# Real-time, continuous-wave terahertz imaging by a pyroelectric camera

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Real-time, continuous-wave terahertz (THz) imaging is demonstrated. A 1.89-THz optically-pumped far-infrared laser is used as the illumination source, and a 124 × 124 element room-temperature pyroelectric camera is adopted as the detector. With this setup, THz images through various wrapping materials are shown. The results show that this imaging system has the potential applications in real-time mail and security inspection.

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Terahertz (THz) imaging has attracted considerable attention since its demonstration by Hu and Nuss for its various applications[1−3]. Because of the lack of coherent sources and detectors, most THz imaging systems are based on the scan of samples to be imaged in two dimensions, which limits the acquisition time of an image[4−7].

Real-time, continuous-wave (CW) THz imaging was previously demonstrated by Lee[8]. In this system, a far-infrared (FIR) gas laser with 2.52-THz frequency and 10-mW average power was employed as the source. And a room temperature microbolometer focal-plane array camera (SCC500L, BAE Systems) was used. This kind of camera was designed for the wavelength range of $7.5 - 14$ $\mu$m, though the camera is sensitive at terahertz, the optical efficiency is unknown. They also used a 4.3-THz quantum cascade laser (QCL) as an illumination source for real-time imaging with a 320 × 240 element microbolometer focal-plane array detector[9,10]. However, this QCL laser must operate in a cryorefrigerator, and is not convenient. In this letter, real-time CW THz imaging by a pyroelectric camera is presented, and this is to our knowledge the first reported use of this thermal imaging camera in real-time THz imaging.

An optically-pumped FIR laser is used as the THz source. This laser system consists of a grating-tuned $CO_2$ laser ($9 - 11$ $\mu$m) to pump the FIR laser. Tunable pump radiation is admitted into the FIR cavity filled with various vapor such as $CH_3OH$, $CH_2F_2$ and $CD_3OH$, and THz radiation with different frequencies is generated. Average output power ranges from a few milliwatts to $>$ 100 mW depending on the output frequency.

The detector is a pyroelectric camera (Pyrocam III) with high performance. The camera contains 124 × 124 element array of detectors, spaced at a pitch of 100 $\mu$m and the active area is 12.4 × 12.4 (mm). Each detector consists of a rugged $LiTaO_3$ pyroelectric crystal mounted with indium bumps to a solid-state readout multiplexer. Light impinging on the pyroelectric crystal is absorbed and converted to heat, which creates charge on the surface. The multiplexer then reads out this charge onto the video line, and real-time imaging is detected. The camera has the wavelength range from 1.06 $\mu$m to over 1000 $\mu$m ($\sim$ 0.3− $>$ 300 THz). When it operates in the THz frequency-range, a polyethylene (PE) window is installed, which is not transparent in visible and near-IR spectral range and can be used as a filter[8,11]. To operate with CW laser, this camera has an internal chopper with 48-Hz chop rate, in this case the sensitivity is 3.2 mW/cm$^2$ and the saturation power is 3.2 W/cm$^2$. The signal-to-noise ratio (SNR) is about 60 dB.

The schematic of the imaging system is shown in Fig. 1(a). The THz laser uses $CH_2F_2$ as active medium and emits radiation at 158.51 $\mu$m (1.89 THz) with 70-mW average power. Using the pyroelectric camera and a high-density polyethylene (HDPE) lens (focal length 25 cm), the far-field output spatial mode is obtained, as shown in Fig. 1(b). And we measure the $M^2$ factors in $x$ and $y$ directions, which are about 2.3 and 2.6, respectively. The result shows the good beam quality. After output from the THz cavity, the THz laser beam backlights the object to be imaged with an area of roughly 1 × 1 (cm).

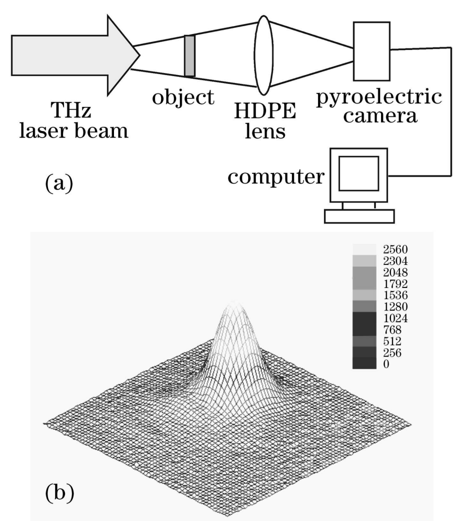


Fig. 1. (a) Schematic of the THz imaging setup and (b) THz beam spatial mode.

 

The transmitted light is collected by a HDPE lens, and imaged on the pyroelectric camera. The HDPE lens is homemade with a focal length of 50 mm, the insertion loss at 1.89 THz is about 2.7 dB.

The feasibility of this transmission imaging mode is demonstrated by Fig. 2, which shows white-light and THz images of the watermark of a banknote covered by a piece of paper. Figure 2(a) is the white-light picture of the test object. Figure 2(b) shows a single frame of the THz image, and the character “5” is evident. In order to decrease the noise, 10 frames of THz images are averaged, as shown in Fig. 2(c). As human eyes are more sensitive to moving objects, the real-time image on a monitor is more impressive than the still images of Figs. 2(b) and (c). The interior features of “5” is clear, as shown in Fig. 2(c), demonstrating good resolution capability. Figure 2(d) shows the part of watermark of narcissus, which is also clear.

THz wave can penetrate mail envelopes and wrappers,

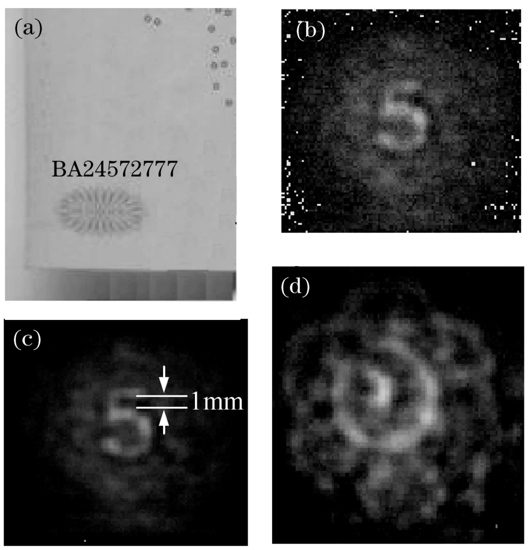


Fig. 2. Images of the watermark of a banknote. (a) White-light image; (b) a single frame of THz image of watermark “5”; (c) image averaged over 10 frames; (d) THz image of the watermark of narcissus.

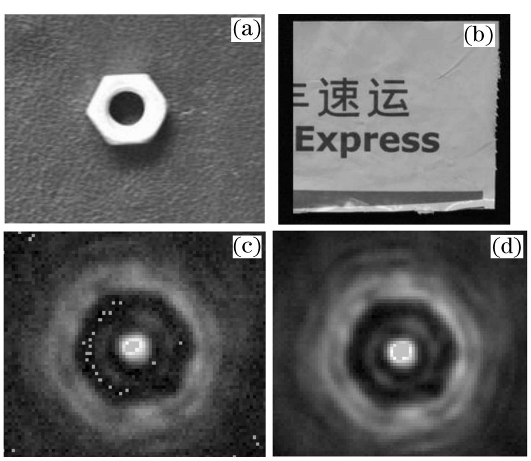


Fig. 3. THz imaging of a nut in an express bag. (a) White-light image of the nut; (b) sample of an express bag (PE material); (c) THz image of a single frame; (d) THz image averaged over 10 frames.

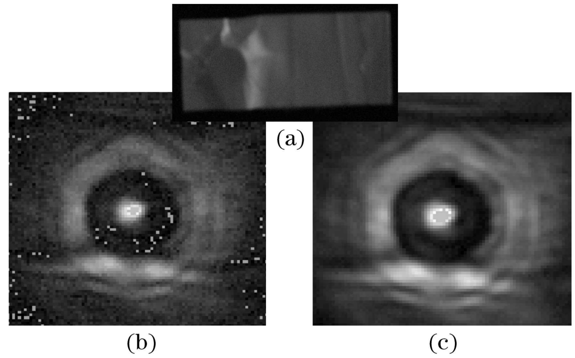


Fig. 4. THz imaging of a nut wrapped in tape. (a) Sample of a nut wrapped in tape; (b) THz image of a single frame; (c) THz image averaged over 10 frames.

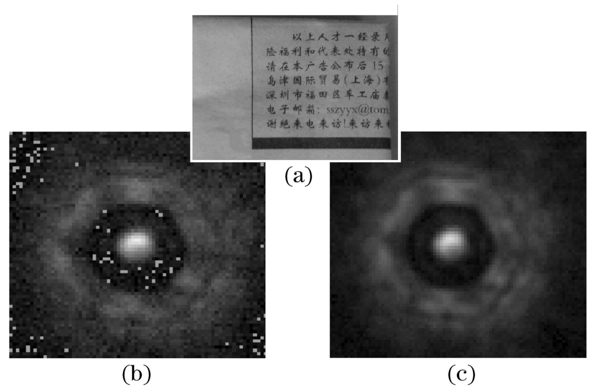


Fig. 5. THz imaging of a nut wrapped in newspaper. (a) Sample of a nut wrapped in newspaper; (b) THz image of a single frame; (c) THz image averaged over 10 frames.

and is a promising security technology. Figure 3 is a demonstration of THz imaging to detect metal. A nut of M6, shown in Fig. 3(a), is wrapped in a PE express bag, as shown in Fig. 3(b). The transmission through one sheet of the bag at 1.89 THz is about 0.91. Figure 3(c) shows a single frame of THz image. The silhouette and the hole are distinct. Fringes around the hole and the nut are due to diffraction effect. An average image of 10 frames is presented in Fig. 3(d), the noise is greatly eliminated.

Other wrapping materials in common use are researched. Figures 4 and 5 show the THz imaging of the nut in tape and newspaper respectively. The transmission of the tape and newspaper at 1.89 THz are about 0.91 and 0.65 respectively. The figures also show a single frame of the image and an average image of 10 frames. In Fig. 4, even the crease of the tape is identifiable.

In conclusion, a real-time THz imaging system based on 1.89-THz optically-pumped FIR laser and a $124 \times 124$ element pyroelectric camera is demonstrated. This is, to our knowledge, the first use of this thermal imaging camera in real-time THz imaging. THz imaging results show that it is a promising technique for application in mail and security inspection. Further researches are being made on improving the performance of this imaging system. The THz beam should be collimated to compensate its high angular divergence. The imaging area is about $1 \times 1$ (cm), which is small for most applications. So the beam should be expanded, the imaging system should be improved, or we can combine the scan imaging with this real-time imaging camera. Software of image processing is researched to improve the imaging quality. How to improve the SNR and spatial resolution is our next aim.

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