Video-rate THz Imaging Using a Microbolometer-based Camera

M. Bolduc, L. Marchese, B. Tremblay, M. Doucet, M. Terroux, H. Oulachgar, L. Le Noc, C. Alain, H. Jerominek, and A. Bergeron
INO, 2740 Einstein, Québec, Québec, Canada, G1P 4S4

Abstract— **A THz 160X120 pixel array camera has been developed at INO. Real-time transmission and reflectance imaging at video rates of 30 frames/s were performed with a low-power 3 THz quantum cascade laser. Various hidden objects were imaged, proving feasibility of real-time THz imaging for security screening applications.**

I. Introduction And Background

Real-time imaging of a small metallic utility-knife blade obscured by opaque plastic tape has been previously demonstrated using an uncooled commercial 160X120 microbolometer pixels array camera from Infrared Systems Inc. illuminated with a milliwatt-range 2.8 terahertz (THz) quantum cascade laser (QCL) source[1]. Other real-time transmission-mode THz images of a razor blade obscured by a polyethylene sheet as well as by a FedEx envelope have been published by Hu *et al.*[2] The images were obtained at a video rate of 60 frames/s using a CO_2 gas THz laser and a 160X120 microbolometer pixels array, from BAE Systems Inc., having a vanadium oxide (VO_x) thin-film on top of the detector. Oda *et al.* used a modified uncooled VO_x-based microbolometer focal plane array (FPA), from NEC Corporation, for real-time imaging of laser beam intensity profile using a 10-μW power 3.1 THz QCL source[3]. In the present paper, we demonstrate real-time THz imaging in both transmission and reflection modes by using a modified INO uncooled microbolometer-based camera equipped with a custom fast THz objective that provides high sensitivity and good image quality[4-5]. A metallic absorber film with optimum thickness has been used to maximize the THz absorption.

The THz detectors are fabricated at the INO facility making use of IRM160A 160X120 pixel microbolometer FPA with nominal pitch of 52 μm. The detector FPA is sealed with a high resistivity float zone silicon (HRFZ-Si) window having an anti-reflective (AR) coating consisting of 15 μm-thick Parylene film, which was optimized for 3 THz operation. The additional THz objective consists of two HRFZ-Si aspheric lenses again with an AR Parylene coating on both sides of each lens. In order to account for a displacement of the nominal image plane, a compensation mechanism is used to focus the image of an object at distances ranging from 30 cm to infinity. The unique and compact THz imaging camera developed at INO provides a promising solution for stand-alone imaging systems.

II. Experimental

Transmission and reflectance imaging experiments were performed using a low-average 8-μW power 3 THz liquid-nitrogen cooled QCL laser source (Laser Components GmbH). The emitted 100-μm wavelength laser beam has a large divergence of about 22° propagating over a 13-cm path length, before it is collected and collimated by an off-axis parabolic (OAP) mirror. In transmission mode, the object is placed within the collimated beam path at about 34 cm in front of the camera. The THz beam passes through the object and the f/0.95 objective attached to the camera focuses the transmitted radiation onto the FPA. A long-pass cut-off filter (LakeShore LPF-075-019) is used at the aperture stop of the camera for elimination of the infrared wavelengths below 40 μm. The transmission curve of the long-pass filter is shown in Fig. 1.

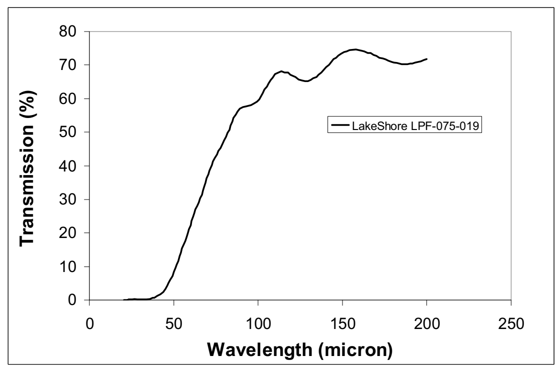

Fig. 1 Transmission curve of the long-pass diffusive filter

In the case of the reflectance mode, a second OAP mirror collects the collimated laser beam and focuses it on the object. The object is placed at the focus point of the illumination system to provide a laser beam spot size of about 0.2 mm in diameter. The obscured object is scanned with an x-y translation stage. The image is then reconstructed point by point using a MatLab routine.

III. Results

Images of the QCL beam are presented in Fig. 2. The QCL beam images have been taken with (a) the THz optimized FPA and (b) a standard infrared FPA. The high level of sensitivity of the THz optimized FPA may be qualitatively seen in Fig. 2. The measured raw data counts from the QCL laser image obtained with the THz optimized FPA camera are on average about 6X higher than for the standard detector.

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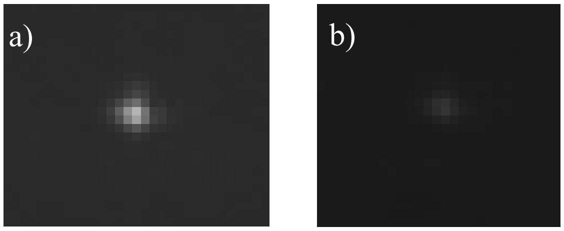

Fig. 2 Image of the QCL beam taken with a (a) THz optimized FPA and a (b) standard infrared FPA.

Transmission and reflectance imaging experiments were performed by placing various metallic and plastic objects as well as an electric cord, obscured by various materials (i.e. newspaper, polyethylene plate, duct tape, Styrofoam, CD case), at about 34 cm in front of the camera. Samples of the resulting images are shown in Fig. 3. The picture of a stainless steel knife blade placed on a 5-mm thick 4×4 cm^2 polyethylene plate used as an obscurant is shown in Fig. 3a). The object may be faced both ways front or back. The THz image obtained without the long-pass diffusive filter (Fig. 3b) may be compared to the one with the filter (Fig. 3c). The difference in the mean intensity of the pixels corresponds to about 40%, which is directly related to the transmission value of the long-pass filter (see Fig. 1). Note that the images obtained are all single snapshot taken from a video sequence at 30 frames/s and have not been image processed, except for the reconstructed reflectance image taken with the long-pass filter (Fig. 3d).

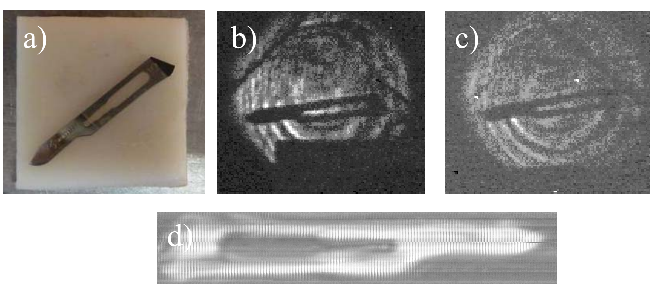

Fig. 3 Stainless steel knife blade obscured by a 5-mm thick polyethylene plate. The picture shows (a) object front of plate. The THz images show in (b) transmission without filter, (c) transmission with filter and (d) reflectance with filter.

The composite image from reflection imaging (Fig. 3d) of the entire razor blade is reconstructed from more than 17,000 scanned image that each represent small sections of the object. Thereafter, the whole image is reconstructed point by point from those sections of 3×2 pixels of 52 μm pitch. The acquisition time of this 263×66 single-snapshot reconstructed image (presented in Fig. 3d) was about 145 minutes, which is limited by the 500-ms waiting time for snapshot and the 10 mm/s traveling time of the x-y translation stage. Note that the low-power QCL laser used in this study can not provide radiation with sufficient power density for imaging with a larger laser beam spot size. However, this preliminary image demonstrates the potential of the THz optimized FPA camera in reflectance imaging.

Various object/obscurant combinations were also imaged in transmission mode using the 3 THz QCL source, such as a plastic knife enveloped in newspaper (Fig. 4a and 4b), while others (presented in a previous work[5]) included a plastic knife within a CD case or wrapped in duct tape, a stainless steel knife blade obscured by Styrofoam, and an electric cord beneath a polyethylene plate. Note that the THz image has been taken without the long-pass filter for better clarity.

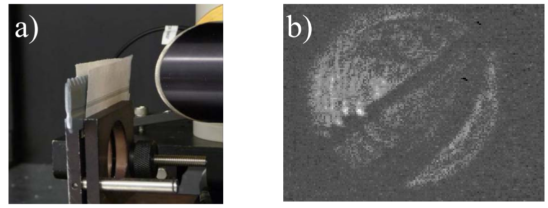

Fig. 4 The picture shows (a) the plastic knife enveloped in newspaper. The THz image shows in (b) transmission mode.

The images shown are all single snapshots taken from a video sequence at 30 frames/s and have not undergone any image processing. They demonstrate the high quality of the THz imaging camera, especially given the low power of the laser source. Fine details can be distinguished, such as the blade edges, even for the plastic knife. Improvements in the image quality are possible. For example, straightforward frame averaging may be performed to reduce the background noise. Meanwhile, methods to reduce the fringes, such as optimized alignment and incoherent averaging schemes are currently being investigated. Finally, the main module of the THz camera composed of a set of electronic boards will be upgraded to the IRXCAM low-noise electronic module that operates at 60 frames/s with random access addressing.

IV. Summary

A THz imaging camera based on an uncooled microbolometer FPA and a custom THz objective optimized for 3 THz radiation has been developed at INO. Successful transmission and reflection imaging using a 3-THz QCL source has been successfully performed. THz images of numerous object/obscurant combinations were captured at video rates and show good quality. It is expected that the current THz imaging system provides a solution for various stand-off screening and detection applications.

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