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Broadband Spectro-Spatial Characterization of CW Terahertz Photoemitter Using CMOS Camera

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***Abstract*—Decoupling the desired spectral signal from scattering events and also from the sporadic signals from the background has been a challenge for fulfilling the promise of real-time applications exhibited by the present broadband terahertz devices. Performing imaging in conjunction with spectroscopy will circumvent this issue, thereby improving the accuracy of the measurement. In this work, the spatial profiles of a widely used CW antenna coupled terahertz photomixer are experimentally investigated using a well-calibrated 32×32 pixel CMOS terahertz camera in a broad frequency range from 0.2 – 0.95 THz. The frequency dependent emission of the THz photomixer exhibited asymmetric and annular beam profiles with intense side lobes.**

I. Introduction

Broadband terahertz (THz) devices and systems have shown tremendous potential in nondestructive detection of concealed materials, chemical elements, and imaging of biological systems. The advances in silicon process technologies are enabling scalable and reconfigurable large-scale THz integrated circuits thereby envisaging real-time applications [1]. Besides the requirement of being lightweight, compact and fast, the promising THz spectroscopes and imagers need to be reproducible, reliable, consistent, and statistically accurate for their usability in real-time applications. The present-day conventional broadband THz spectroscopes or imagers are best suited in a static environment for objects of limited dimensions and surface quality. Performing THz spectroscopy on objects beyond planar thin films or gases is highly error-prone due to a lack of appropriate calibration that distinguishes the desired spectral signal from scattering signals, and sporadic signals arising from the etalonic effect, spill-over signals from optomechanics and background radiation. The mitigation of etalonic effect arising from the intermediate optical paths has been discussed in [2]. Several techniques and theoretical models have been proposed to mitigate the scattering effects in THz spectroscopy [3]. These approaches rely on specific information about the sample or require special, rather tedious, sample preparation techniques. As a result, they are not suitable for real-world applications. Combining imaging in conjunction with spectroscopy will circumvent parts of the errors related to the scattering and sporadic radiation thereby improving accuracy of the measurement. While the spatial profile will enlighten the origins of the acquired signals, the spectral either transmission or reflection signal obtained by integrating the relevant spatial intensity will lead to a high-accuracy estimate of the pursued measurement. To achieve these peculiarities, THz instruments must be well-calibrated for their spectral as well as spatial characteristics. This is especially important for broadband devices, as these spectro-spatial characteristics are extremely frequency sensitive. In a mobile dynamic environment, the apriori knowledge of spectro-spatial characteristics is indispensable to distinguish the light-matter interaction of the objects from the artifacts of the measuring instruments.

This work investigates broadband spectro-spatial characteristics of a photomixer source using a CMOS THz camera to gain insight into its emission characteristics. The harmonics free continuous wave (CW) sources based on antenna coupled THz photomixers have shown a lot of promise in the field of broadband frequency-domain spectroscopy, and are currently being explored in optoelectronic communications [4]. On the other hand, compact broadband CMOS terahertz cameras based on silicon-integrated technologies are facilitating the terahertz imaging to a wider scientific community [5]. The radiation pattern constructed using 1D measurements in E-plane and H-plane has its limitation in case of asymmetric and spatially higher-order beam profiles. Moreover, measuring far-field radiation of sources with inherently weak output power requires either cryocooled high-sensitive detectors or alternative techniques which enable far-field patterns at short range. In this work, the broadband 2D spatial characteristics between 0.2 – 0.95 THz of a CW THz photomixer emitter using a portable room-temperature operational CMOS THz camera are investigated. The far-field measurement technique along with the computational processing for obtaining high resolution images is first briefly described. The frequency-dependent far-field patterns of the broadband photomixer source are then discussed.

II. Results & Discussions

The far-field profiles were measured using compact antenna test range (CATR) method with a lens-integrated 32×32 pixel CMOS camera [6]. In a lens-type CATR, the plane wave illumination, normally provided by a long far-field range, of a source under test placed at the focal spot is achieved by the wavefront transformation at the lens curvature in a short distance [7]. The advantages of

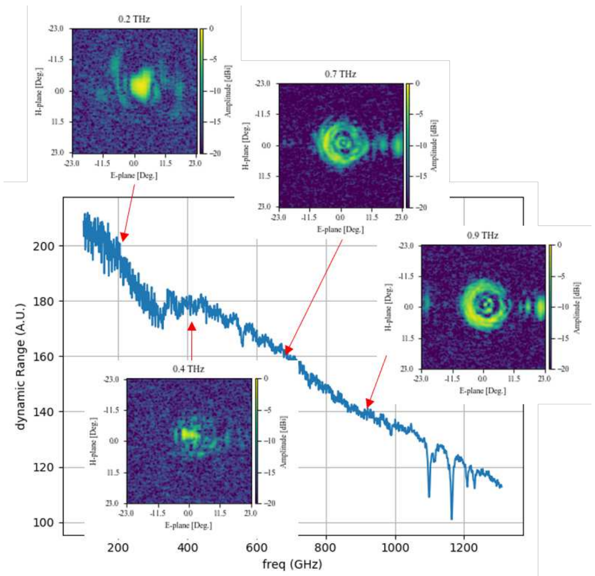

Fig. 1. Far field beam profiles at selected frequencies (0.2 THz, 0.4 THz, 0.7 THz and 0.9 THz) on the emission dynamic range of the THz photomixer measured using CMOS THz camera.

implementing a lens-integrated CMOS THz camera as a far-field measuring unit are 1) the integrated hyper-hemispherical lens on the camera achieves CATR based far-field within few mms thereby reducing the path losses and improving signal-to-noise (SNR) ratio, 2) this measurement set-up is compact with no requirement of additional optics, 3) use of 2D focal plane array provides the pattern in a single measurement, and 4) the CMOS camera operates in a large broad frequency range. The camera was operated in video mode with averaging of 2048 frames per frequency to suppress background noise. The pixel count of the processed images was improved with a super-resolution algorithm by supercomposing 4x4 frames of single 2D images obtained by scanning the camera in sub-pixel spacing in both E- and H-plane [8].

Figure 1 illustrates the high resolution far-field beam profiles of the photomixer emitter at selected frequencies ranging from 0.2 – 0.9 THz. As depicted, the spatial profile depends on the different roll-off spectral regions of the emission. At low frequencies, the profile is asymmetric in both E- and H-plane. At high frequencies above 0.6 THz, the emission is of annular beam with null intensity on-axis and strong side lobes. These side-lobes, if not suppressed within the proximity of the emission region, can lead to undesired background signals in a spectroscopic measurement. Figure 2 depicts the resembling far-field patterns measured using two methods. The first one on the left is measured using the herein implemented integrated lens-type CATR. The second on the right is measured with high-sensitive heterodyne receiver and by placing the emitter in far-field distance according to Fraunhofer far-field criterion. The CATR image showcases finer details of the emission pattern with a 20 dB SNR and low divergence angle due to image plane being in

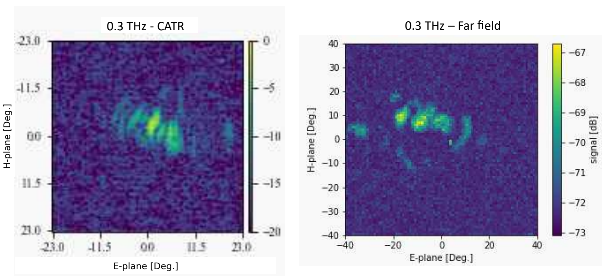

Fig. 2. Comparison of far field beam profiles at 0.3 THz measured using CATR using CMOS THz camera (left) and using high-sensitive heterodyne detector (right) of a THz photomixer emitter.

the dielectric medium as compared to the classical method which suffers from excessive free path losses and large divergence resulting in a 5 dB SNR only.

III. Summary

In this paper, the broadband spectro-spatial characteristics of a THz photomixer emitter were investigated from 0.2–0.95 THz using a CMOS camera-type THz CATR. The measured far-field profiles revealed the evolution of fundamental Gaussian at low frequencies into an annular beam profile with intense side lobes in higher frequencies above 0.7 THz. Combining imaging with spectroscopy using robust broadband source and CMOS camera allows decoupling source artifacts and enables fast and accurate THz analysis of samples under test.

Acknowledgements

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