Traceable Measurement of Terahertz Power and Intensity using Optical Methods

Yuqiang Deng* (1), Qing Sun(1), and Mark Bieler(2)
(1) National Institute of Metrology, Beijing 100029, China
(2) Physikalisch-Technische Bundesanstalt,Braunschweig 38116, Germany
* yqdeng@nim.ac.cn

Abstract

We report the progress of traceable measurement of terahertz (THz) power and intensity using optical methods. We fabricated a THz radiometer and used it for THz power measurement traceable to the International System of Units (SI). Excellent agreement was achieved with the radiometer in the first international THz power measurement comparison. Applications of this radiometer for absolute intensity measurement of THz radiation and for pulsed THz power measurement of a THz time-domain spectrometer (THz-TDS) are also described.

1. Introduction

Progress and applications of terahertz (THz) technology demands the measurement of THz power and intensity traceable to the International System of Units (SI). Yet, due to the lack of THz measurement standards, such traceable THz measurements have been elusive for a long time. In recent years, great progress in THz metrology has been achieved at national metrology institutes. At the National Institute of Metrology (NIM) in China, we fabricated an absorptive coating for THz frequencies, and constructed a THz radiometer with this coating as absorber. Traceable measurement of THz power and intensity using this radiometer is described in this paper.

2. Fabrication and Measurement of Absorptive coating

We have developed a coating consisting of silicon carbide (SiC) particles and 3M Velvet-coating paint for THz radiometry [1]. For a 1.2 mm thick coating with SiC particles of 300 μm diameter, high absorbance is obtained from 50 GHz to visible-light wavelengths. The measured reflectance using a THz time-domain spectrometer (THz-TDS) is less than 1% ranging from 0.1 THz to 3.0 THz, see Fig. 1.

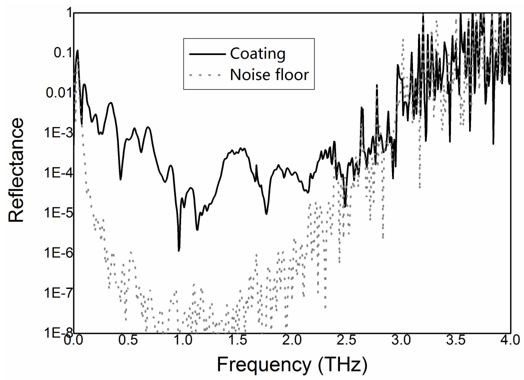

Figure 1. Measured reflectance of the self-fabricated coating (solid line) and the noise floor of the THz-TDS (dotted line).

3. THz Radiometer Fabrication and Traceable Measurement to the SI

With the coating as absorber, we constructed a THz radiometer. In the front of the absorber, we attached a hemisphere dome to further improve the cavity absorbance. We constructed a compensating radiometer to reduce the ambient temperature fluctuations during the measurement [2]. Then the two radiometers were wrapped together in Teflon housing. A photo of the two-cavity radiometer is shown in Fig. 2.

The coating is also highly absorptive at visible light wavelengths. Measurements with an integrating sphere showed that the reflectance of the coating at 632.8 nm is higher than 99%. Therefore, the responsivity of the radiometer at THz frequencies is traceable to the Chinese Laser Primary Standard comprising a He-Ne Laser at a wavelength of 632.8 nm.

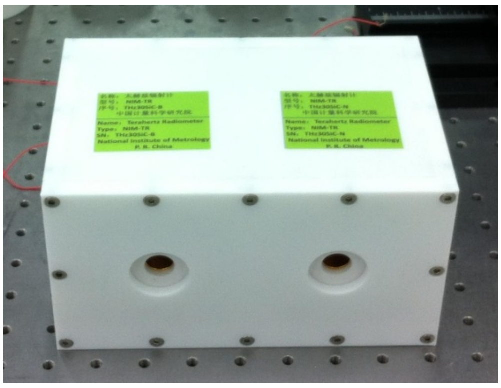

Figure 2. Photo of the two-cavity radiometer.

4. First International Comparison of THz Power Measurement

The first international comparison of THz radiant power measurements took place at the Physikalisch-Technische Bundesanstalt (PTB) in Berlin in 2015. Three NMIs, PTB, NIM, and the National Institute of Standards and Technology (NIST), participated in the comparison.

In this comparison the radiant power was measured at two different frequencies. At both frequencies, excellent agreement was achieved [3]. The deviations of the measurements from the reference value at 2.52 THz and 0.762 THz are depicted in Fig. 3 and Fig. 4, respectively. Both figures show that all measurements are consistent with the reference value.

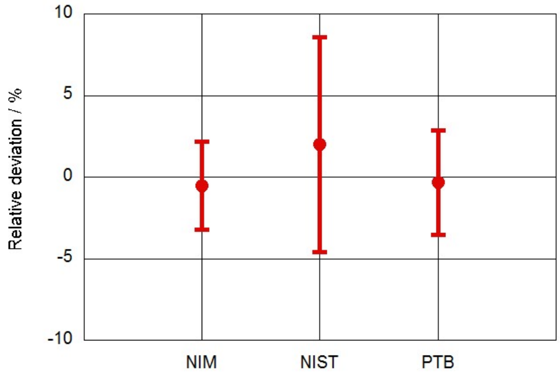

Figure 3. THz radiant power measurement result at 2.52 THz in the first international comparison.

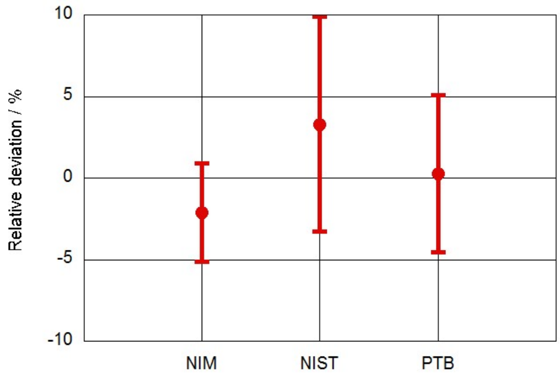

Figure 4. THz radiant power measurement result at 0.762 THz in the first international comparison.

5. Absolute Spatially Resolved Intensity Measurement

We developed a setup for spatially resolved measurement of GHz and THz sources using electro-optic (EO) sampling and measured the spatial intensity of a horn antenna at 100 GHz [4].

We first used the radiometer to measure the total radiant power of the horn antenna. With this value, we could calibrate our EO sampling system such that a traceable measurement of THz intensity to the SI was achieved. The spatially resolved absolute intensity of the horn antenna is shown in Fig. 5.

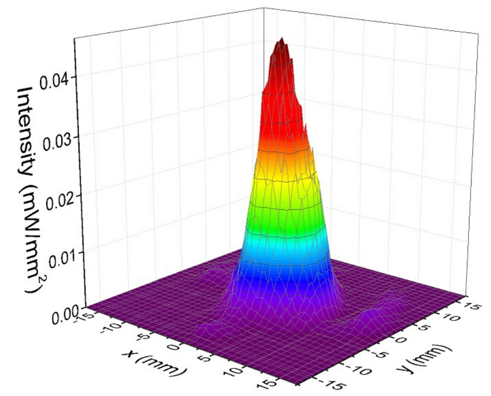

Figure 5. Absolute intensity measurement of a 100 GHz source.

6. Traceable Measurement of Pulsed THz Radiation from a THz-TDS

We fabricated a THz-TDS based upon a photoconductive antenna (PCA) as emitter and a Zinc Telluride (ZnTe) crystal for EO detection [5]. The THz beam was collected from the emitter and focused on the detector with two parabolic mirrors. An additional parabolic mirror could be placed in the parallel THz beam to focus it onto the THz radiometer instead of the EO crystal.

We applied different bias voltages to the PCA, and measured the radiant power of the THz-TDS with the radiometer [2]. The results are shown in Fig. 6.

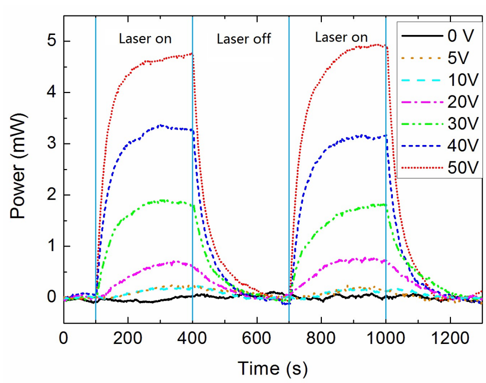

Figure 6. Measured THz radiant power from the THz-TDS with different bias voltages applied to the PCA.

We also measured the pulsed waveforms and spectra of the THz-TDS with the same bias voltages. The recorded waveforms and spectra are shown in Fig. 7. With the help of Fig. 6 it is now possible to calibrate the THz-TDS.

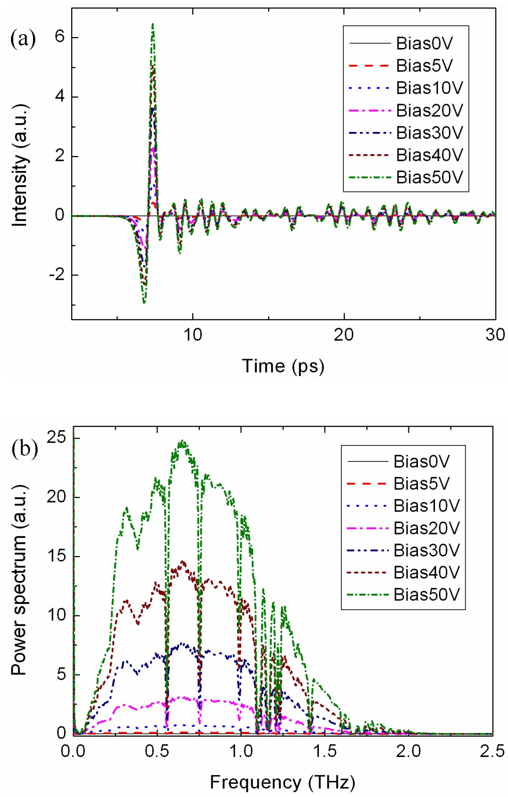

Figure 7. Measured THz waveforms (a) and spectra (b) of the THz-TDS with different bias voltages.

7. Conclusions and Outlooks

The fabrication of a THz radiometer was described and applications utilizing this radiometer were introduced. A first international comparison of THz power measurements was conducted with an excellent agreement. Absolute intensity measurement of a GHz and THz source was performed. Moreover, CW and pulsed THz radiant power were measured traceable to the SI. As a next step we will work on the characterization of CW and pulsed THz electric-field intensities and the calibration of a THz array detector will be investigated.

References

[1]Y. Deng, Q. Sun, J. Yu, Y. Lin, and J. Wang, "Broadband high-absorbance coating for terahertz radiometry," *Optics Express* **21**, 5, pp. 5737-5742, 2013. doi: 10.1364/OE.21.005737.

[2]Y. Deng, J. Li, Q. Sun, "Traceable Measurement of CW and Pulse Terahertz Power with Terahertz Radiometer," *IEEE Journal of Selected Topics in Quantum Electronics* **23**, 4, 2017. doi: 10.1109/JSTQE.2016.2573052.

[3] A. Steiger, R. Müller, A. Remesal Oliva, Y. Deng, Q. Sun, M. White, and J. Lehman, "Terahertz Laser Power Measurement Comparison", *IEEE Transactions on Terahertz Science and Technology* **6**, 5, pp. 664-669,2016. doi:10.1109/TTHZ.2016.2590260.

[4] Y. Deng, H. Füser, and M. Bieler, "Absolute intensity measurements of CW GHz and THz radiation using electro-optic sampling," *IEEE Transactions on Instrumentation and Measurement* **64**, 6, pp. 1734-1740,2015. doi: 10.1109/TIM.2014.2375692.

[5] Y. Deng, Q. Sun, and J. Yu, "On-line calibration for linear time-base error correction of terahertz spectrometers with echo pulses," *Metrologia* **51**, 1, pp. 18-24, 2014. doi: 10.1088/0026-1394/51/1/18.