Comprehensive research on the use of terahertz technology

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Abstract

In recent years, terahertz technology has attracted widespread attention due to its important theoretical research value and wide application prospects. In this paper, the time domain spectroscopy and imaging technology of terahertz are briefly introduced. Then the terahertz introduces the three aspects of tablet detection, painting detection and biological tissue detection. The analysis shows some researchers' work in these fields.

Keywords

Terahertz, time domain spectroscopy, imaging technology, tablet detection, biological tissue detection.

1. Introduction

The terahertz wave generally refers to an electromagnetic wave with a frequency between 0.1 and 10 THz, and its wavelength is approximately in the range of 0.03 to 3 mm, which is just between the microwave and the infrared wave. The band is in a special position in the electromagnetic spectrum, and the related theory is between the transition region between macroscopic electromagnetics and micro-visuals [1]. Compared with traditional light sources, terahertz waves have many unique advantages such as low energy, broadband and coherence. At the same time, terahertz waves have been applied to many fields because of their good transmission performance and high resolution. Prior to the 1980s, the study of terahertz was relatively slow due to the lack of effective terahertz sources and detection methods. This period was called "Terahertz Gap." Later, with the advent of femtosecond lasers, technical support was provided for terahertz research [2], which enabled the rapid development of terahertz research. The development of terahertz technology has been comprehensively applied in many aspects such as quality control, biomedicine and safety monitoring.

2. Terahertz time domain spectroscopy and imaging technology

2.1 Terahertz time domain spectroscopy

The evolution of the electric field of the terahertz pulse over time is recorded in the detection of the pulsed terahertz wave [3]. The time domain waveform of a terahertz pulse generally consists of half to several electromagnetic oscillation periods, wherein each oscillation period can range from tens of femtoseconds to 1 to 2 ps for different spectral widths of terahertz pulses. The Fourier transform of the terahertz pulse time domain waveform can be used to obtain the distribution of the electromagnetic pulse in the frequency domain.

$$\tilde{E}(\omega) = A(\omega)\exp[-i\Phi(\omega)] = \int E(t)\exp(-i\omega t)dt \tag{1}$$

It can be seen from equation (1) that the electric field strength generally expressed in the frequency domain is a complex number containing the amplitude and phase of the electric field. A terahertz pulse contains only a finite number of electromagnetic wave oscillation periods, so it contains a broadband spectral distribution. The spectral widths of terahertz pulses emitted by different sources are not the same, ranging from 0.1 terahertz to terahertz, while others can reach spectral widths above 100 THz. The spectral width of a terahertz pulse is of the same order of magnitude as its center frequency and is a broadband electromagnetic wave. The pulsed terahertz technique directly measures the electric field strength in the time domain when measuring spectral information, so this spectroscopy technique is called terahertz time domain spectroscopy.

The spectral resolution $\delta\omega$ of the terahertz time-domain spectrum is determined by the time range T of the time domain waveform measurement, and the spectral range Ω it covers is determined by the time resolution δt used in the time domain waveform measurement:

$$\delta\omega = \frac{2\pi}{\mathrm{T}}, 2\Omega = \frac{2\pi}{\delta t} \tag{2}$$

Since the distribution of the frequency domain in the fast Fourier transform is symmetrical with respect to $\omega = 0$, the frequency range contained in the terahertz spectrum is $-\Omega$ to Ω.

Compared with other spectroscopy techniques, terahertz time-domain spectroscopy has its unique properties [4, 5]. First, the spectral range of terahertz time-domain spectroscopy is the terahertz band, which is difficult to obtain with other spectroscopy techniques. Second, since the terahertz pulse has a picosecond pulse width, it is very easy to use for time-resolved spectral measurements to detect the dynamic properties of the sample. The measurement of the terahertz pulse is a coherent measurement that can detect the coherent process of the carrier.

2.2 Imaging technology

Imaging technology can be divided into two-dimensional terahertz wave imaging technology in the form of spatial scanning, time-of-flight imaging and synthetic aperture imaging. A brief introduction to these methods will be given below.

(1) Two-dimensional terahertz wave imaging technology

The terahertz wave transmitted through the object (or reflected by the surface of the object) is directly imaged by an imaging optical element onto a two-dimensional array of terahertz wave detectors. And through the detector array directly to the terahertz image of the object. Two-dimensional terahertz wave detection array (including pyroelectric detector array, micro bolometer array, difference frequency detector array, etc.).

(2) Time-of-flight imaging

The pulsed terahertz waves imaging records the time waveform of the terahertz pulse at each pixel. When a terahertz pulse is reflected by two different surfaces, the terahertz pulse imaging will not only describe the terahertz reflectance distribution of the object due to the difference in optical path length, so the pulse terahertz wave imaging can not only describe the terahertz reflectance distribution of the object, but also The flight time of the terahertz pulse can be utilized to describe the three-dimensional topography of the object. This type of imaging is called terahertz time-of-flight imaging. Figure 1 depicts a schematic of terahertz wave time-of-flight imaging.

(3) Synthetic aperture imaging

In the two-dimensional imaging of terahertz waves, because of the long wavelength of terahertz radiation, large-diameter imaging elements must be used in order to maintain high spatial resolution in long-distance terahertz wave two-dimensional imaging. Due to the large size and weight of the components, it is inconvenient to carry and use. In this case, the resolution of the image will not be limited by the optical aperture of each detector element, but by the distance the detector moves or the distance between discrete detectors. Thus, with synthetic aperture imaging and interference imaging techniques, imaging resolutions up to the order of wavelength can be obtained using relatively small imaging elements.

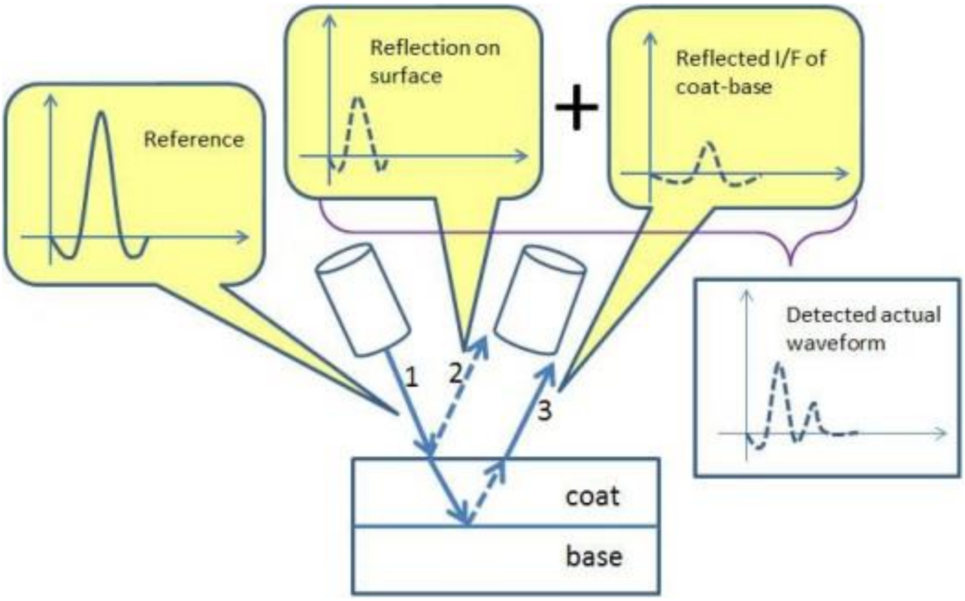

Fig. 1 Time of flight

3. Comprehensive application of terahertz technology

3.1 Tablet detection

Traditional drug detection techniques use process analysis techniques. This technology is designed, analyzed, and controlled by a system of pharmaceutical compound manufacturing through key quality and performance attributes of materials and processes during processing, with the goal of ensuring the quality of the final product. However, most of the methods of PAT require a Partial Least Square (PLS) calibration model in the process of use, and multivariate data analysis and preprocessing make the workload very complicated. Terahertz technology is a non-destructive technology that can be used for drug detection and imaging. This method differs from weighing or dissolving. terahertz is a non-invasive technique that ensures that the drug does not deteriorate during the imaging process and does not affect the drug itself. The terahertz wave can penetrate the drug coating material and image its internal structure, reflecting the thickness of the drug structure and the characteristics of the reflection.

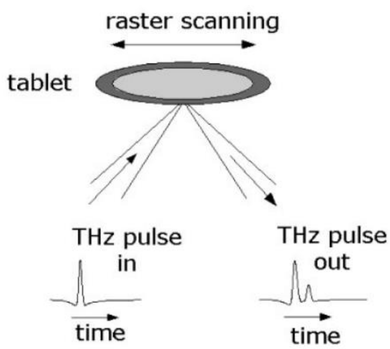

Fig. 2 Schematic diagram of tablet detection

Fitzgerald et al. [6] successfully evaluated the coating thickness of ibuprofen drugs using Terahertz Pulsed Imaging (TPI) technology. In addition, some studies have utilized TPI's ability to penetrate samples deeply and identify coating defects and buried structures [7-10]. Momose et al. [11] reported a non-destructive TPI method for detecting the formation of film layer cracks in coatings of coated tablets stored at elevated temperatures (60-70 ° C). Some reports have TPI results. Compared with other spectral methods [12-14]. TPI can also be used to measure the thickness of a tablet randomly moving in a commercial scale pan coater using an online terahertz probe [15]. Masafumi Dohi et al. [16] used the TPI method to explore the risk of cracking of film-coated tablets.

3.2 Detection of Painting oil painting

The application of terahertz detection technology can be extended to the analysis and protection of paintings. Krimi S et al. proposed a high-precision multilayer coating thickness measurement method using terahertz time-domain spectral reflection geometry [17]. Jackson JB et al. applied terahertz spectral imaging to evaluate primers and paint layers embedded in murals. Metal and dielectric coating patterns and graphite drawings are resolved by paint and gypsum overlays using pulsed terahertz reflectometers and imaging systems. [18] Abraham E et al. demonstrated the ability of terahertz imaging technology to be used in art painting research. Terahertz imaging can display buried layer information and can also assess changes in coating thickness [19].

3.3 Biological tissue testing

According to the unique performance of terahertz, it can also be applied to the medical field. Ahuja A T et al. [20] studied the effect of the Freeze-Thaw cycle on the terahertz properties of pig muscle and fat samples. For normal freezing, the terahertz properties changed significantly after thawing muscle tissue rather than fat.

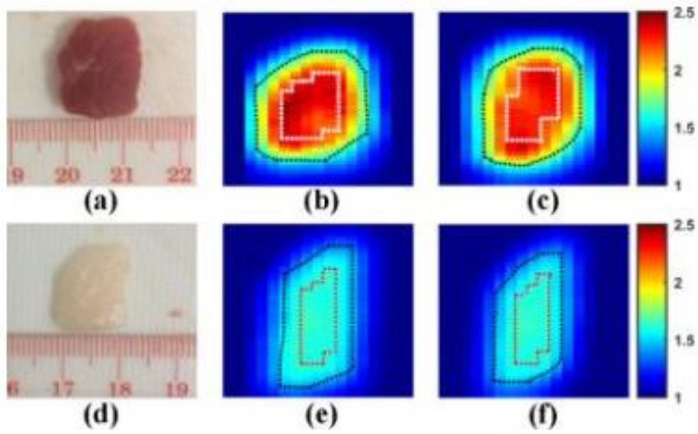

Fig. 3 Terahertz imaging of pig muscle and fat samples [20]

Rahman A et al. [21] introduced a new method for early detection of skin and other skin diseases through terahertz technology. In particular, terahertz scanning reflectometry of biopsy skin samples with basal cell carcinoma, terahertz three-dimensional imaging and terahertz time-domain spectroscopy have been used to identify features in human skin biopsy samples diagnosed as basal cells. In 2017, Doradla P et al. [22] used terahertz and combined with the principle of endoscope to create a single-channel terahertz endoscope, analyze the terahertz response in colorectal tissue, and display normal tissue and when imaging in reflective form. Endogenous contrast levels between diseased tissues.

4. Conclusion

This paper first introduces the terahertz time-domain spectroscopy and imaging technology, and then briefly describes the application field of terahertz. The three areas of drug testing, painting oil painting and biological tissue testing were introduced. As far as the current stage is concerned, there is still much room for improvement in the study of terahertz. Especially in the field of medical research, its future prospects are great, which can complement the shortcomings of X-ray imaging and ultrasound imaging.

References

[1] Zhang Zhuo-yong, Zhang Xin. Spectroscopy and Spectral Analysis, 2016, 36: 54.

[2] Moulton P F. Spectroscopic and laser characteristics of Ti:Al2O3 [J]. Journal of the Optical Society of America B, 1986, 3(1): 125-133.

[3] Zhang X C , Xu J . Introduction to THz Wave Photonics[M]. Springer US, 2010.
[4] Auston D H , Cheung K P , Valdmanis J A , et al. Cherenkov Radiation from Femtosecond Optical Pulses in Electro-Optic Media[J]. Physical Review Letters, 1984, 53(16):1555-1558.
[5] Fattinger C , Grischkowsky D . Point source terahertz optics[J]. Applied Physics Letters, 1988, 53(16):1480-1482.
[6] Fitzgerald A J . Nondestructive analysis of tablet coating thicknesses using terahertz pulsed imaging.[J]. Journal of Pharmaceutical Sciences, 2010, 94(1):-.
[7] Wallace V P . Terahertz pulsed imaging and spectroscopy for biomedical and pharmaceutical applications[J]. Faraday Discuss. 2004, 126.
[8] Malaterre V , Pedersen M , Ogorka J , et al. Terahertz pulsed imaging, a novel process analytical tool to investigate the coating characteristics of push–pull osmotic systems[J]. European Journal of Pharmaceutics & Biopharmaceutics, 2010, 74(1):0-25.
[9] Niwa M , Hiraishi Y , Iwasaki N , et al. Quantitative analysis of the layer separation risk in bilayer tablets using terahertz pulsed imaging[J]. International Journal of Pharmaceutics, 2013, 452(1-2):249-256.
[10] Niwa M , Hiraishi Y . Quantitative analysis of visible surface defect risk in tablets during film coating using terahertz pulsed imaging[J]. International Journal of Pharmaceutics, 2014, 461(1-2):342-350.
[11] Momose W , Yoshino H , Katakawa Y , et al. Applying terahertz technology for nondestructive detection of crack initiation in a film-coated layer on a swelling tablet[J]. Results in Pharma Sciences, 2012, 2(Complete):29-37.
[12] Comparison of Terahertz Pulse Imaging and Near-Infrared Spectroscopy for Rapid, Non-Destructive Analysis of Tablet Coating Thickness and Uniformity[J]. Journal of Pharmaceutical Innovation, 2007, 2(1-2):29-36.
[13] Maurer L , Leuenberger H . Terahertz pulsed imaging and near infrared imaging to monitor the coating process of pharmaceutical tablets.[J]. International Journal of Pharmaceutics, 2009, 370(1):8-16.
[14] Joshua Müller, Brock D , Knop K , et al. Prediction of dissolution time and coating thickness of sustained release formulations using Raman spectroscopy and terahertz pulsed imaging[J]. European Journal of Pharmaceutics & Biopharmaceutics Official Journal of Arbeitsgemeinschaft Für Pharmazeutische Verfahrenstechnik E V, 2012, 80(3):0-697.
[15] Terahertz in-line sensor for direct coating thickness measurement of individual tablets during film coating in real-time[J]. Journal of Pharmaceutical Sciences, 2011, 100(4):1535-1544.
[16] Dohi M , Momose W , Yoshino H , et al. Application of terahertz pulse imaging as PAT tool for non-destructive evaluation of film-coated tablets under different manufacturing conditions[J]. J Pharm Biomed Anal, 2016, 119:104-113.
[17] Krimi S , Klier J , Jonuscheit J , et al. Highly accurate thickness measurement of multi-layered automotive paints using terahertz technology[J]. Applied Physics Letters, 2016, 109(2):021105.
[18] Jackson J B , Mourou M , Whitaker J F , et al. Terahertz imaging for non-destructive evaluation of mural paintings[J]. Optics Communications, 2008, 281(4):527-532.
[19] Abraham E , Younus A , Delagnes J C , et al. Non-invasive investigation of art paintings by terahertz imaging[J]. Applied Physics A, 2010, 100(3):585-590.
[20] Ahuja A T , Ung B S Y , Parrott E P J , et al. Freeze-thaw hysteresis effects in terahertz imaging of biomedical tissues[J]. Biomedical Optics Express, 2016, 7(11):4711-4717.
[21] Rahman A , Rahman A K , Rao B . Early detection of skin cancer via terahertz spectral profiling and 3D imaging[J]. Biosensors and Bioelectronics, 2016:S0956566316302421.
[22] Doradla P , Joseph C , Giles R H . Terahertz endoscopic imaging for colorectal cancer detection:Current status and future perspectives[J]. World Journal of Gastrointestinal Endoscopy, 2017(08):7-19.