Traceable Terahertz Power Measurement from 1 THz to 5 THz

A. Steiger
THz Detector Calibration Facility at PTB

to measure the power responsivity traceable to SI

D – diaphragm as a spatial filter for a Gaussian beam profile
S – standard detector,  M – monitor detector,
C – THz camera to measure the beam profile
Terahertz Laser

a FIR molecular gas laser operated cw

- 1 THz – 5 THz, now also 762 GHz
- optically pumped by a grating tuned CO₂ laser
- CO₂ laser frequency stabilized
- molecular lines in different gases CH₂OH, CH₂F₂, HCOOH
- THz resonator with a fixed hole output coupler
- stable output: >5 mW
THz Standard Detector of PTB

THz absorber in the range 1 THz – 5 THz

- special NG1 optical glass from SCHOTT (neutral density filter)
- optically polished surface, back side: Au coating

- sufficient absorption for THz frequencies > 0.8 THz
- only radiation losses due to surface reflections
THz Standard Detector of PTB

THz absorber in the range 1 THz – 5 THz

- special **NG1** optical glass from SCHOTT (neutral density filter)
- optically **polished surface**, back side: **Au coating**
- mounted inside a **thermopile**: model 3A-P from Ophir Optronics
- calibrated at **HeNe laser** frequency with low uncertainty
- only different **surface reflections**

- model: \[ s(v) = s_{HeNe} \times \frac{1 - R_{HeNe}}{1 - R(v)} \]
THz absorber in the range 1 THz – 5 THz

\[ s(\nu) = s_{HeNe} \times \frac{1 - R_{HeNe}}{1 - R(\nu)} \]
up to now, no other NMI offers this kind of services

- traceable to the International System of Units SI
- spectral responsivity with respect to THz radiant power
- spectral range: 1 THz – 5 THz
- standard uncertainty: < 2%
- offered worldwide to customers by
- for suitable THz detectors
Requirements of Calibratable Detectors

often shortcomings of commercial THz detectors

• large **sensitive area**: > 4 mm in diameter
• homogeneous responsivity: **spatial variation** < 3 %
• high and **linear responsivity**: NL < 3 %
• sufficiently fast **time response**: < 10 s
• known **spectral variation**: spectrally flat response preferred
• no specular **back reflection** to the laser: no standing waves
• no **polarization** dependence even if the detector has to be turned out of normal position to avoid interference
Pyroelectric Thin-Film (PTF) Detectors

in cooperation with Sensor- und Lasertechnik

- **innovation**: no extra absorbing coating
- read out **electrodes** act as THz absorber
- absorbing layers made from **metal-oxide**
- layer thickness carefully adjusted to get **50 % absorbance**
- **25 % transmission and reflection**
- **Woltersdorff condition (1934*)**: thickness << wavelength frequency independent absorption, i.e. spectrally flat to GHz

* Wilhelm Woltersdorff, Z. Physik 91, 230-252
First International THz Comparison

- NIM – China, NIST – USA, PTB – Germany as pilot
- excellent agreement within stated uncertainty ($k = 2$)
PTB’s thermopile standard detector (1 THz – 5 THz)

- result: agreement much better than stated uncertainty
Conclusion and Outlook

- PTB’s **standard THz detector** for 1 THz – 5 THz
  a thermopile with special NG1 absorber
calibrated at 633 nm with **low uncertainty**

- used for **calibration service** of THz detectors of customers

- novel **pyroelectric thin-film** detectors
  developed in cooperation with **Sensor- und Lasertechnik**
calibrated at 1 THz, valid at all GHz frequencies

- spectrally **flat**, spatially large + **uniform**, fast and **sensitive**
  enough for total THz power measurements of THz-TDS

- confirmed by the **first international THz comparison**
at 2.52 THz and 762 GHz – extended calibration service