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Use of 2.7-THz Quantum Cascade Laser and Microbolometer Camera for Imaging of Concealed Objects

Barry N. Behnken, Gamani Karunasiri, Danielle Chamberlin, Peter Robrish, and Jérôme Faist

Abstract—**Imaging in the terahertz regime (0.3-10 THz) is currently conducted primarily through the use of antenna-coupled semiconductor detectors or superconducting bolometers. These detection schemes are often bulky and unable to support real-time imaging due to their dependence upon complex scanning mechanisms. For imaging applications it is desirable to employ focal plane arrays (FPAs) which leads to more compact systems. Microbolometer FPAs, which produce images based on temperature change due to infrared absorption, have a broad wavelength response and, unlike photon-based FPAs, can be operated at room temperature. While advances in microbolometer technology allow real-time imaging in the 7-13 µm wavelength range with high sensitivity, the ability to detect THz radiation with such devices is relatively unknown. In this paper, we report the successful imaging of various objects using a 2.7 THz (110 µm) quantum cascade laser source and optically modified microbolometer camera. Imaging results—produced through single-frame and video recordings of metallic objects obscured by opaque plastic—confirm that this detection scheme allows for high-contrast differentiation between metallic and non-metallic materials, and supports the viability of this method for use in security screening applications.**

Index Terms—**THz, microbolometer, uncooled, quantum cascade laser, imaging, detection, camera.**

DUE to its unique spectral characteristics, radiation in the 0.3-10 THz spectral range has gained recent popularity as a new and potentially powerful medium for next-generation imaging technology.[1-5] Equipped with a proper illuminating source and sensor, THz imaging systems are capable of stand-off imaging of concealed objects and of human body tissue—particularly cancerous growths, which can elude x-ray based imaging detection.[4,5] Such detection agility is due to the fact that THz wavelengths are short enough to provide sub-millimeter resolution capability, but are also long enough to penetrate non-metallic materials.[6,7] Due to a dearth of THz-tuned sensors and sources, however, this frequency range has not been fully exploited to date. Currently, most THz imaging systems are based on either antenna-coupled semiconductor detectors or cryogenically cooled bolometers operating in the scan mode. More recently, the potential use of uncooled microbolometer cameras for THz imaging using quantum cascade laser (QCL) sources has been reported.[8-10] In this paper, we report on the successful use of an uncooled microbolometer infrared camera to image concealed objects using radiation produced by a 2.7 THz quantum cascade laser.

The QCL used in these experiments was fabricated via molecular beam epitaxy (MBE) on a semi-insulating GaAs substrate, and consists of a 200-µm wide by 14-µm thick multiple quantum well (MQW) active region comprised of 120 periods.[11] To mitigate heating in the active region, the laser was nominally operated at a 200-300 KHz repetition rate and a duty cycle of 8-15%. The detection system is a commercially available, uncooled 160x120 pixel microbolometer focal plane array camera (IR-160, Infrared Systems) designed for imaging in the 7-13 µm wavelength range. The pixels are constructed, using conventional MEMS techniques, of a composite film of vanadium oxide (VO_x) and silicon nitride (Si_3N_4) with dimensions 50x50 µm^2. The camera has a dynamic range of 66 dB and noise equivalent temperature difference (NETD) of less than 100 mK with f/0.8 optics. At THz frequencies, calculations indicate that NETD increases to approximately 2 K. The difference in NETD values for these two regimes confirms that external illumination is a necessary prerequisite for successful imaging at THz frequencies.

The speed of the camera is limited by the 10-ms thermal time constant of the individual pixels, allowing operation at 30 Hz TV frame rates. Due to the relatively long wavelengths involved, modifications to the camera's optics were necessary to maximize the amount of THz radiation received by the focal plane array (FPA). Initial measurements using the original germanium lens indicated that an applied anti-reflection coating heavily attenuated the incident THz beam. To correct this deficiency, the Ge lens was replaced with a 1-inch diameter, 20-mm focal length bi-convex lens made of picarin (PPL-1"-20mm-BC, Microtech Instruments). Picarin, which has a transmittance of approximately 65% for radiation oscillating at 2.7 THz, was also used as the source material for the window to the cryostat.

To accommodate the laser's stringent cooling requirements, the QCL was attached to a closed-cycle refrigerator using a copper-based laser mount. The laser was positioned as close to the edge of the cryostat as possible to maximize transmission of the laser beam through the picarin window. External to the cryostat were placed two 50.8-mm

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diameter, 90-degree off-axis parabolic for focusing and steering the beam toward the detector as shown in Fig 1. Both mirrors were gold-plated to allow maximum reflection of the QCL beam and were mounted along the same vertical post to minimize alignment error. Imaging experiments were performed by placing various material types (plastic, paper, metal, cloth and ceramic) between the external parabolic mirrors.

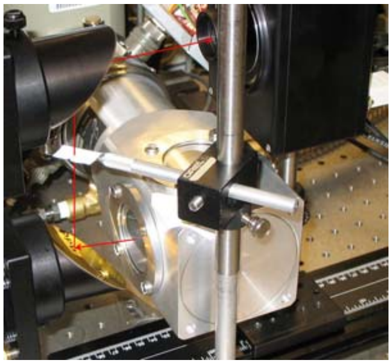

Fig. 1. Optical configuration used for THz imaging. Lower and upper mirrors (50.8-mm and 101.6-mm focal length, respectively) are used to focus and steer the THz beam emerging from the picarin window of the cryostat to the focal plane array of the microbolometer (beam path illustrated by red arrow).

Using the optical arrangement described above, various objects were imaged while wrapped in plastic obscurant. Nominal laser operating conditions for single-frame imaging were, an applied current of 700-800 mA at 300 KHz repetition rate and 15% duty cycle. Figure 2 is representative of the results obtained and demonstrates the methodology used to refine the image quality of a utility knife blade wrapped in opaque plastic tape (Fig 2a).

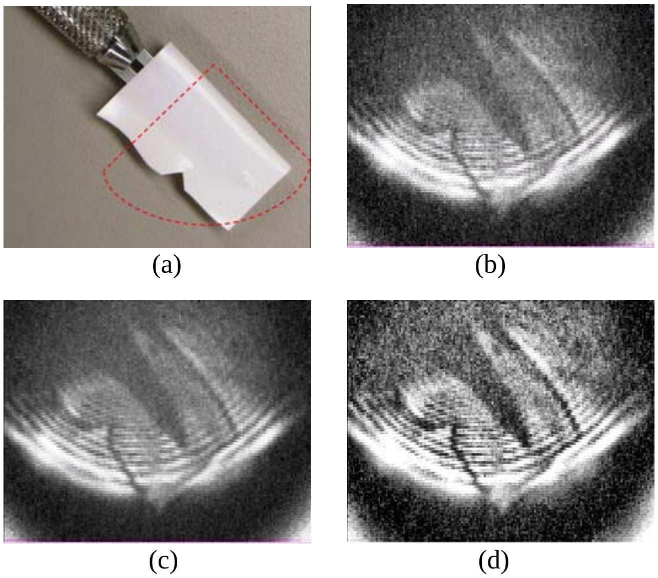

Fig. 2. Imaging of a small utility knife blade wrapped in opaque plastic tape. (a) Conventional digital photograph. Red dotted region represents approximate area of illumination. (b) Single frame image of blade assembly illuminated with 2.7 THz QCL radiation and imaged with microbolometer camera. (c) Image generated by computationally averaging 50 individual frames. (d) Figure 2(c) refined using MATLAB image processing utility software.

While single-frame images provide good contrast between the blade and plastic regions of the combined object (Fig 2b), superior results can be obtained by taking multiple individual images of the stationary ensemble. When image averaging techniques are used to combine these individual frames into a composite image (Fig 2c), variations in the illumination source are mitigated and the imaged object can be seen with greater clarity due to the improved contrast. Finally, using noise reduction software applications still greater contrast can be achieved as shown in Fig 2d.

As previously mentioned, the primary limiting factor to this imaging arrangement is rapid heating of the laser due to joule heating from the input current. Heating effects were mitigated by chopping the 300 kHz driving signal with a 20 Hz gating frequency and slow sweep rate to allow the device to cool intermittently. Due to its intermittent nature, such an illumination scheme is not useful for extended-duration imaging of moving objects. To allow imaging for several continuous seconds, the external gate generator was disabled and input current and duty cycle of the input signal were both appreciably decreased (to roughly 500 mA and 8%, respectively) to mitigate heating effects.

In summary, we have demonstrated the ability to image metallic objects obscured by opaque plastics by using 2.7 THz radiation and a commercially-available microbolometer camera. These results confirm that microbolometer pixel membranes remain absorptive well beyond the 8-14 μm wavelength range, and that uncooled microbolometer cameras hold promise as an inexpensive, compact platform for THz imaging of objects under certain scenarios.

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