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Terahertz Imaging: a Breakthrough in Non-Destructive inspection

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Abstract:

Terahertz technology and its imaging methodologies are around for almost more than a decade. Although THz is not something new but when it comes to its applications in spectroscopy and imaging, it all started after the publication of an article by Hu & Nuss in 1995. After that, a very rapid development of detection methodologies and algorithm development made it possible to boost the applications of THz imaging in various areas. Because of its non-destructive in nature, scientists and engineers explored its imaging capabilities in many areas with very good success rate. In this article, a brief discussion of the applications of THz imaging have been discussed and especially how it is safer than X-Ray with quite remarkable results.

1. **Introduction:** Because of its transparent nature in many non-polar materials and relatively low energy, THz imaging gained its momentum gradually in various application areas without any commercial implementation yet. The first terahertz image was generated by Hu *et all* back in 1995 [1]. THz has its own advantages when compared to X-Rays, which is widely used in many industries, including healthcare and security industry. The most promising advantage of THz is its non-ionizing nature. Because of its low energy, it does not ionize or damage living cells or tissues, as X-Ray does. Naturally, it is preferred to use THz in living tissue or in sensitive places where human involvement is an unavoidable fact. THz spectroscopy and its imaging technique has already captured the attention of some sectors where the use of X-Rays is either not suitable or results from X-Rays are not satisfactory.

The advancement of semi-conductor physics and photonics has led to the development of very compact terahertz transmitter and detector systems, both pulse and CW. Now a days nice and compact tunable terahertz Laser sources are also available, including but limited to quantum cascade Lasers. In spite of all these advancements, the major challenges faced by the industry is to develop a great detector in the THz region of the electromagnetic spectrum. Since THz wave record both phase and as well as amplitude, so the detector should also be able to record both phase and amplitude. Photodetectors like bolometers and Schottky-diode-based detectors lack these qualities and cannot be used as a terahertz detector. Normally a THz system consists of a transmitter and a detector system. In a pulsed terahertz beam, both amplitude and phase information is hidden can be extracted at the same time during data processing. The measurement mechanism is based on both transmission and as well as reflection based approach, depending upon requirement and feasibility. Because of its non-ionizing properties, it is widely preferred by several engineers and scientists across the globe.

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Although it has its own advantages and disadvantages, researchers are focussed to eliminate the number of disadvantages from the list, so that it can be widely used commercially.

2. **Non-destructive imaging by THz beam:** A plenty of work have been reported on the non-destructive imaging by both CW and pulsed terahertz waves. Here a very few of the important works will be discussed. There has been always a concern of the smuggling of illicit drugs across international borders by using international mail delivery system. Criminals keep those drugs inside a mailing envelop or inside a package along with other materials (allowed by shipment agency) to smuggle some illicit drugs and law enforcement agencies find it very difficult to inspect every package. In 2003 Kodo Kawase *et all* reported a very novel work of identification of illicit drugs by terahertz spectroscopy [2]. The authors studied the terahertz transmission imaging of the MDMA, aspirin, and methamphetamine. In the scanning process, those drugs were kept inside polyethylene bags that were kept inside an envelope. The authors reported spectroscopic imaging data between 1THz-2THz. From the reported results, one can clearly see those three drugs inside bags from its images and from absorption data, the drug materials are clearly distinguishable even if they are kept inside the envelop or any packaging materials. In 2006, David Zimdars *et all* performed both transmission and reflection imaging to study the NDT of several articles contained in large areas *viz.* briefcase and satisfactorily able to identify knife, pistol, bottle etc [3]. This type of imaging is in need to many security agencies like homeland security etc. There is always security risk at the airport, offices of the law enforcement agencies etc and a non-destructive type-scanning machine for bags, suitcase, human body etc is in demand. Especially terrorist carries explosive, chemical weapons, guns, liquid explosives etc and it is not that easy to open every bags to carry out a thorough search. The authors performed many experiments keeping the above-mentioned items inside bags/brief cases and carried out transmission/reflection raster scanning by THz beam. From those reproduced images, the objects were clearly visible, hidden inside. A knife has been detected comfortably kept inside the pocket of a jacket, with the help of their experiment. Authors could able to obtain a lateral resolution of around 2mm and depth resolution less than 100 micro-meter, which is quite impressive.

Use of terahertz NDT not only limits itself in the security area, it also spreads in its wings in other areas. There has already been a huge need of the techniques to measure the quality of artwork like paintings for its preservation and quality assurance. UV, X-Rays, infrared has already been used extensively for this purpose [4]. Because of many limitations of the use UV, X-Rays, infrared radiations, THz gets its own place in non-destructive evaluation of painting and similar kind of artwork. X-Rays cannot travel deep inside lead painting and the same does not get reflected from the painting surface and because of its high energy, it is very difficult to obtain absorption or diffraction spectroscopy using X-Rays. Mid-infrared also lacks sufficient resolution and consequently is not that much suitable for this purpose. So, there is a need for something better and T-Ray, because of its non-destructive nature takes the place for the investigation of paintings materials. It not only provides any defect hidden beneath the surface of the painting, it can also provide information about the quality of the materials. Abraham *et all* reported a nice piece of work on the investigation of paintings by

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THz imaging [5]. Authors studied terahertz time domain spectroscopy (THz-TDS) to study several paintings by both transmission and reflected spectroscopy. One can obtain the quality of the material used in the painting from the attenuation data and the thickness of different layers of the painting from the time delay measurement of the signal data in reflection mode. From the THz-TDS reproduced images, those paintings can be clearly distinguished. J.B.Jackson *et all* also investigated THz imaging of mural paintings [6, 7].

THz non-destructive imaging has comfortably been accepted in pharmaceutical industry too to investigate the quality control of drugs. In 2011 Zhong *et all* studied the quantification of tablet coatings using THz pulsed imaging and optical coherent tomography [8]. The quality of tablet coatings is very important aspect when it comes to the performance of the drugs inside human body. It is very important to monitor the optimum thickness of the tablet coatings and its uniformity. The present day mechanism to monitor the quality of the coating is not optimum enough to deliver desired results. Terahertz pulsed imaging can be used as a powerful technique to quantitatively characterize the tablet coatings successfully. The authors investigated the tablet coatings at a thickness ranging from 10-140 micro-meter. The experiment was done by THz beam with a frequency range of 0.15 THz-3 THz and spot size of the beam was around 200 micro-meter. From the experimental data, authors not only could able to identify the materials used as a coating but they also calculated the thicknesses of the materials used from time delayed signal in flection measurement.

3. **Conclusion**: THz NDT not only gets very popular among the scientist but it also gains its importance in industry gradually. Before we can implement these novel techniques for any industrial implementations, we need to improve a faster and better detection mechanism. In this short review article, a few of the works reported by some scientists have been discussed. In future, we are hopeful that terahertz imaging technology will be accepted by many industries. However, we also need to focus on the development of faster detection mechanism of the pulsed terahertz beam. The presently available technology is slow and not suitable for acceptable in industry in any area, be it airport security scanning or any form of scanning mechanism in manufacturing or quality control industry, wherever mass production or scanning can be done at a large scale.

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