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A Compact THz imaging set-up at 750 microns

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ABSTRACT

Advances in infrared (IR) detector technologies over the last decade have led to compact low-cost thermal imaging systems that have become almost ubiquitous. They are now used in such market applications as automotive, security and construction. Terahertz (THz) imagers can take advantage of the state-of-the-art in the infrared domain to reduce their size and cost. Such an example is the IRXCAM-THz-384 Terahertz camera whose electronics core is based on the IRXCAM camera core and whose detector has been specifically designed and optimized for the THz. The 384 x 288 35-micron-sized pixel detectors of both cameras are uncooled microbolometers. A micro-electronics core is currently being developed for both platforms that will yield ultra-compact IR and THz cameras.

While IR systems are passive and thus do not require an illumination source, the THz system does. Thus, the THz source must be included when talking about overall imaging system size and cost. There are a wide variety of THz sources, from quantum cascade lasers on the optical side of the radiation spectrum to different types of diodes on the electromagnetic micro-wave side. When considering a source for a given application, the output wavelength, output power, size, weight and cost are primary factors that must be taken into account.

This paper presents a description of a compact real-time imaging system at 750 μm wavelength. An overview of the motivation for the wavelength choice is discussed, a description of the imaging components is given and finally image results are presented.

Keywords: terahertz, THz camera, microbolometer, THz source, submillimeter

1. INTRODUCTION

The THz domain covers a large spectrum from 0.3 to 3 THz. In terms of wavelength this is 100 μm to 1 mm, thus there is an order of magnitude difference from the shortest to longest wavelength and its different information may be found in various sub-divisions. The most studied sub-division in the THz band with respect to imaging has been around 1.5 - 4 THz that covers wavelengths from 75 μm to 200 μm [1-4]. The prominence of this sub-division is mainly due to the availability of relatively compact sources, such as Quantum Cascade Lasers (QCL) and detector focal plane arrays with good sensitivity in this region. Imaging results in the laboratory have been quite good at these shorter wavelengths, however, for many reasons, there is still a great interest in imaging beyond these wavelengths. One specific reason is atmospheric attenuation. Figure 1 is a plot of the atmospheric attenuation at 5 meters distance for wavelengths from 0.1 m to 1 m. The curves indicate that only 22.6% of the radiation at 118 μm is transmitted after 5 meters. Thus 118 μm is less useful for stand-off applications. The same graph shows that other longer wavelengths such as 432 μm (89% transmission at 5m), 663 μm (79%) and 750 μm (94%) do not exhibit as high absorption as 118 μm and could thus be of interest for various long-range applications.

INO's microbolometer-based camera is sensitive to the entire THz band, and thus by using a multi-wavelength source, imaging tests at longer wavelengths are possible [5-6]. Figure 2 presents the results from imaging tests performed in transmission and reflection of a simulated set of brass knuckles (shown in Figure 3) packed in bubble wrapping and paper. The images were taken at wavelengths 118 μm, 432 μm and 663 μm. The images in Figure 2 show that as the wavelength increases, the image of the simulated set of brass knuckles is still clearly visible, although finer details such as the outline of the bubbles from the packing material, may be blurred out. Photographs of the critical components of the imaging set-up are presented in Figure 4 that are an optically pumped gas far-infrared laser (top left), the IRXCAM-THz-384 camera core (top right), the THz optimized F/0.95 objective (bottom left) and large diameter plastic lenses (bottom right) for beam expansion.

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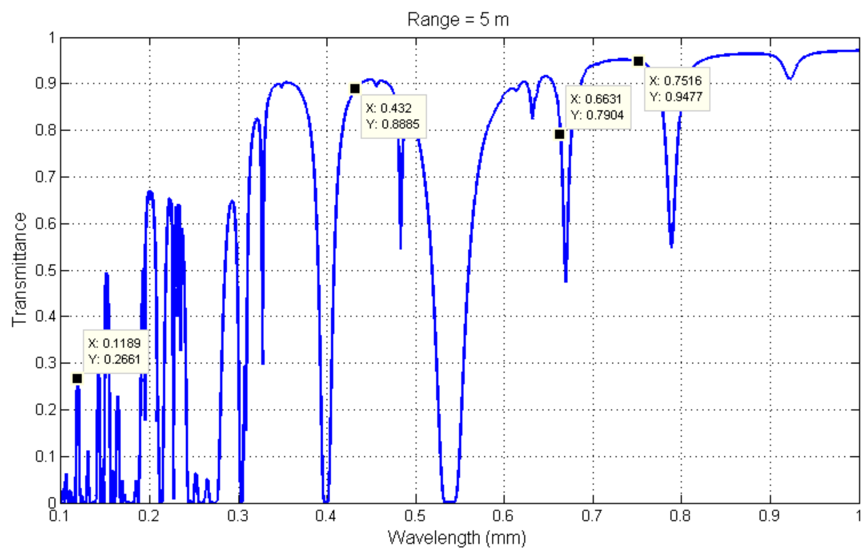

Figure 1. Atmospheric transmission (in relative units) for THz wavelengths from 0.1 mm to 1 mm after 5 m of horizontal travel. Atmospheric conditions were 76% relative humidity, 21 C temperature and 1013 mb pressure.

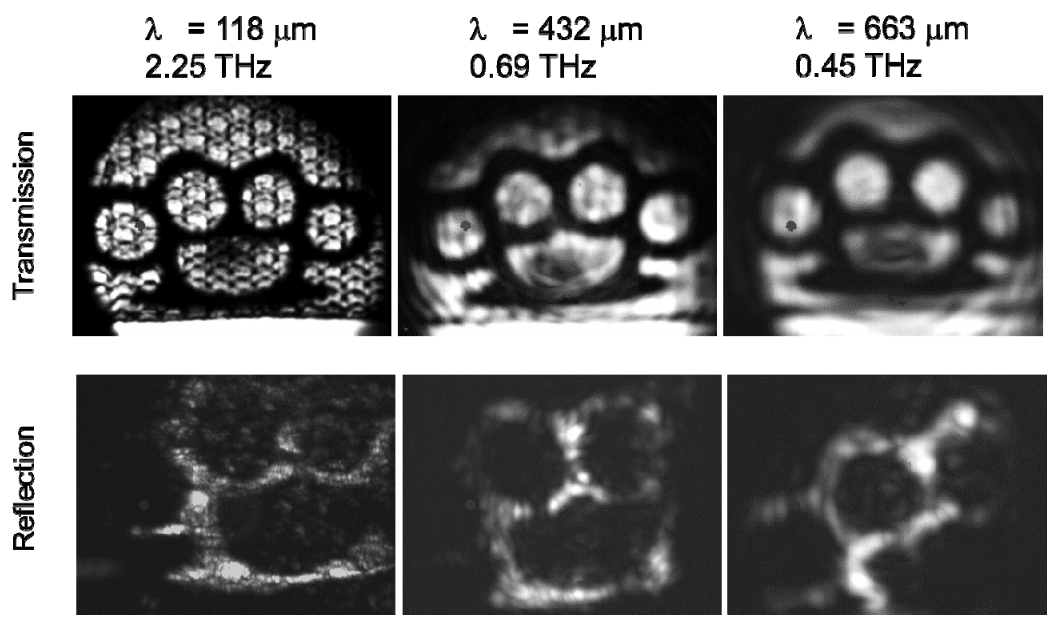

Figure 2. THz images taken in transmission (top row) and reflection (bottom row) of simulated brass knuckles hid within packing material taken at 2.25 THz (left column), 0.69 THz (center column) and 0.45 THz (right column)

Figure 3. Visible image of brass knuckles

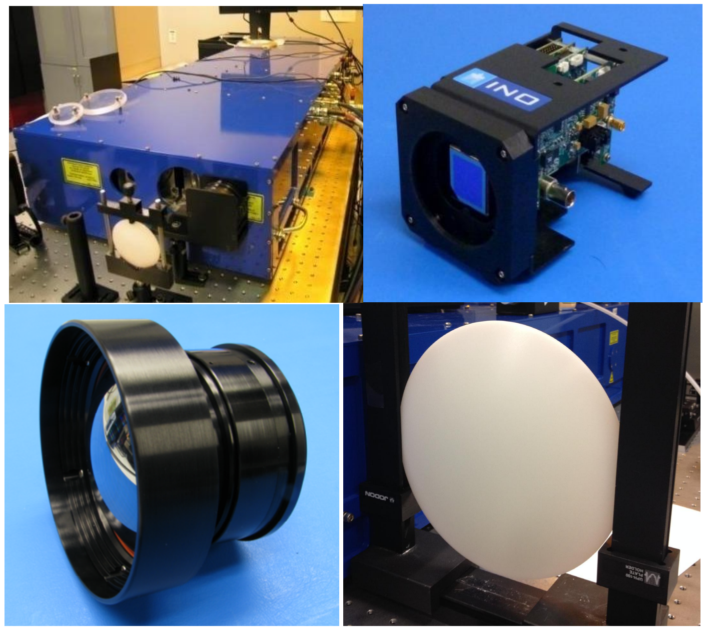

Figure 4. Photographs of the multi-wavelength Coherent SIFIR-50 laser (top left), the IRXCAM-THz-384 camera core (top right), THz optimized F/0.94 lens barrel and large diameter plastic lens for illumination expansion

2. COMPACT IMAGING SET-UP AT 750 µM

Given the good imaging results at 663 µm, it was decided to try imaging at 750 µm using a compact single-wavelength source that could be portable. The source chosen was a Virginia Diodes oscillator amplifier/multiplier chain combination shown in the left panel of Figure 5 with output wavelength of 750 µm and output power of 7 mW. In addition, a faster THz lens barrel was developed, having an F-number of 0.7 compared to the original barrel that has an F-number of 0.95. Both lens barrel have focal lengths of 44 mm.

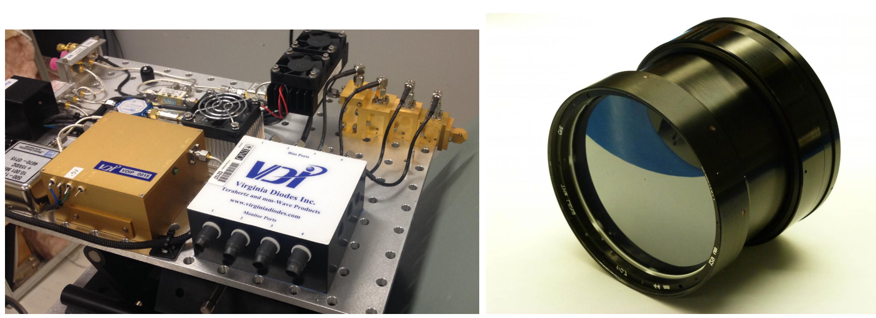

Figure 5. Photographs of diode oscillator with amplifier/multiplier chain (left) and new F/0.7 THz lens barrel (right)

An example of the imaging results using the source at 750 µm is shown in Figure 6. The THz images, taken in transmission were of a musical circuit wrapped within thick paper. The left panel of Figure 6 shows the transmission image using the F/0.95 THz objective and the image in the center panel show the transmission image using the F/0.7 objective. A visible image of the electronic circuit is shown in the right panel of Figure 6. The results show that both images exhibit good quality where details of the circuit and wires can be seen, and that the F/0.7 objective shows improvement over the F/0.95 objective in terms of image clarity and detail.

Figure 6. THz images taken in transmission at 750 μm with an F/0.95 objective (left) and with an F/0.7 objective (center) of an electronic circuit and a visible image of the circuit (right)

As a continuation of the resolution testing, an image of two wires, one 32-gauge (0.3 mm diameter) and one 40-gauge (0.08 mm diameter) was taken at 750 μm with the F/0.7 lens barrel. Figure 7 shows the THz image (left) and a visible image (right) of the two wires that were crossed in the form of an ‘X’. The downward sloping wire is the 40-gauge wire and the upward sloping wire is the 32-gauge wire. The two wires are clearly seen in the THz image, whereas in the visible image the 40-gauge wire is more difficult to see.

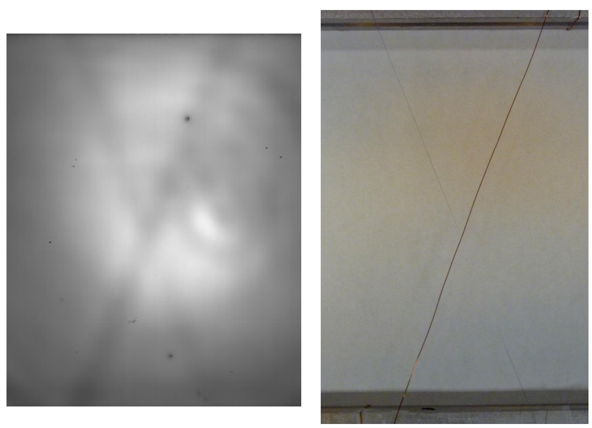

Figure 7. THz transmission image (left) and visible image (right) of two wires in the shape of a ‘X.’ The downward sloped wire has diameter 0.08 mm and the upward sloped wire has diameter 0.2 mm

3. PRELIMINARY LOOK AT APPLICATIONS

Given the good atmospheric transmission of THz radiation at 750 μm, stand-off applications such as remote surveillance and threat detection may be envisaged. In addition, given the good resolution capabilities but deeper penetration depth at 750 μm and the compactness of the imaging system, it is ideally suited for non-intrusive inspection applications. As an initial investigation, different types of plastic laminates were imaged. A perfect example of a plastic laminate is a credit card. Typically the core of a credit card is made of a polyvinyl chloride acetate (PVCA) resin that is mixed with dyes and plasticizers that is then glued with layers of plastic sheets [7]. THz images were taken in transmission of a credit card at 118 μm, 432 μm and 750 μm. These images, shown in Figure 8 (top left, top right and bottom left, respectively) along with the visible image of the credit card (bottom right) show that the material is opaque at 188 μm and 432 μm but at

750 µm, the radiation is able to pass through the credit card. The one exception is the chip that is made of a metallic film, seen as a dark spot in the left side of the 750 µm image.

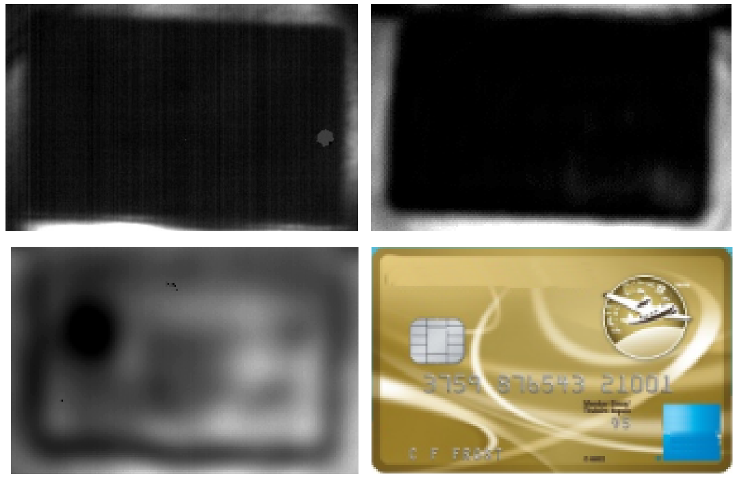

Figure 8. THz transmission images of a credit card taken at 118 µm (top left), 432 µm (top right) and 750 µm (bottom left) using the VDI source with output power 7 mW, and visible image of credit card (bottom right)

Kitchen countertops are often made from plastic laminates. An imaging experiment was performed where a flat aluminum plate, with 5 holes drilled through it with successively larger diameters - 7 mm, 10 mm, 13 mm, 17 mm and 20 mm – was covered with a thin (< 1 mm thick) strip of dark countertop plastic laminate. Figure 9 shows the visible images of the metal plate (top), the strip of plastic laminate (center) and the THz transmission image at 750 µm (bottom). The image shows that at 750 µm, the countertop plastic laminate is transparent to the THz radiation. The image that was taken at a distance of about 2.5 meters also demonstrates the good resolving capabilities of the imaging system, as all 5 holes can be seen.

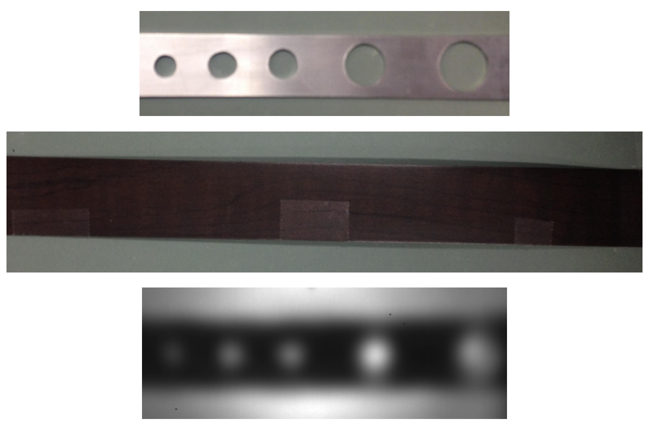

Figure 9. Visible image of a metal bar with a 5 holes drilled out of it (top), visible image of a strip of countertop plastic laminate (center) and transmission image at 750 µm of the metal bar with the laminate covering it (bottom).

Tests were also performed to determine if it were possible to image through flooring materials. Figure 10 shows two types, a 2 mm thick piece of a flexible vinyl floor strip (left) and a rigid 3 mm thick vinyl composite tile or VCT (right). The difference between the two floor samples is that the vinyl sheet is made from 100% polyvinyl chloride (PVC) whereas the VCT is made up of a mixture of limestone, plasticizer and a copolymer of vinyl chloride and vinyl acetate [8]. Figure 10 presents the THz transmission images of the metal bar from Figure 9 and a 24 gauge (0.51 mm diameter) wire partially behind a piece of the flexible vinyl flooring (left) and completely hidden behind the RPVC tile (right). In both cases the 750 µm wavelength radiation is able to pass through the flooring material, although there is some attenuation visible in the image in the left panel of Figure 10, when comparing the uncovered section (right side of image) to the side blocked by the PVC strip (left side of image). The wire is clearly seen as well as the 5 holes of the aluminum bar.

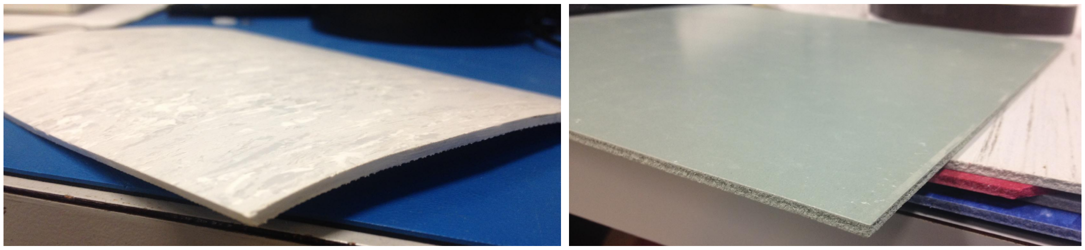

Figure 10. Photographs of a piece flexible vinyl flooring (left) and a rigid vinyl composite tile (right)

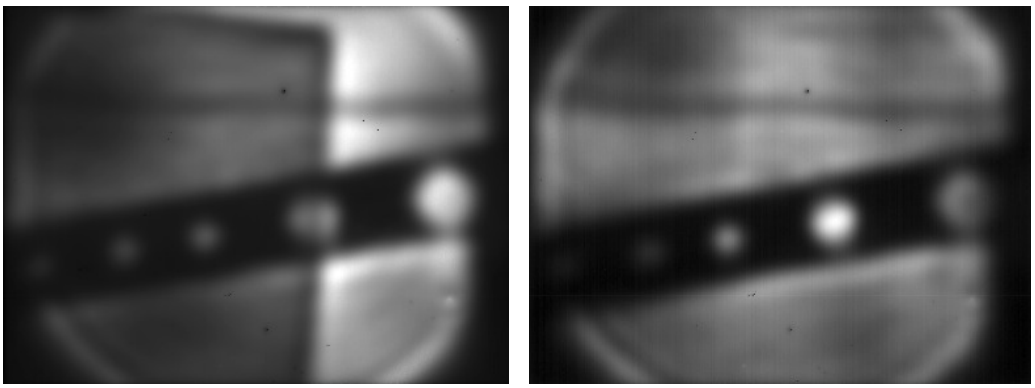

Figure 11. THz transmission images of the metal bar and a 24-gauge wire partially behind a piece of vinyl flooring (left) and completely behind a piece of vinyl composite tile (right)

4. CONCLUSIONS

This paper has presented results of a compact imaging system based on a broadband THz camera core with custom optimized THz objectives and a compact source emitting at 750 µm. The system is able to penetrate through plastic laminate materials and can achieve high resolution, able to image a 40 gauge wire with 0.08 mm diameter. Given its large field of view, it is ideal for large surface real-time imaging and with its excellent transmission through the atmosphere, remote image applications are foreseeable.

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