Real-Time Imaging using a 4.3-THz Quantum Cascade Laser and a 240×320 Element Focal-plane Array

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Abstract: A real-time reflection/transmission imaging system is demonstrated using a 50-mW, 4.3-THz quantum cascade laser source in a closed-cycle cryorefrigerator, with a 240x320 pixel microbolometer detector. A signal-to-noise ratio of 340 is achieved with a 20-frame/sec acquisition rate.

OCIS codes: (110.2970) Image detection systems; (110.3080) Infrared imaging; (140.3070) Infrared and far-infrared lasers

1. Introduction

Terahertz (0.3 – 10 THz) radiation has several properties that make it attractive for imaging applications: compared to longer wavelength microwaves, higher resolution images are possible; compared to shorter wavelength infrared radiation, terahertz radiation has better penetration of materials such as plastics, clothing and envelopes. Combined with the terahertz spectral signatures of illicit drugs [1] and explosives [2], terahertz imaging might one day be used for real-time screening. For such applications, recently developed quantum cascade lasers (QCLs) are a likely choice of source due to their high output powers of up to ~250 mW [3], broad spectral coverage of 1.9 – 5 THz [3,4], and operating temperatures of up to 164 K [5], compatible with closed-cycle cryorefrigerators. Furthermore, QCLs are dimensionally compact, allowing multiple QCLs, centered at different frequencies, to reside in a single cryorefrigerator for the spectral identification of a sample.

While the feasibility of such a system has been demonstrated using a far-infrared gas laser source [6], in this work we demonstrate a high-power, 4.3-THz QCL source using a differential detection scheme. This laser was grown by molecular beam epitaxy in the GaAs/AlGaAs materials system and is based on the resonant-phonon depopulation design. The device was processed into a semi-insulating surface-plasmon ridge waveguide for high output coupling, resulting in 125 mW of power at 10 K. When operated at 33 K in a closed-cycle, pulse-tube cooler (PT60, Cryomech), the maximum power is reduced to 50 mW for 25% duty cycle. The 4.3-THz frequency is conveniently centered in an atmospheric transmission window, which is calculated to have 95% transmission through a path of 30 cm at 30% relative humidity.

The detector is a commercial 240x320 pixel, uncooled, vanadium oxide microbolometer focal-plane array camera (model SCC500L, courtesy of BAE Systems, Lexington, MA). Though designed for the 7.5 – 14 μm "night vision" wavelengths, this camera has residual sensitivity at the 70-μm (4.3 THz) wavelength due to the broadband absorbing silicon nitride and vanadium oxide materials used in the bolometer elements. When used with the QCL in a differential imaging scheme described below, an average signal-to-noise ratio of 340 is achieved over the whole focal plane with a 20-frame/sec acquisition rate.

2. Experimental Setup

The transmission mode imaging setup is shown in Fig. 1 part (a). The laser is mounted on a copper block in the cryorefrigerator and an f/1, 50-mm diameter off-axis parabolic mirror is used to collimate ~85% of the emerging radiation. The beam is refocused by an off-axis parabolic mirror (f/2) and back-illuminates an object. The transmitted light is imaged by an f/1, 25-mm diameter silicon meniscus lens, through a germanium vacuum window onto the focal-plane array. The illuminated area in the object plane is roughly 3x3 cm^2, limited by the diameter of the first off-axis paraboloid. Also shown in Fig. 1 is the modified reflection mode setup. In this mode a specular reflection from the object is collected by the repositioned silicon lens.

The 60-Hz (16.6-ms/frame) frame rate of the camera allows for a simple differencing scheme to reduce $1/f$ noise, and the infrared background present in the scene. The differencing procedure is done over 3 frames and begins with the terahertz radiation applied during the first frame. During the second frame, the microbolometers are still warm from the THz radiation, and their values are discarded. By the third frame, the microbolometers have had adequate time to cool, and this frame is subtracted from the first frame, resulting in a differential image. Because $1/f$ noise and slow moving thermal imagery are relatively constant from frame to frame, they are effectively canceled by this scheme, leaving only the terahertz signal.

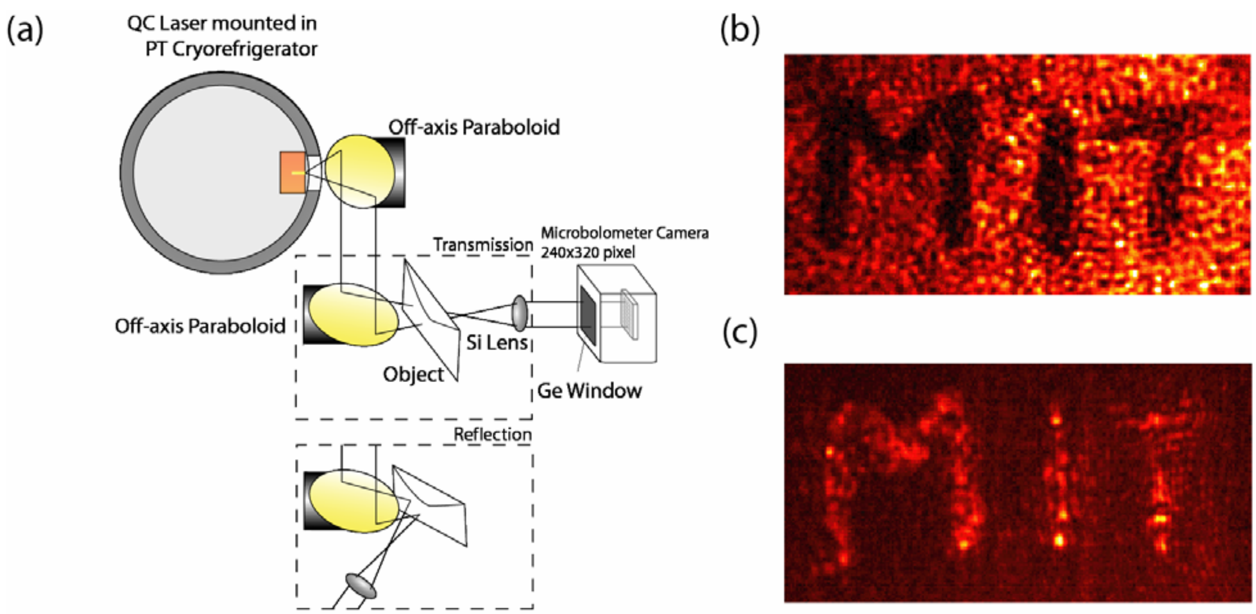

Fig. 1. (a) Experimental Setup: The QCL mounted in closed-cycle, pulse-tube cryorefrigerator operating at 33 K (QCL is depicted as a small bar). THz beam is collected and focused with off-axis paraboloid mirrors, f/1 and f/2 respectively. The THz illuminated object is imaged by silicon meniscus lens (f/1, 25-mm diameter) onto the microbolometer focal plane array. Cutaway depicts alternate reflection mode setup. “MIT” letters written on the inside of a paper security envelope as seen in transmission mode (b) and reflection mode (c).

3. Terahertz Images

A typical image obtained in transmission mode is shown in Fig. 1 part (b). It is composed of the letters “MIT” written in pencil on the inside of a paper security envelope. The image shows a single differential frame of the terahertz acquired in 50 ms. The same image is shown in reflection mode in Fig. 1 part (c). In this image a 20-frame average is shown due to the weaker reflected signal. While these still images are recognizable, when they are viewed in real-time the integration of the eye and pattern recognition of the brain aid tremendously, making more impressive demonstrations of possible screening applications.

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