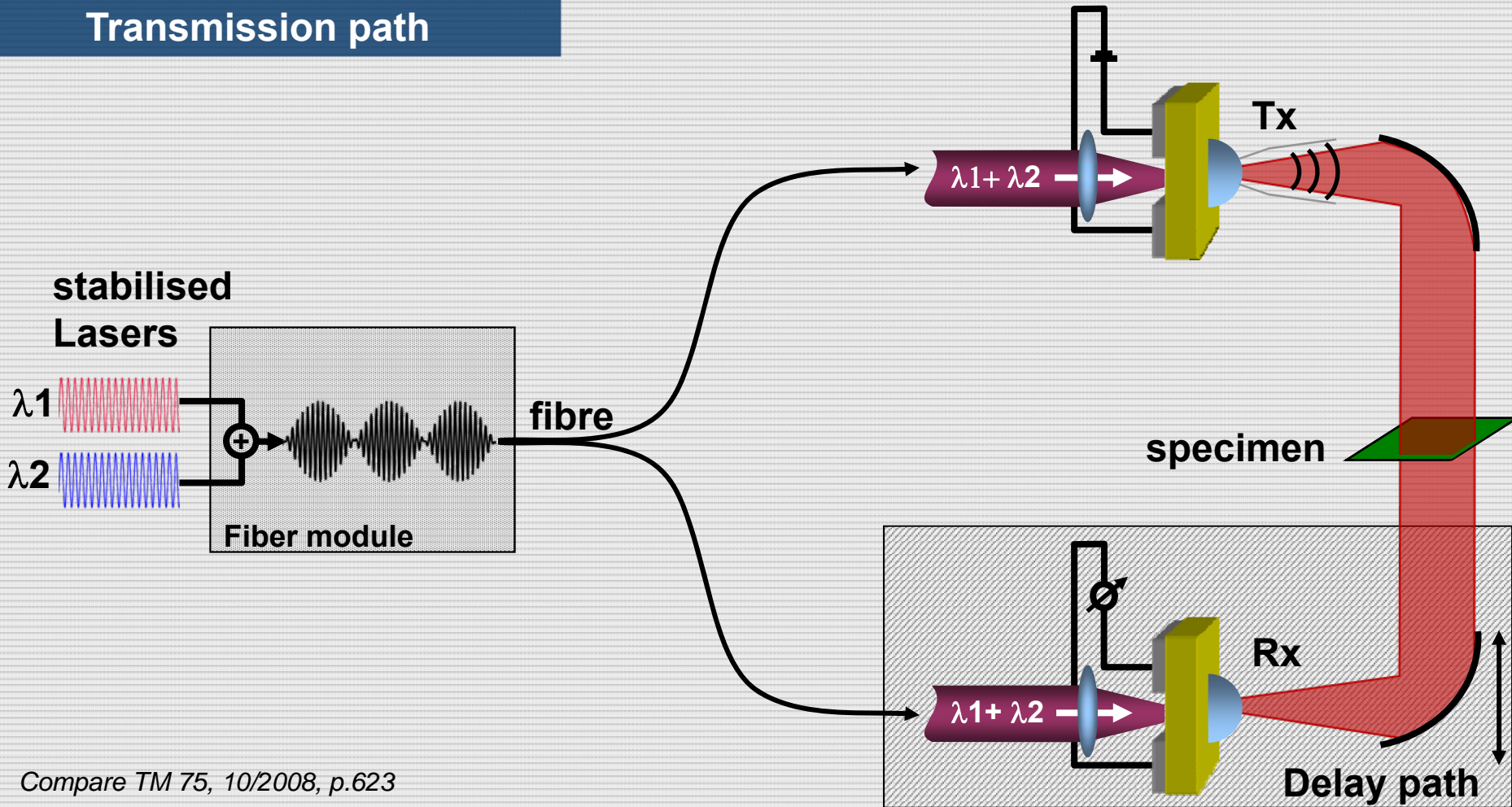
Generation of continuous THz-radiation (cw)

Photon mixing



Generation of continuous THz-radiation (cw)

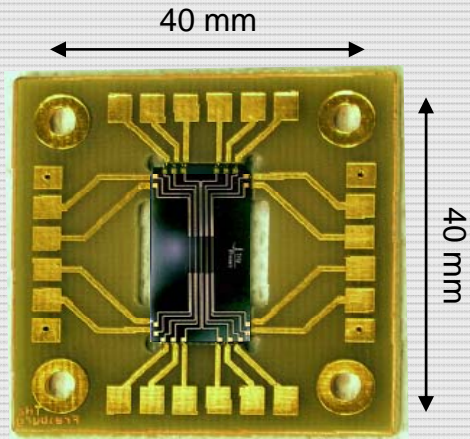
Transmission path



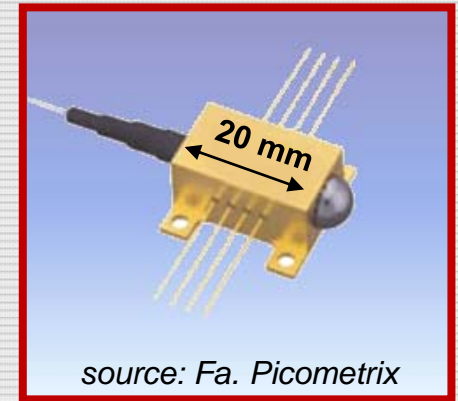
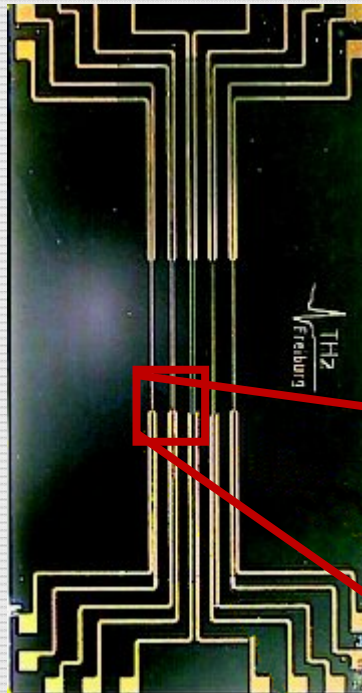
Compare TM 75, 10/2008, p.623

Technical realization of THz-antennas

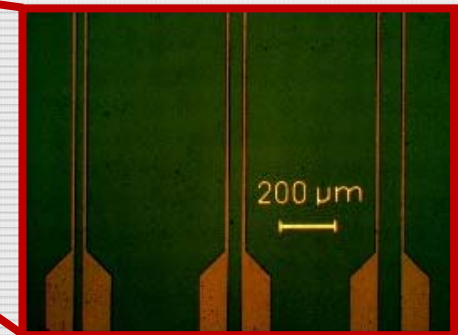
THz-antenna



FreiTEC
(Freiburger THz Emitter-Chip)



source: Fa. Picometrix

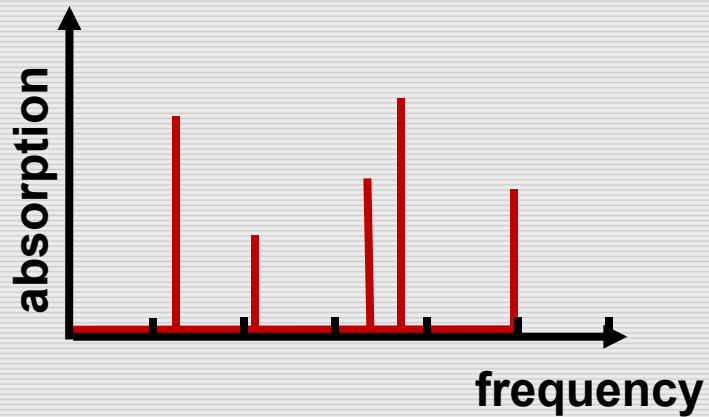
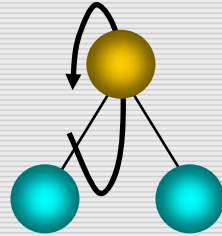


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- **Imaging THz-systems**
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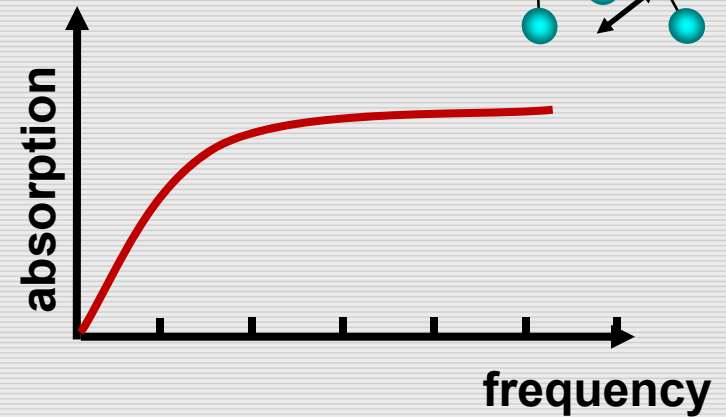
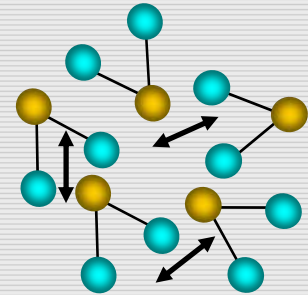
Dynamic procedures in THz-range

Gas



transitions between discrete rotation states of polar molecules

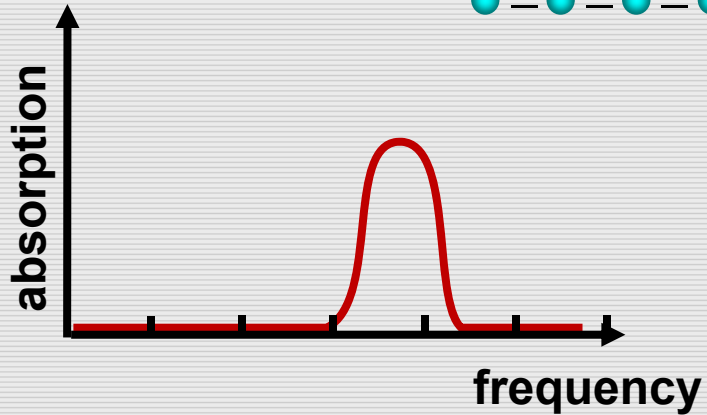
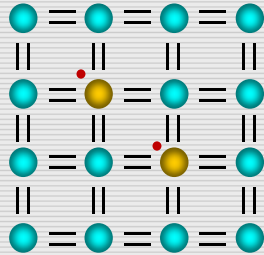
Liquids



translational movement (damped vibrations of network)

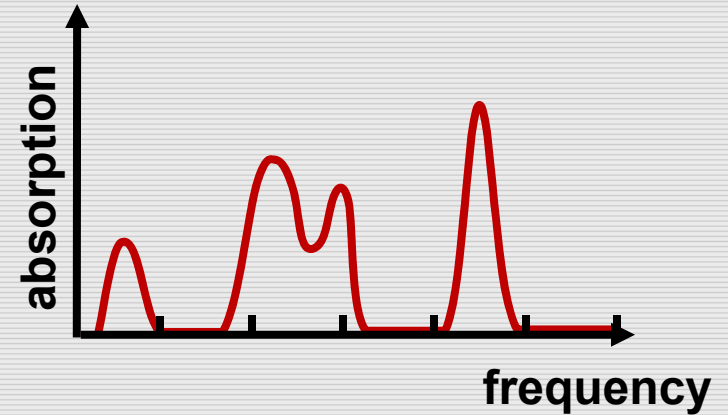
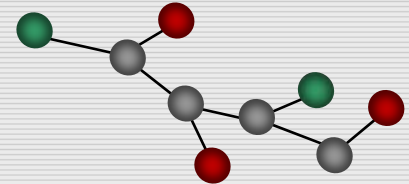
Dynamic procedures in THz-range

Semiconductor



lattice vibration (transversal optical phonons)

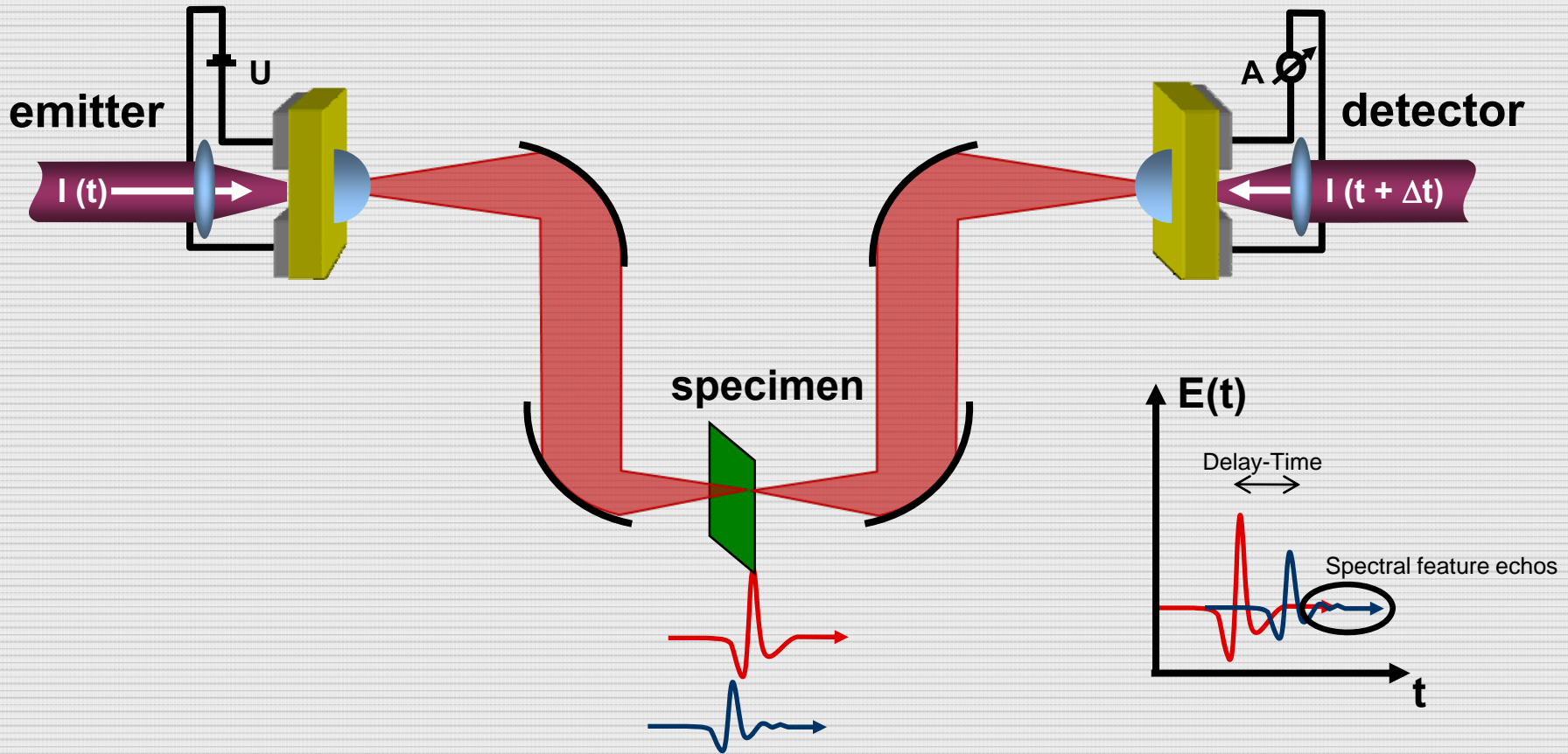
Complex molecule



Oscillation between atomic groups inside complex molecules

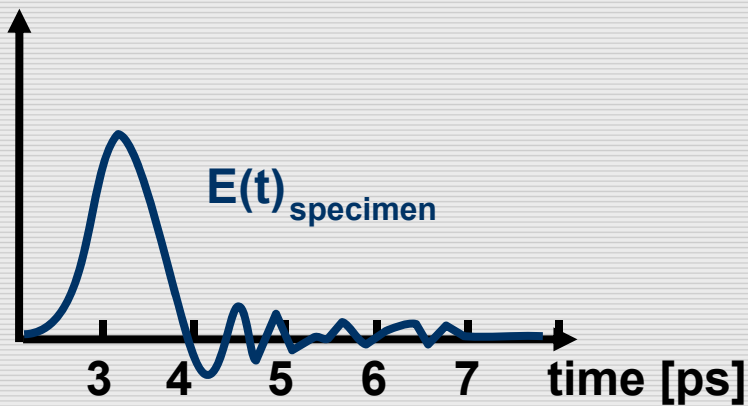
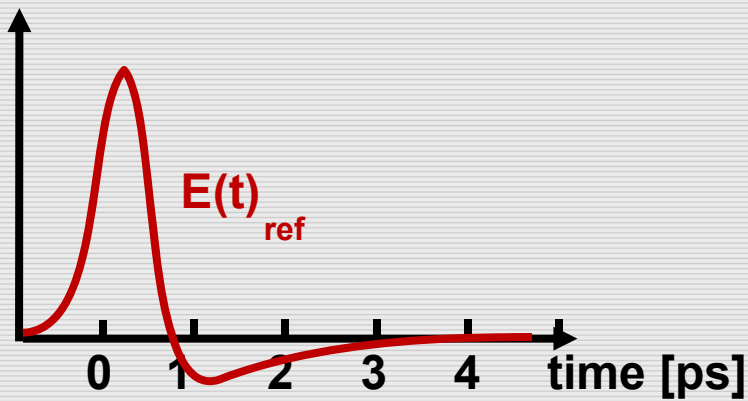
Time-domain-spectroscopy

THz-spectrometer

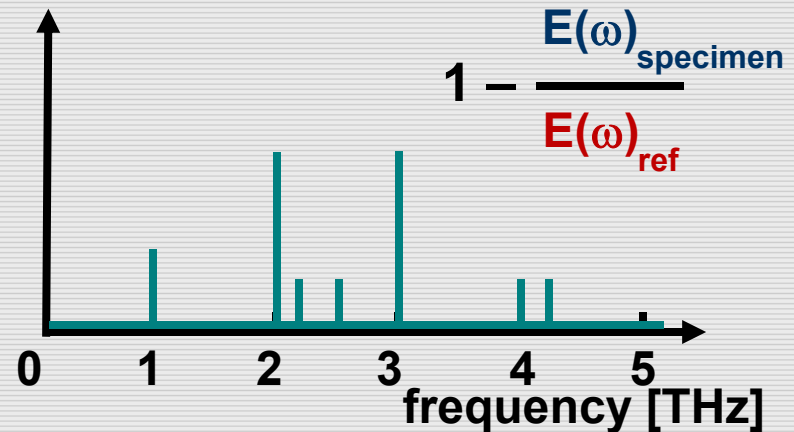
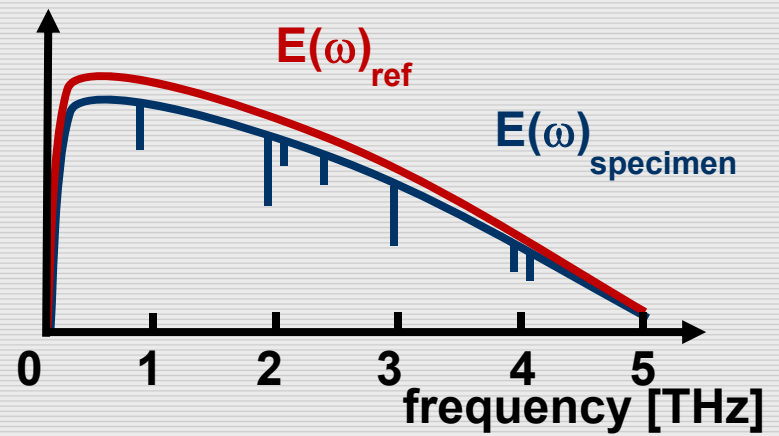


THz-spectroscopy

Time domain

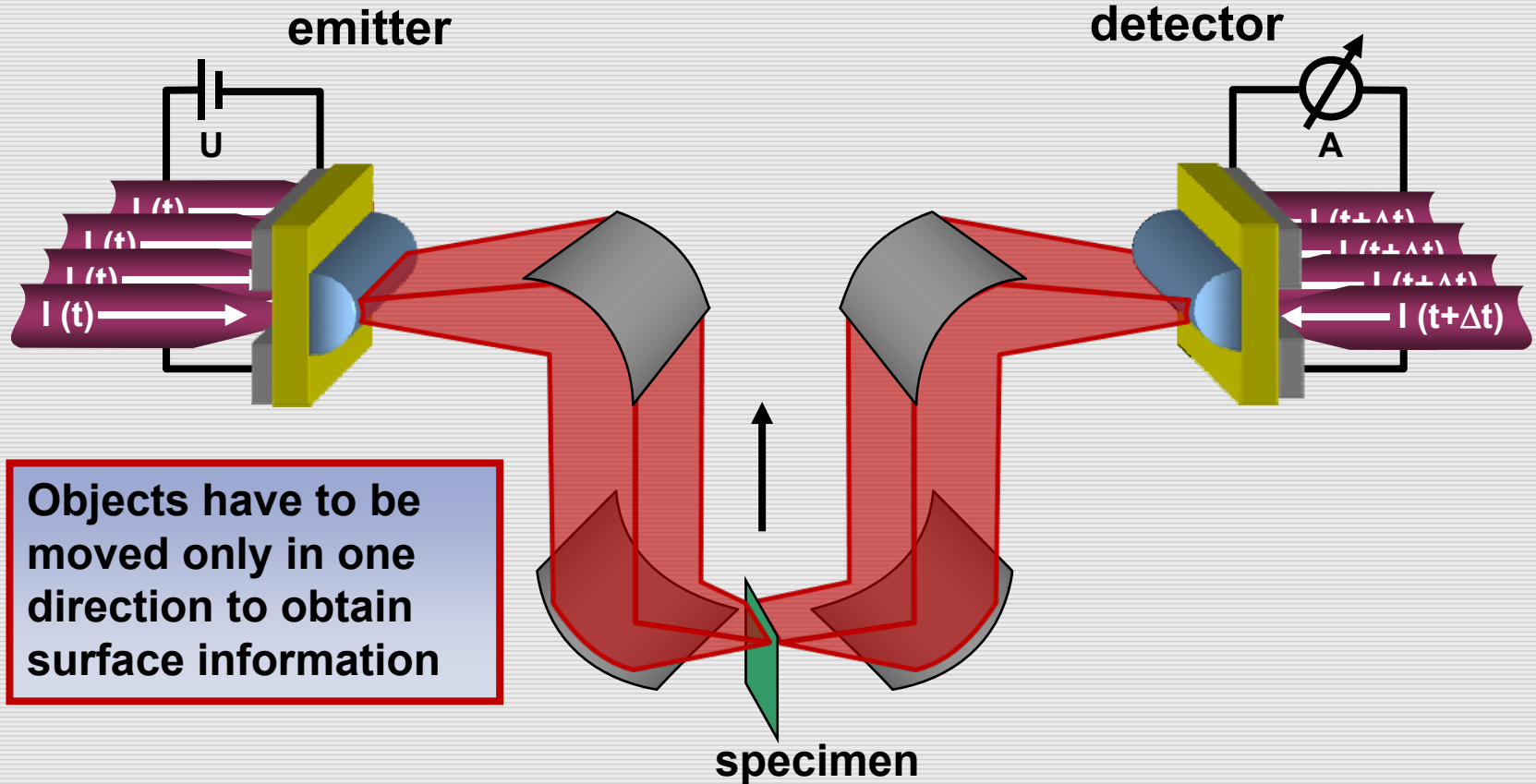


Frequency domain



THz-antenna arrays

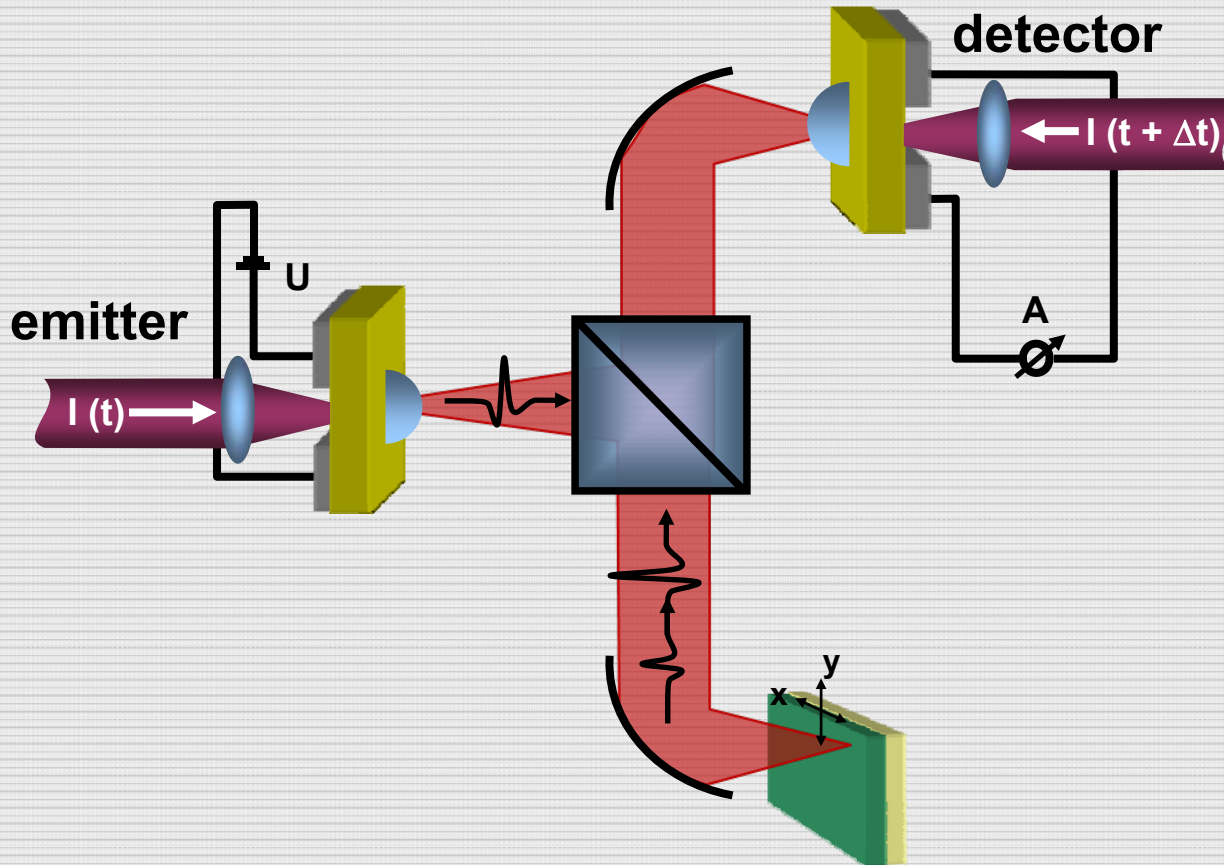
THz-scanning



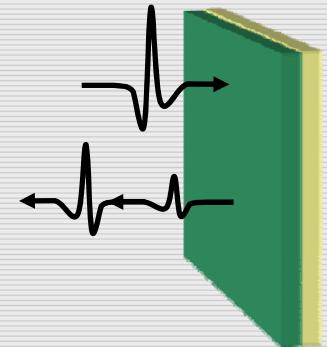
courtesy of: TU-Braunschweig

THz-tomography

Measurement of layer thickness



Zoom



Outline

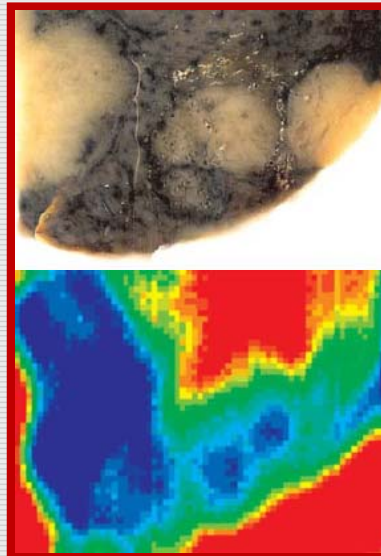
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Markets for THz-technologies

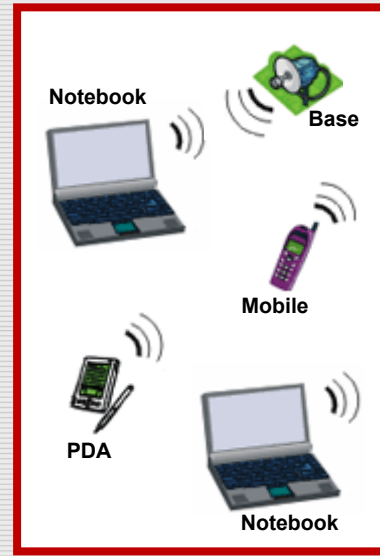
Markets for THz-technologies



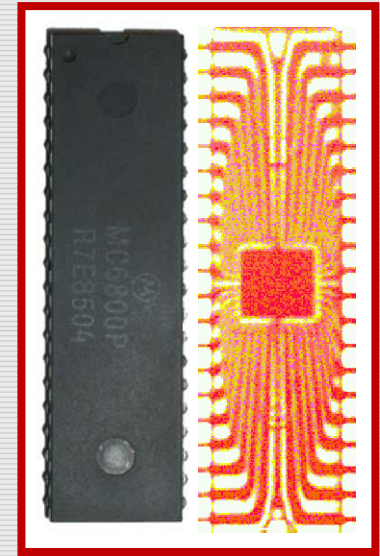
**safety
engineering**



**medical and
biotechnologies**



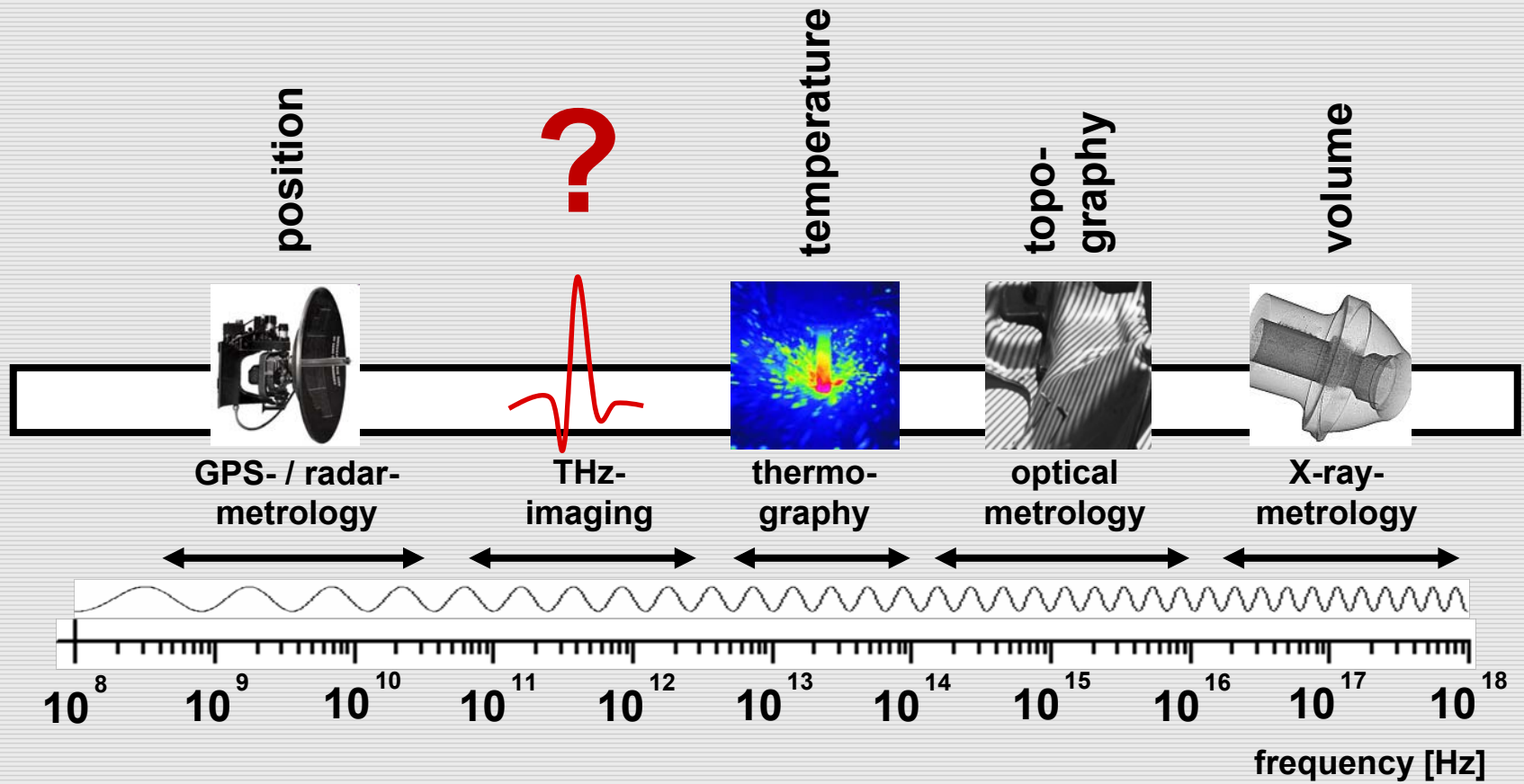
**wireless data
transmission**



quality control

Metrological applications

Spectrum of EM-radiation



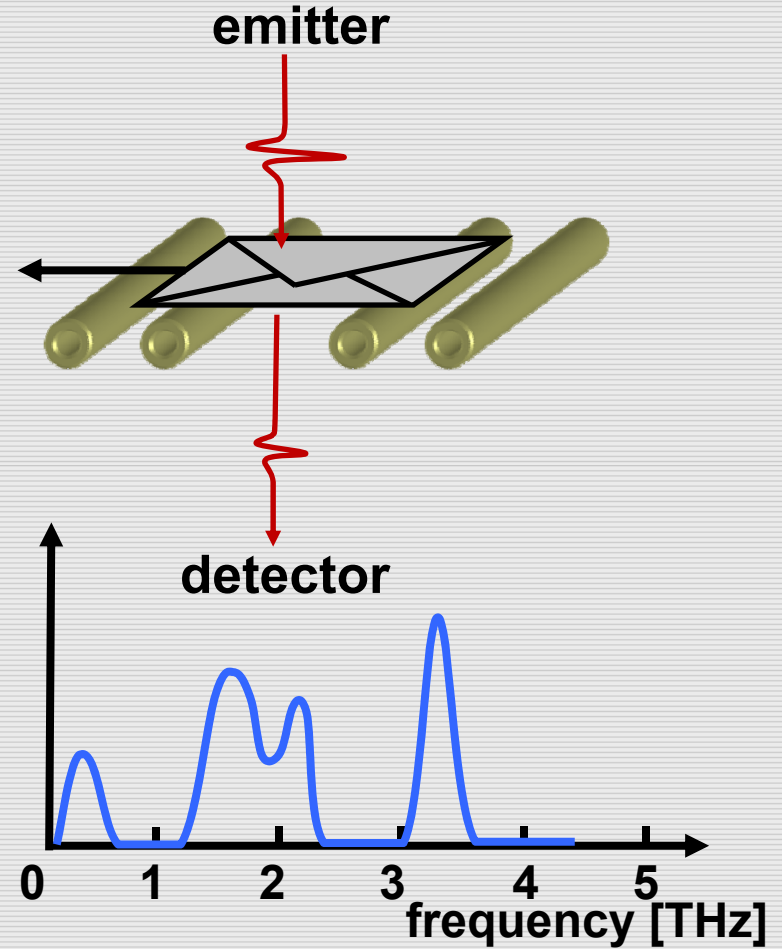
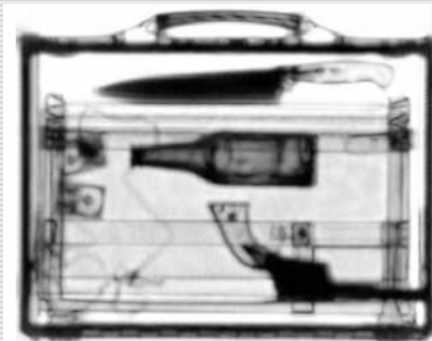
Industrial and spectroscopic inspection with THz-radiation

Overview

- **Security**
 - drugs, explosives
- **Quality control**
 - surface inspection
 - thickness measurement
 - impurity detection
 - humidity detection
 - Packaging
- **Material science**
 - concentration of charge carrier
- **Pharmaceutical industry**
 - purity, compounding
- **Life Science**

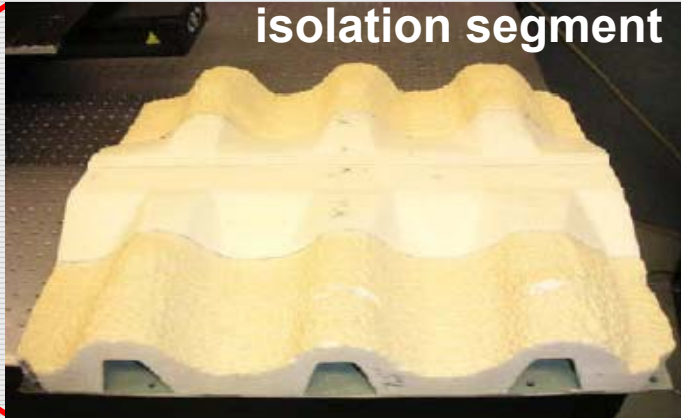
THz-Analysis in Safety Applications

Imaging and Spectroscopy

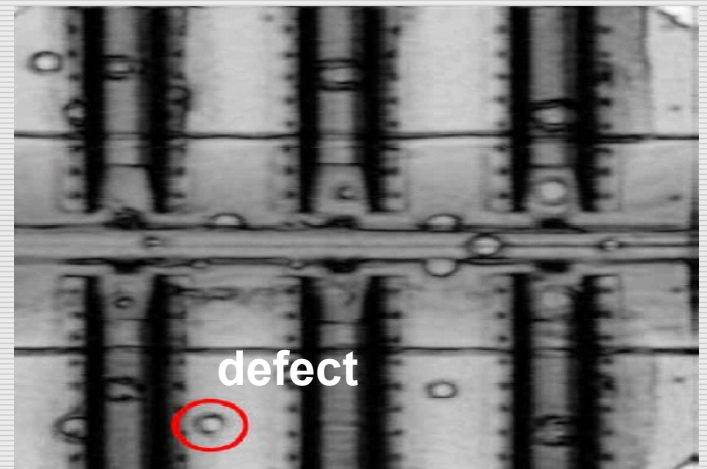


Quality control in aerospace

Example: fuel tank

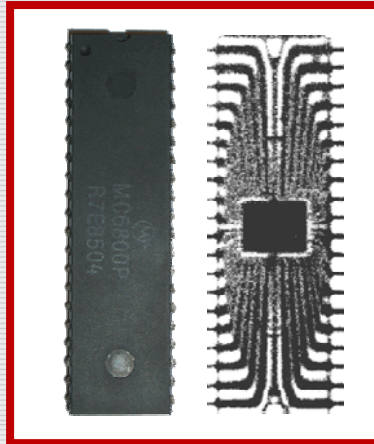


THz-image

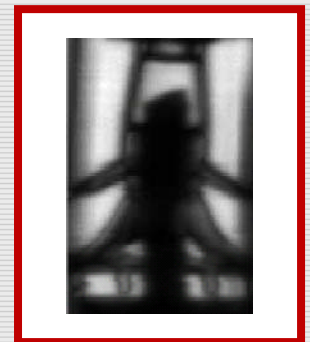
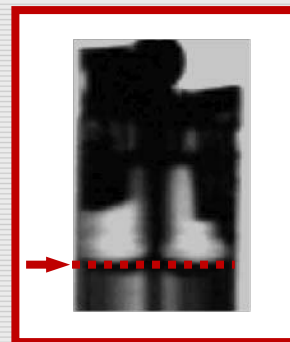


Control of completeness and fill level

Completeness

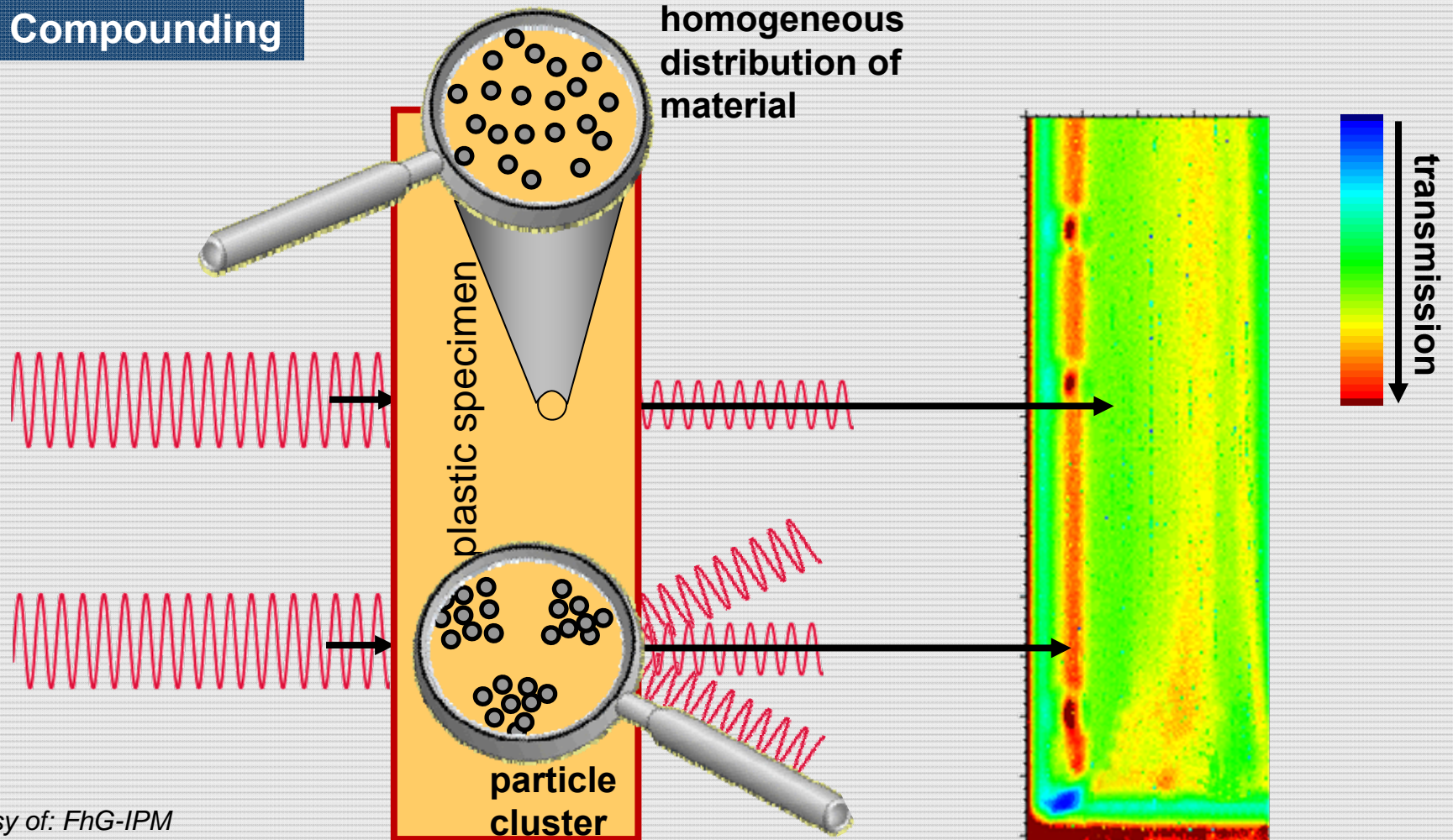


Level measurement



Control of inhomogeneity in materials

Compounding



courtesy of: FhG-IPM

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State of the technology: Multi-Sensor-CMM

Measuring task

Flexible measurement of geometric characteristics on 3 dimensional surfaces

Possible realizations

Multi-Sensor-coordinate measuring machine

Disadvantages

- No information about properties of material
- Impossible to measure different layers
- Pure geometrical quality control



Multi-Sensor-CMM of Werth

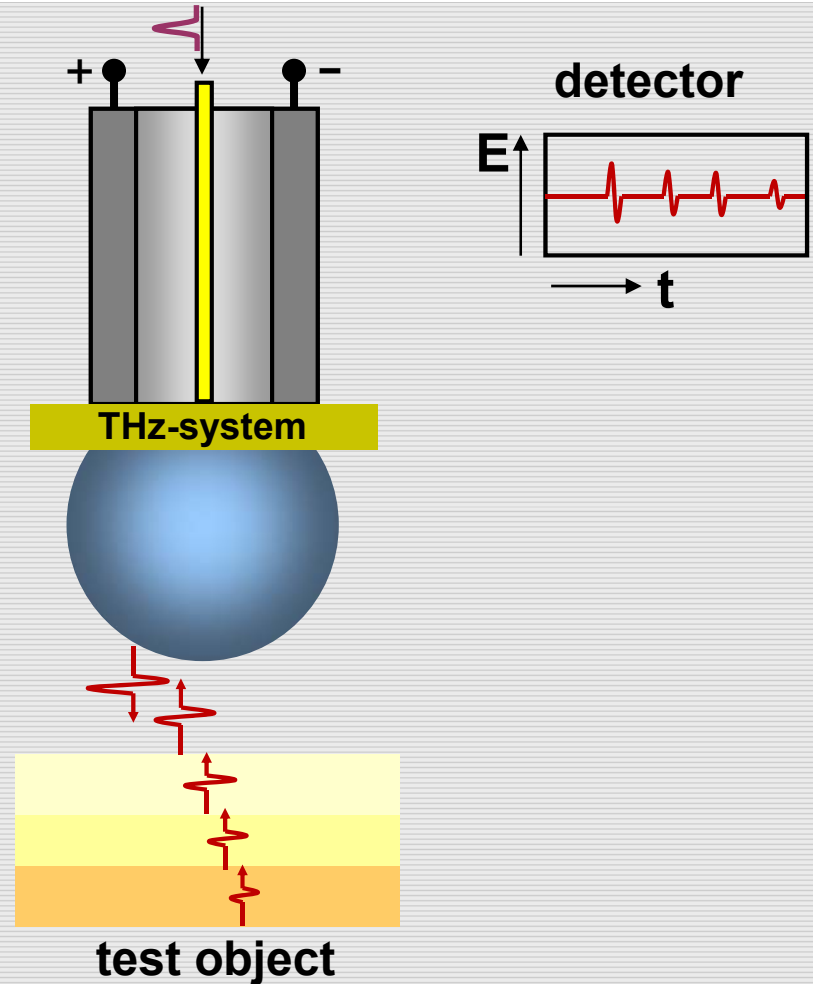
THz-radiation as extension for the CMT

Approach

- THz-antenna as extension for the multi-sensor-concept
- Combination of emitter and detector in one probe head
- Different strategies for evaluation for distinct requirements

Advantages

- Measurement of layer thickness
- Spectroscopic material analysis
- Measurement of inhomogeneities in Material



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Summary

- The key innovation for generation and detection of THz-waves was the optoelectronic switch and the resulting optoelectronics
- THz-waves radiograph dielectrics, characterize molecules and are suitable for tomography
- Fields of application are in particular safety engineering, quality control and medical technology
- **But:** For the industrial application THz-systems have to be *faster, more compact and low priced*

**Thank you
for your
attention**

Acknowledgement to:

Prof. Dr.-Ing. Elmar Wagner
Dr.-Ing. Stephan Bichmann