TOPTICA PHOTONICS

All Wavelengths.
190 nm - 0.1 THz

Photonic THz Systems meet Industrial Applications: Past, Present & Future

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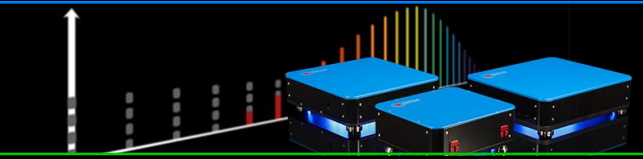
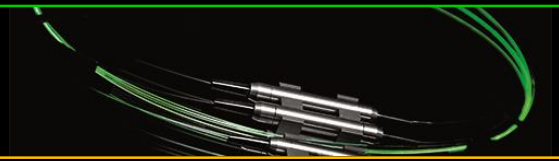
Dr. Björn Globisch, Heinrich Hertz Institute, Berlin

Prof. Dr. Sascha Preu, Uni Darmstadt

Prof. Dr. Andreas Stör, Uni Duisburg



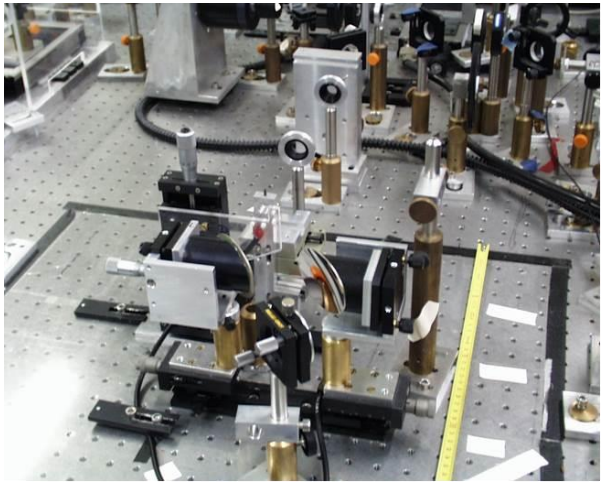


Agenda

- Snap shot from 1992
- Market analysis from 2000 to 2030
- Unique features & selling points
- Emerging technologies and applications
- Conclusion: Bright future with >20% CAGR

A journey though time from 1992 to 2018

- RWTH Aachen: THz from 0.1-10 THz via Bloch Oszillations
- Improvements: femtoW to μW, 500k€ to 50k€,10h to 10000h

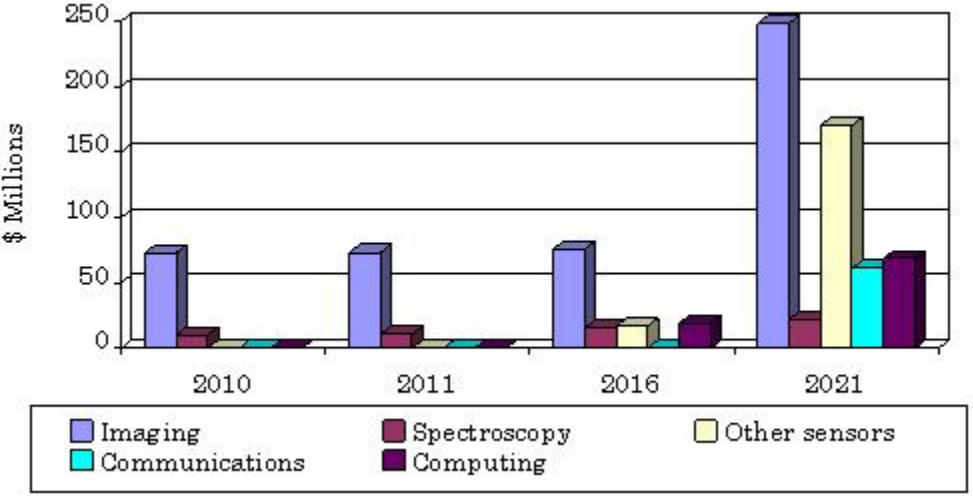


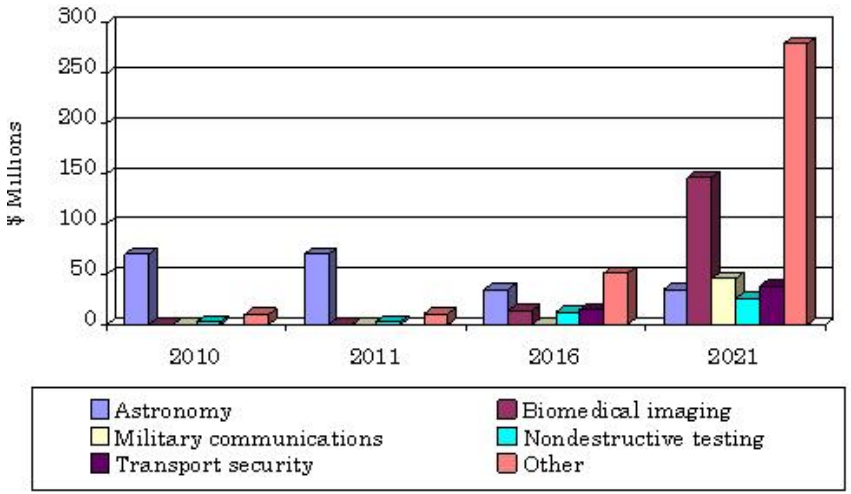
C. Waschke, H. Roskos, H. Kurz et al, PRL 70, 3319 (1993)

TOPTICA Photonics AG 2018

The THz years 2000-2010: never flies, never dies?

2000: First commercial system available
2010: 50M€ at stake, so the analysts show up





Do not trust analysts, think on your own !

D.R. Grischkowsky and D. Middleman „Introduction in Sensing with THz Radiation“, Springer, Berlin 2003.
T. Hochrein „Markets, Availability, Notice, and Technical Performance of THz Systems: historic Developments, Present and Trends“, https://www.bccresearch.com/pressroom/ias/global-market-terahertz-radiation-devices-systems-reach-$570-million-2021

Which data can you trust then?

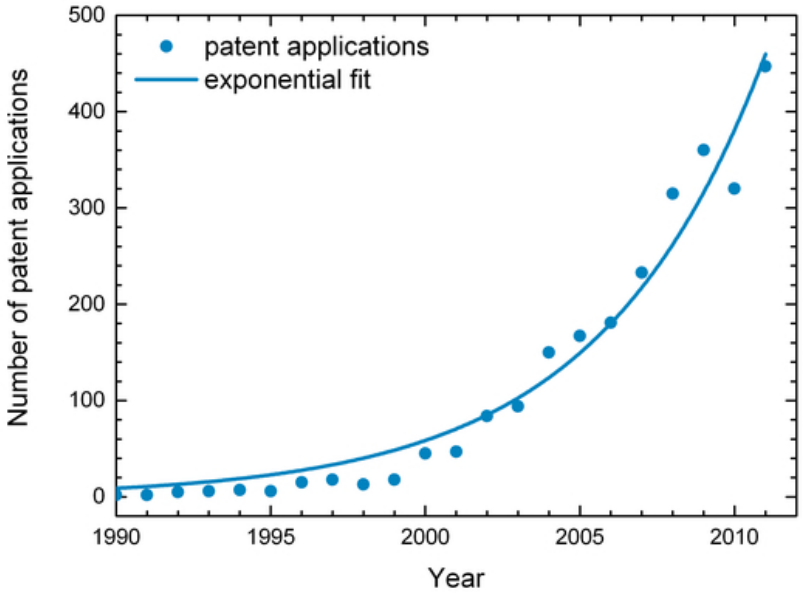
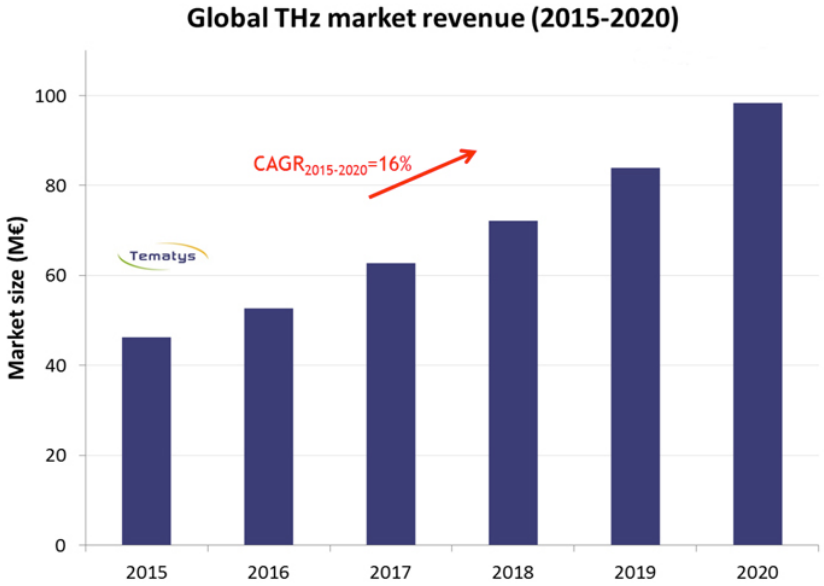


Fig. 1: Chronological chart from 1990 to 2011 and exponential fit for the global number of patent applications containing the term “terahertz”



The terahertz technology market was valued at US$185.98 million in 2017 and is projected to expand at a CAGR of 25.91% over the forecast period to reach US$741.19 million by 2023.

…the global terahertz technology market is expected to reach USD 489.8 Million by 2022, growing at a CAGR of 31.83% between 2016 and 2022

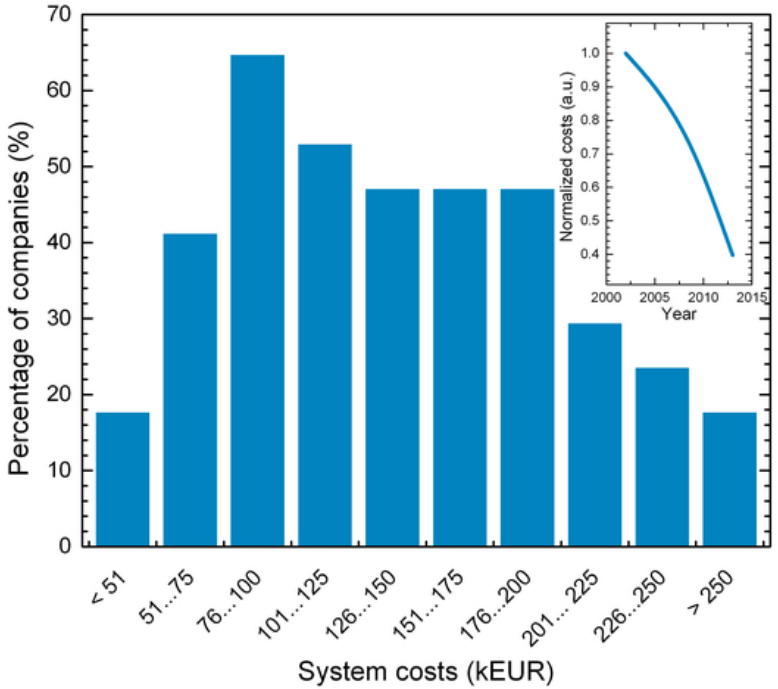
CAGR>20% from 2020 to 2030 for 0.1-10THz systems

http://www.skz.de/en/news/5120.Terahertz-Technology-is-Advancing.html

http://optics.org/news/7/7/27
https://www.researchandmarkets.com/research/xmr4gt/global_terahertz?w=4
https://www.marketsandmarkets.com/PressReleases/terahertz-technology.asp

Gold Standard and what makes THz growth happen: Cost & compact & robust & SNR

X-Ray subsystem: 30k€
Ultrasonic sensor: 1k€



2018: Customer "Cost" down to 0.2 now !

https://4nsi.com/innovations/robotix
http://www.atslab.com/nondestructive-testing/ultrasonic-testing.php
http://www.skz.de/en/news/5120.Terahertz-Technology-is-Advancing.html

Where can photonic THz play its unique selling factors:

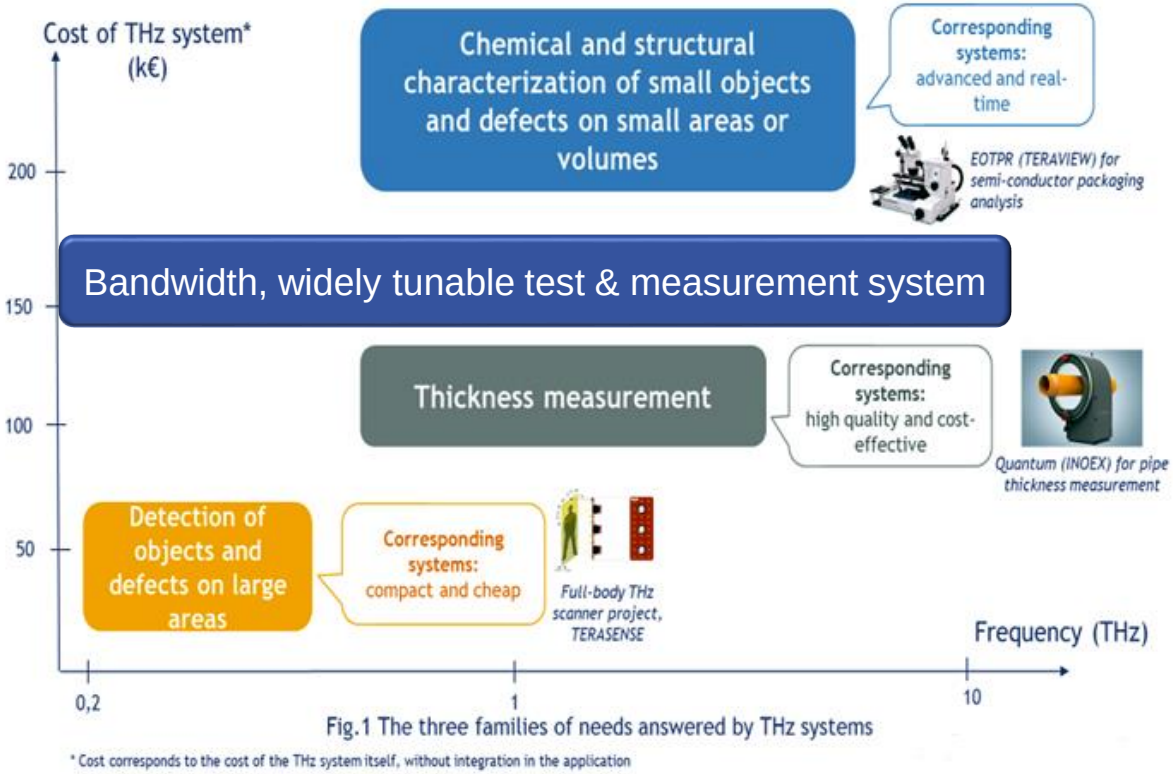


Fig.1 The three families of needs answered by THz systems

* Cost corresponds to the cost of the THz system itself, without integration in the application

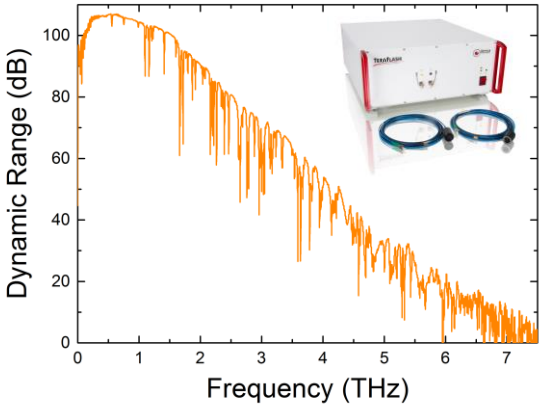
"Healthy", contact free, large bandwith, widely tunable, thin multilayer systems, chemical and structural information, miniaturization & mass production

Selected technologies & applications

- THz Systems and Applications Overview
- Photomixers and Photoconductors: State-of-the-Art
- Future THz Photonics Devices
- THz Communication
- THz and Biophotonic Applications
- THz Test & Measurement Systems

TOPTICA‘s THz track record: >125 systems with >500 lasers in field

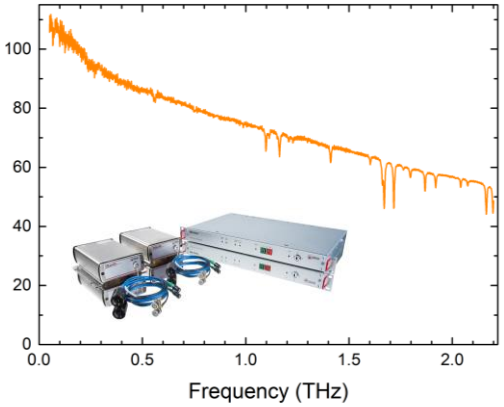
Time-domain platform



TeraFlash = €€€€

- Robust ultrafast fiber lasers (1550)
- Fiber-coupled photoconductive antennas
- > 5 THz bandwidth, up to 90 dB dynamic range

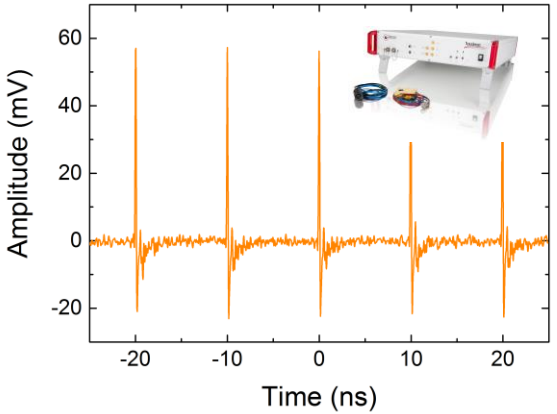
Frequency-domain platform



TeraScan = €€€

- Tunable DFB lasers (1550nm)
- Fiber-coupled photoconductive antennas
- < 10 MHz resolution, up to 100 dB dynamic range

Superfast screening platform



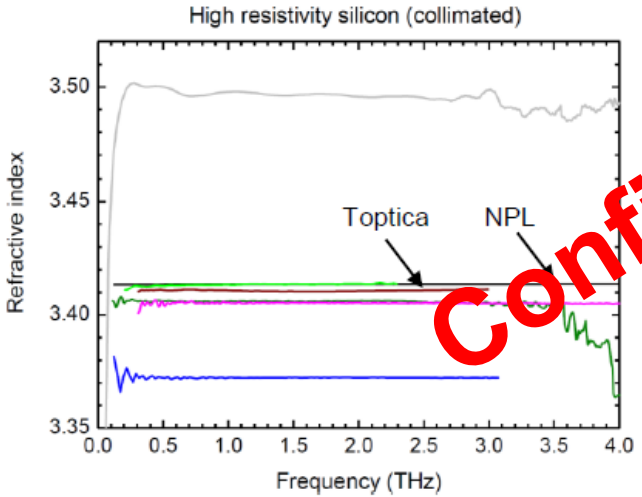
TeraSpeed = €€

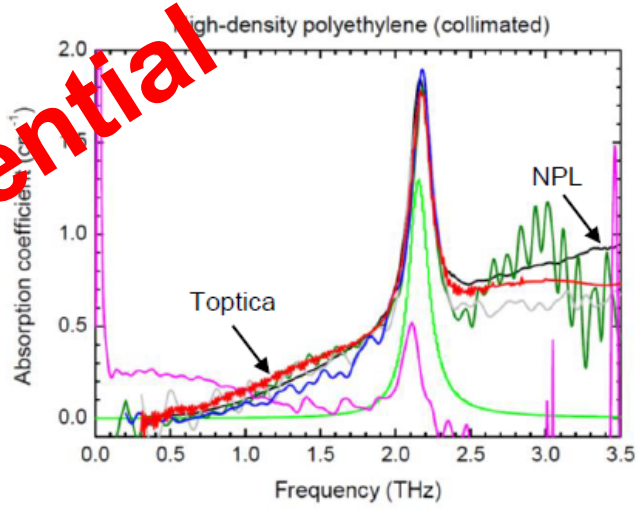
- Robust ultrafast fiber lasers
- Photoconductive emitter + high-bandwidth Schottky receiver
- 500 kS/s (digital), 100 MS/s (analog)

Material research: International intercomparison study

Intercomparison study of THz-TDS systems, initiated by NPL (UK)

- 18 participants determined refractive index and absorption coefficient of 5 reference samples
- Samples included polyethylene, fused silica, quartz glass, HR silicon and lactose





Result: TOPTICA's measurements agreed well with NPL's own results

- But: significant differences between laboratories & optical setups

Applications

Plastic Inspection

Layer Thickness

Industrial Quality Control

Material Research

Paper Screening

Gas Sensing

Hydration Monitoring

Ultrafast Dynamics

Security

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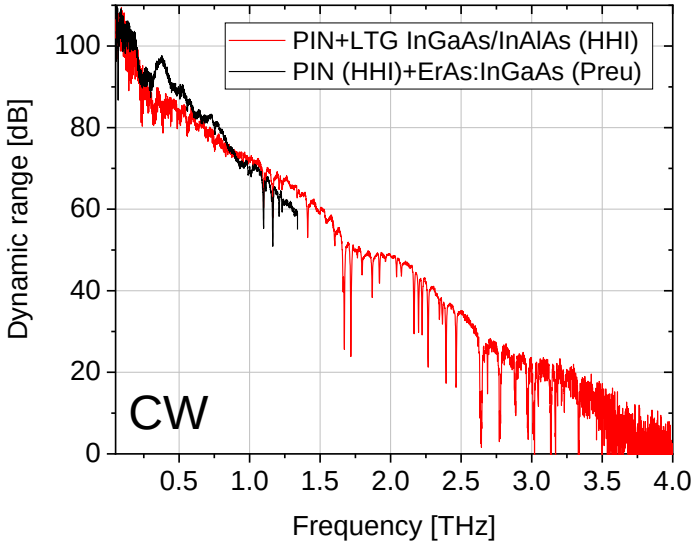
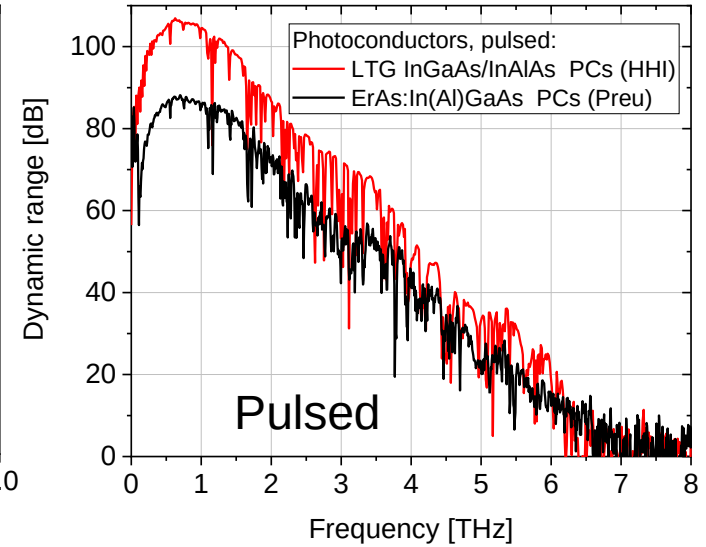
2019: OEM THz Systems ECOPS with 2kHz sampling rate

The ultimate engineering step: Replacement of mechanical delay-stage by an electronical delay-stage

Photomixers & Photoconductors: State-of-the-Art

- Photonic systems offer unprecedented bandwidth:
  - CW: 50 GHz - ~3.7 THz
  - Pulsed: 100 GHz- 6.5 THz
- Telecom-wavelength compatible (1550 nm)
- CW & pulsed comb systems: ~Hz-level linewidth
- There is plenty of room for enhancing performance!





European groups set the state of the art!

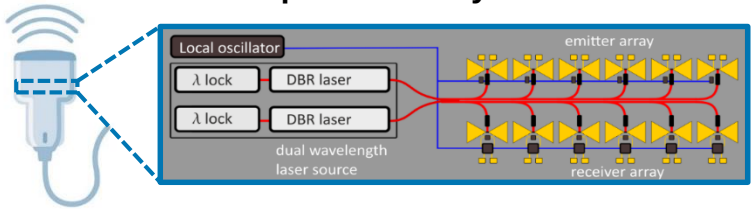
Future THz Photonic Devices and Systems: €

New materials and integration technologies for THz devices and components:

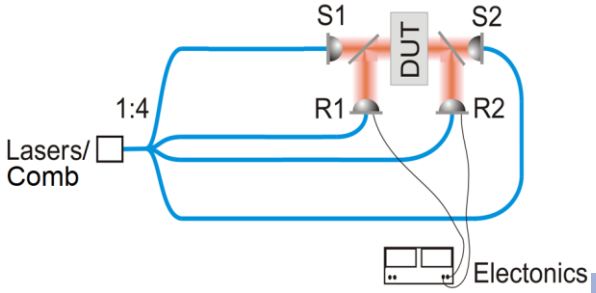
- Transition metal doping (Fe, Rh, Ru, Ir) of photoconductors (HHI, Björn Globisch)
- Rare earth:photoconductors, Perovskite-based devices (TU Darmstadt, Sascha Preu)
- SiN/InP waveguide integration for THz beam steering (UDE, Andreas Stöhr)

Innovative, large bandwidth systems:

On-chip terahertz system



Photonic vector network analyzer



Features:

- Electronic and photonic integration
- Multiple THz bandwidth

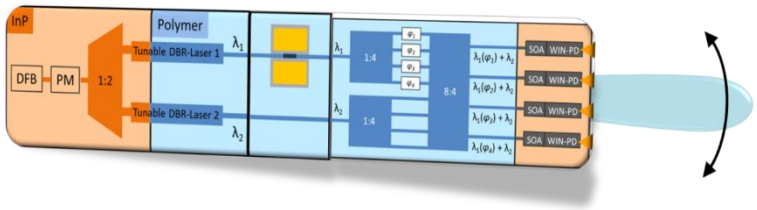
Applications:

- THz characterization
- Quality control/non-destructive testing
- Spectroscopy
- Layer thickness measurements
- ….

THz Communication: <€

Future directions: Broadband on-chip THz systems (Heinrich Hertz Institute)

Driven by photonic/hybrid integration



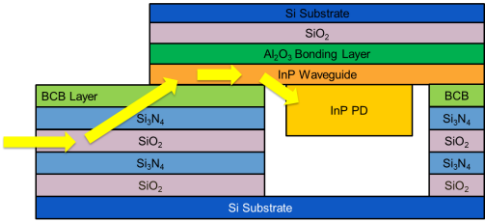
Features:

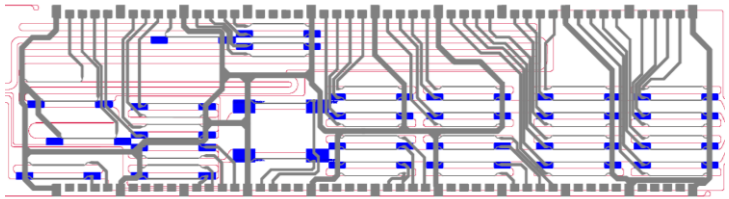
- Electronic and photonic integration
- Multiple THz bandwidth
- Beam steering via phased arrays

Applications:

- Mobile backhauling
- Kiosk down- / and upload
- Non-communication applictions (spectroscopy, quality control, security)

Future directions: Integrated THz beam steering chips (Univ. Duisburg-Essen)





THz Communication

Spectral-efficient THz Communications (University Duisburg-Essen)

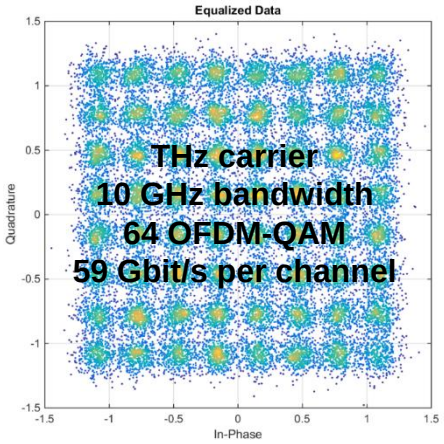
Driven by photonic/hybrid integration

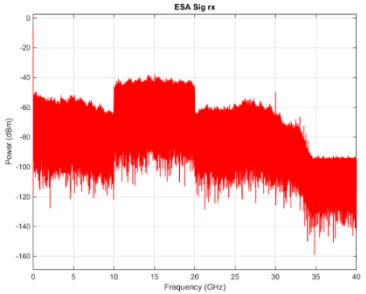
Features:

- Electronic and photonic integration
- THz integration/ packaging

Applications:

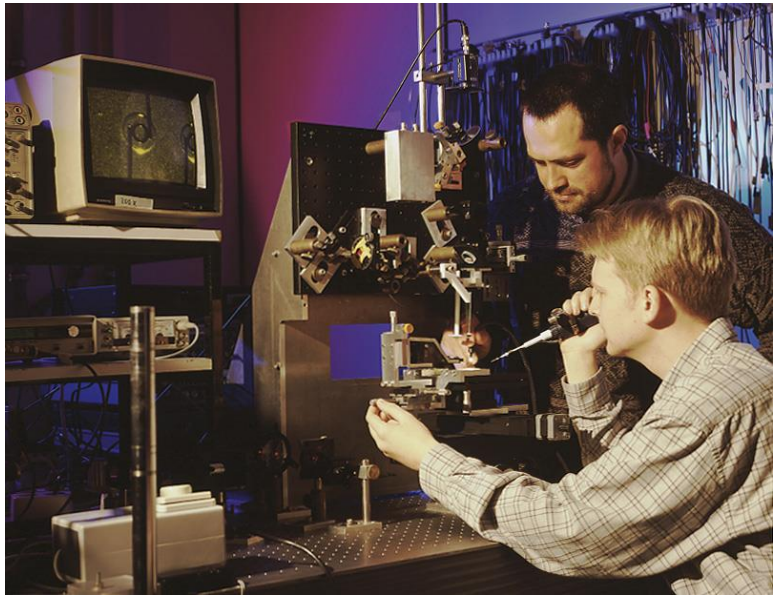
- Mobile backhauling
- Small cell THz hot spot

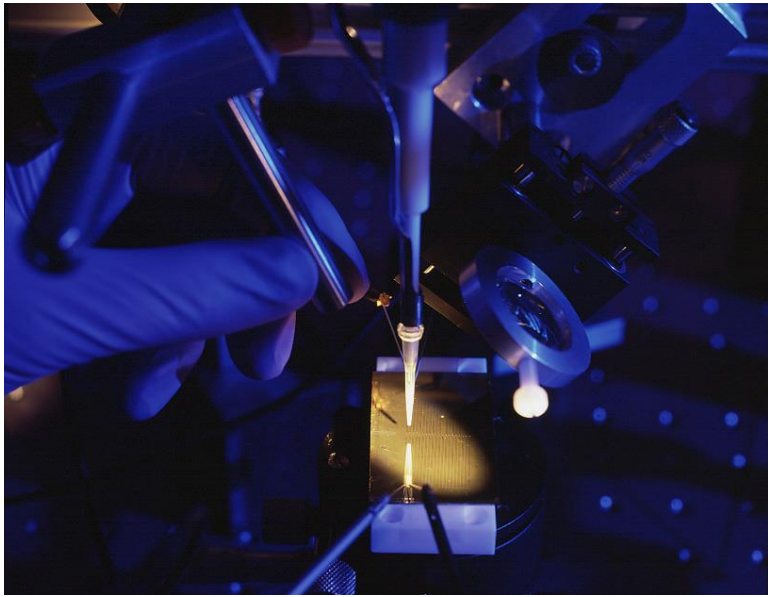


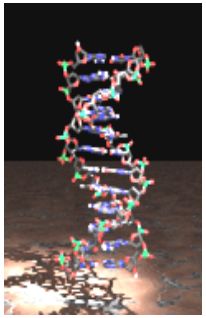


Biomedical sensorics with THz systems: €

Where is all began … year 2000 (Markelz et al, Brucherseifer et al., …)







RWTH Institut für Halbleitertechnik

- Label-free direct analysis of biomolecules (here demo of DNA sensing capability)
- … **but** at prohibitively high analyte quantity/density requirements

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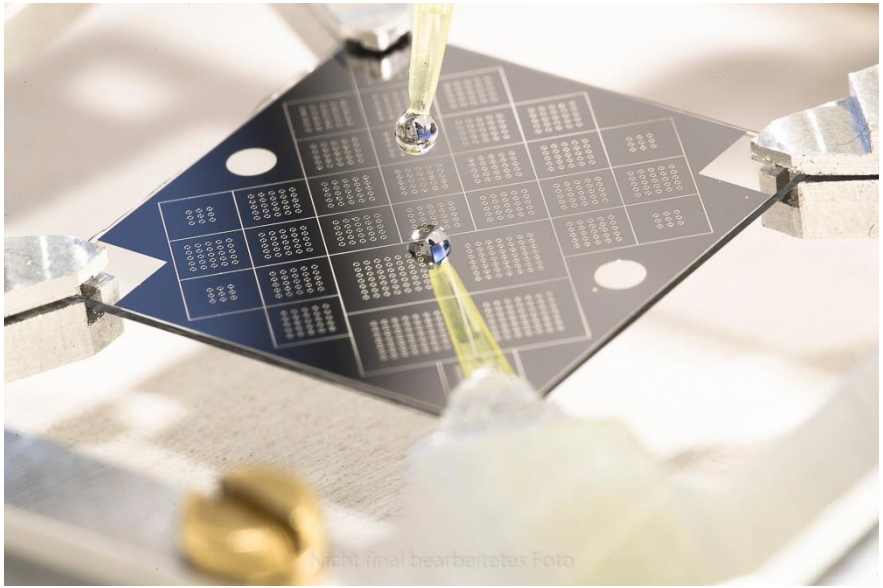
Biomedical sensorics with THz frequency selective surfaces

Status 2018 for biomolecular sensing



- Competitive sensitivity to established techniques reached
- Direct + PCR-free sensing of tumor markers at pathophysiological concentrations in humans!

FAU FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

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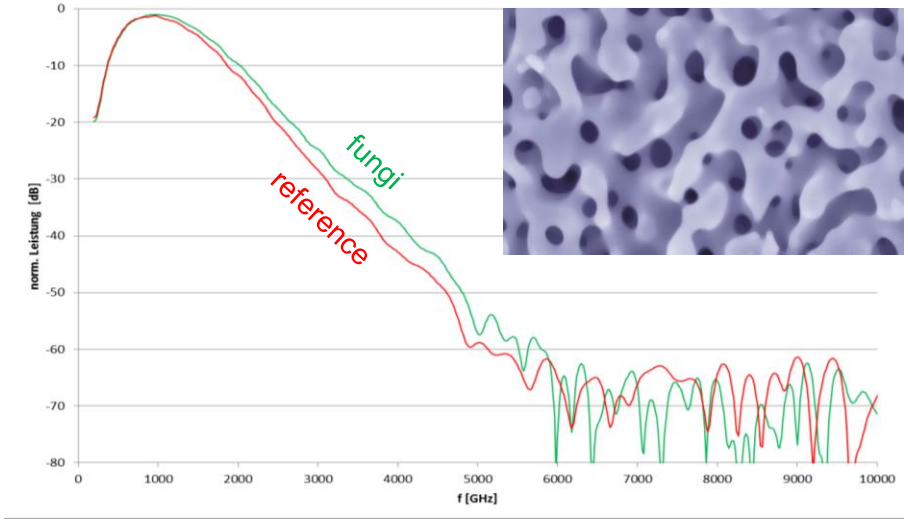
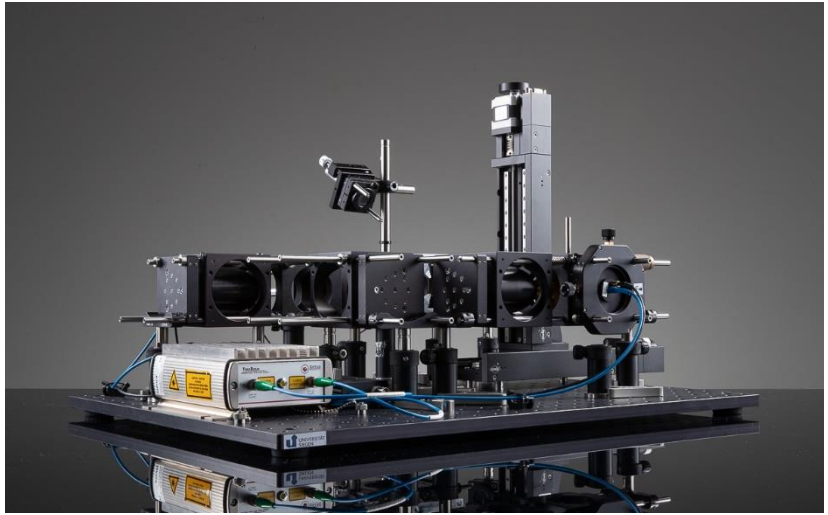
Biomedical sensorics with THz systems

Extension to other biomedical application areas …





- Extension of biomedical application beyond molecules, to sense virus, bacteria, …..
- e.g. here: direct detection of fungi on nanoporous glass for early detection of invasive fungal infections in humans

TOPTICA PHOTONICS A Passion for Precision.

ANTERAL Innovative Antenna and Terahertz Imaging Technologies

FUNDACIÓN MIGUEL SERVET

upna Universidad Pública de Navarra

UNIVERSITÄT SIEGEN

Conclusion

Past

- Significant research started in early 1990
- THE killer application for THz was missing from 2000-2015
- There are low-cost NDT alternatives
- The technology was not industry grade: cost, size, robustness, SNR…

Present

- Cost, robustness, size & SNR improved, thanks to all the funding €
- Technology move from 800/1060nm to 1550nm
- The unique selling points are understood now
- Value chains established: components, systems, solutions & infrastructure

Future

- A CAGR of >20% p.a. is expected from 2020 to 2030
- Market size depends on value chain & definititon
- Widely tunable test & measurement needed
- Miniaturization will enable future mass-applications at low cost
- Emerging industrial applications in NDT, communication & biophotonic

“Healthy”
Contact free
Large Bandwidth
Widely tunable
Thin multilayer systems
Chemical & structural inform.
Miniaturization & mass prod.

Some forecasts:

Cost for Customer

- Time-domain: ~~€€€~~
- Frequency domain: ~~€€~~€
- Single shot: ~~€€~~
- Miniaturized systems: NDT €, Communication <<€

Applications

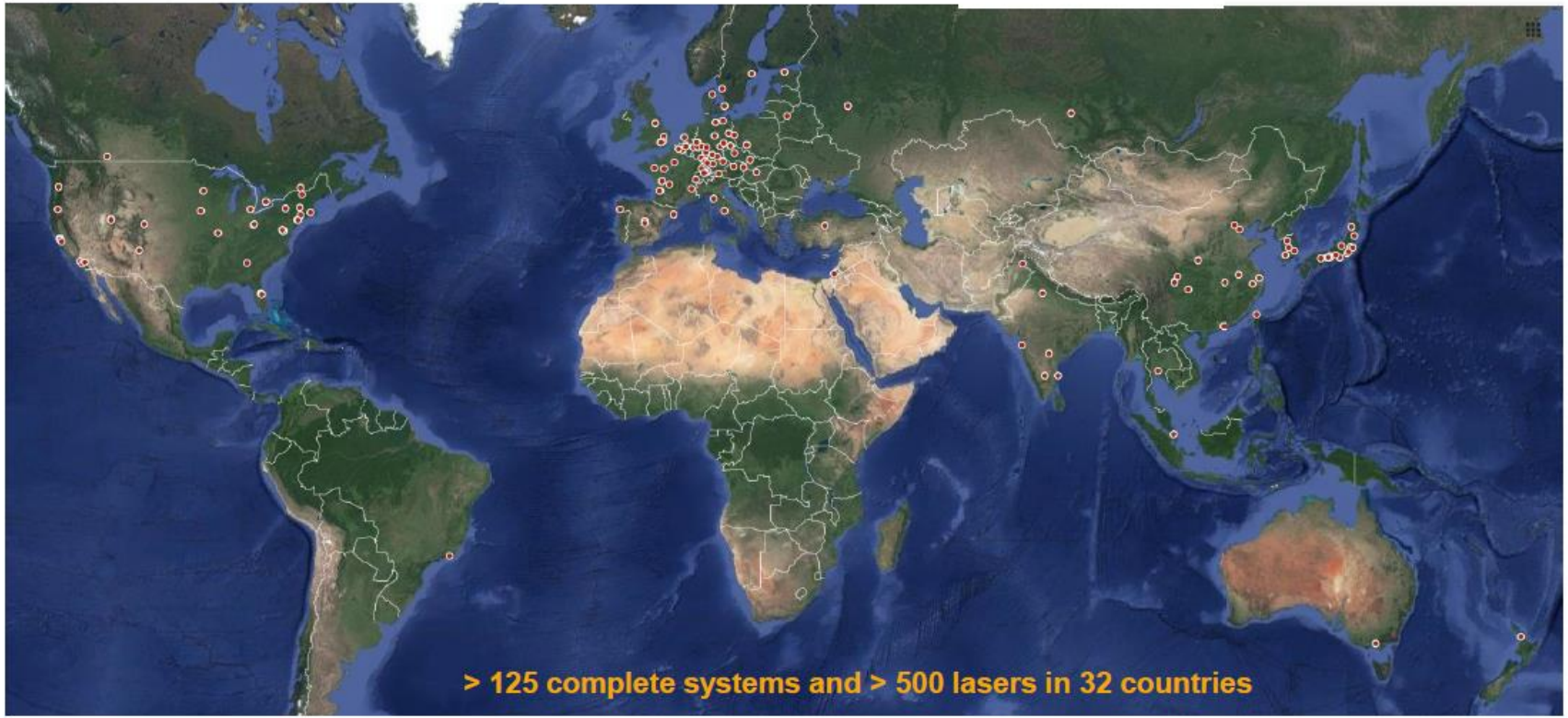
- Industrial NDT: ready to go, system integration & standardization needed (e.g. RED)
- Industrial NDT imaging: parallization needed, miniaturization is must
- Communication: cost cost cost….miniaturization needed
- Biophotonic: fundamental research and miniaturization
- Industrial test & measurement: e.g. RED ???

Technologies

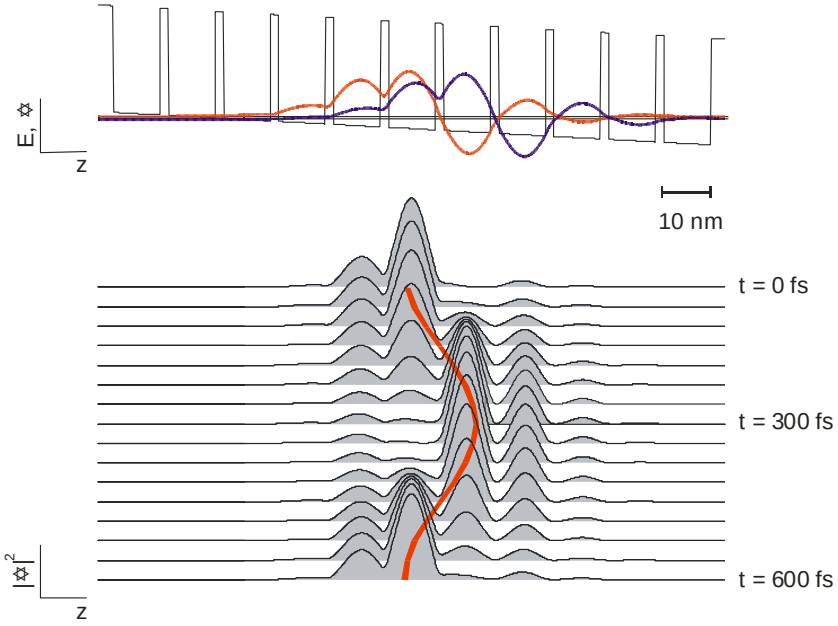
- On-chip THz systems
- Integrated THz beam steering via phased arrarys
- Imaging with synthetic aperture or other innovations for 3D analysis
- New SW algorithms to allow for 1D or 2D online process monitoring

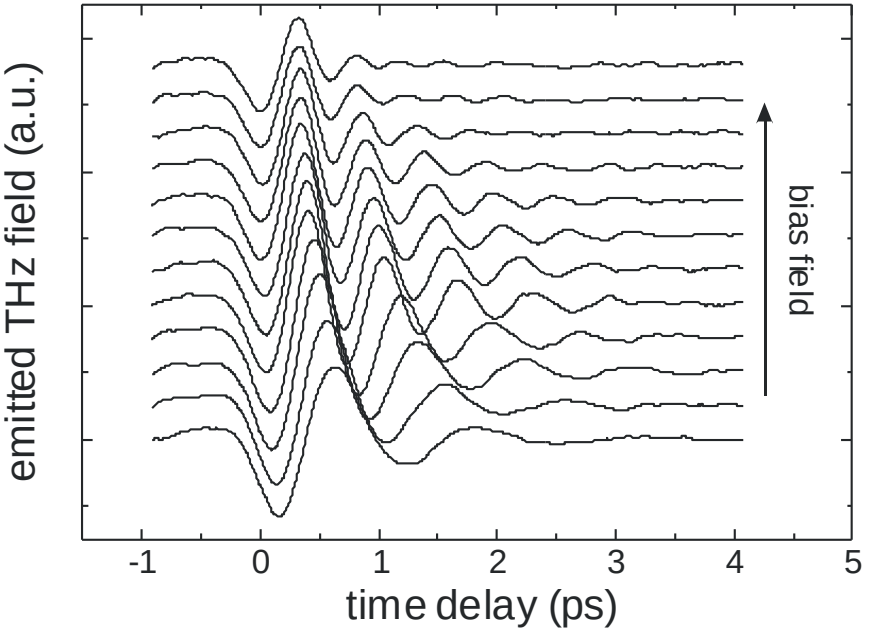
Back-ups

TOPTICA's terahertz map of the world



One historic slide..





Waschke, et al PRL 70, 3319 (1993)