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Terahertz Technology and Its Biomedical Application

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Abstract

The terahertz wave is an electromagnetic wave with a spectrum ranged between the microwave and the infrared. Some studies found that terahertz had the advantages of low energy, non-invasive, high resolution and penetration. Based on these advantages, THz is relatively safe for biomolecules and it has been applied in terahertz imaging. So we summarized these reports in this mini-review.

Keywords

Terahertz, THz Biomedical Interaction, THz Imaging

1. Introduction

The terahertz wave in general term is a small electromagnetic wave between the microwave and the infrared in the electromagnetic spectrum [1], as shown in Figure 1. Terahertz frequency band is the only area with insufficient research in the whole electromagnetic frequency range [2]. With the development of electronic and optical technologies, terahertz source and detection technology have made creative breakthroughs, resulting in the rapid development of THz technology. At present, THz technology has been used in many scientific researches and application fields such as military, security inspection, biomedical health [3].

As the photon energy of THz waves is only one in a million of that of X-rays [4] [5], the THz does not cause chemical or physical damage to biological systems. One of the advantages for THz is safe in application. THz waves have very high spectral resolution for macromolecules [6] and can be used for detection of biomacromolecule conformation, which is difficult to detect by conventional

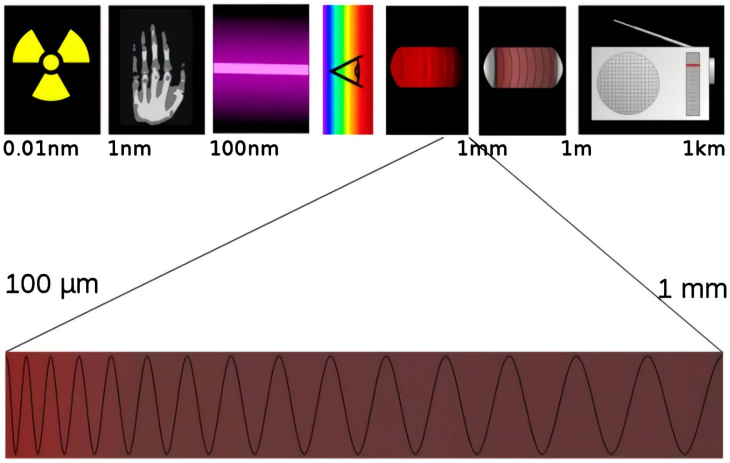

Figure 1. Terahertz band.

detection methods. THz wave has strong penetration [7], due to the interference and diffraction ability, it interacts very strongly with polar molecules, thus it is better in biological tissue imaging than other electromagnetic waves such as X-rays. The THz wave has very good coherence [8]. The parameters of the object radiated by THz such as dielectric constant and refractive index, can be obtained more accurately [9], as shown in **Figure 2**.

2. The Biological Effect of Terahertz

In terms of the THz influence on biomolecules, the vibrational levels of many biomolecules such as sugars, proteins, DNA, RNA are in the range of THz wave band. When THz waves are radiated onto biomolecules or organisms, the high-intensity absorption of THz by biomolecules alter the biomolecule's conformation and function, which may have a series of unpredictable effects on organisms. Therefore, we summarized several studies regarding the effects of THz wave on biological molecules.

Recent study by Turton *et al.* showed that THz vibrational motion affects efficiency of protein-ligand binding and alters function of protein molecules [10]. Changes in protein conformation can also be caused by low-frequency intramolecular [11]. Brandt *et al.* used THz wave to detect the interaction in proteins to predict the changes of protein function [12]. Olshevskaya *et al.* found that long term exposed to THz (40 - 50 hours) caused the morphological abnormalities of the cell membranes and intracellular structures [13]. By using a 0.1 THz continuous laser to irradiate the separated lymphocytes and Korenstein *et al.* found that all stains of cells showed an unsynchronized replication after 24 h of radiation. The authors believe that these phenomena are caused by THz induction of instability DNA molecules [14]. Kulipanovt *et al.* found that high-power THz radiation (2.3 THz) can destroy DNA double-stranded hybridization and disrupt hydrogen bonds between target DNA double-strands in the absence of free water [15]. In addition, Alexandrov *et al.* studied the response of mouse stem cells to THz waves and found that the transcriptional activity of thermo-sensitive genes

were increased [16]. Researchers at Ruhr University in Germany clearly observed the interaction between water molecules and proteins using THz waves [17]. Edwards *et al.* have also demonstrated that THz mainly interacts with hydrogen bonds in biomolecules [18] [19]. Study about THz absorption peaks of human serum demonstrated that the THz absorption peak of protein thermal denaturation is of a reversal characteristic, which reflected the dynamic change of serum albumin hydration structure [20]. The above experiments demonstrate that non-ionizing electric field of THz waves influences the function of organisms by a non-thermal mechanism, which is quite different from the mechanism by which high-energy rays such as UV and X-ray. This kind of nonlinear resonant mechanism often appears in THz stimulation [21] [22]. Conformational changes resulting from this mechanism can subsequently interfere with protein transfer and binding processes, thus profoundly impacts on gene expression in cells. Research has found that terahertz radiation destroys the barrier properties of the membrane and this process is reversible, so terahertz can be an inducer for the transmission of bioactive compounds [23]. BOROVKOVA has found that terahertz radiation increases the number of apoptotic cells, they believe that the diagnostic application of THz radiation may be limited by radiation power density and irradiation time [24].

Taken together, THz affects biomolecules only under a condition of high power (>1 THz) and long time (>24 h), so THz is relatively safe for biomolecules.

3. Terahertz Imaging

THz imaging is one of the most promising methods in biomedical science. THz time-domain spectroscopy has been applied to biological macromolecules detection, cancer research, determination of burn severity. THz waves are sensitive to polar molecules such as water molecules in biomolecules, thus THz imaging of biological tissues has more advantageous than other ways. THz imaging is of high spatial resolution, which reaches several tens of micrometers. Its penetration ability is also very strong, which can be used for tomography of biological systems. Started by Hu [25], Fitzgerald *et al.* [26] tested the THz refractive index and absorptivity of human blood, muscle, skin, fat, vein and even nerve tissue. The results showed that THz had a good identification for different tissues, and confirmed the feasibility of its clinical application. The study of THz imaging on 22 isolated breast cancer patients [27] showed that a high correlation in breast cancer detection between pathological examination microscopic image and THz image. The study of THz imaging on brain tissue demonstrated that THz wave spectrum can distinguish between gray matter (neuron body) and white matter (nerve axon) and that there are reflection spectrum differences between gray matter and white matter. Seung Jae Oh obtained the terahertz images of fresh brains with and without tumor by using reflection type terahertz pulses imaging system [28], as shown in **Figure 3**. From terahertz images of different biological specimens, the water content and dehydration characteristics of fat

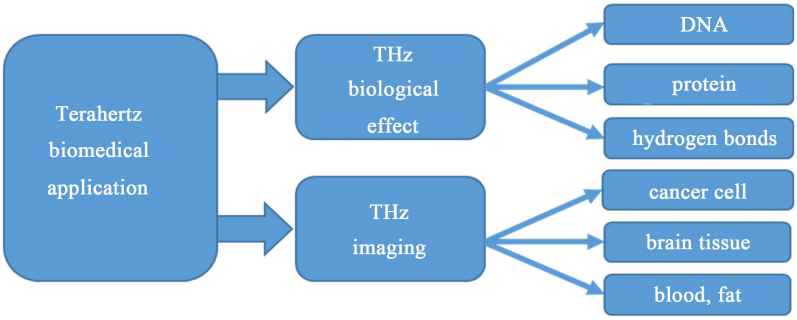

Figure 2. Terahertz research direction.

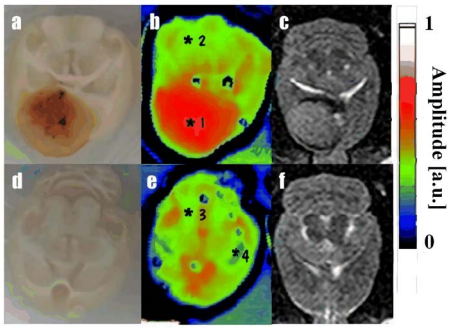

Figure 3. Terahertz pulses imaging system.

and muscle tissue are accurately distinguished and the results show that terahertz imaging technology provides a valuable measuring platform for biological sensing [29]. Zhang M found that terahertz can be combined with nanotechnology to help improve terahertz biometric imaging capabilities and provide advanced imaging results [30]. The research of terahertz imaging have shown that the amplitude of reflected signal in severely scalded tissues was lower than that in normal tissues, so the terahertz may be used to detect scald wounds.

4. Conclusion

Based on the low energy, non-invasive, high resolution and penetration, it is foreseeable that THz will be widely applied in biomolecules detection and clinical imaging.

Conflicts of Interest

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

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