A Continuous-Wave THz Imaging System

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Abstract

We develop a continuous wave terehertz (THz) imaging system operating at 288 GHz. This imaging system simply consitutes three parts including the source, two optical lenses, and the detector. The entire size is smaller than the tranditional pulsed THz imaging system. In this developed system, the THz wave is generated by a horn attenna which concentrates the wave in an azimuth angle of 3° ~ 5°. The source originates from a singnal generator, and then the frequency increases to 288 GHz after passing through an 8X multiplier. Next, THz wave is focused by a THz lens on the test sample. By controling the sample position in the *x-z* plane, we can scan it pixel-by-pixel in which each step along the *x*- or *z*- axes is 0.1 mm. After penetrating the test sample, another lens collects the transmitted THz wave and focuses them into the thermal detector. This detector can disply the collected THz power. Finally, by drawing the detected power of each pixel, a transmitted-intensity figure for all pixels is obtained. The resolution of this THz imaging system is about 1~2 mm at present. We have measured human molar tooth and obtained its transmitted figures. Besides, we also develop a technology to adjust the positions of the source and detector by a system containing one laser, one beamsplitter, and two mirrors. The relative positions between the source and detector is very important. The input of the source and the output of the detector are small so that they have to aim at each other very accurately in order to collect maximum transmitted power in the detector.

Key Words: THz wave, Imaging system

1. INTRODUCTION

The terahertz (THz) wave is one kind of the electromagnetic wave from 300 GHz to 3 THz. Comparing to X-ray, it benefits the realization of the invasively medical detection owing to its much lower energy. By using the characteristic that different organizations have different absorptions, one can obtain the transmitted imaging after the THz wave passes through the target and scans it pixel-by-pixel. Traditionally, the femtosecond laser combine with optical mirrors, lens, and beam splitters to form a huge THz system [1-12]. Then the pulsed THz wave is produced to detect the target and form an imaging eventually. It is a very direct method to obtain the 2D THz imaging by collecting the transmitted power. Although the 3D imaging applications have been reached by measuring the time of flight of reflected pulses in a reflection-mode THz tomography system [3], and by measuring the amplitude and phase of transmitted pulses in a THz computed tomography system [8], both the system sizes are large and hard to minimize. It is the fact that the pulsed THz wave imaging system includes several parts, and some of them are hardly reduced in size. In some applications such as the biochip, the pulsed THz imaging system is not an appropriate consideration.

Recently, the continuous-wave THz imaging systems were reported [13-23]. The continuous-wave system is relatively simpler than the pulsed system. Most of these reports used the optoelectric generation to produce continuous THz wave by mixing the visible and infrared lasers in photoconductive antennas. In a certain degree, the continuous-wave system is the progressive one from the pulsed system. Unlike the pulsed system, the source includes two light beams with different frequencies. The detector or the photomixer generates the photocurrent which can induce the detector power [14,15,18,23]. However, the continuous-wave THz imaging system is still a little complicated and has to be simplified. In this paper, we purpose a much simpler continuous-wave THz imaging system which contains the source, the detector, and two focal lenses. We also show two imaging demonstrations.

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2. A CONTINUOUS-WAVE THZ IMAGING SYSTEM

In our continuous-wave THz imaging system, it can be divided into four parts including the source, the focal lenses, the detector, and the alignment. The schematic figure is shown in Fig. 1. The source, the focal lenses, and the detector must be set on a line in order to collect the maximal power. If these three parts have a little deviations, the collected power will decrease sharply. The alignment is very important for this system. In our system, both the source and detector are horn antennas. Their open ports are only about 0.36 cm^2. When the distance between the source and detector increases, the dislocation easily exists and has to be overcame. We adopt a visible laser system including the beam splitter and a mirror to align the source and detector.

Nowadays, there are several commercial continuous-wave THz sources. In our system, we adopt the products from Agilent Technologies Ltd. and Virginia Diodes Inc. (VDI). First, the signal generator with the product type E8257D from Agilent Technologies Ltd. is used. This signal generator can transmit 250 KHz to 67 GHz signal. Next, the signal from E8257D is transmitted to a VDI module, AMC 307, and then the signal frequency is multiplied by this module to a higher frequency. This module is shown in Fig. 2(a), where a horn antenna combined with a cascade consists of three waveguides is shown in Fig. 2(b). The horn antenna radiates the continuous THz wave as the source for this imaging system. Types for three waveguides are all WR 3.4, of which the operating frequency is within 220 to 325 GHz. The function of each waveguide can produce frequency 2 times of the input frequency, so three waveguides output the frequency 8 times as large as the initial one. The initial signal frequency is 36 GHz, and the frequency and the wavelength at the source port are 288 GHz and 1.04 mm, respectively. The reason for this choice is that the maximum output power of this module in its operating frequency region is 288 GHz.

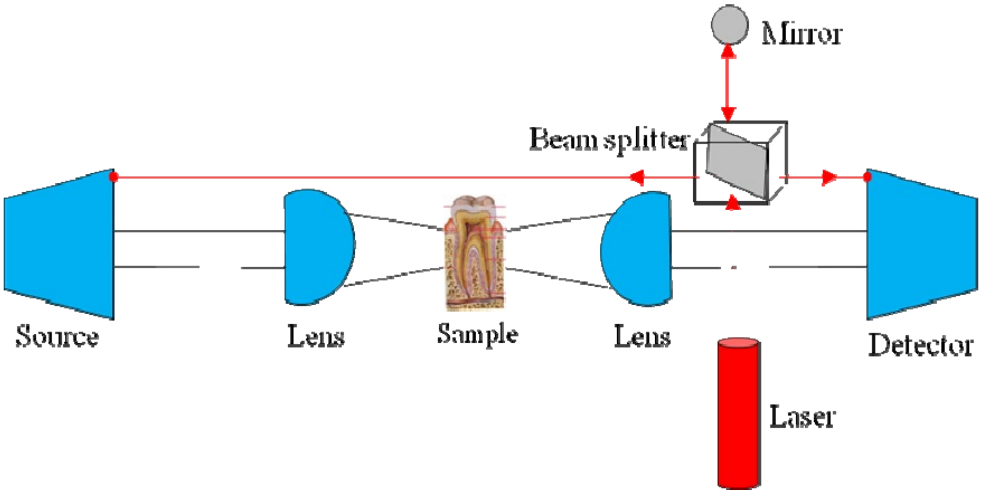
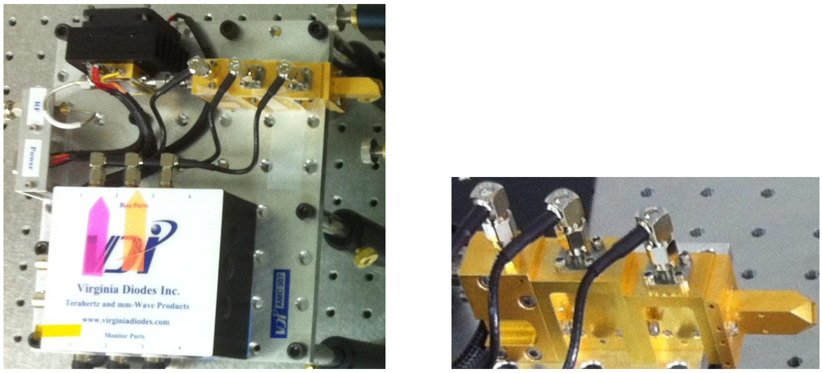


Figure 1. The schematic figure for the continuous-wave THz imaging system and a visible laser system for aligning the source and detector.

Before setting up the lenses into the system, we have to align the positions of the source and detector. As mentioned before, the dislocation will affect the imaging quality, so two open ports of the source and detector need to aim at each other very accurately. We use a visible laser to align the source and detector as shown in Fig. 3. Light from a green laser is divided into two beams by the beam splitter, one is toward the detector, and the other is reflected by a mirror and then redirected to the source by the beam splitter. If one beam along the horn antenna at the source port is parallel to another beam along the horn antenna at the detector port, the source and detector are aligned and aim at each other. We use the edges of two horn antennas at the same side as the reference. The experimental data tell us that this method carry out the alignment very well. A demonstration of the alignment is shown in Fig. 3. Two light beams toward the source and detector are parallel to each other. After finishing the alignment, the focal lenses can be put into the space between the source and detector.



(a) (b)

Figure 2. (a) AMC 307 module form VDI. (b) The horn antenna combined with a cascade consists of three waveguides.

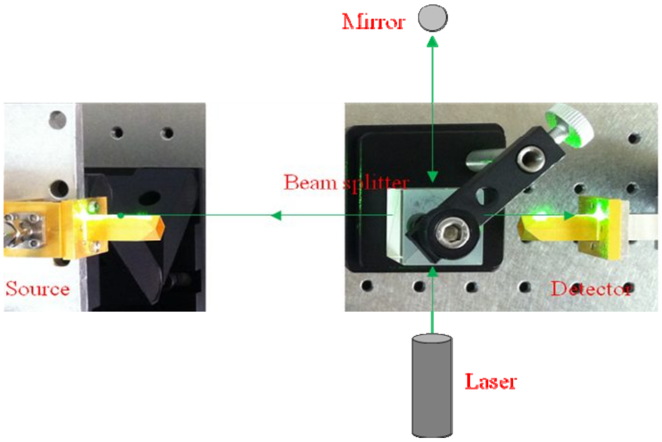


Figure 3. The alignment system by using the visible laser, the beam splitter, and a mirror.

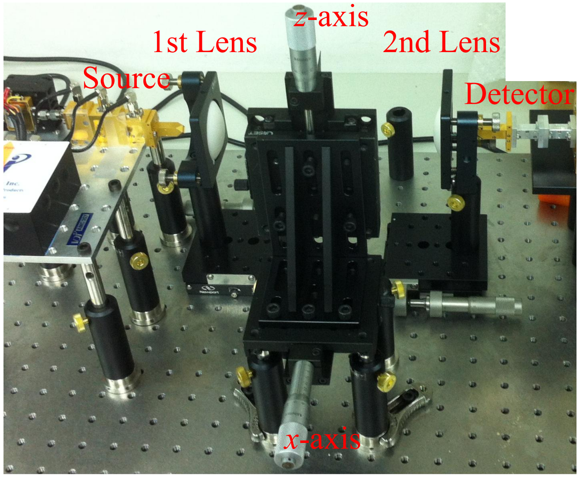


Figure 4. The THz imaging system with two focal lenses.

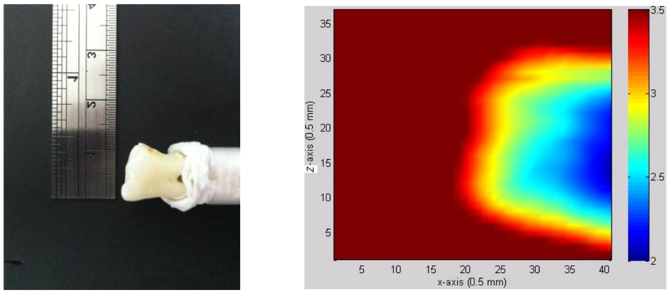
The THz wave radiated from the source port has an azimuth angle of 3° ~ 5°. If the distance between the source and detector, a lot of power will be recieved by the detector in realization. In order to increase the detected power, a lens system is needed. It includes two lenses, one collects the THz wave and focuses the THz wave on the sample, and the other collects the THz wave from the sample and then transmits the THz wave into the detector. Two lenses are the TPX lenses with the focal length of 100 mm. The sample is put at the middle axis of two lenses, and the stage carrying the sample can shift parallel the axis of two lenses (*x*-axis) and perpendicular to the axis (*z*-axis). When taking an imaging, the stage slowly moves along the *x*- and *z*- axes. Then we obtain a pixel-by-pixel image. Theoretically speaking, the smaller the size of each pixel, the more accuracy imaging we obtain.

After finishing the alignment of the source and detector and adding two focal lenses, the continuous wave THz imaging system is set up. The imaging process is simply described as follows. The THz wave is radiated from the source and collected by the first lens and then focus on the sample. After the THz wave passes the sample, the second lens collects it and transmits to detector. The transmitted power collected by the detector is read by a power meter as shown in Fig. 5. The power meter is also the VDI product whose type is Erickson PM4. It can detect the THz power to the lowest value of 1μW, and to the largest value of 200 *m*W.

Figure 5. The power meter for detecting the transmitted power.

3. A DEMONSTRATION OF THE THZ IMAGING

After setting up the continuous-wave THz imaging system, a human molar tooth as shown in Fig. 6, is taken as the sample to demonstrate the THz imaging. The sample is put on the stage at the middle of two lenses. By scanning the sample pixel-by-pixel, we obtain the THz imaging by recording the transmitted power of each pixel. Each pixel size is $(0.5)^2$ mm, and the total number of pixels is 41×37=1513. The scanning THz imaging is shown in Fig. 6(b), and the color bar is also shown at the right with the unit of *m*W. The color displays different transmitted power, and the transmitted power increases gradually from blue to red. Investigation the right half part of Fig. 6(b), the light red corresponds to the enamel with the thickness about 1.0 mm. The yellow region corresponds to the dentin, which is about 1.5~2.0 mm. The blue region is the place deep inside the tooth, where the transmitted power is relatively lower. According to this THz imaging, the resolution is about 1~2 mm.



(a) (b)

Figure 6. (a) A human molar tooth as the sample. (b) The THz imaging of (a).

4. SUMMARY

We displayed a continuous-wave THz imaging system and demonstrated an imaging of a human molar tooth. By investigating the distribution of the transmitted powers, different layers of the tooth can be resolved and the resolution is about 1~2 mm. We also developed a method to align the source and detector. Reducing the dislocation between the source and detector helps us to obtain more high quality THz imaging. Because our continuous-wave THz imaging system is much simpler than the traditional pulsed-wave THz imaging system, it is possible to design a much smaller system that the source, the lenses, and the detector are all small.

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