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TERAHERTZ PULSE IMAGING: A NOVEL IMAGING TECHNIQUE IN DENTISTRY

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ABSTRACT

Terahertz radiation is a part of electromagnetic spectrum that lies between infrared and microwaves. This technology is non-invasive and non-ionising radiation is used for the imaging purpose thus causes no damage to biological tissues. Terahertz waves have an inherent sensitivity to the water content. Thus, different biological tissues have different unique absorption spectra, thus making terahertz more attractive and promising for biomedical applications and can provide complimentary information to existing imaging modalities. This article reviews this novel imaging technique and its application in dentistry.

KEYWORDS: Terahertz, Terahertz pulse imaging, THz gap

INTRODUCTION

Dentistry has witnessed huge advances in all its branches including the imaging technologies in the past few decades.[1] Imaging technologies have made their mark in the field of diagnosis and therapeutics in the present era. Newer advances in various technologies have led to the use of various less frequently applied imaging systems including Terahertz waves.[1,2]

Terahertz radiation (1 THz = 10^{12} Hz) is electromagnetic radiation whose frequency lies between the microwave and infrared regions of the spectrum. The terahertz region is typically defined as ranging from 0.1 to 10 THz in frequency or 3.33 cm−1 to 33.3 cm−1 in wave numbers. In wavelength terms this corresponds to 3 mm to 30 µm.[3] This spectrum of radiation is of significant importance to the biological sciences because additional information to traditional spectrometric measurements on low-frequency bond vibrations, hydrogen bond stretching, and bond torsions may be obtained.[4]

It was first isolated by Heinrich Rubens in the year 1897. For a long time, this spectrum of radiation remained unexplored due to a lack of good sources and detectors [3] and was commonly referred to as the "THz gap". In 1975, David Auston developed a photoconductive emitter gated with optical pulse that could be used to generate broadband terahertz radiation upto 1 mW which bridged the THz gap.[2] In the following decades many improvements in the generation and detection of coherent terahertz radiation enabled terahertz time domain spectroscopy and imaging techniques to be pioneered.

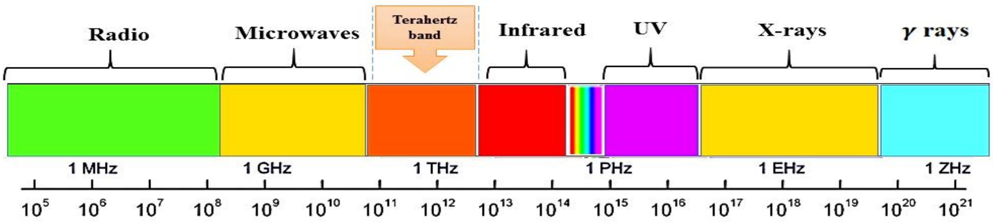

Figure 1: Terahertz Radiation In The Electromagnetic Spectrum

Principle of terahertz imaging

In the past few years technology has advanced considerably for generating and detecting THz radiation.[2]

Generation of THz radiation: The terahertz radiation is both emitted and detected by low-temperature-grown photoconductive devices. The following is the sequential steps in the production of THz radiation and Figure 2 shows the diagrammatic representation.[3]

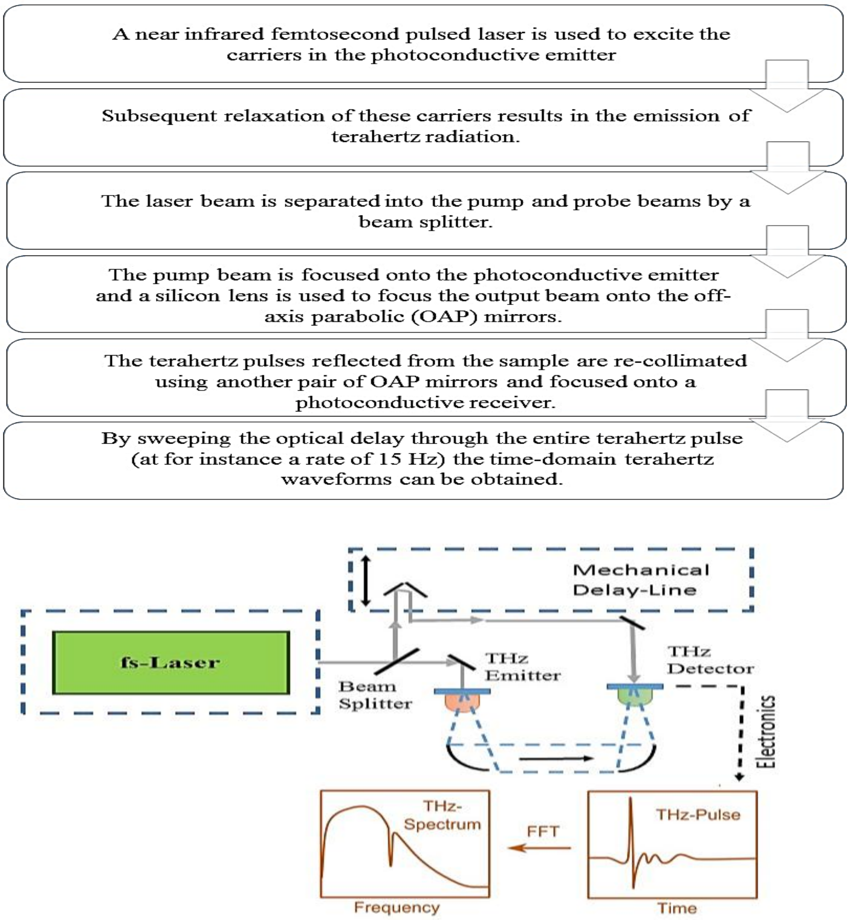

Figure 2: Daigrammatic Representation Of Thz System

Based on the type of laser source used, the THz systems are broadly categorized into two general classes.[2]

A. Continuous wave (CW)
B. Pulsed wave (PW)

Pulsed wave THz systems give a broadband emission of the waves and thus are more commonly employed for biomedical applications.

Applications of Terahertz imaging

Initial applications of THz technology were limited mainly to space science and molecular spectroscopy. Introduction of THz pulsed imaging (TPI) in 1995 by Hu and Nuss for biological sample has laid down the steps for the widespread application of THz radiation in biomedical sciences.[5]

Its medical applications include tissue characterization in dermatology, burn depth diagnosis and in pharmaceutical industry.

Unique features that make THz very suitable for dental and medical applications:

1) Terahertz waves are non-ionizing and thus do not pose any hazard to biological tissues.
2) It has very low photon energy, which is insufficient to cause chemical damage to molecules, or knock particles out of atoms. Thus, it will not cause harmful ionization in biological tissues; this makes it very attractive for medical applications.
3) It is very sensitive to polar substances, such as water and hydration state. For this reason, THz waves can provide a better contrast for soft tissues than X-rays.
4) Shorter wavelengths of the THz band allow for greater spatial resolution
5) The energy of rotational and vibrational transitions exhibits different spectral characteristics in the THz range.[6]

Potential application in dentistry

i. **Detection of dental caries and erosion of teeth:** TPI (Terahertz pulsed imaging) system is a novel technique for detection caries using non ionizing impulses of terahertz radiation, (an electromagnetic radiation). This technique identify early stages of carious lesion that are often missed by visual inspection and conventional radiographic examinations. Cavities reduce the mineral content of the enamel and dentine and hence caries appears as regions of higher absorption in a panchromatic transmission image. It has no adverse thermal effects.[7,8,9]

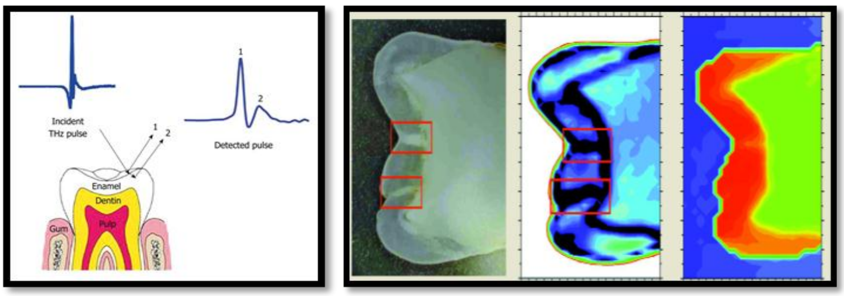

Figure 3: on THz imaging caries appears as regions of higher absorption in a panchromatic transmission image.[9]

ii. **Imaging of periodontal diseases:** in diseased periodontal tissues there is increase in the water content and this variation can be measured by terahertz pulse imaging. This is a very favourable application, principally as the depth of penetration is considerably larger than that is possible with Optical Coherence Tomography (OCT).

iii. **Non-invasive detection of oral malignant melanoma:** Carolyn et al conducted a study where the terahertz image of a frozen excised oral melanoma tissue from the mandibular gingiva was obtained and compared to the image that was taken at room temperature. After THz imaging at -20 °C and 20 °C, the tissue was stored in formalin solution for further histological analysis. The size, shape, and internal position of the oral melanoma were mapped by this modality. Characteristics of the THz radiation on the melanoma were clearly different from those of the healthy adjacent tissue. Thus the study proved that this imaging modality can be an alternative diagnostic method to substitute cryogenic histology.[10]

iv. **Nanoparticle-enabled terahertz imaging for cancer diagnosis:** Cancer identification with THz waves has lured much attention as they can detect the variation of cells caused by cancer. The sensitivity of THz electromagnetic (EM) waves to water molecules allows to employ THz technique to diagnose cancers because in cancerous tumors, Diseased tissues contain more interstitial water compared to healthy tissues. The higher water content along with structural changes such as increased cell and protein density, larger the THz absorption and refractive index for tissues with tumors. The only difficulty is in identifying the tumor in tissues unless the cancer is already well developed. The interaction between nanoparticles and THz waves is expected to be small as the size of nanoparticles is from three to four orders of magnitude smaller than the THz wavelength. The cell with nanoparticles can be heated up with surface plasma polaritons by illuminating it with an infrared (IR) laser beam. The THz absorption and refractive indices are sensitive to the temperature change in water or in cells that contain large amounts of water, and this property enables the modulation of the THz signal with an IR laser irradiation. The employment of IR laser beam for imaging and signal detection realizes a practical THz endoscopy for diagnosing cancers.[11,12]

v. **Terahertz spectroscopy for monitoring dental restorative materials:** THz-TDS terahertz time domain spectroscopy) is capable of monitoring the curing of dental composites. Small but significant changes of the THz refractive index and absorption coefficient could be detected during stepwise light exposure and the changes in the refractive index could be correlated with changes in the density of the materials.[13]

Limitations, concerns and challenges related to THz imaging

With the increasing application of THz imaging technology for medical purposes there are several challenges presented by THz waves. First and foremost is safety, which involves signal power. In addition there are challenges presented by acquisition speed, absorption rates, resolution, size, and cost.

Safety: Current power used in Thz wave systems are in the order of mW which is well below the safety limits. However, it should be noted that these values are typically used for shorter wavelengths. As discussed THz waves have high absorption rates with water content, more power is required and this could lead to more tissue damage than expected.

Acquisition speed and signal to noise ratio: Thz imaging is comparatively a slow process than other imaging modalities. THz imaging system can be realized using an electro-optic detector in conjunction with a CCD camera. Unfortunately, the use of the CCD camera precludes the use of phase sensitive detection techniques, which decreases the SNR (signal to noise ratio) by several orders of magnitude.

Absorption rates: Water and other polar liquids leads to high absorption rate for THz waves, in the order of 150cm^{-1} at 1 THz.[7] This limits the depth at which THz waves can be effective because most THz applications rely on THz passing though the samples. Therefore, because of limited penetration most current applications in medical imaging rely on skin conditions.

Resolution: THz imaging has a limited resolution which is in the order of 1μm to 3mm. this range is not suitable for many medical applications. Few ways have been tried to overcome this limitation like near-field imaging which come with their own drawbacks.

Size and cost: THz imaging equipment requires a large space for its installation as well Currently THz systems cost up to $300,000 total, this is for sensing and imaging of THz waves. Before THz imaging can be adopted by the mainstream medical community the cost may have to be reduced.[14,15,16]

CONCLUSION

THz imaging is still in its infancy, but has a huge potential to become an indispensable imaging technique in the future. In the past decade, its application in biomedical fields has drawn massive interest and lead to development of newer advancements in imaging methods and theoretical analysis. More research is required to further improve the THz wave applications. As the system becomes more readily available and cost-effective and once some of the challenges are met and limitation are overcome THz will become a true, practical benefit.

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