Static Terahertz Imaging at a Distance for Concealed Weapon Detection

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Abstract— **Using a high-powered pulsed terahertz source and electro-optic detection, a method for and examples of static THz imaging of targets at a distance of greater than 3 meters (no THz component is closer than 3 m from the target) are presented. The THz signal in all 200X200 pixels of an image are collected simultaneously to generate THz imagery of targets over the 0.3 THz to 2.0 THz frequency range. The field of view, restricted by a simple single lens optical system, is approximately 10 cm across with sub-millimeter spatial resolution. This capability demonstrates the viability of static electro-optic THz imaging without the need to raster-scan a scene to generate an image.**

Index Terms— **Concealed weapons detection, Standoff terahertz imaging, Submillimeter wave imaging, Terahertz focal plane array**

I. Introduction

OVER the past several years there has been a push for camera systems capable of imaging far-infrared, or terahertz (1 THz = 10^12 Hz) radiation. Attractive properties of THz radiation, including partial transmission through many non-metallic materials and unique spectral characteristics of several materials of interest, have driven the surge in research and development. There are several challenges inherent to exploiting these properties in an imaging system, stemming primarily from pixel-wise sensitivity over a broad range of THz frequencies.

Electro-optic THz detection, also known as optical rectification of ultra-fast THz pulses, provides a means to standoff, static THz imaging. The overall sensitivity of electro-optic detection is well documented [1], yet there has been a sentiment that there is not sufficient THz pulse energy in traditional ultra-fast THz pulse sources [2] to perform static, reflection-mode imaging of targets. In this case, static imaging refers to simultaneous measurement of the THz pulse in all pixels in the image, versus raster-scanning a THz beam over a target to generate an image [3].

The integration of a large-area photoconductive antenna (PCA) with the THz imaging system enables static THz imaging of targets at standoff distances of upwards of 3 meters. Static imaging has the benefit of providing a user a comprehensive THz image of an object or person, potentially revealing concealed weapons.

Manuscript received July 11, 2007. This work was supported in part by the U.S. Department of Commerce under Grant 70NANB6H6062.

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II. Experimental Methods

The experiment is driven with a 40 fsec, 1 kHz, ~1 mJ/pulse 800 nm laser beam produced by a regeneratively amplified mode-locked titanium-sapphire laser. A small fraction (~1%) of the beam is split off for detection and the rest is used to illuminate a large area photoconductive antenna (PCA) to generate THz radiation [4]. The PCA consists of a 3 cm X 3 cm X 0.05 cm gallium arsenide (GaAs) wafer. Metallic stripes are applied to the top and bottom sides of the wafer with silver paint and an electrode is attached to each side. One electrode is connected to ground, the other is connected to a high-voltage pulser. The high-voltage pulser, which utilizes an automotive ignition coil to up-convert DC voltage, supplies 5 kV-10 kV pulses at a repetition rate of 1 kHz.

The 800 nm laser beam is telescoped up to fully illuminate the GaAs wafer at normal incidence. The arrival of the 40 fsec laser pulse to the PCA is synchronized to the peak of the high voltage pulse applied across the wafer. The laser pulse promotes electrons from the insulating band to the conduction band which accelerate in the applied field, resulting in a 1-2 psec FWHM THz radiation pulse centered at ~0.8 THz.

THz radiation freely propagates away from the PCA in both the forward and backward directions as a radiating dipole antenna. No radiation collection or collimation optics were used in the experiments described. THz radiation reflected/scattered from a target is collected with a 7.6 cm diameter, 180 mm focal length high density polyethylene (HDPE) lens and is imaged on a 1 cm X 1 cm X 1 mm zinc telluride (ZnTe) crystal. A pellicle is used to co-propagate the THz radiation and 800 nm laser beam through the ZnTe crystal. The instantaneous electric field of the THz pulse induces birefringence in the ZnTe crystal, and the spatial variance in the 800 nm probe laser beam is recorded for "THz on" and "THz off" with a CCD camera [5]. A 400 X 400 pixel region of the CCD camera is illuminated with the 800 nm light passing through the ZnTe crystal, with 2 X 2 pixel binning used to generate a 200 X 200 pixel image. The relative delay between the 800 nm laser pulse and the returning THz pulse is scanned to generate a full THz waveform in each pixel of the image. The finite Fourier transform of the waveform provides the power spectrum in

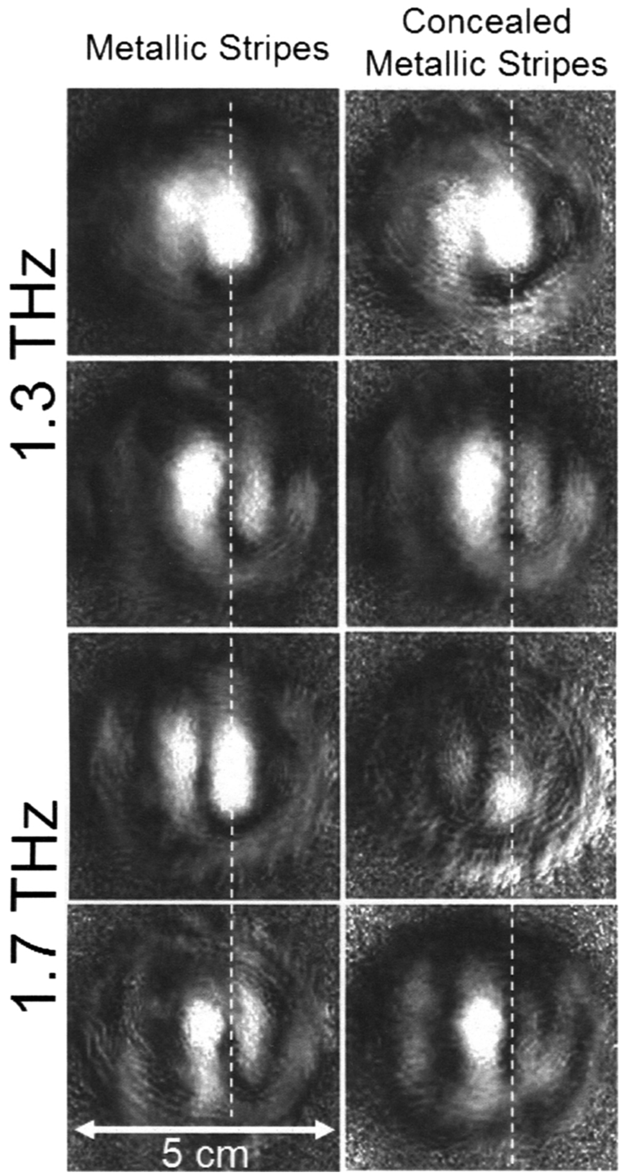

Fig. 1. Examples of static, reflection-mode THz images of vertical metallic stripes 2 meters away from THz radiation source and THz imaging optic. The stripes are clearly observed in the right column, even though they are concealed by an article of clothing. The dashed lines are present to facilitate comparison between images.

each pixel.

III. Results

Examples of standoff, static THz imaging are shown in Figures 1 and 2. Figure 1 shows multiple reflection-mode THz images of a series of vertical metallic stripes placed 2 meters from the PCA and HDPE THz lens at multiple THz frequencies. The first and second row show intensity at 1.3 THz, with the target object translated approximately 6 mm along the horizontal axis between the rows. The third and fourth rows show the THz intensity of the same corresponding scenes at 1.7 THz. The images shown in the left column are of the target out in the open, whereas the images in the right column are of the target concealed by a tee shirt. To the best of our knowledge, this is the first demonstration of static electro-optic THz imaging for objects greater than 1 meter from both the THz source and any THz optics. In addition, this demonstrates the viability of THz imaging of concealed objects. All frequency information is available over the 0.3 THz to 2.0 THz frequency range, meaning spectral classification of items in the field of view is potentially possible. However, several challenges are faced in deciphering the THz pulse waveform returning from an arbitrary target to extract accurate spectral information.

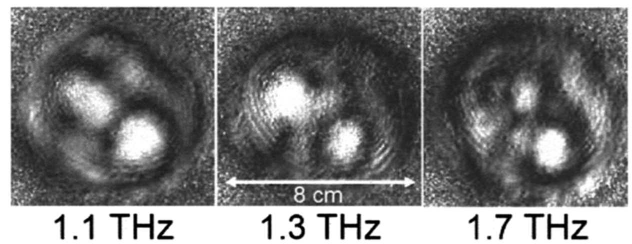

Fig. 2. Static THz images at different frequencies for 2 metallic circles placed 3 meters from the THz radiation source and imaging optic.

Figure 2 shows static images at multiple THz frequencies of two metallic circles placed 3 meters from the THz radiation source and imaging optics. Image quality is limited primarily due to the quality of the THz optic. These results, however, demonstrate that large are PCA are useful for standoff THz imaging at ranges of upwards of 3 meters.

IV. Conclusion

Experiments presented here demonstrate static, two dimensional THz imaging at standoff distances of several meters is viable. Progress in reducing the footprint of the THz imaging system is required to make the imaging system described here viable outside the laboratory.

References

[1] Many examples are provided throughout D. Mittleman, “Sensing with Terahertz Radiation,” Springer Series in Optical Sciences (2003). In particular, we refer to detection methods described by J. Ziang and X. C. Zhang and references therein on pages159-161.

[2] By ‘traditional ultra-fast THz pulse sources’ the authors refer to terahertz optoelectronic switches where the gaps across the semiconductor are 30 μm to 50 μm, such as those presented by Picometrix and TeraView, Ltd. at the SURA 2005 Terahertz Applications Symposium in Washington, DC June 2-3, 2005.

[3] X. C. Zhang, “THz Sensing & Imaging,” and S. Williamson, “Terahertz Application Solutions,” SURA 2005 Terahertz Applications Symposium in Washington, DC, 2-3 June 2005.

[4] The PCA is based on the original Auston Switch, D.H. Auston, K. P. Cheung, P. R. Smith, “Picosecond photoconductive hertzian dipoles,” Appl. Phys. Lett. 45, 284 (1984) and is modeled after the one described by D. You, R. R. Jones, P. H. Bucksbaum, D. R. Dykaar, “Generation of high-power sub-single-cycle 500-fs electromagnetic pulses,” Opt. Lett., 18, 290 (1993).

[5] X.-C. Zhang , Q. Wu, and T. D. Hewitt, “Electro-Optic Imaging of Terahertz Beams,” Ultrafast Phenomena X, Springer Series in Chemical Physics, 54 (1996). Z.G. Lu and X.-C. Zhang, "Real time THz Imaging System Based on Electro-Optic Crystals," SPIE-Applications of Photonic technology III, 3491, 334 (1998). Method follows that described at:

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