A THz Camera for Real-Time Imaging Applications

Georgios C. Trichopoulos[1], Kagan Topalli[1], H. Lee Mosbacker[2], and Kubilay Sertel[1]
[1]ElectroScience Laboratory, Department of ECE, The Ohio State University, Columbus, OH USA
[2]Traycer Inc., Columbus, OH USA
E-mail: {trichopoulos.1, topalli.1, sertel.1}@osu.edu, lee.mosbacker@gmail.com

***Abstract* — We present a large-format, sub-millimeter-resolution, real-time focal plane array sensor for THz imaging. Each pixel in sensor array consists of THz antennas monolithically integrated with ultra-fast heterostructure backward diodes. The antennas are optimized for diffraction limited image resolution and conjugate impedance match for highest THz sensitivity. The camera is designed to cover the 0.6 – 1.2 THz band with real-time (60 Hz) image acquisition speeds, making it ideal for a wide range of THz imaging applications such as biomedical imaging, security screening, non-destructive evaluation, and chemical spectroscopy.**

Keywords - terahertz imaging, focal plane array, terahertz sensors

I. Introduction

The THz band provides unique sensing opportunities that enable several key applications such as biomedical imaging [1], security screening [2], and non-destructive evaluation [3]. However, wide range utilization of THz spectroscopy is hindered by the persistent lack of low-cost sensors and high power sources. In particular, lack of large-format (many-pixel) sensor arrays is hindering the proliferation of THz imaging applications. For example, X-rays can provide accurate radiological images; however, they lack physiological information. Frequency sensitivity of THz absorption can help identify differences in biological tissues. More importantly, unlike X-rays, T-rays are non-ionizing and thus safer for living organisms.

Other imaging modalities, like infrared (IR), suffer from low penetration depths and are thus not attractive for non-destructive evaluation applications. In contrast, THz waves can penetrate most materials and can provide unique spectral information in the 0.1-10 THz band with high resolution.

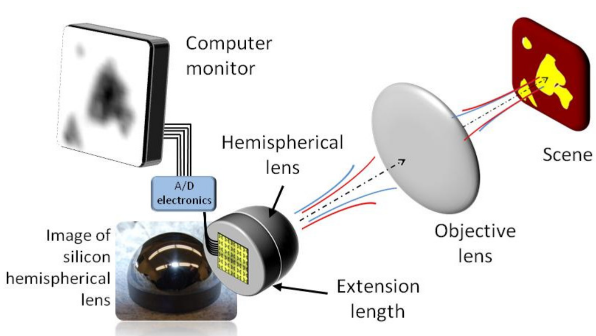

Figure 1: The THz camera: the scene is placed in front of the camera optics and its image is projected on the sensors behind the hemispherical lens. ROIC electronics convert THz waves into a digital image.

State-of-the-art THz systems employ mechanical raster scans (using single detector) to acquire two-dimensional images. As such, this scan process often takes tens of minutes to generate a high-resolution THz picture of a scene. Additionally, such devices tend to be bulky and complicated due to the necessary mechanical parts. Alternatively, an integrated focal plane array (FPA) can be used as the THz sensor, enabling much faster image acquisition through parallel operation. We recently developed such a FPA THz sensor that consists of ultra fast heterostructure backward diodes (HBDs) [4] integrated with specially designed THz antennas [5]. The new THz antennas compensate the optical aberrations experienced by off-axis pixel performance, leading to increased field of view for the camera. Our more recent antenna design allows for broadband operation, more suitable for spectroscopy applications.

II. THz Focal Plane Array Camera

The proposed THz camera architecture has characteristics similar to those of a typical digital video camera. As illustrated in Fig. 1, the "optics" consists of the "reverse microscope" configuration. An objective lens focuses the image scene onto a hyper-hemispherical high-resistivity silicon lens. A pixilated receiver array is placed at the focal point of the lens, as illustrated in Fig 2. Each pixel consists of a butterfly-shaped dual-slot antenna fabricated monolithically with an integrated fast heterostructure backward diode (HBD) [4]. When a direct detection system is implemented, appropriate A/D readout electronics can be attached to each pixel in the FPA to convert the received (rectified) signals into a digital image.

In order to implement a FPA with highest possibly THz sensitivity and high resolution, the THz antennas need to be optimally designed by respecting wave propagation phenomena. That is, a full-scale electromagnetic modeling of the antenna and the optical components is necessary. For

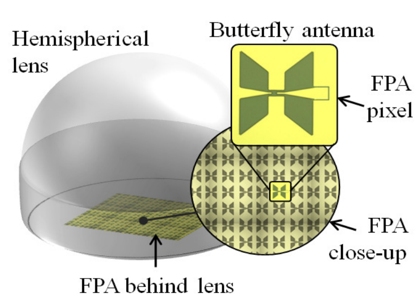

Figure 2: Pixilated THz imaging sensor placed behind the extended hemispherical lens (Inset: Butterfly-shaped THz antenna).

example, maximum sensor response can only be harnessed if the antenna is impedance matched to the integrated sensor diode [5]. Moreover, the external optics must be designed properly to allow for maximum THz radiation to couple into the THz antennas [6]. The new THz camera we present here achieves those two goals for a broad range of frequencies (0.6 THz – 1.2 THz). Additionally, antenna miniaturization techniques are employed to enable densely packed arrays, leading to high spatial resolution.

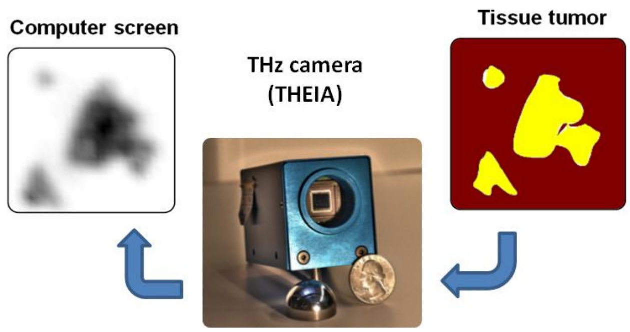

Figure 3: An example of THz imaging application where a slice of excised tissue is imaged at THz frequencies.

III. THz Camera Imaging performance

The image resolution performance of the camera can be evaluated by calculating the *E*-field intensity distribution on the object plane by assuming that all FPA antennas are excited concurrently (see Fig. 4). That is, the reciprocal problem where each antenna element is radiating toward the object plane. Here, we compute the camera image of a "THz" shaped screen located in front of the camera. As seen, the current setup exhibits a spatial resolution on the order of one wavelength. Using the intensity patterns, we can also predict overall imaging performance as shown in Fig. 5.

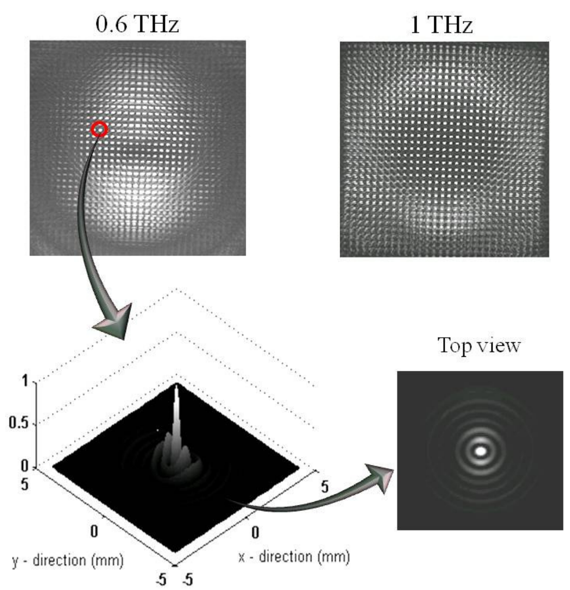

Figure 4: The focal plane array's radiation intensity on the object plane. Off-axis pixel performance typically degrades due to aberrations.

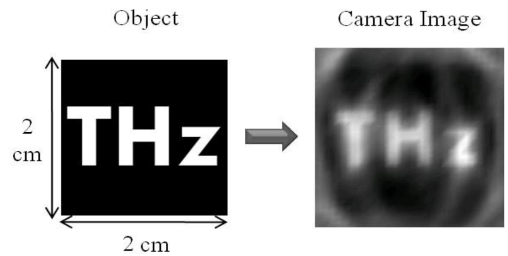

Figure 5: Computed THz image of an opaque screen placed in front of the THz camera.

IV. Conclussions

We outlined our recent work aimed at developing world's first real-time THz camera sensor. The FPA sensor consist of densely packed array of THz antennas with integrated HBD diodes for high-sensitivity direct detection of incoming THz radiation. Overall, the new FPA sensor enables a compact THz camera. More importantly, due to the standard manufacturing techniques employed, it is also a very cost effective solution for a wide range of imaging applications. Future work involves further improvement of the diodes performance as well as more broadband FPAs.

Acknowledgement

This work was supported in part by the National Science Foundation (#1028911).

References

[1] U. A. Khan, N. Al-Moayed, N. Nguyen, K. A. Korolev, M. N. Afsar and S. P. Naber, "Broadband dielectric characterization of tumorous and nontumorous breast tissues", *IEEE Trans. Microwave Theory and Tech.*, vol. 55, no 12, pp. 2887-2893, December 2007.

[2] Hai-Bo Liu, Hua Zhong, N. Karpowicz, Chen Yunqing, Xi-Cheng Zhang , "Terahertz Spectroscopy and Imaging for Defense and Security Applications," *Proceedings of the IEEE* , vol.95, no.8, pp.1514-1527, Aug. 2007.

[3] R.K. May, Lianghao Han, J. Alton, Shuncong Zhong, J.A. Elliott, C. Byers, L.F. Gladden, M. Evans, Shen Yaochun, J.A. Zeitler, "Pharmaceutical Tablet Hardness Measurements with THz Pulsed Imaging," *Infrared, Millimeter, and Terahertz Waves, 2009. IRMMW-THz 2009. 34th International Conference on* , vol., no., pp.1-2, 21-25 Sept. 2009.

[4] N. Su, R. Rajavel, P. Deelman, J. N. Schulman and P. Fay, "Sb-Heterostructure millimeter-wave detectors with reduced capacitance and noise equivalent power", *IEEE Electron device Letters*, vol. 29, No. 6, June 2008.

[5] G. C. Trichopoulos, G. Mumcu, K. Sertel, H. L. Mosbacker, P. Smith, "A Novel Approach for Improving Off-Axis Pixel Performance of Terahertz Focal Plane Arrays," *Microwave Theory and Techniques, IEEE Transactions on* , vol.58, no.7, pp.2014-2021, July 2010.

[6] J. W. Goodman, Introduciton to Fourier Optics, chap. 5, Roberts Publishers, 3rd edition, 2005.