A Terahertz Imaging System with Rotation Mirror

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Abstract

In this article, a THz imaging system with rotation mirror is built. The system considers both imaging speed and cost of hardware. The transmission-mode design realizes miniaturization of the system. With the system, we are able to acquire image size of $60 \times 80 \text{ mm}^2$ in 60 seconds, while a raster-scan THz imaging system with the same hardware conditions needs more than 30 minutes. Moreover, internal information of object could be got with the THz imaging system reported in this article.

Keywords

Terahertz, Imaging, Nondestructive Testing, Rotation Mirror

1. Introduction

Terahertz (THz) radiation is a kind of electromagnetic radiation located in a specific wave band. The specific wave band, locating between the microwave and infrared frequencies, is from $10^{11} \text{ Hz}$ to $10^{13} \text{ Hz}$ [1]. Terahertz radiation has an ability to penetrate many materials, such as foam [2], ceramic [3], magnetic material [4] and polymer composites [5] and so on. Therefore, THz technology has been widely used in non-destructive testing as an established powerful tool [6] [7] [8]. THz applications in such fields as pharmaceutical solid dosage forms [9], dental tissues [10], coating layers [11] [12] [13] [14], glass fiber [15], painting on canvas [16], corrosion under metallic source material [17] et al. have proved to be significant scientific and practical. With the development of THz technology, research for THz spectroscopy and imaging is held on a large scale [18] [19]. However, imaging speed and cost of hardware are contradictory in THz imaging. While the terahertz camera is expensive, the imaging speed of raster-scan THz imaging system is slow. In this paper, a THz imaging system with rotation mirror is built. The system considers both imaging speed and cost of hardware. The transmission-mode design realizes miniaturization of the system. With the system, we are able to acquire image size of $60 \times 80 \text{ mm}^2$ in 60 seconds, while a raster-scan THz imaging system with the same hardware conditions needs more than 30 minutes. Moreover, internal information of object could be got with the THz imaging system reported in this article.
mirror is built. The system is an effective THz imaging system, considering both speed and cost. The transmission-mode design miniaturizes the system. With the system, we are able to acquire image size of 60 × 80 mm² in 60 seconds, while a raster-scan THz imaging system with the same hardware conditions needs more than 30 minutes. Moreover, internal information of object could be got with the THz imaging system.

2. General Setup
2.1. Diagram of the System

Diagram of the THz imaging system with rotation mirror is shown in Figure 1. When a sample is scanned, the probe wave transmitted by the 0.3 THz source passes through the shaping lens and then casts on the rotation mirror. As the rotation mirror rotates reflected wave scans the sample. Reflected waves through the sample are converged at the detector by collecting lens.

2.2. Source of the System

The source of the system is a THz Impact Ionization Avalanche Transit-Time (IMPATT) diode produced by TeraSense Company. A physical map of the source is shown in Figure 2. Table 1 shows the specifications of the IMPATT diode.

![Diagram of the THz imaging system with rotation mirror.](image1)

![Physical map of the THz source.](image2)
Table 1. Specifications of the IMPATT diode.

| Performance parameters of the IMPATT diode | Value          |
|-------------------------------------------|----------------|
| frequency                                 | 0.3 THz        |
| input power                               | 80 mW          |
| Output power                              | 2 mW           |
| Working current                           | 110 - 120 mA   |
| Typical linewidth                         | 1 MHz          |
| TTL modulation                            | 1 μs rise/fall time |

2.3. Detector of the System

The detector of the system is a high electron mobility field-effect transistor (FET) based on GaN/AlGaN bow-tie antenna enhancement technique. Physical map of the source can be found in Figure 3 and more specifications of the FET can be found in Table 2.

2.4. Electric Control Rotation Mirror of the System

The electric control rotation mirror of the System, including a fast rotation bearing, a slow rotation bearing and a reflector, is produced by OP Mount Instrument Inc. Physical map of the rotation mirror can be found in Figure 4 and more specifications of the FET can be found in Table 3.

3. Data Acquisition and Image Reconstruction

3.1. Data Acquisition

When the THz imaging system is working, the quick bearing is rotating at 60°/s and the slow bearing is rotating at 0.2°/s. The system recorded the signal when the fast bearing angular displacement is round number in angular unit. Diagram of sampling is shown in Figure 5.

3.2. Image Reconstruction

Firstly, data collected from the system are mapped to corresponding points in Cartesian coordinates. Then, the points are connected with triangles as shown in Figure 6, using the Delaunay algorithm [20]. Padding triangles mentioned above, final image can be obtained.

4. Experiment and Results

4.1. Experiment Setup

Photography of the experimental set up is shown in Figure 7. The sample is composed of three layers. As shown in Figure 8, there is a metal layer sandwiched between 2 pieces of cardboard.

4.2. Experiment

3 samples with metal layer in different shapes are tested in the experiment. The
Figure 3. Physical map of the THz detector.

Figure 4. Physical map of the electric control rotation mirror.

Figure 5. Diagram of sampling.
samples were named “sample A”, “sample B” and “sample C” respectively. The shape of sample A’s metal layer can be found in Figure 9(a); the shape of sample B’s metal layer can be found in Figure 9(b); the shape of sample C’s metal layer can be found in Figure 9(c). Experiment results of the 3 samples are shown in Figures 9(d)-(f). According to Figure 9, it can be clearly seen that the shape of the metal layer can be recognized effectively.
Table 2. Specifications of the FET.

| Performance parameters of the FET                  | Value       |
|---------------------------------------------------|-------------|
| Frequency response range                          | 0.1 - 1.15 THz |
| Responsivity                                      | $1 \times 10^7$ V/W |
| NEP                                               | 10 pW/Hz$^{0.5}$ |
| Response Speed                                    | 500 kHz     |
| Input mode                                        | AC/DC       |
| Gain of voltage amplifier                         | 200/100     |

Table 3. Specifications of the electric control rotation mirror.

| Performance parameters of the FET                  | Value       |
|---------------------------------------------------|-------------|
| Speed of fast rotation bearing                    | 0˚ - 100˚/s |
| Speed of low rotation bearing                     | 0˚ - 50˚/s  |
| Icline angle of reflector                         | 5˚          |

Figure 9. Photography of the metal layer in the 3 samples and experimental results. (a) sample A's metal layer; (b) sample B's metal layer; (c) sample C's metal layer; (d) experimental results of sample A; (e) experimental results of sample B; (f) experimental results of sample C.

5. Conclusion

A THz imaging system with rotation mirror is built in this article. The system based on a two-dimensional rotating scanner has the ability to acquire an image sized at $60 \times 80$ mm$^2$ in 60 seconds while a raster-scan THz imaging system with the same hardware conditions needs more than 30 minutes. According to the experiment in chapter 4, it can be found that the system has the ability to detect the information of inner layer of objects effectively.
Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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