Terahertz imaging of large objects with high resolution

Spisser, Helene, Ouellet, Samuel, Vachon, Carl, Terroux, Marc, Briand, Martin, et al.

Helene Spisser, Samuel Ouellet, Carl Vachon, Marc Terroux, Martin Briand, François Berthiaume, Michel Doucet, Alex Paquet, Hassane Oulachgar, Francis Genereux, Linda Marchese, "Terahertz imaging of large objects with high resolution," Proc. SPIE 11541, Millimetre Wave and Terahertz Sensors and Technology XIII, 1154106 (20 September 2020); doi: 10.1117/12.2574297

Event: SPIE Security + Defence, 2020, Online Only

Terahertz imaging of large objects with high resolution

Helene Spisser*, Samuel Ouellet, Carl Vachon, Marc Terroux, Martin Briand, François Berthiaume,
Michel Doucet, Alex Paquet, Hassane Oulachgar, Francis Genereux, Linda Marchese
Institut National d'Optique (INO), 2740 Einstein street, Quebec city (QC) G1P 4S4, Canada;

ABSTRACT

For over 28 years, INO has been developing microbolometer arrays for the infrared and Terahertz (THz) domains. INO's microbolometer array is the key component of INO's broadband THz cameras. Using this detector, INO has developed active Terahertz imaging systems ranging from 250 GHz to 750 GHz. See-through THz imaging is particularly well suited for security screening of persons and non-destructive inspection of objects. Materials such as cardboard, plastic, leather and denim are transparent to THz radiation and can provide insights on objects hidden from the naked eye or from infrared cameras. In addition, Terahertz provides high resolution images and is non ionizing. In particular, the frequency range of 150 – 550 GHz is of interest for its properties of see-through imaging that enable a wide variety of potential applications. In this paper, we present images obtained around 400 GHz and 200 GHz (corresponding to wavelengths of 0.76 mm and 1.52 mm). We have chosen these two wavelengths to allow for a wide range of objects and obscuring materials to be tested. The 400 GHz wavelength allows better image resolution, while the 200 GHz provides better penetration through the materials.

The THz imaging system can obtain images of objects with dimensions up to 1 meter x 0.75 meter with sub-centimeter resolution. To achieve this, we use diffraction-limited imaging optics with high numerical aperture and a microbolometer array detector. For each object, multiple images are acquired that are then stitched together. Each instantaneous image can be seen in real-time during the acquisition and has the same resolution as the global reconstructed image. In the context of an application, the operator does not need to wait until the scan has been completed to identify a hidden object if the size of its features is compatible with the instantaneous field-of-view. When a more global image is required, the reconstructed image shows the features of the whole object under investigation without resolution loss. Images are acquired in two different configurations: transmission and reflection. Each imaging configuration provides different information about the features inside the object as well as its composition. In summary, this paper demonstrates the potential for our THz imaging systems by providing see-through high-resolution THz images of large objects. An analysis of the impact of wavelength and imaging configuration on the image results is also provided.

Keywords: Terahertz imaging, Terahertz focal-plane-array, non-destructive testing

1. INTRODUCTION

Terahertz-imaging offers the unique potential for see-through imaging since many materials that are opaque in the visible are transparent in the Terahertz (THz) domain. Furthermore, THz radiation is non-ionizing. Many industrial applications could benefit widely of THz imaging[1]. Specifically, non-destructive testing for quality control[2,3].

INO's focal plane array (FPA) offers great potential for these applications, as it provides video-rate imaging on a 384 X 288 pixel detector, where most of the other THz imaging methods are single-point detection and can not acquire an image in a single shot[1,4]. The object of the present article is to present INO's THz imaging capabilities. In the following section, two imaging setups are presented. Next, the choice of illumination wavelength is discussed. As the bolometer technology allows for a very large detection band, the choice of the illumination wavelength is not limited by the sensor and can be chosen after consideration of sample properties and imaging requirements. The final section presents a method to increase the size of the object field, and the size of the object under investigation, without resolution loss. This method combined with INO's designed THz optics for video-rate imaging[5] gives high-quality large-area images.

Millimetre Wave and Terahertz Sensors and Technology XIII, edited by Neil A. Salmon,
Frank Gumbmann, Proc. of SPIE Vol. 11541, 1154106 · © 2020 SPIE
CCC code: 0277-786X/20/$21 · doi: 10.1117/12.2574297

2. THE IMAGINGS SETUPS

Focal plane array detector

Images presented in this paper are obtained using INO's THz FPA detector. This detector is a 384 X 288 microbolometer array with a 35 µm pixel-pitch. The FPA active area is 13.4 mm X 10.1 mm. The detector is integrated in INO's microxcam-THz camera. It provides real-time images over a large band (70 µm to 3 mm wavelength)[6]. The camera has a small footprint (61 mm X 61 mm X 65 mm) and is lightweight (360 g), which allows easy installation in any imaging setup. Figure 1 presents a photograph of the microxcam-THz camera with one of INO's custom THz objectives.

Figure 1. INO's microxcam-THz camera with a THz objective

Large-field real-time imaging setup

The large-field imaging setup of 1 meter by 0.75 meter consist of three sections: illumination, transmission imaging and reflection imaging. The three parts are highlighted Figure 2.

The illumination source is an oscillator from Virginia Diode. When used directly, the radiation wavelength is 3.04 mm (99 GHz). With one doubler, the radiation wavelength is 1.52 mm (197 GHz), and with two doublers 0.76 mm (395 GHz). A photograph of the illumination source is presented Figure 3.

To obtain a uniform illumination and harvest maximum power on the detector, specific illumination optics have been designed. These optics are shown in the illumination block of Figure 2. Further details on the illumination optics may be found in a previous proceeding[5].

Imaging optics for the transmission and reflection paths are the same. They have a 105 mm focal length and F/# = 0.75. These high-aperture diffraction-limited optics produce high THz resolution. For the configuration shown on Figure 2, the magnification is 0.25 for the reflection as well as for the transmission path. A 54 mm X 40 mm object field can be imaged at 50 images per second. With the same optics in a different configuration, an instantaneous object field of 110 mm X 80 mm can be achieved. By scaling up the illumination optics, an instantaneous object field of 150 mm X 200 mm has been obtained but is not a part of the setups presented here.

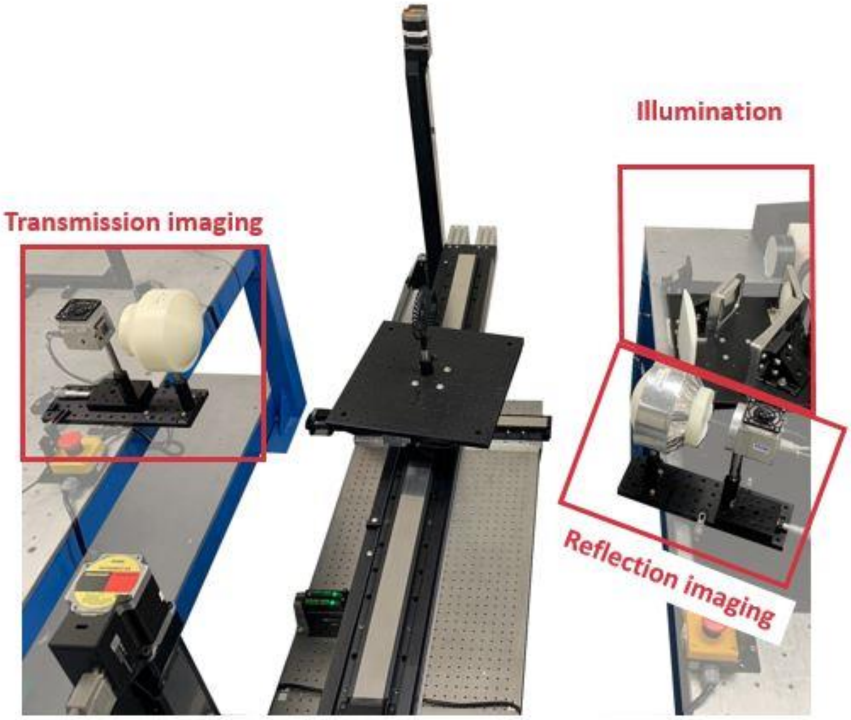

Figure 2. Large-field setup. The sample under investigation is set on the black plate in the center of the picture

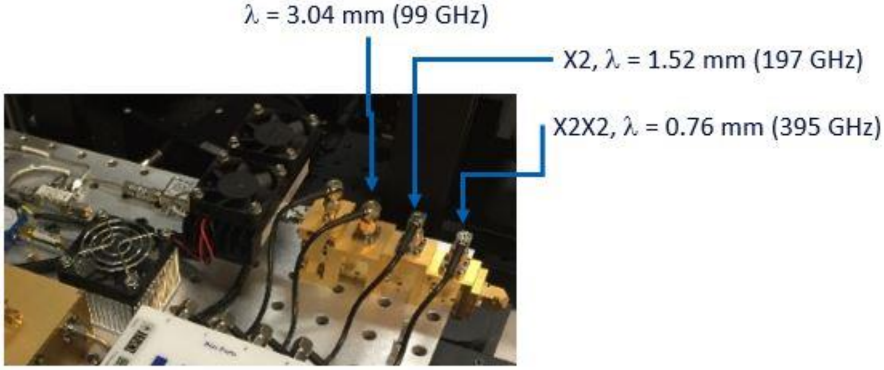

Figure 3. Picture of the illumination source with 2 doublers on

High-resolution real-time imaging setup

The second setup presented here is a compact reflection setup with a X1 magnification. The sample is illuminated and imaged along the same axis using a beamsplitter (Figure 4). The diffraction-limited optics have an aperture number F/# = 0.94. The resolution then strongly depends on the wavelength. With this setup a 13.4 mm X 10.1 mm field can be imaged at a rate of 50 images /s.

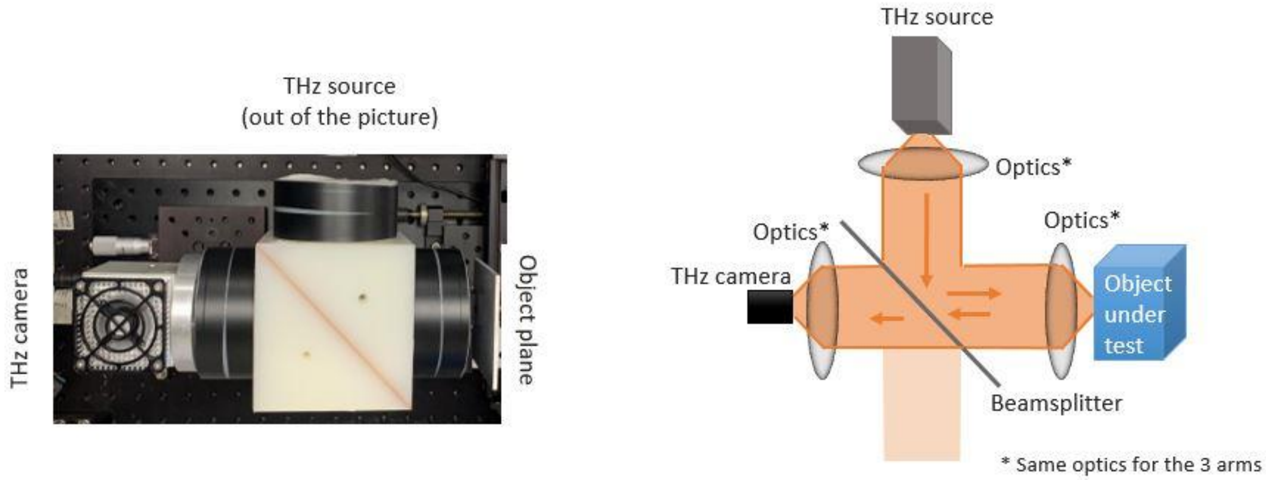

Figure 4. Picture (left) and scheme (right) of the high-resolution setup

3. CHOOSING AN ILLUMINATION WAVELENGTH

The THz band offers great opportunities for see-through imaging as many materials that are opaque in the visible are transparent in the THz-range. With the system presented here, it is possible to image samples from 0.76 mm (395 GHz) to 3.04 mm (99 GHz). It can be useful or even necessary in some cases to choose a wavelength close to 3 mm, because the penetration in many materials is better for longer wavelengths. However, the resolution of diffraction-limited optical systems decreases when the wavelength gets longer. The choice of the wavelength must then be made for each sample, considering the type and thickness of the materials to see-through and the resolution required, as well as the availability of the illumination source.

The theoretical resolution is given by the diameter of the Airy pattern. Figure 5 illustrates the impact of the wavelength on the resolution by displaying an Airy pattern relatively to the size of our detector for different wavelength and an f-number F/# = 0.75. Furthermore, longer wavelengths encounter more wavelength-sized features in typical optical systems and can be subject to parasitical interference[5] that decreases the illumination uniformity if not considered in a system design. An example representing two typical images obtained at 0.76 mm and 1.52 mm wavelength is presented Figure 6.

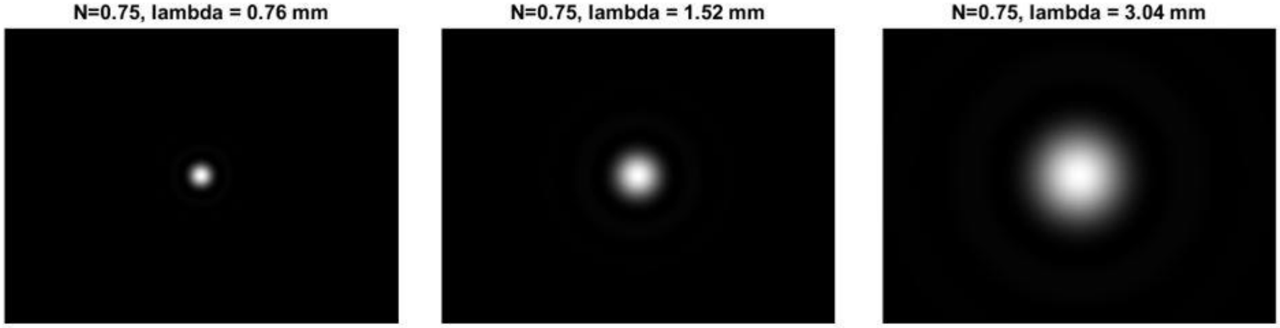

Figure 5. Representation of Airy patterns for a F/#=0.75 optic at 0.76 mm, 1.52 mm and 3.04 mm wavelengths. The black rectangle is 13.4 mm X 10.1 mm and represents the size of the FPA

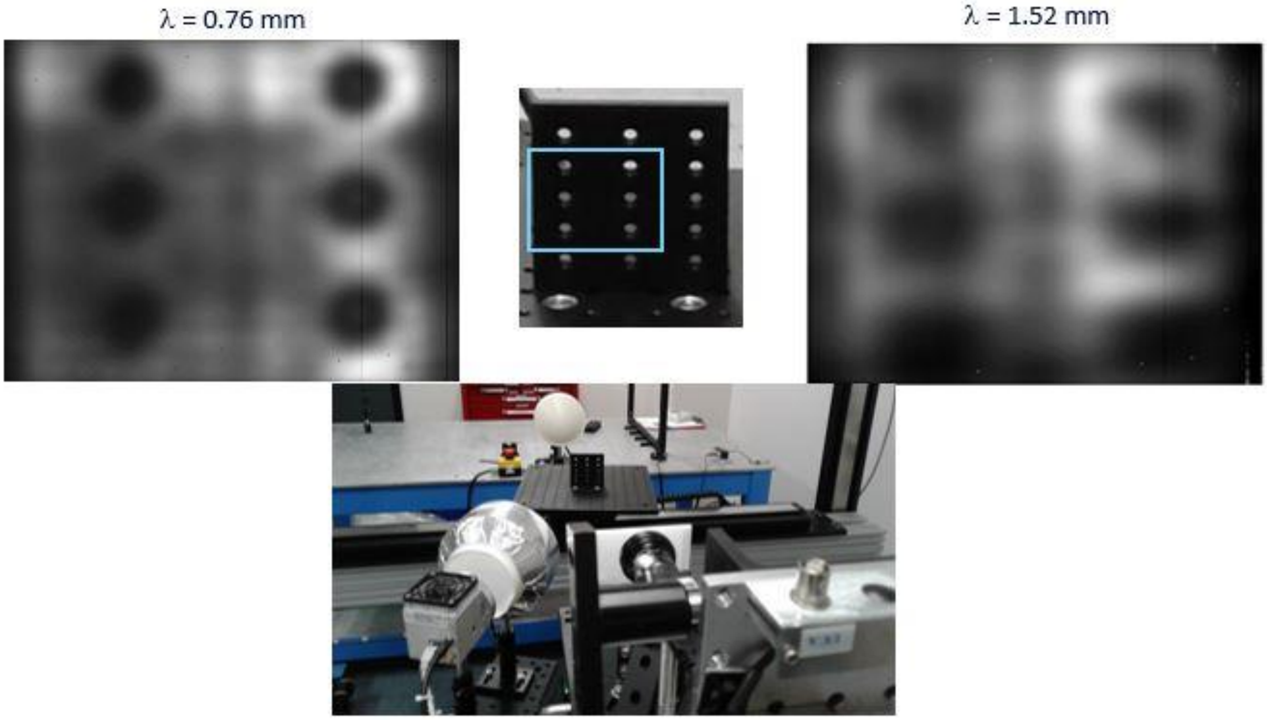

Figure 6. THz image of a metal plate with holes for an illumination wavelength of 0.76 mm (top left) and 1.52 mm (top right). The imaged area is highlighted by a blue square on the visible image of the object in the top center. Bottom is a picture of the imaging setup.

4. SCANNING AND STITCHING FOR LARGE FIELD IMAGING

Taking advantage of the high imaging rate (50 images/s) of the THz-camera, a simple way to get a larger object field and maintaining the resolution, is to scan the object. This method is particularly appropriate for non-destructive testing. The object under investigation is attached to 2D-translation stages and is scanned during camera acquisition. After scanning, the images are stitched together to get one larger image.

Figure 7 (right) shows an example of an image acquired in reflection at 0.76 mm wavelength after stitching with the setup of Figure 2. The right side of the figure shows one of the images used for the stitching. In this case, the step of the 2D-scan has been chosen in order to have an overlap between two successive pictures. This allows to get a better image quality by averaging the illumination non-uniformity over the different images overlapping. As a result, the illumination non-uniformity looking like blobs on the left side of Figure 7 have been eliminated on the stitched image on the right side of Figure 7.

Figure 8 shows a stitched image of a USB-stick obtained with the high-resolution setup shown on Figure 4 with a 0.76 mm wavelength.

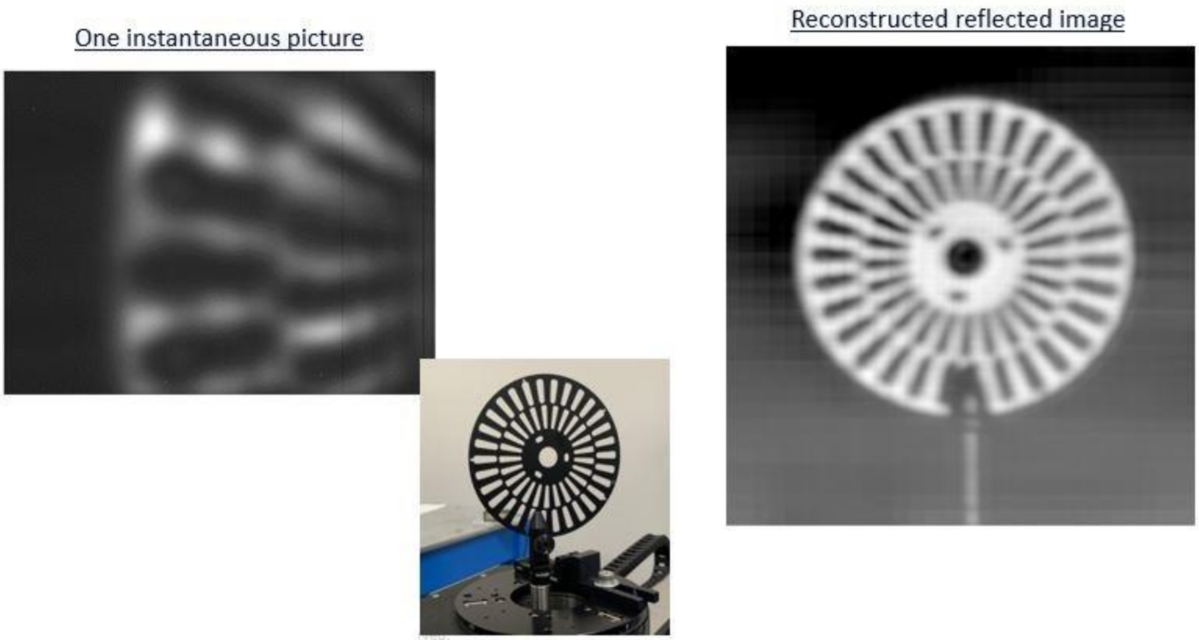

Figure 7 Instantaneous THz image of a chopper wheel (left), THz-image of the whole chopper wheel after stitching (rigt), and visible image of the chopper wheel (bottom)

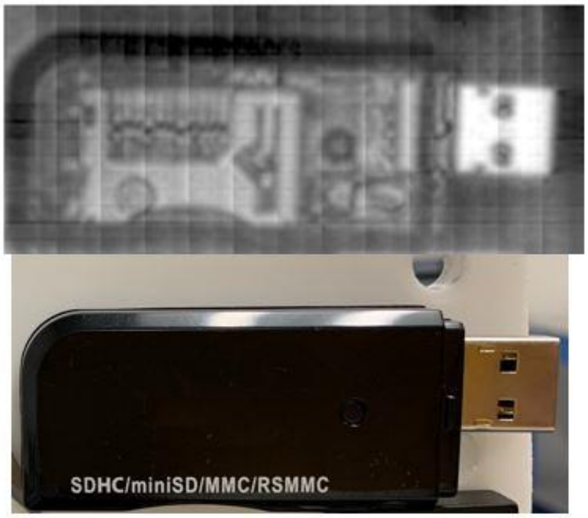

Figure 8. THz stitched image (top) in reflection mode and visible image (bottom) of a USB-stick

5. CONCLUSION

We presented here some of the capabilities of INO for active THz-imaging. INO's THz FPA allows for real-time imaging for wavelengths from 0.07 mm to 3 mm. Such a broadband detector permits one to choose the most adequate wavelength for any THz see-through application after consideration of the required penetration depth and resolution. The limitation of the field size with respect to the diffraction-limited resolution is overcome using a 2D-scan of the object under investigation and stitching of the acquired images. With the setups presented here, objects as large as 1 meter X 0.75 meter with a magnification of X0.25, and as large 0.15 meter X 0.15 meter with a magnification of X1 can be imaged.

REFERENCES

[1] Tao, Y. H., Fitzgerald, J. A. and Wallace, W. P., "Non-Contact, Non-Destructive Testing in Various Industral Sectors with Terahertz Technology" *Sensors* 20 (712), (2020).

[2] Naftalny, M., Vieweg, N. and Anselm Deninger "Industrial Applications of Terahertz Sensing: Stat of Play.» *Sensors* 19 (4203), (2019)

[3] Ahi, K., Shahbazmohamadi, S. and Asadizanjani, N. "Quality-control and authentification of packaged integrated circuits using enhanced-saptial resolution terahertz time-domain spectroscopy and imaging" *Optics and Lasers in Engineering*, 0143-8166. (2017)

[4] Marchese, L., Terroux, M., Doucet, M., Blanchard, N., Pancrati, O., Dufour, D., and Bergeron, A. "Reflection Imaging in the mm-wave range using a video-rate THz camera" Proc. SPIE *9836* - 98362S (2016)

[5] Marchese, L., Doucet, M., Blanchard, N., Terroux, M., Briand, M., Otis, M., Jacob, M. et al. "Overcoming the challenges of active THz/mm-wave imaging: an optics perspective," Proc. of SPIE Vol. 10639, 106392B (2018).

[6] Marchese, L., Terroux, M., Genereux, F. Tremblay, B., Briand, M., Bergeron, A., "Review of the characteristics of 384 X 288 pixel THz camera for see-through imaging," Proc. of SPIE Vol. 8900, 890009 (2013).