A Flexible Phase-Insensitive System for Broadband CW-Terahertz Spectroscopy and Imaging

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Abstract—**We present a compact, robust, and flexible continuous-wave (CW) terahertz system, ideally suited for both imaging and high-resolution broadband spectroscopy. The setup employs an incoherent detection scheme: A photomixer transmitter is combined with a zero-bias Schottky diode on the receiver side. The useable bandwidth extends to 1500 GHz, with a spectral resolution on the 10 MHz level. In proof-of-principle measurements, we apply our setup to imaging of objects within a paper envelope as well as transmission and reflection-mode spectroscopy, taking advantage of the high spectral resolution of the terahertz source and the broad bandwidth and efficiency of the Schottky receiver.**

Index Terms—**Frequency-domain terahertz spectroscopy, incoherent detection, photomixer, terahertz imaging, zero-bias Schottky diode.**

I. INTRODUCTION

A PLURALITY of security [1] and nondestructive-testing applications [2] calls for terahertz instruments that both generate an image and perform a spectroscopic analysis of samples under test. Continuous-wave (CW) systems based on photomixing appear as promising candidates, owing to their broadband-tuning characteristics on one side and the flexibility in the choice of the frequency on the other side—the frequency employed for terahertz imaging can be selected according to the transmission properties and image resolution required. Indeed, photomixing systems have proven to be applicable in a broad range of applications, including spectroscopy of gases and solids [3], [4], imaging of medical samples [5], nondestructive testing of plastics [6], and astronomy [7].

The CW-terahertz generation process is based on heterodyne difference frequency generation in high-bandwidth photoconductors: The beat signal of two lasers is converted into a CW-terahertz wave, exactly at the difference frequency of the lasers. In comparison to time-domain terahertz systems, a CW-terahertz setup enables spectrally selective measurements, offers a significantly better frequency resolution, and has advantages both in terms of mechanical robustness and material costs. Over the past few years, CW-terahertz systems have matured considerably, and recently reached dynamic-range levels in excess of 100 dB and a spectral bandwidth greater than 3 THz [8]–[10].

In a typical coherent-detection experiment, a first photomixer generates the CW-terahertz wave and a second photomixer serves as a terahertz receiver, producing a photocurrent signal that is sensitive to the *phase* of the incident terahertz wave. Data acquisition thus necessitates the use of either a delay-stage [11], [12] or highly accurate means for frequency control [13]. The phase data are exploited in spectroscopy, e.g., for refractive-index measurements [13], or for layer thickness assessments [14]. On the other hand, an inherent disadvantage of coherent-detection schemes is a rather limited flexibility to changes in the length of the terahertz beam path [12], [15], [16]. Furthermore, in imaging applications, the signal phase must be adjusted for each pixel individually, in order to compensate for variations in the thickness or material composition of the sample. In practice, therefore, a coherent-detection system is simply too slow for terahertz imaging.

Recently, Schottky detectors with a broadband response in the terahertz range [17] have become commercially available. The Schottky receiver works as "power law detector", producing a signal that has no phase relation with that of the transmitter-photomixer.

Schottky receivers have already been used successfully in conjunction with optoelectronic terahertz sources. Authors from TOPTICA Photonics AG and ACST GmbH have shown that a fast, AC-coupled Schottky receiver can measure the field intensity of individual terahertz pulses [18]. Ito *et al*. described a broadband polarization-sensitive Schottky receiver, which operated at frequencies from 30 GHz to 1 THz. However, the receiver still had a rather low sensitivity of approx. 300 V/W at 100 GHz and 4 V/W at 1000 GHz [19]. Han *et al*. demonstrated terahertz imaging with a line array of 20 zero-bias Schottky diodes, employing either a photoconductive switch or a CW-Gunn diode as terahertz sources. Yet, the 3 dB bandwidth of the receivers turned out to be limited to 180 GHz [20]. Nagatsuma *et al*. combined a uni-travelling-carrier photodiode with a Schottky receiver to build an optical-coherence tomography system. Whilst their system enabled precise thickness measurements, the reflection properties of the utilized beam splitter limited the useable frequency range to 400–800 GHz [21].

In this work, we combine a photomixer as a CW-terahertz source with a *broadband*, DC-coupled Schottky receiver, and we demonstrate the suitability of this incoherent assembly for both imaging and high-resolution terahertz spectroscopy. Our system accesses the entire frequency range from 50 to 1500 GHz with a frequency resolution on the 10 MHz level. It thus lends itself to terahertz imaging at any frequency within the aforementioned range, as well as for spectroscopic investigations, without the need for any beam-path realignments in between.

Manuscript received April 18, 2016; accepted June 22, 2016. Date of publication August 12, 2016; date of current version August 31, 2016.

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Digital Object Identifier 10.1109/TTHZ.2016.2589540

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