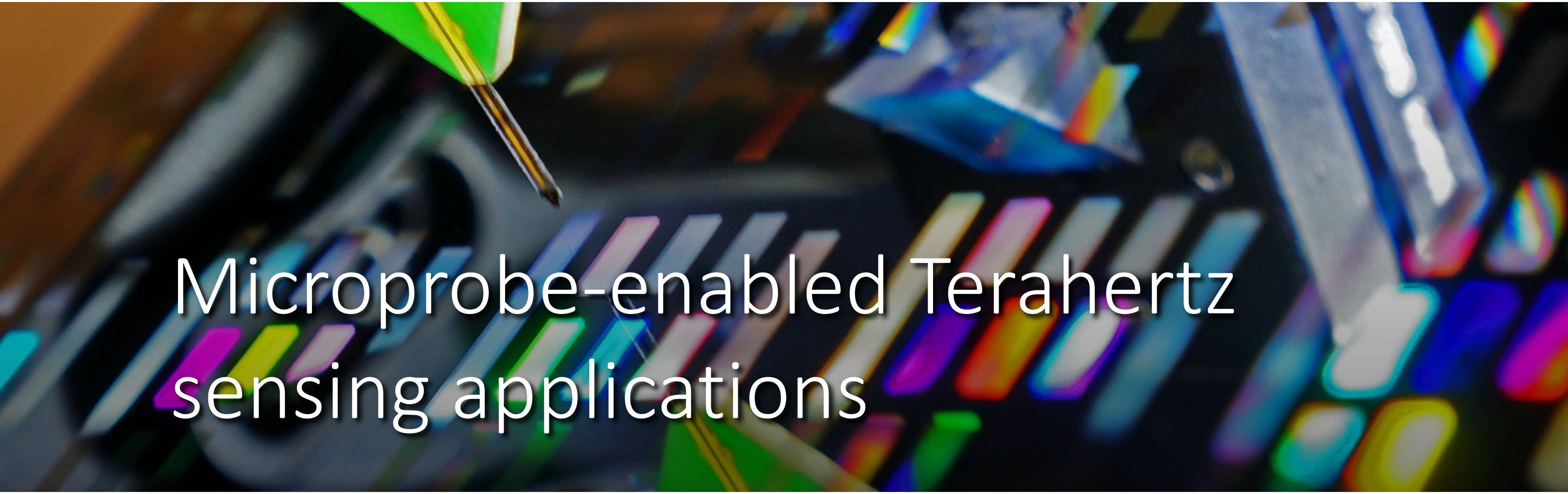


Microprobe-enabled Terahertz sensing applications

World of Photonics, Laser 2015, Munich

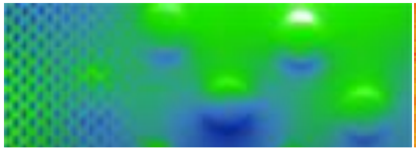
Protemics GmbH
Aachen, Germany

protemics

© Protemics GmbH

Terahertz microprobing technology:

Taking advantage of Terahertz range benefits without being compromised by wavelength-based resolution limitations.



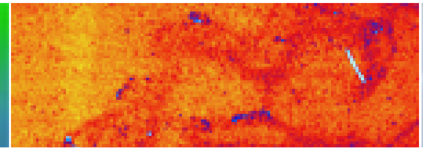
Terahertz Research

Application areas:

- Metamaterials
- Plasmonics
- Devices
- Waveguides
- Sensor surfaces
- Graphene

Benefits:

- Near-field access
- High-sensitivity
- Low-invasiveness
- Polarisation sensitive
- Broadband



Thin-film Analysis

Application areas:

- Solar cells
- Displays
- Flexible electronics
- Doping layers
- Graphene
- Transparent conductors

Benefits:

- Sheet resistance imaging
- Contactless
- Micron-scale resolution
- Large-area scanning
- High-speed scanning

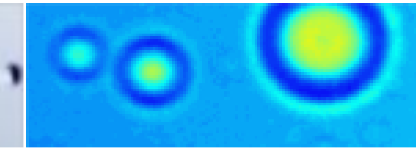
Chip-Testing

Application areas:

- Time-domain reflectometry
- Fault isolation
- Packaging level inspection
- 3D integration
- Through silicon via (TSV)

Benefits:

- Market leading TDR resolution
- Contactless
- Non-destructive
- Cost advantage



Volume Screening

Application areas:

- Plastic weld inspection
- Fiber inforced polymers
- Chip underfill inspection
- Organic layer screening

Benefits:

- Non-destructive
- Fast inspection
- Screening of opaque plastics
- Detection of microdefects

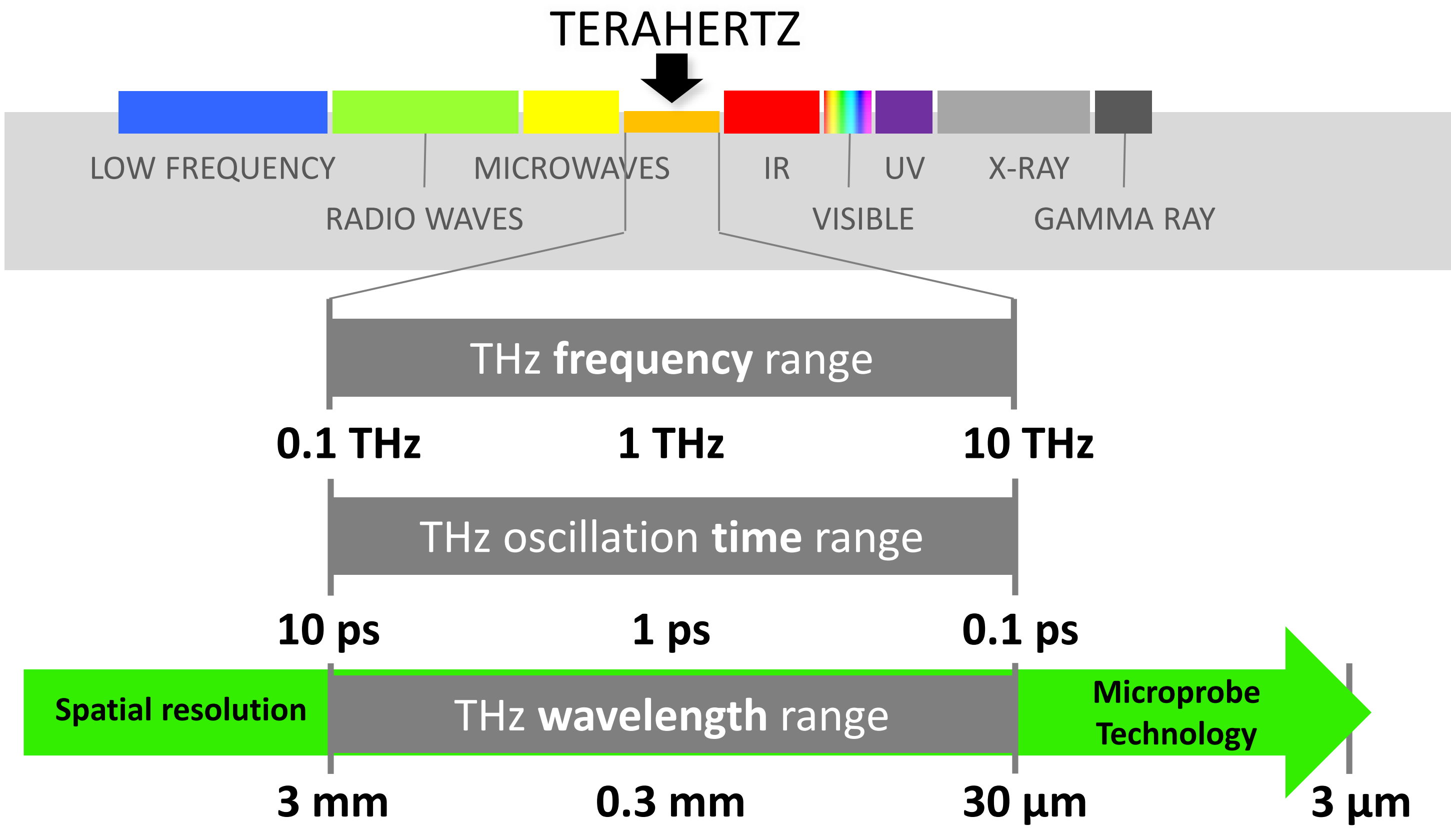
© Protemics GmbH

Outline

- Introduction
  - Mismatch between THz radiation wavelengths and micro/nanostructure size
- THz microprobes
  - Working principle
- Thin-film analysis with sub-wavelength resolution on large areas
  - Thin-film conductors (Metals, Graphene, Semiconductors, ITO and ITO-replacement materials)
- THz Metamaterials
  - THz-Metamaterials, Metamaterial-based sensing
- Plastic laser weld inspection
  - Near-field detection of micro-defects
- THz device analysis
  - THz on-chip device characterization
  - Failure localization in chip packages

© Protemics GmbH

Introduction



© Protemics GmbH

Introduction

Large THz wavelengths are problematic:

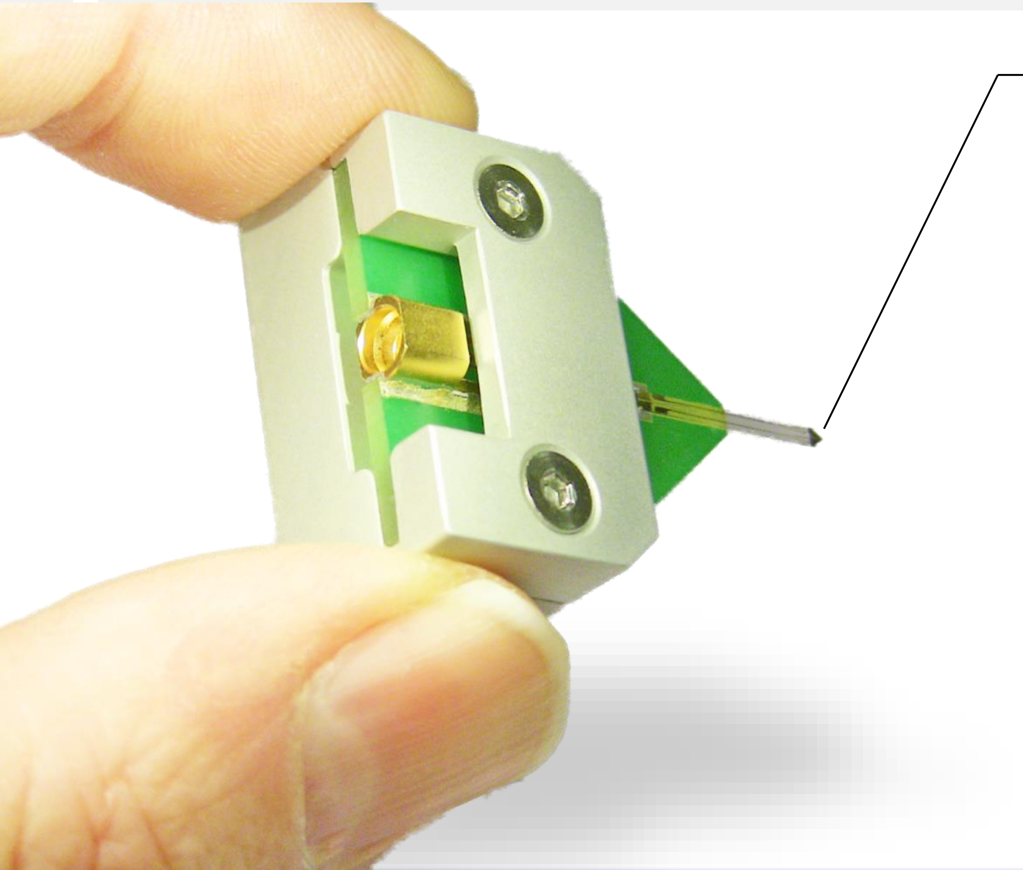
- When structures under test are too small (similar to λ or even smaller)
  - Lateral Micro/Nanostructures (Solar cells, electronic structures, micro defects, …)
  - Only minute (pl) sample volumes available (-> biosensing)
- On signal transfer to or from THz field confining structures
  - Waveguides
  - Integrated devices

Solution:

- Make THz emitter and/or detector smaller than the wavelength
- Bring the miniaturized emitter/detector in sub-wavelength distance to structure under test

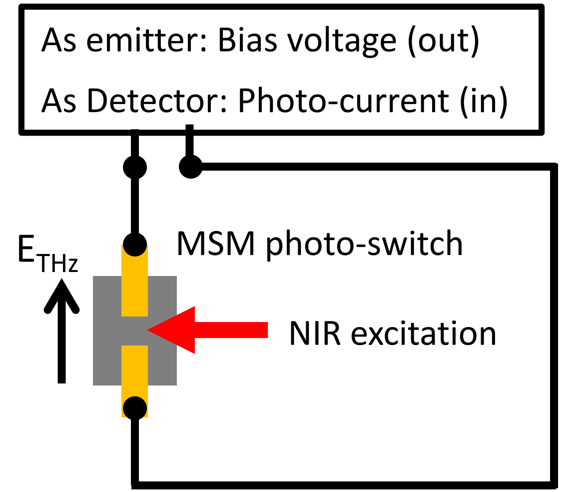
© Protemics GmbH

THz micro-emitters/detectors



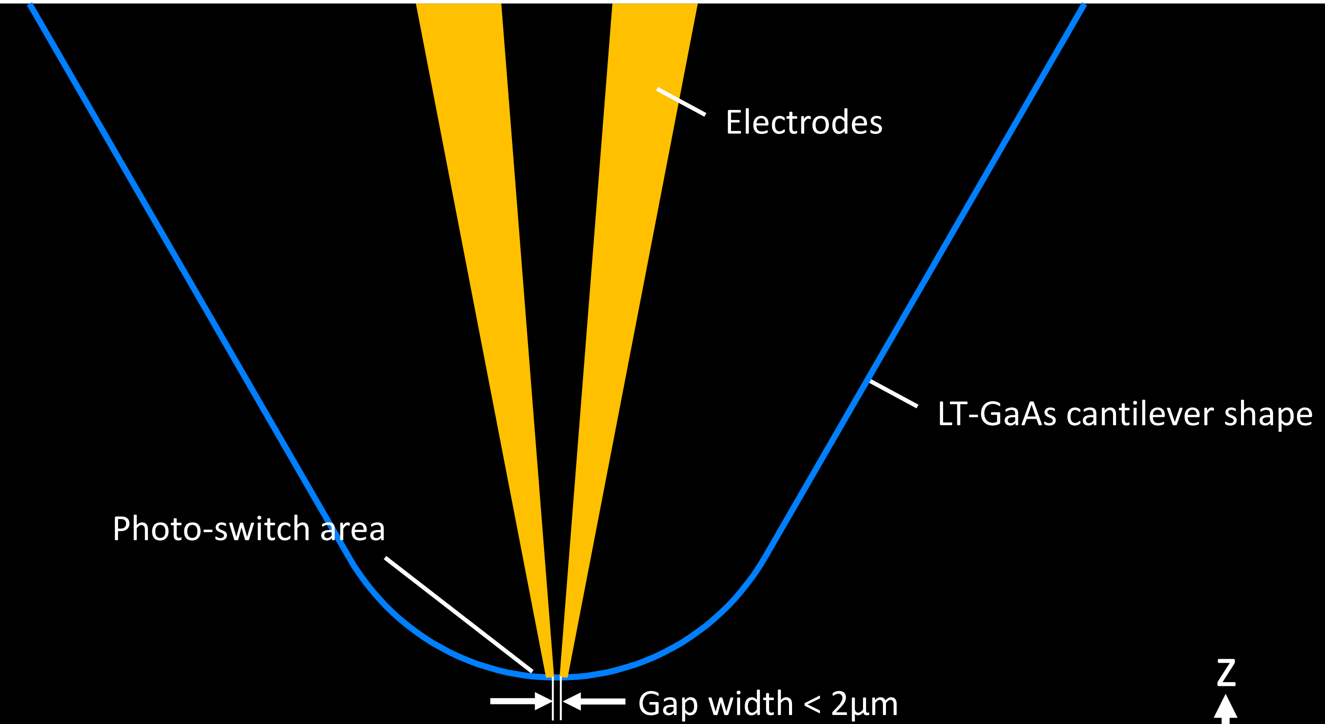
Active microstructure

Cantilever thickness = 1 µm



© Protemics GmbH

Application specific designs

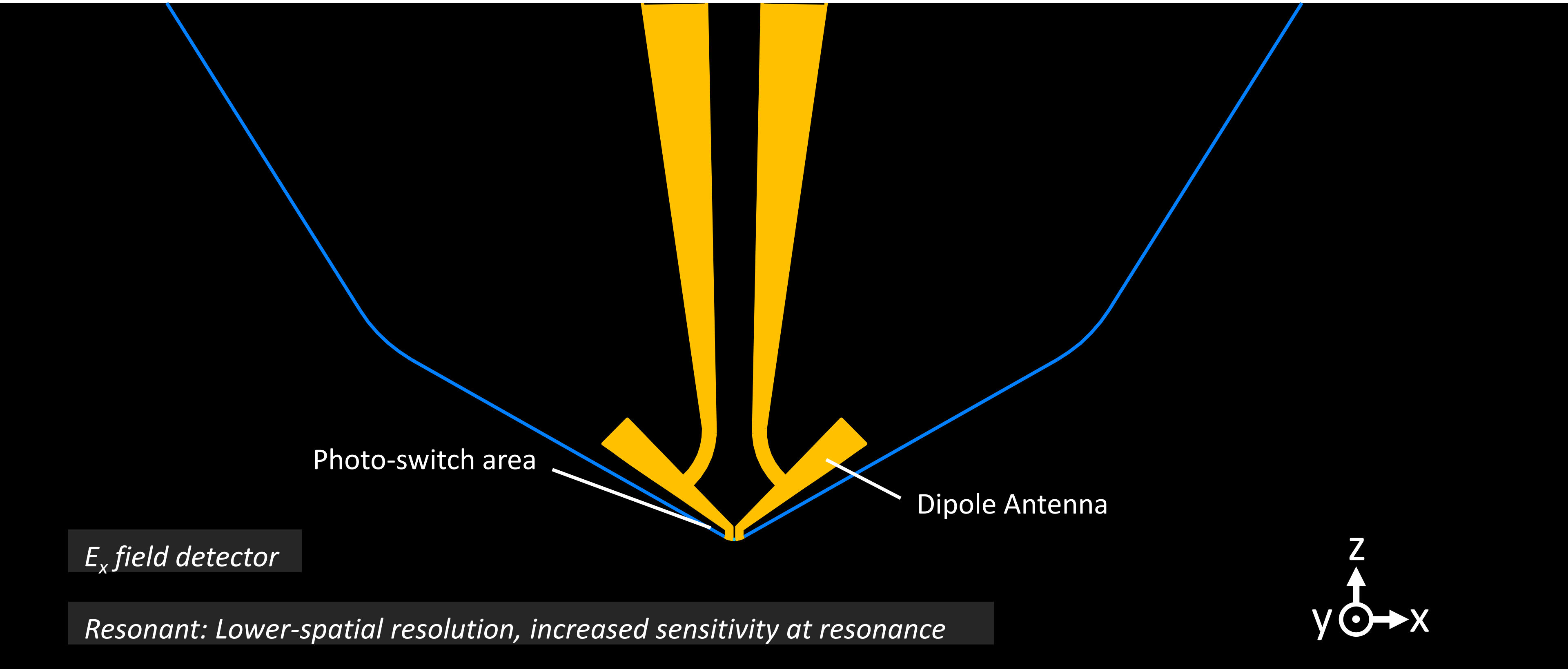


E_x field detector

Non-resonant: high-spatial resolution, homogeneous spectral response

© Protemics GmbH

Application specific designs

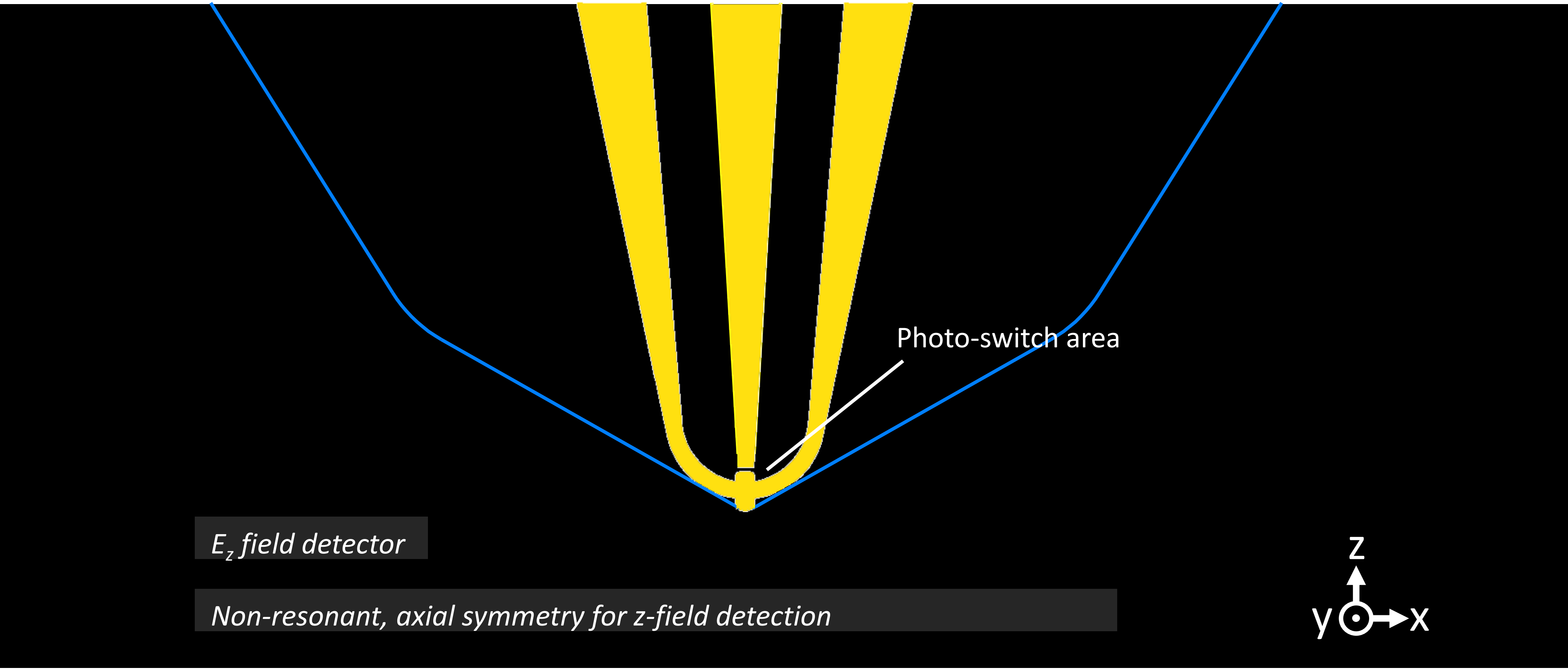


E_x field detector

Resonant: Lower-spatial resolution, increased sensitivity at resonance

© Protemics GmbH

Application specific designs

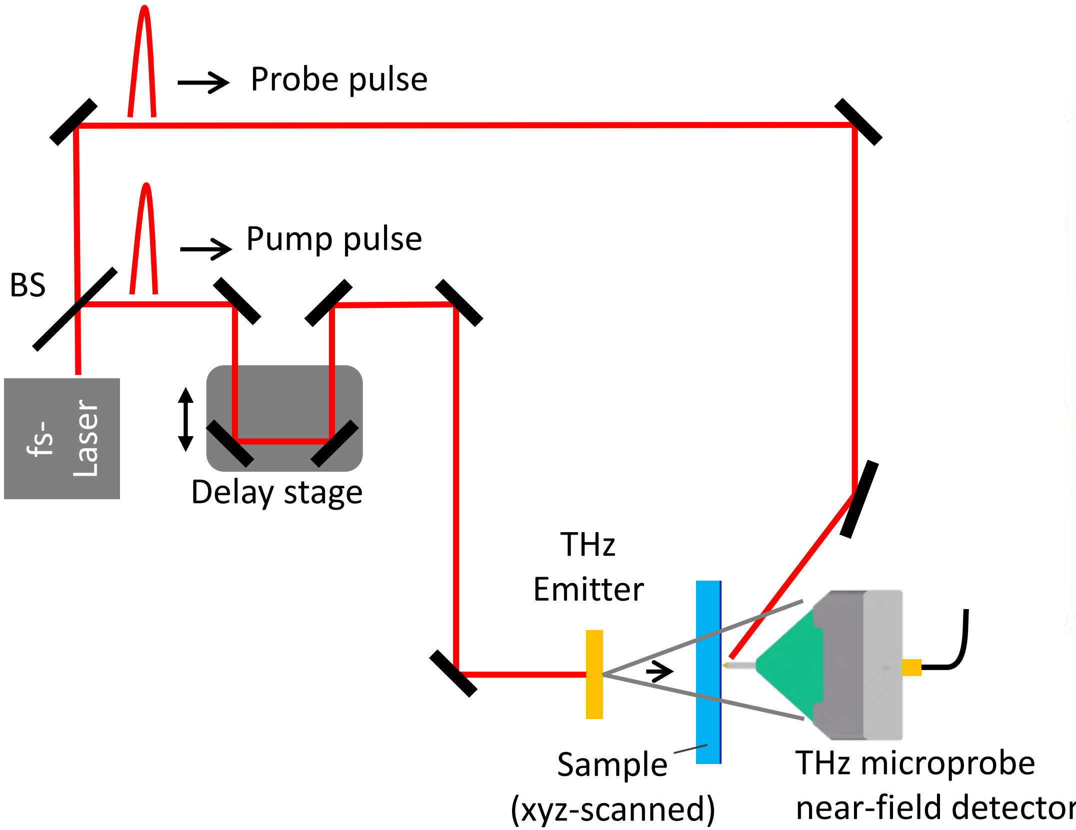


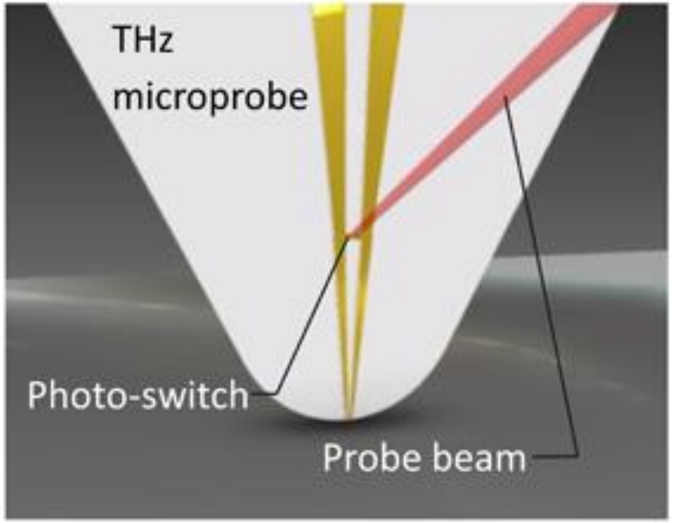
E_z field detector

Non-resonant, axial symmetry for z-field detection

protemics
© Protemics GmbH

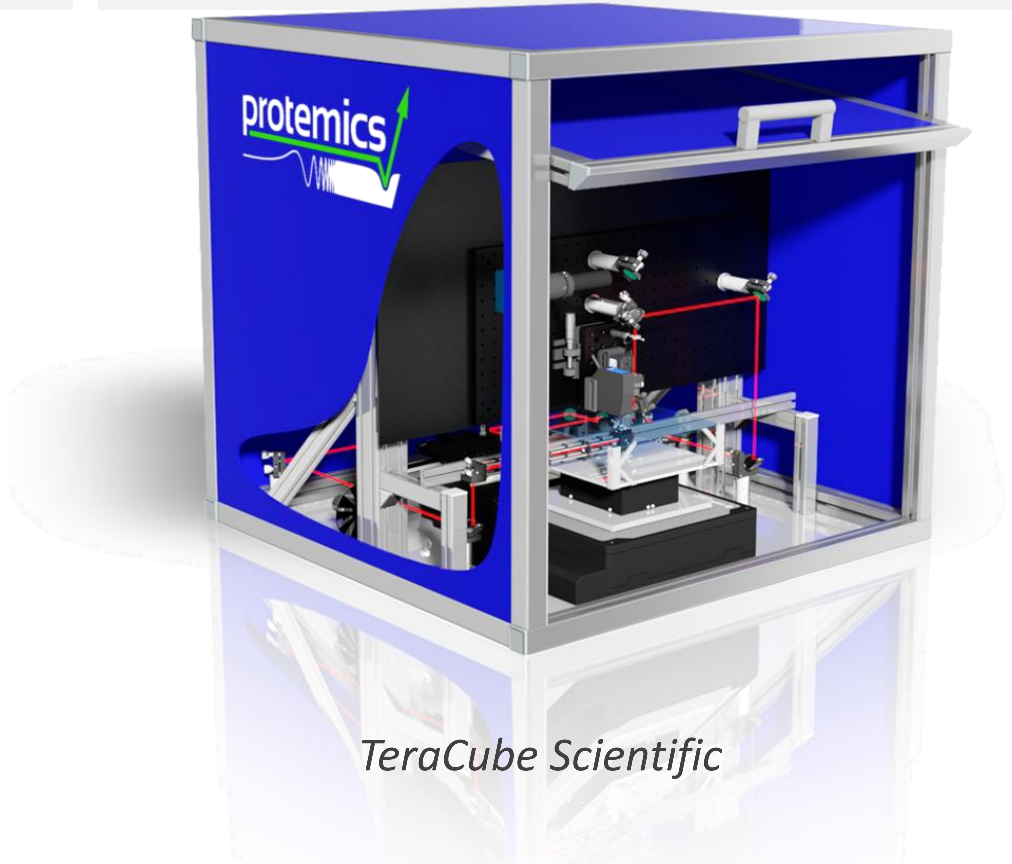
TD near-field sampling





© Protemics GmbH

TD near-field system



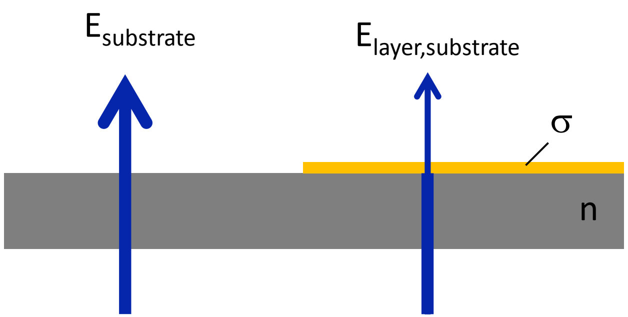
TeraCube Scientific

- **Automated table-top system**
  - 90x90x90 cm box including:
    - Laser
    - Scanning components
    - Opto-mechanics
    - Optics
    - Electronics
  - External components
    - PC
    - Supply unit

© Protemics GmbH

Thin-film conductors

- **Surface analysis with sub-wavelength resolution on large areas**
  - Sheet resistance imaging of thin-film conductors such as
    - Metals
    - Graphene
    - Doped semiconductors
    - Optically transparent conductors: ITO and ITO-replacement materials



Tinkham Formula:

$$\frac{E_{layer,substrate}(\omega)}{E_{substrate}(\omega)} = \frac{1+n}{1+n+Z_0\sigma(\omega)d}$$

Accessible sheet resistance range: 0.1 – 10000 Ohm

© Protemics GmbH

Thin-film conductors

Short-comings of state-of-the-art sheet-resistance measurement tools

Contact-based four-point probe measurements are problematic:

- On **large-bandgap** semiconductors (e.g. GaN or SiC)
  -> Imprecise measurements because of nonlinear contacts
- On **passivated** samples (e.g. Solar cells)
  -> No contact
- On **nanostructures** (e.g. metal mesh nanostructures)
  -> Requires formation of additional contact pads

- If measurement **time** matters
  -> Extremely time-consuming (5s/measurement point)
- If non-**destructive**ness matters
  -> Puncturing from contact needles

© Protemics GmbH

Thin-film conductors

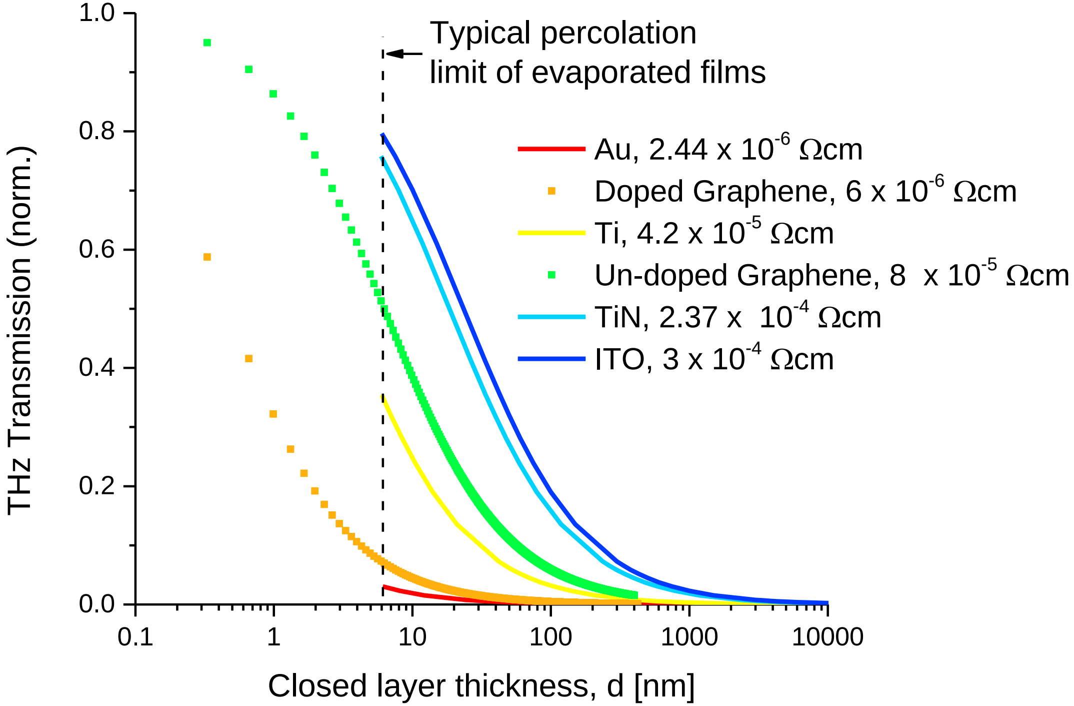
Short-comings of the state-of-the-art sheet-resistance measurement tools

Non-contact Eddy current measurements:

- Spatial resolution is limited to 1 cm for **quantitative** measurements
- Spatial resolution is limited to 2 mm for **qualitative** measurements.

© Protemics GmbH

Thin-film conductors



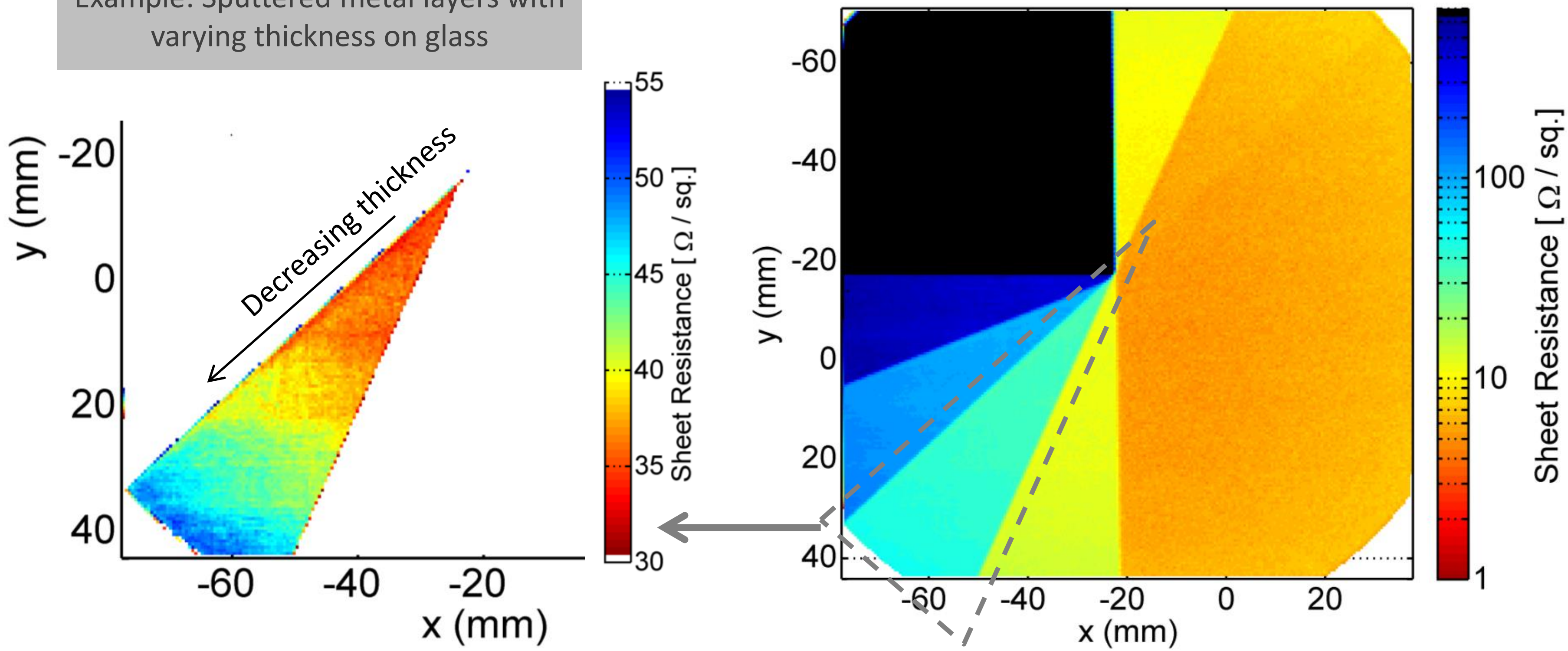
Substrate:
Silicon

© Protemics GmbH

Thin-film conductors

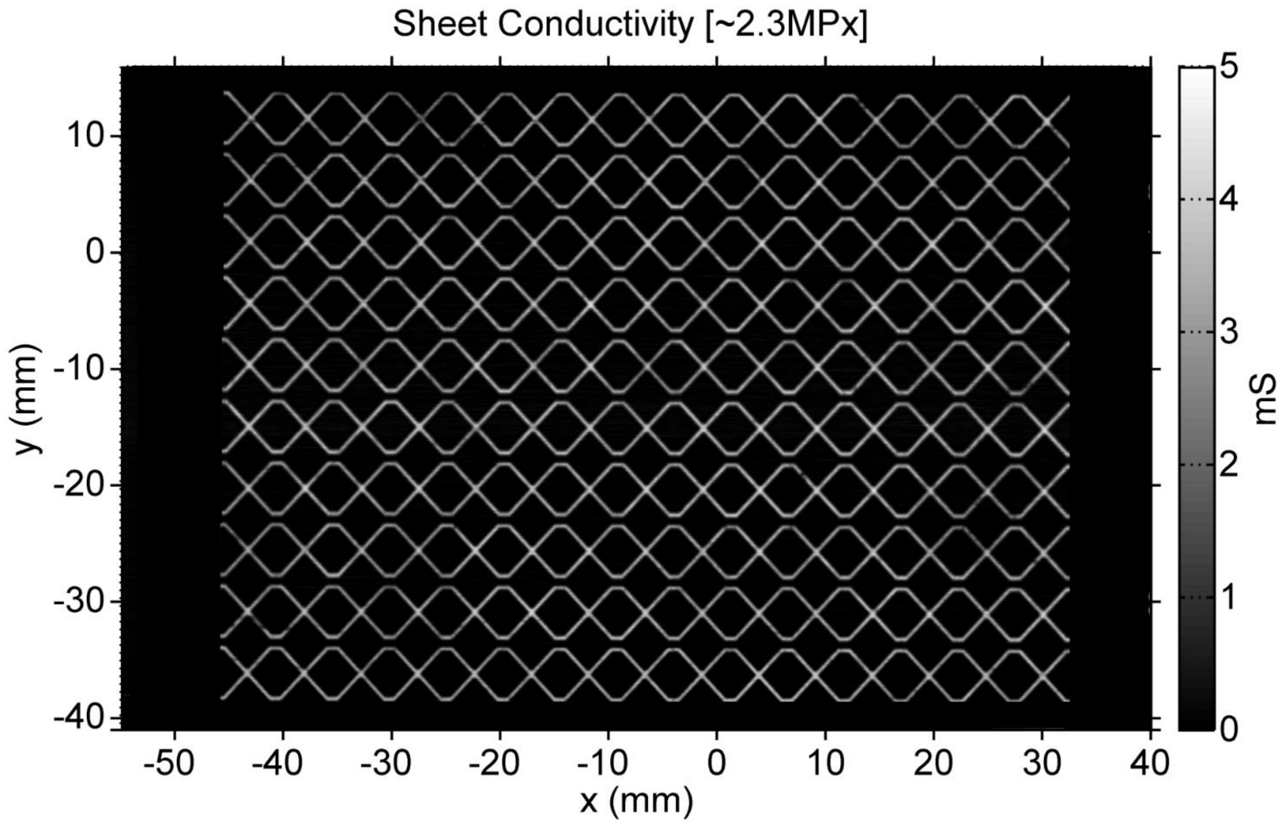
Example: Sputtered metal layers with varying thickness on glass

Measured with THz microprobe



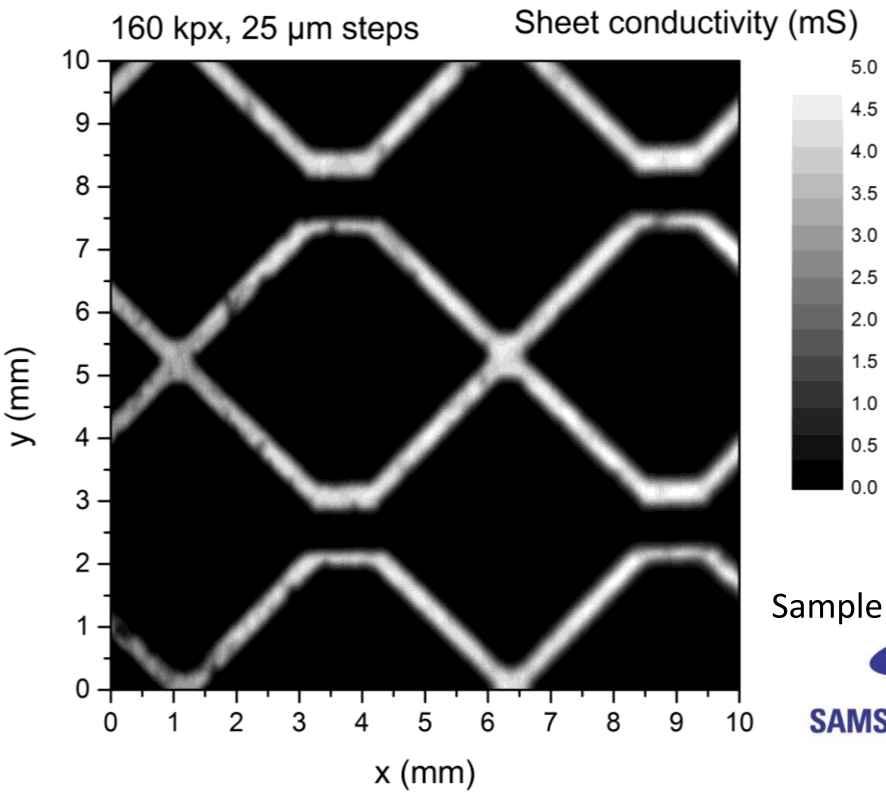
© Protemics GmbH

Thin-film conductors: Graphene



© Protemics GmbH

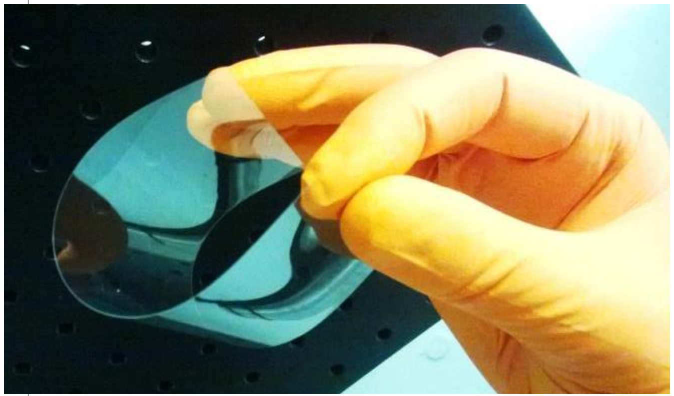
Thin-film conductors: Graphene



Sample:

SAMSUNG

SAMSUNG TECHWIN

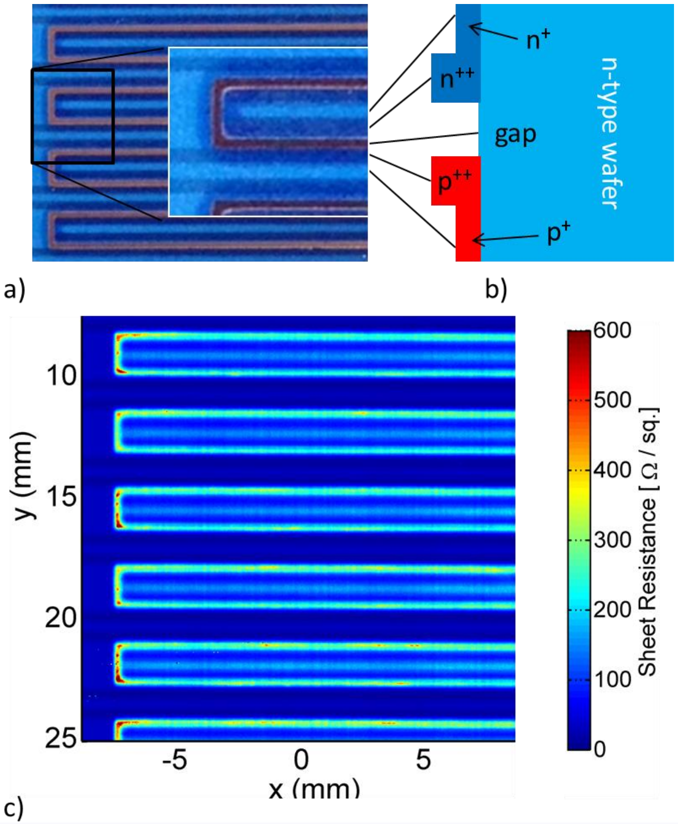


- Graphene pattern on PET foil
- Flexible display application

High-speed contactless raster scanning on **bended** surfaces

© Protemics GmbH

Thin-film conductors: Doped mc-Si



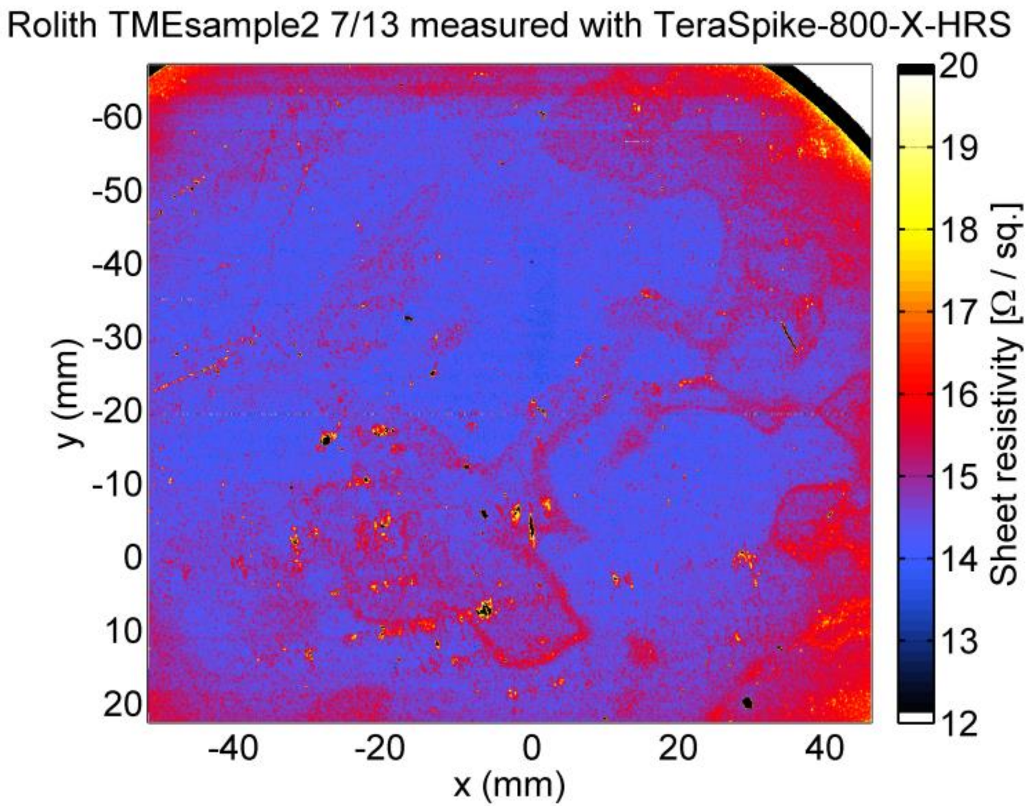
- IBC solar cell structure
- Laser-based material ablation process

- Sheet resistance image reveals areas of process induced inhomogenuity
- Applicable on full cell area and textured surfaces

In collaboration with: ECN

© Protemics GmbH

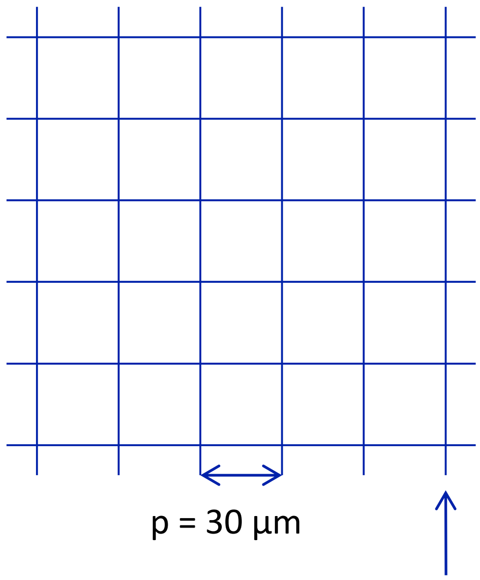
Thin-film conductors: ITO-replacements



Sample:

ROLITH

Al nanowire mesh on glass

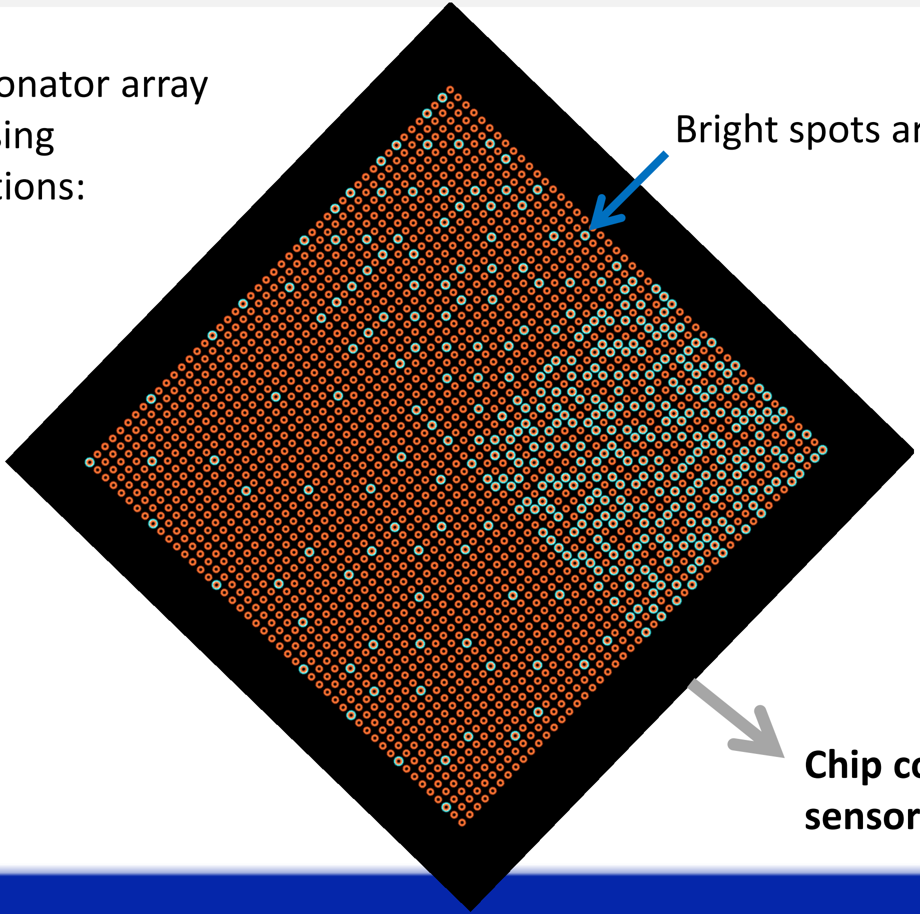


Transparency > 94%

© Protemics GmbH

Metamaterials for sensing

Ringresonator array for sensing applications:

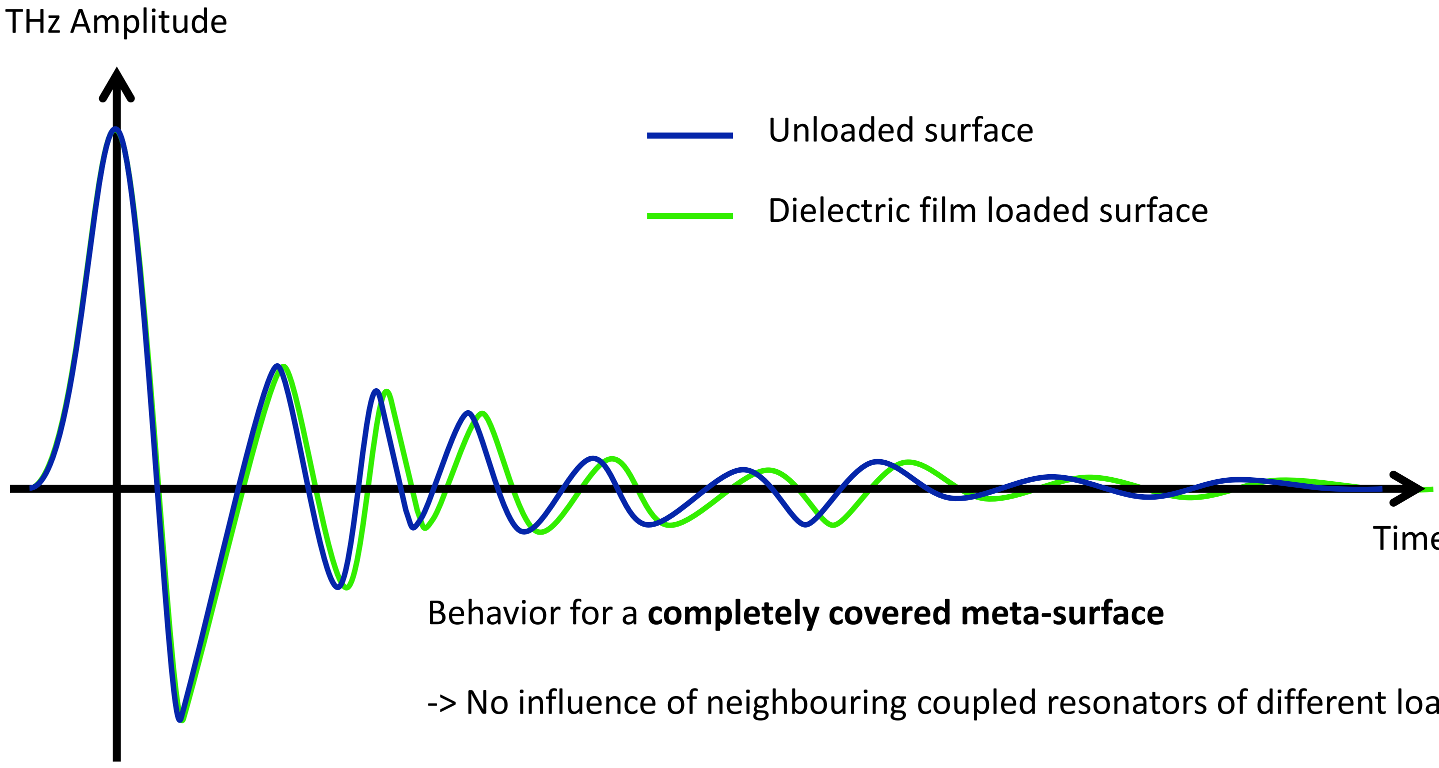


Bright spots are dielectrically loaded

Chip contains 2304 sensor spots

© Protemics GmbH

Metamaterials for sensing



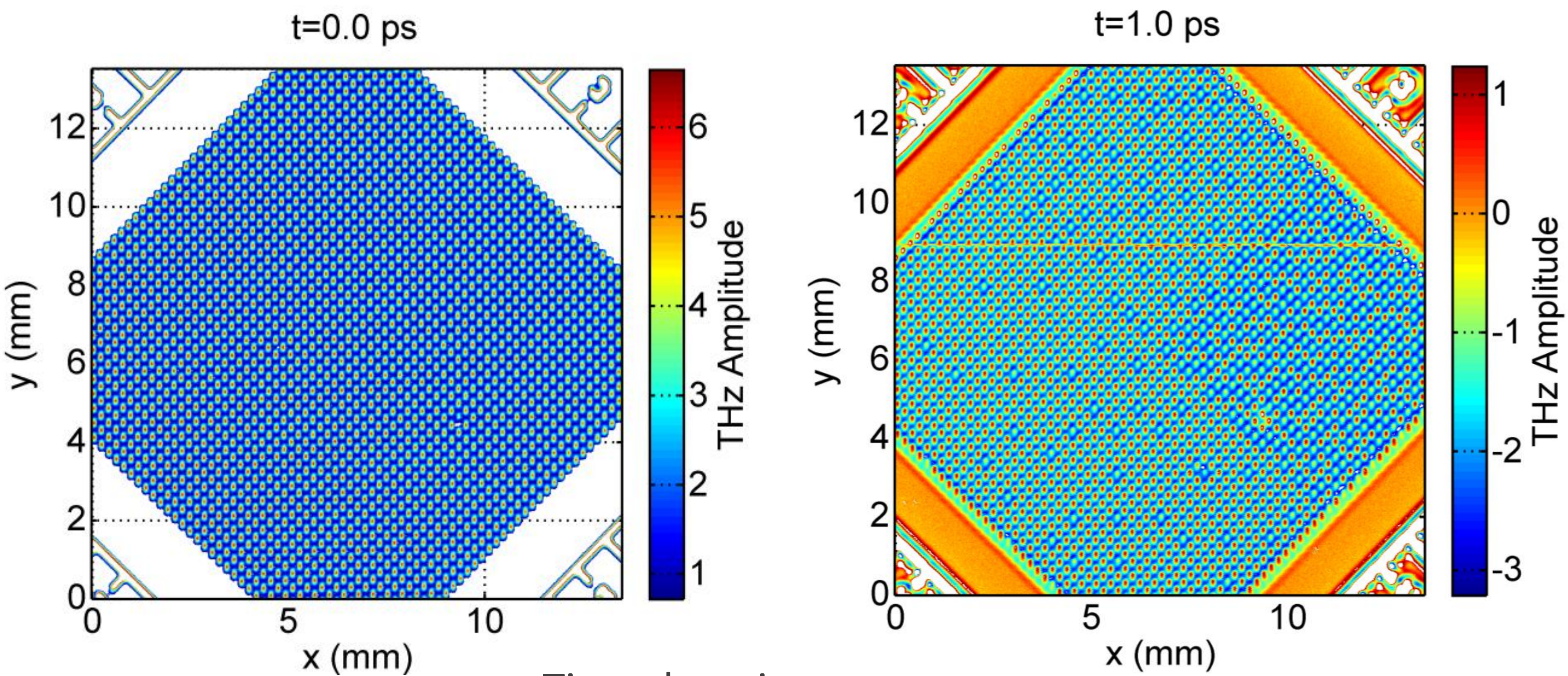
Behavior for a **completely covered meta-surface**

-> No influence of neighbouring coupled resonators of different loading state.

What about single element loading?

© Protemics GmbH

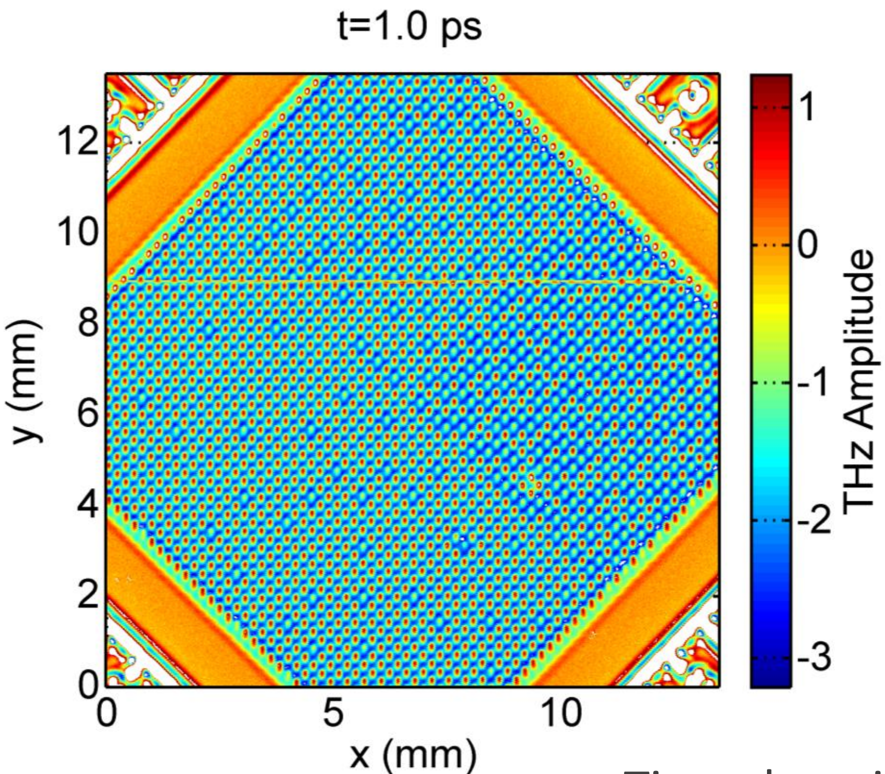
Metamaterials for sensing

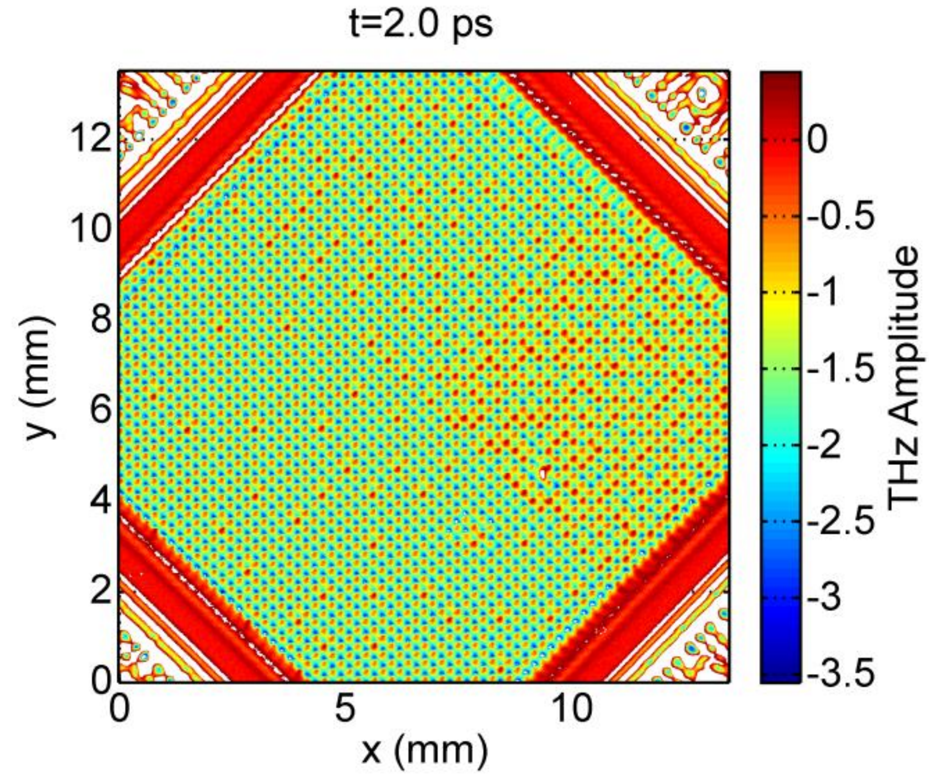


Time-domain measurements

© Protemics GmbH

Metamaterials for sensing

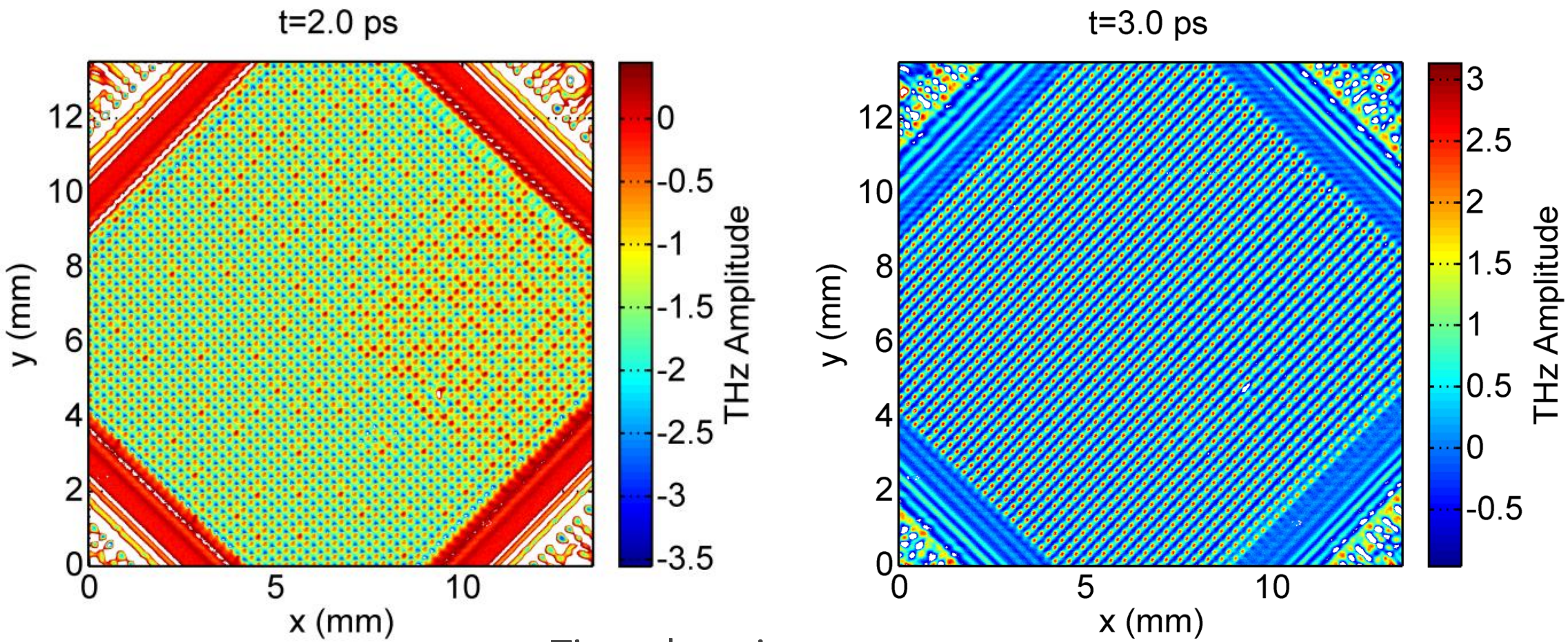




Time-domain measurements

© Protemics GmbH

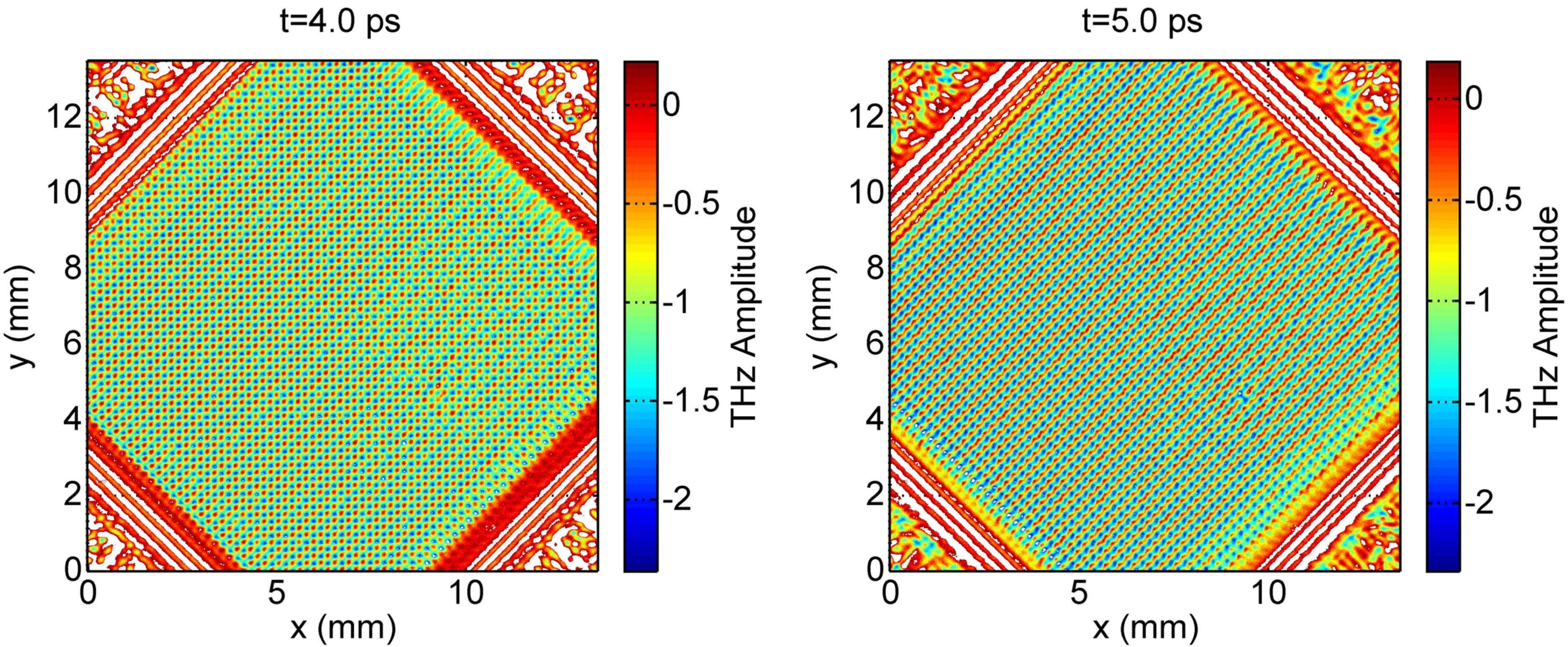
Metamaterials for sensing



Time-domain measurements

© Protemics GmbH

Metamaterials for sensing

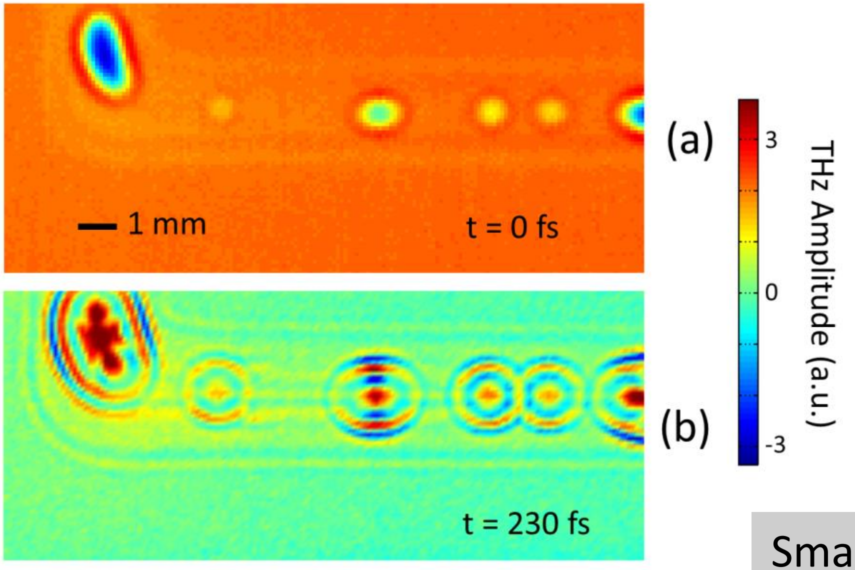


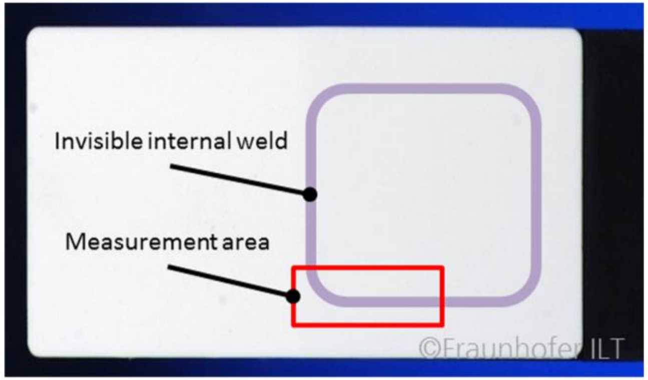
Time-domain measurements

© Protemics GmbH

Laser plastic weld inspection

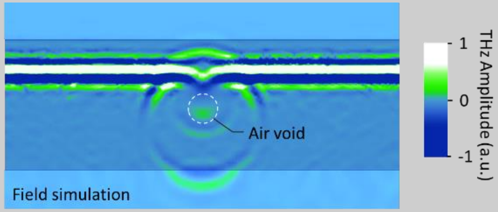
THz microprobe measurement data





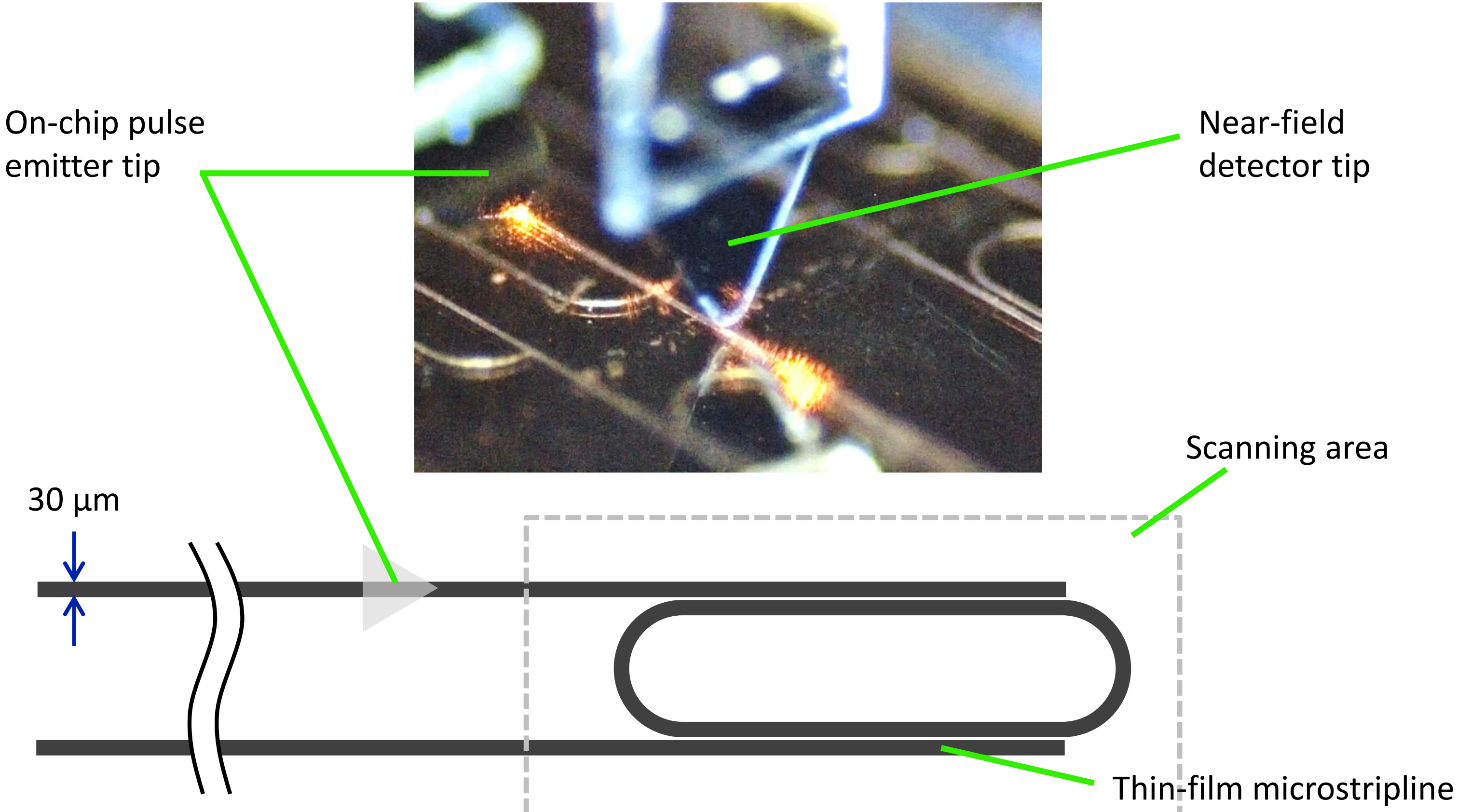
(c)

Small objects become visible by scattering light in the near-field:



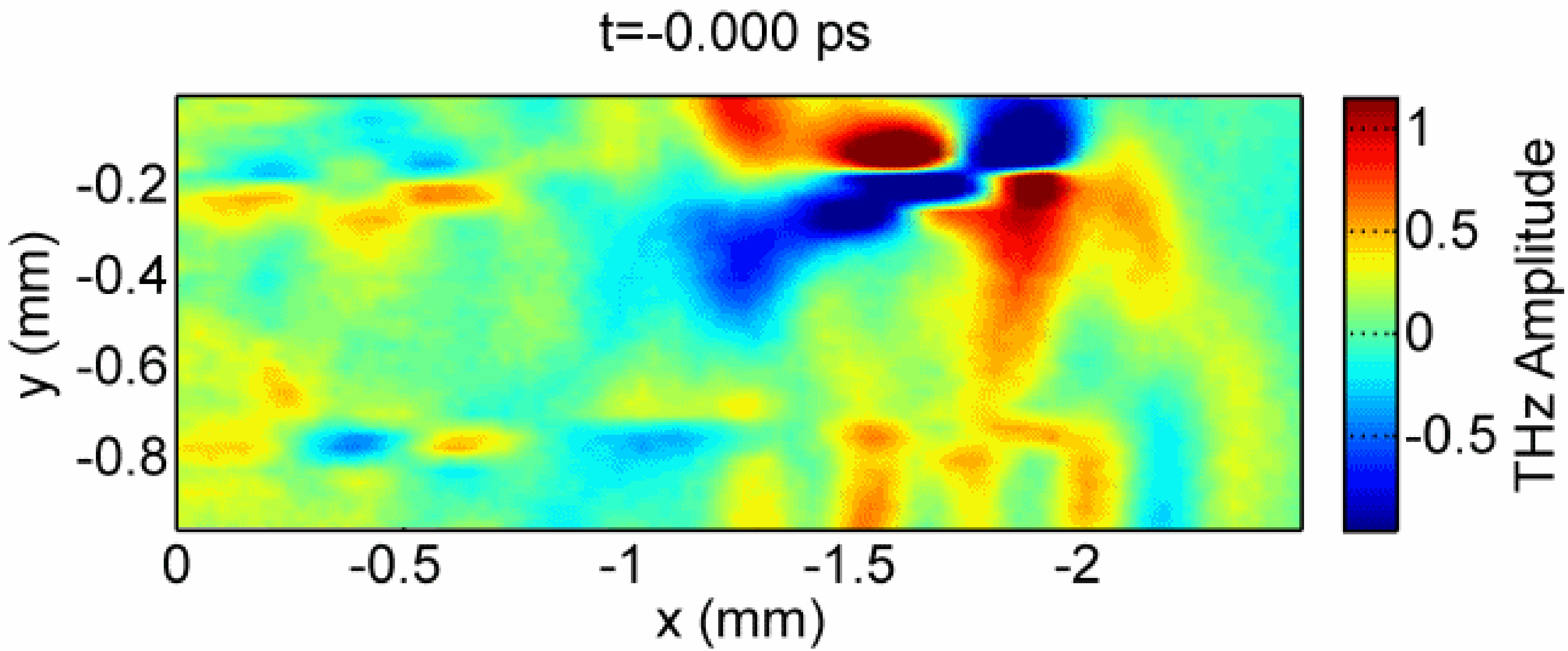
© Protemics GmbH

THz on-chip analysis



© Protemics GmbH

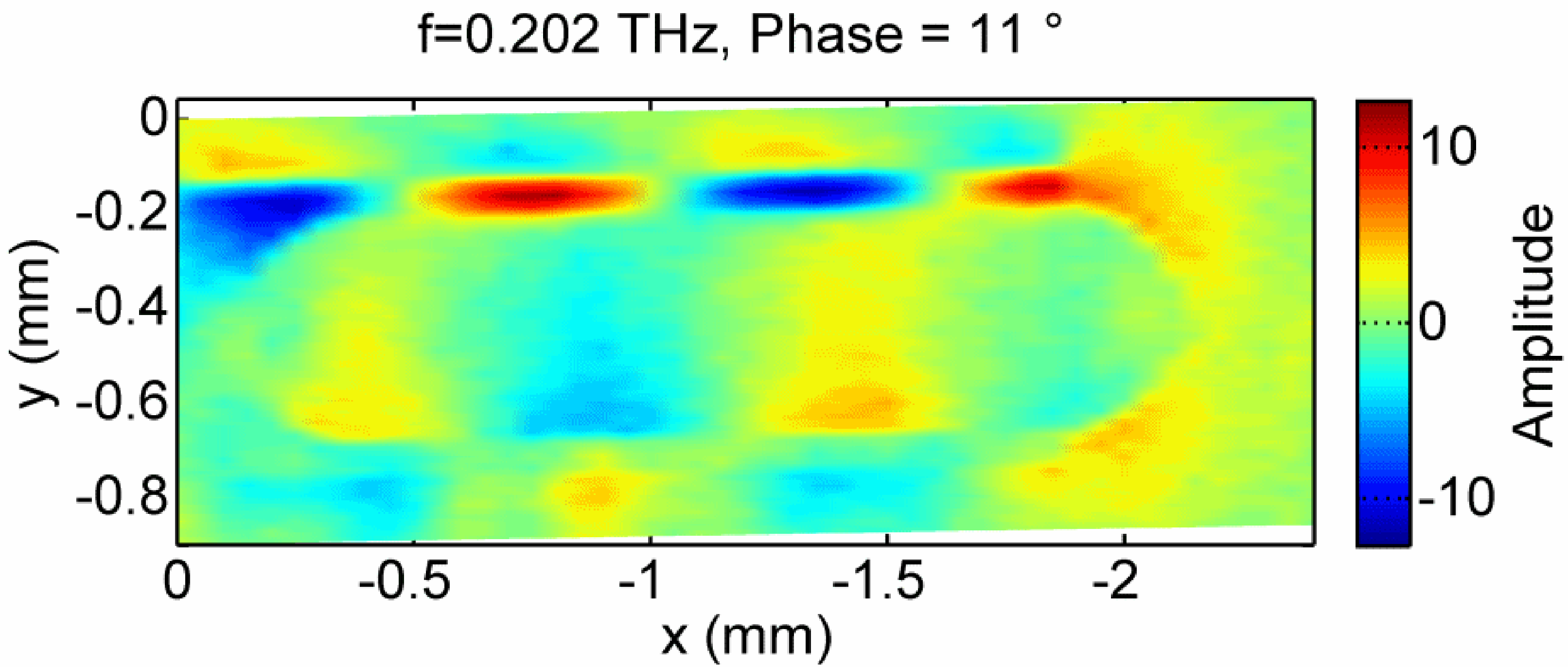
THz on-chip analysis



Time-domain measurement

© Protemics GmbH

THz on-chip analysis



Frequency-domain measurement data extraction

© Protemics GmbH

Failure localization

Failure localization → Target preparation → Failure analysis → Material characterization

(non-destructive)
LIT, **TDR**, X-ray, …

(destructive)
Laser, FIB, RIE, wet chemistry, milling, abrasive blasting, ...

(image defect & physical analysis)
SEM / EBSD, EDX, TEM, ToF-SIMS...

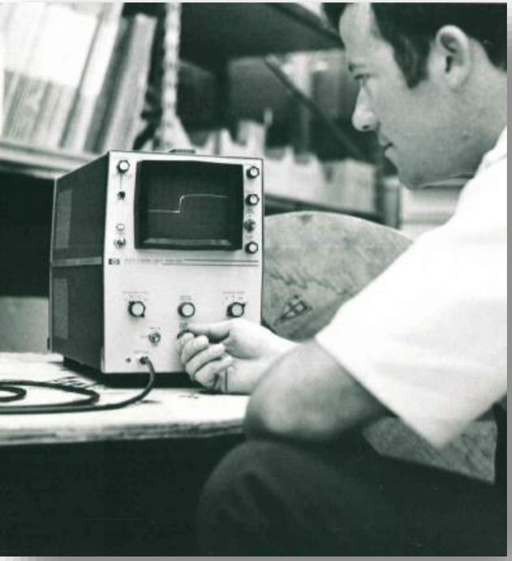
Image correlation, ESPI, …

Limited accuracy/information but fast

Expensive & time consuming

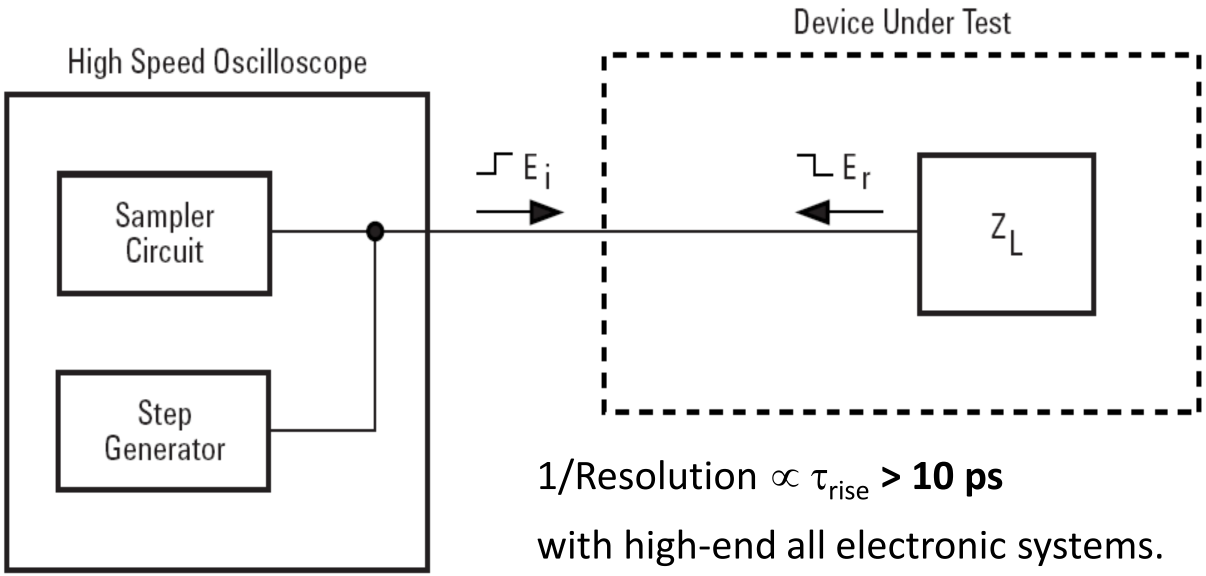
© Protemics GmbH

Failure localization



Hewlett-Packard Journal,
“Time domain reflectometry“
June 1969, Vol. 20, No. 10

TDR principle scheme:

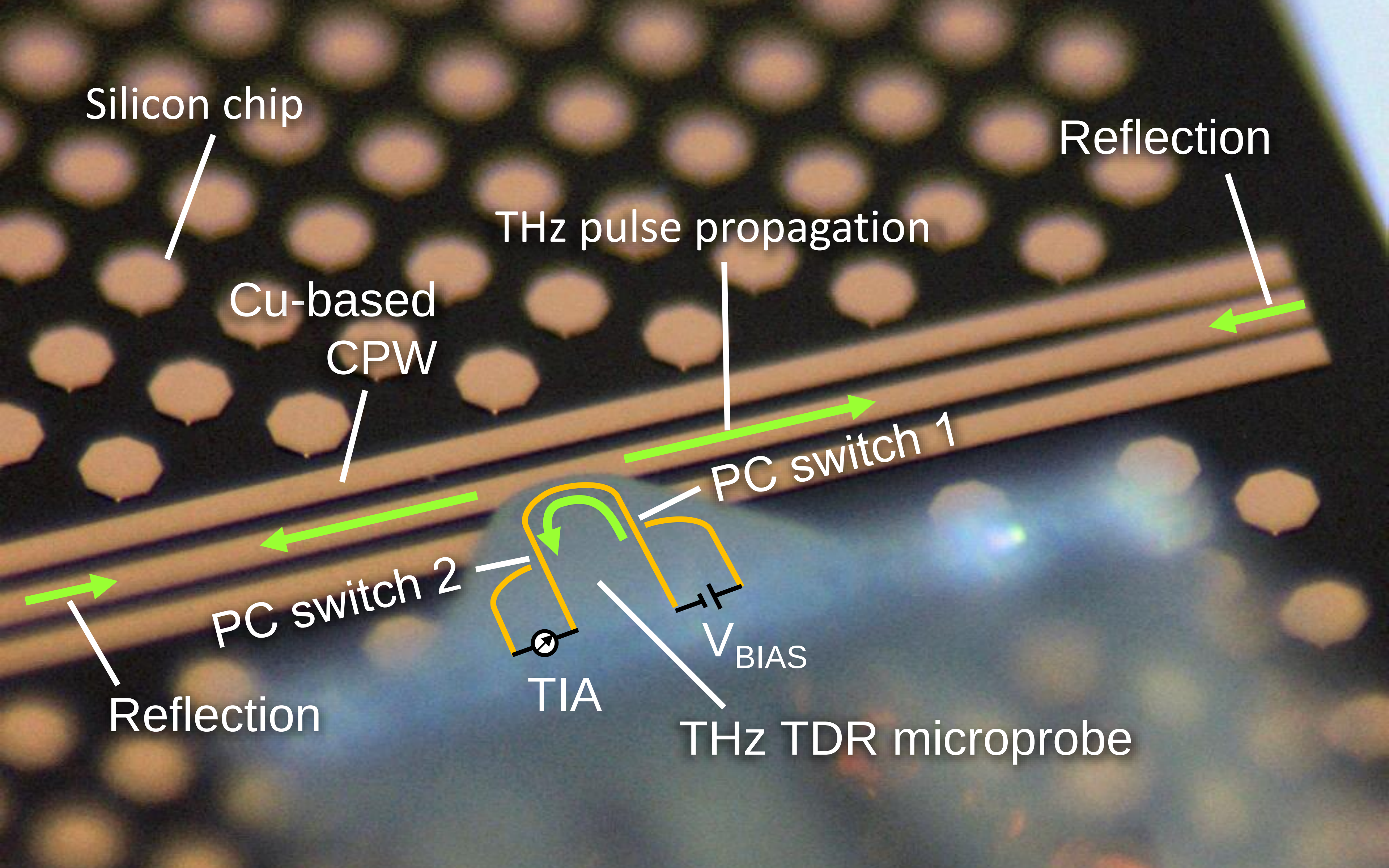


1/Resolution $\propto \tau_{rise}$ **> 10 ps**

with high-end all electronic systems.

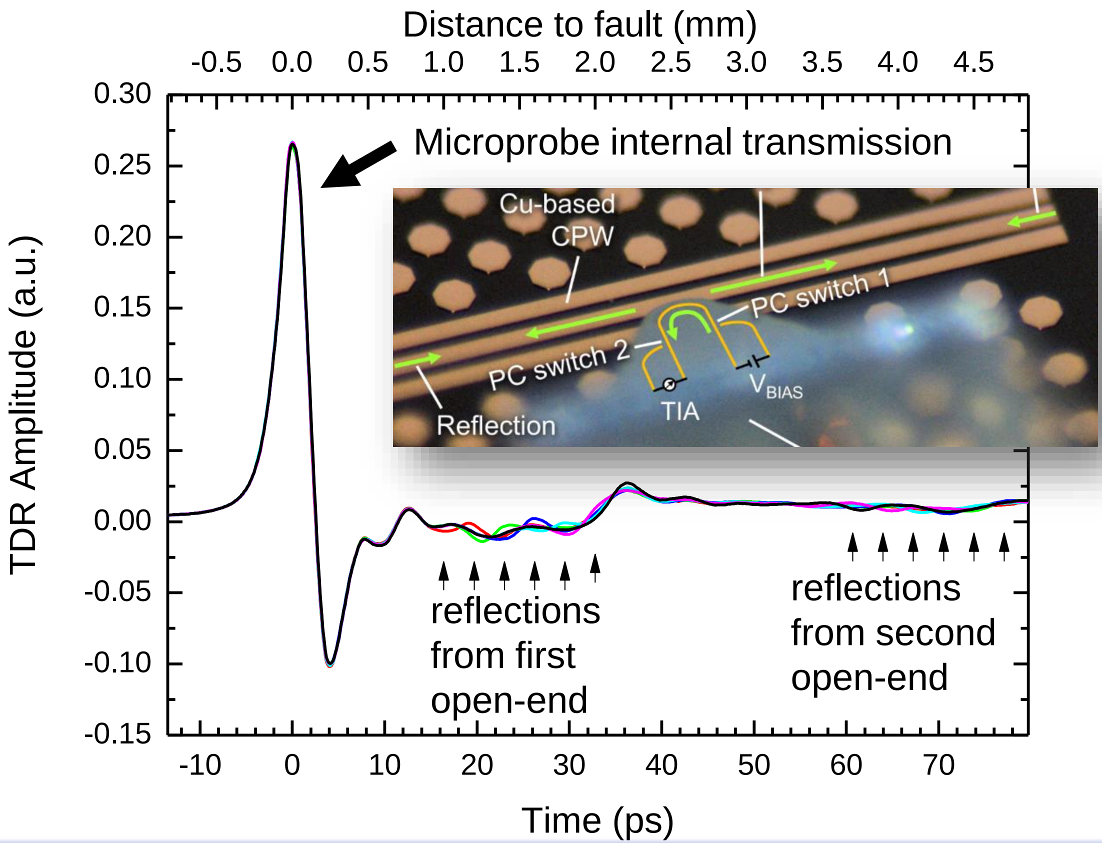
Our Terahertz microprobes achieve up to sub-1 ps rise-times!

© Protemics GmbH



Silicon chip
Reflection
THz pulse propagation
Cu-based
CPW
PC switch 1
PC switch 2
TIA
V
BIAS
Reflection
THz TDR microprobe

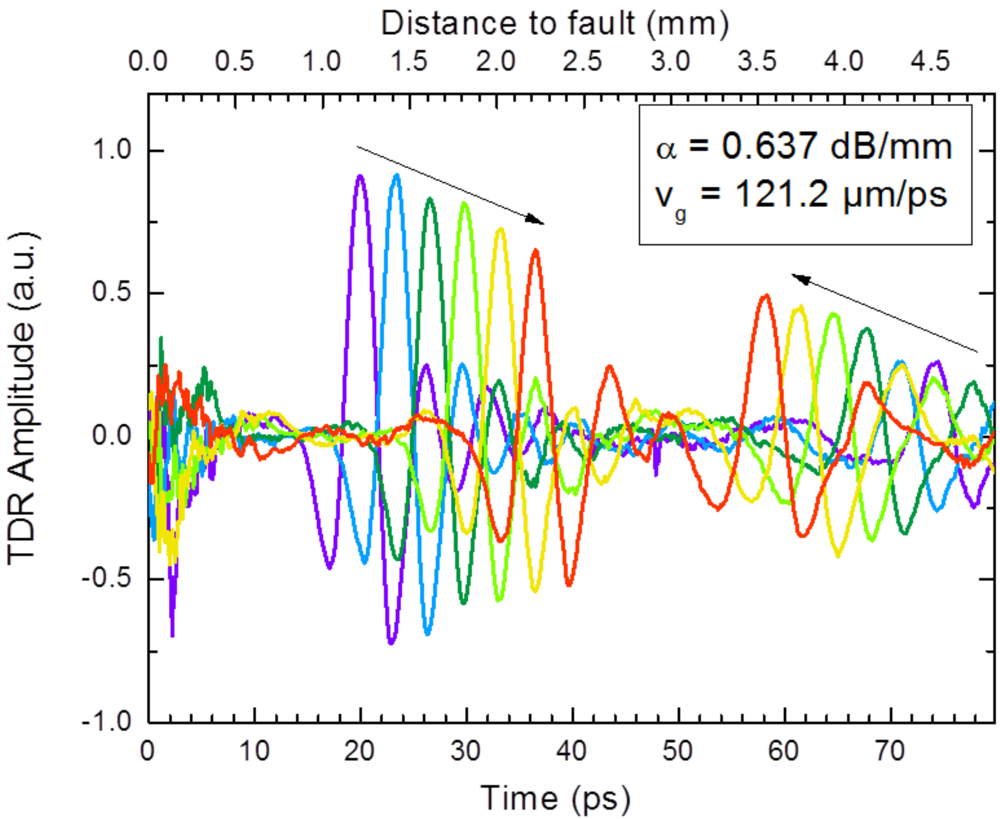
Failure localization



- Internal transmission as reference signal
- Multiple transient scans at different distances to fault
- Reflection signals from short and far distance opens

© Protemics GmbH

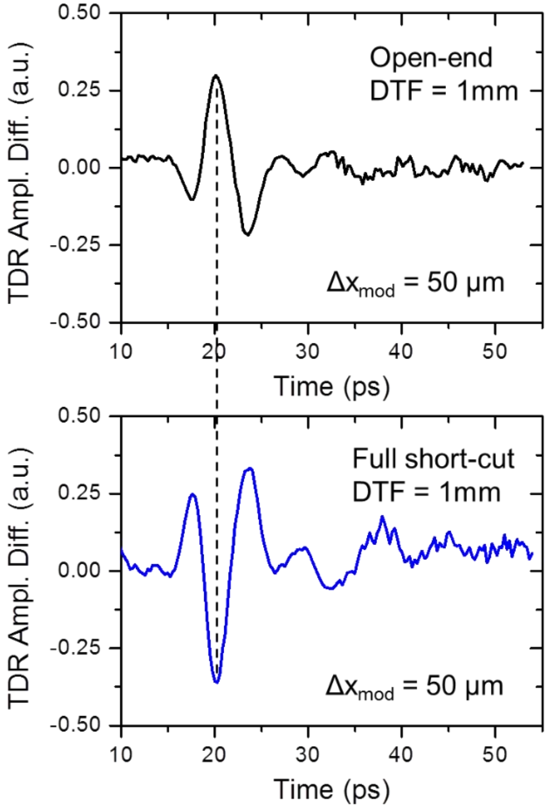
Failure localization

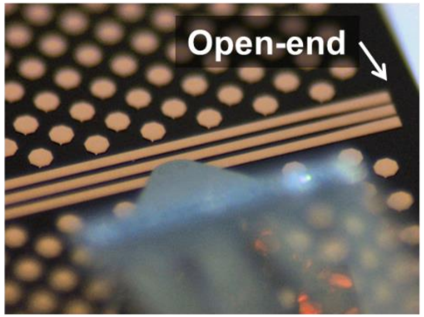


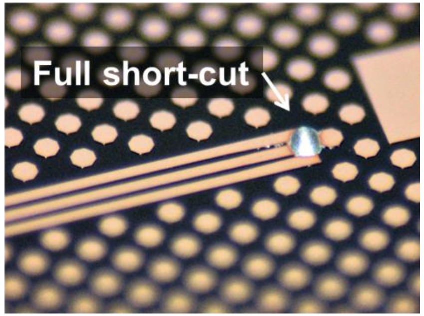
- Suppression of internal transmission signal through distance-to-fault modulation
- Determination of propagation dynamics:
  - Attenuation
  - Group/phase velocities

© Protemics GmbH

Failure localization



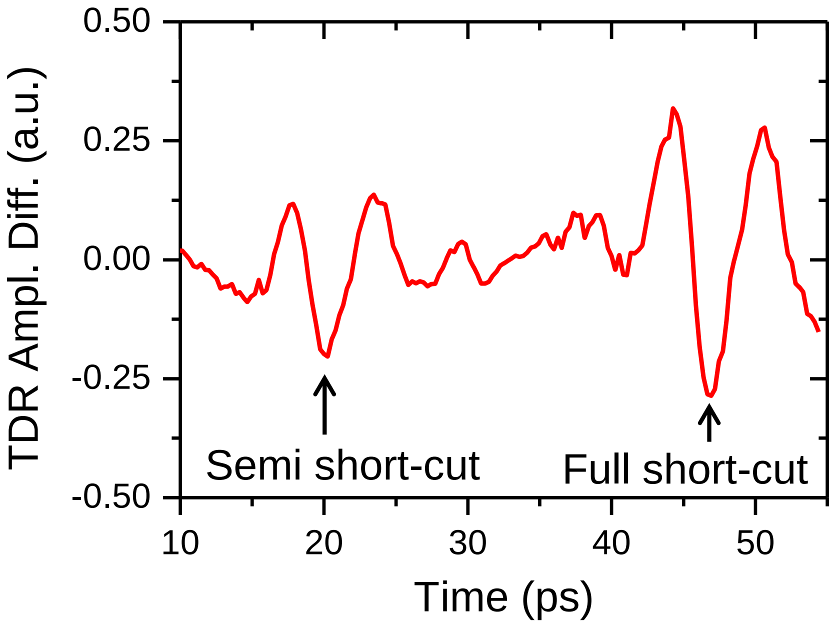


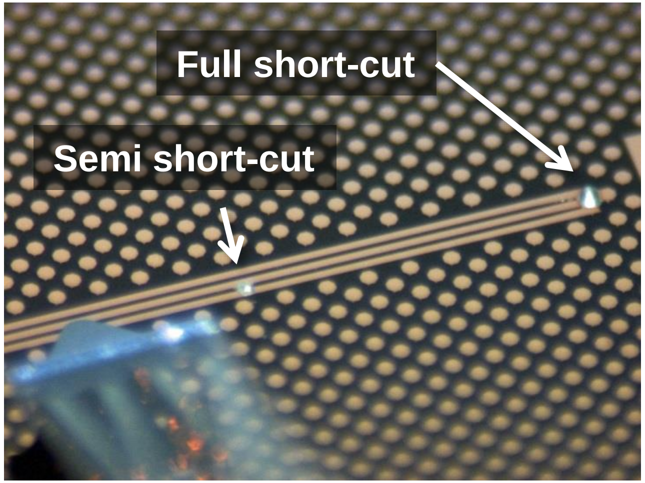


- Type of fault discrimination
- Open vs. Short-cut
- Resistive faults
- Resonant faults

© Protemics GmbH

Failure localization





- Detection of consecutive faults

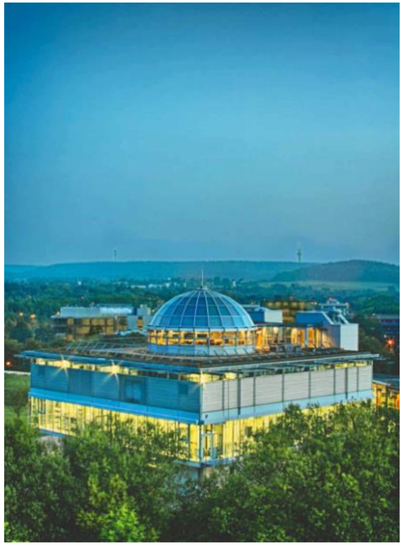
© Protemics GmbH

Conclusion

- **THz microprobes**
  - Efficient and versatile tools to avoid inefficient coupling of free-space THz radiation to micro/nanostructures
- **Examples: Surface analysis**
  - **Sheet resistance imaging**
    - Non-destructive (contactless), Fast (< 5ms/Pixel)
    - Quantitative (R_{sh} range: 0.1 – 10000 Ohm)
    - High resolution (ca. 10 µm)
  - **Metamaterial-based sensing**
    - Increased sensitivity through near-field single element read-out
- **Examples: THz device analysis**
  - **THz on-chip testing:** Access to field vector components, amplitude, phase, time- & frequency domain information
  - **Failure localization in chip packages:** > 10-times increased fault location resolution through sub-ps rise-time THz signals

© Protemics GmbH

Contact information



Protemics GmbH
Otto-Blumenthal-Str. 25
D-52074 Aachen
Germany

www.protemics.com
info@protemics.com
Phone: +49 241 8867 140
Fax: +49 241 8867 560

© Protemics GmbH