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Real-time continuous-wave imaging with a 1.63THz OPTL and a pyroelectric camera*

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Real-time continuous-wave terahertz imaging is demonstrated with a 1.63 THz (184.31μm) optically-pumped terahertz laser (OPTL) and a 124 × 124 element room-temperature pyroelectric camera. Transmission-mode THz imaging is presented for the samples hidden in various wrapping materials. These experimental results reveal the possibility to construct a simple real-time THz imaging system applied to nondestructive inspection.

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Terahertz (THz) imaging has become a rapid expanding research field since its first demonstration by Hu and Nuss[1]. The property that many materials which are opaque to visible and infrared light are transparent to THz radiation[2] makes it a novel nondestructive testing technology and safety inspection techonology. Unlike pulse THz imaging, continuous-wave (CW) THz imaging usually yields only intensity data and does not provide any depth, time-domain or frequency-domain information. However, the transmitted energy is sufficient for most imaging applications. In the exchange for the loss of plentiful information, CW imaging offers a compact, simple and fast system[3-5] .However, because of the lack of powerful coherent sources and multielement detectors, most THz imaging systems are based on the scan of samples in two dimensions, which limits the acquisition time of an image[6-8]. Usually it at least takes minutes to acquire a complete image. Real-time CW terahertz imaging was previously demonstrated by Lee and Hu[9,10]. In this setup, high-speed terahertz imaging at the video rate of 60 frames/s was achieved with a 10 mW, 2.52 THz (118.8 μm) far-infrared gas laser and a 160 × 120 element microbolometer focal-plane array camera (SCC 500 L, BAE Systems). However, the microbolometer camera is designed for the wavelength of 7.5-14 μm, though it retains sensitivity at terahertz, its optical efficiency is unknown.

We reported real-time continuous-wave THz imaging by use of a pyroelectric camera and an optically-pumped terahertz laser (OPTL)[11], but the imaging size was small. In this letter, the imaging system is improved and a more stable pump line is applied. Transmission mode THz images of samples through various wrapping materials in common use are demonstrated, and clear real-time CW THz images are achieved. The best advantage of this THz imaging system is its ability of real-time imaging.

An optically-pumped far-infrared laser (Coherent Sifir-50 FPL) is used as the THz source, which is an integrated far infrared (FIR) laser system with a thermally-stabilized Fabry-Perot reference pump-frequency lock to generate good beam pattern. It consists of a grating-tuned CO_2 laser (emission in 9 - 11 μm) to pump the FIR laser. The 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. The output power ranges from a few mW to over a hundred of mW depending on the output frequency.

The detector is a pyroelectric camera (Pyrocam III) with high performance. The camera consists of a 124 × 124 element array of detectors that are spaced at a pitch of 100 μm and the active area is 12.4 mm × 12.4 mm. The detector material is $LiTaO_3$, which has the wavelength range from 1.06 μm to over 1000 μm (~ 0.3 THz-300 THz). When it operates in the THz frequency-range, a polyethylene window is installed. To operate with CW laser, this camera has an internal chopper with a 48Hz chopping rate, and the sensitivity is 3.2 mW/cm^2.

Fig.1 shows the schematic diagram of the imaging system. In this experiment, THz laser uses CH_2F_2 as active medium and emits radiation at the wavelength of 184.31 μm (1.63 THz). This line is used for its high stability and high output

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power. In the experiment, the average output power is about 60 mW. The THz beam is collected by a polished Picarin lens-Lens1 (Microtech, *f* = 10 cm) and backlights the object. Then the transmitted light is collimated by another Picarin lens-Lens2 with the focal length of 5 cm and imaged on the pyroelectric camera. At the frequency of 1.63 THz, the insertion losses for Lens1 and Lens2 are about 0.8 dB and 1.9 dB, respectively. The distance between Lens1 and Lens2 is fixed to collimate the incident light on the camera. The position of the object, Lens2 and pyroelectic camera should meet the law of imagery.

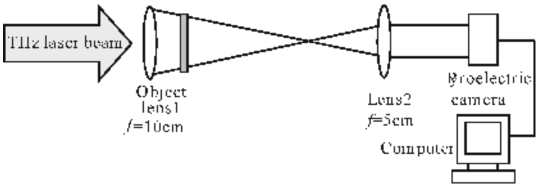
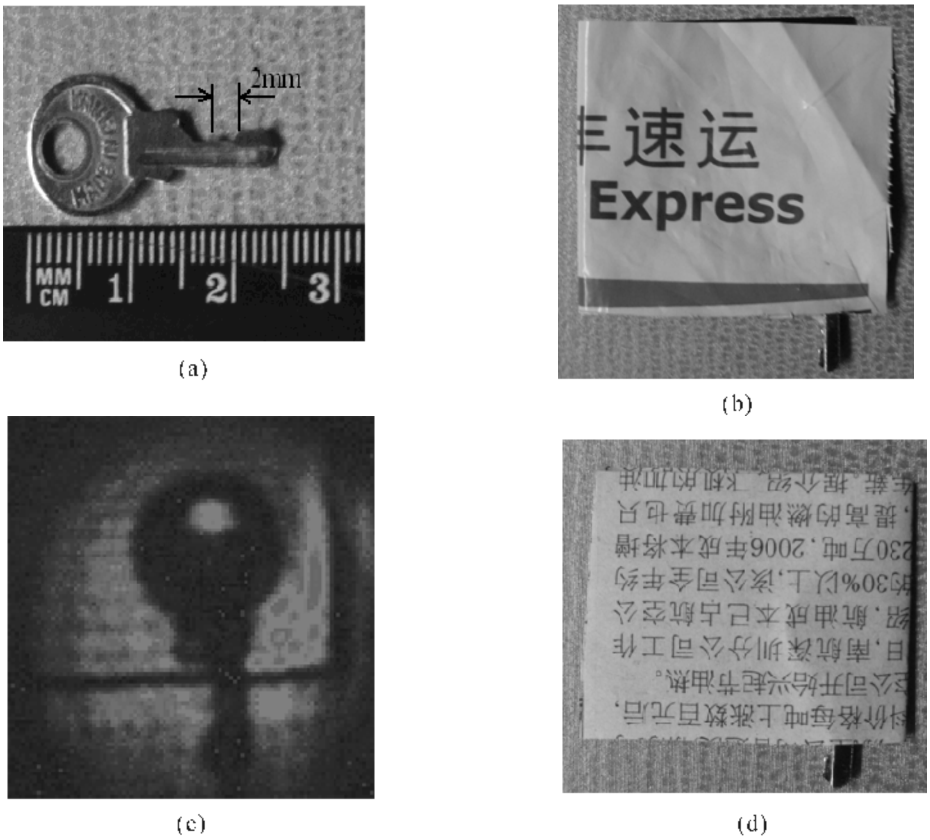
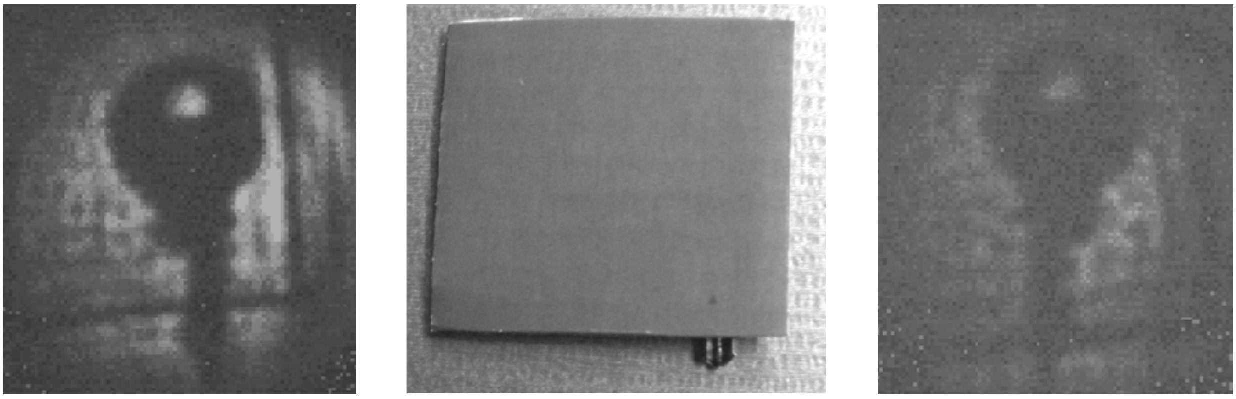


Fig.1 Schematic illustration of the experimental setup.

As a carrier wave is used for non-destructive inspection, its loss in the medium should be low, thus it can penetrate the medium carrying information about the medium. Because there should be some loss in the medium, the imaging has enough contrast. THz wave can penetrate mail envelopes and wrappers, and it is a promising security technology. To test the potential of this THz imaging system for non-destructive inspection, especially for mail inspection, THz imaging through various wrapping materials in common use is studied. Fig.2(a) shows the white-light picture of the tested sample: a steel key which is about 25 mm in length. Fig.2(b) shows a picture of the same key partially wrapped in a PE express bag, the insert loss of one sheet of the bag at 1.63 THz is about 0.7 dB. Its THz imaging is presented in Fig.2(c). The silhouette and features of the key can be clearly seen, as well as the edge of the bag. Here, in order to reduce the ground noise, 10 frames of real-time video are averaged. The features in the key of about 2 mm are resolved. According to the Rayleigh criterion $\theta \approx 1.22\ \lambda/\mathrm{d}$, at the object plane, the limited resolution is calculated as about 1.6 mm. So the resolution of the system is good. The fringes in the imaging are due to the diffraction effect of the edge of the bag.

The sample is also wrapped in a piece of newspaper as shown in Fig.2(d), and partially obscured by a piece of cardboard as shown in Fig.2(f). Losses at 1.63 THz of one sheet of newspaper and cardboard are about 1.2 dB and 7 dB, respectively. In Fig.2(e), the key is distinct, as well as the edge of the newspaper. However, the THz imaging shown in Fig.2(g) is not so evident for the higher loss of the cardboard. since human eyes are more sensitive to moving objects, the real-time image on a monitor is more impressive than the still image here.

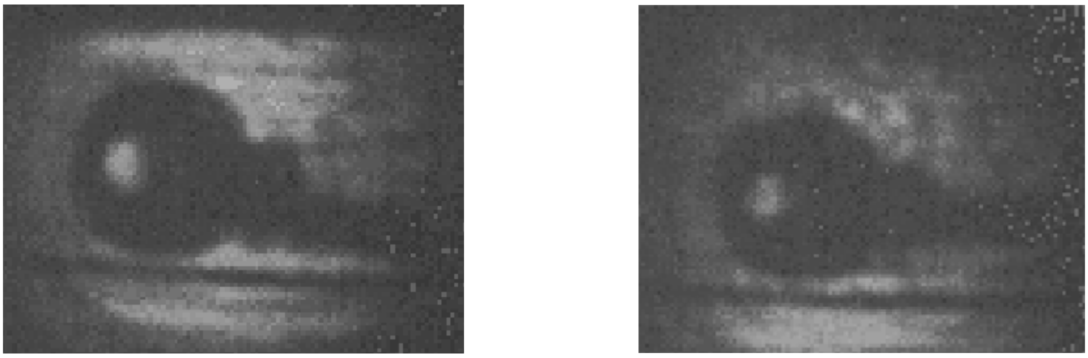




(e) (f) (g)

Fig.2 White-light and THz images of a key. (a) the white-light image of the sample, (b) the white-light image of the sample partially in an opaque PE bag, (c) the THz image of (b), (d) the white-light image of the sample partially in a piece of newspaper, (e) the THz image of (d), (f) the white-light image of the sample partially obscured by a piece of cardboard, (g) the THz image of (f).

Fig.3 shows the THz images of the key inside two envelopes of different material, one is made from white paper, the other is from brown paper, as shown in Fig.3 (a) and Fig. 3 (b), respectively. From Fig.3(a) and (b), the key is identifiable, but the loss of the sheet of brown paper, about 2.5 dB, is higher than that of the sheet of white paper, about 2.1 dB. So the key in Fig.3(a) is clearer than that in Fig.3(b).



(a) (b)

Fig.3 THz images of the sample in different envelopes. (a) in an envelop made from white paper, (b) in an envelop made from brown paper.

During the above research, the environmental humidity is above 60%, and THz absorption by the water vapor is intense, which affects the intensity and the diameter of THz beam during its propagation. In our experiments, the diameter of THz radiation on the samples is not so large, about 2.5 cm, which restricts the imaging size. In order to expand the imaging area, the system should be enclosed in a box which is purged with dry nitrogen. To improve the performance of this imaging system, we are considering on the combination of the scan imaging with this real-time imaging. The software of imaging processing is on programming to improve the imaging quality. The THz source is a tunable laser, the next step we will take advantage of it. The comparison of THz imaging at various frequencies will give more interesting information about the test sample.

In conclusion, a real-time THz imaging system based on a 1.63 THz optically-pumped far-infrared laser and a 124× 124 element pyroelectric camera is presented. Transmission mode THz images with good spatial resolution are demonstrated with steel keys wrapped in usual wrapping materials and inside common envelopes. The key advantage of this CW THz imaging system is its simplicity and high speed. The results show that this system is promising for real-time mail inspection and security inspection.

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