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Imagistic and spectral observation of the hidden objects with terahertz radiation

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This paper presents an experiment witch use THz radiation for detection and identification of the metallic objects and illegal substances inserted in nonmetallic boxes. Using THz imagistic technique was obtained 2D images of the metallic objects hidden, and with THz spec troscopy was identified the substances from paper box. In this experiment was used the Terahertz Time - Domain Spectroscopy kit from EKSPLA witch have frequency domain 0.1-5THz, and 50GHz precision.

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1. Introduction

Terahertz Spectroscopy System is a versatile tool for researchers who are interested in extending systems capabilities into THz frequency region. The weapons detection which are hidden in clothes, the analyze of the content from various wrapping or the early identifications of the cancer forms are just some application fields of the terahertz radiation.

Terahertz radiation is the electromagnetic waves with a frequency from 100GHz to 10THz and is found between microwave and infrared of the electromagnetic spectrum. Lately, interest for THz radiation was increased because THz ray can penetrate common packaging materials and provide spectroscopic information about the materials within. Terahertz waves can penetrate smoke, plastic, wood, ceramics, rubber or few brick inches.

Metals has a short penetration depth and highly reflectivity in the THz domain, so the mettalic objects completley block the THz ray .

In the interaction of the nonmetallic materials with THz ray the scattering of the THz radiation is not significant.

Liquid water and all wet materials, including most biological tissues, have a very high absorption coefficient, about six orders of magnitude higher than for visible wavelength. Non-polar substances are transparent for THz rays. Comparative with X-ray, THz radiation not damage the biological tissues when are scanned, because THz photons have 1.000.000 times lower energy than X radiation.

With THz imaging technique we can to distinguish between tissues with varying water content for example, fat versus lean meat. This radiation region of the spectrum found utility in security and defense applications but can be used also in medicine, pharmacy, and astronomy. Because of their properties, THz rays can be use in congested areas for the detecting of the weapons and of the banned substances.

The spectroscopy and imaging investigations presented in this paper are realized using Time-Domain Spectroscopy (THz-TDS) Kit from EKSPLA Company, Latvia.

2. Basic system description

The THz Time Domain Spectroscopy system (Fig.1) includes ultrafast pumping laser, photoconductive antenna THz emitter and detector, pump laser beam guiding optics, motorized delay line with controller, THz beam guiding mirrors, sample holder, a lock-in amplifier type SR-810 from Stanford Research Systems and Labview software for data acquisition. The main components for any THz system are THz radiation emitter and detector. THz emitter and/or THz detector consists of a microstrip photoconductive antenna fabricated on low-temperature grown GaAs (LT-GaAs) substrate. In the photoconduction approach a photoconductor (GaAs, InP) is illuminated with ultrafast laser pulses (with photon energy greater than the bandgap of the material) to create electron hole pairs. An electric field of about 10V/cm is generated in the semiconductor by applying a DC voltage. Then the free carriers accelerate in the static bias field and form a short photocurrent. Because of the acceleration this moving electrons radiate electromagnetic waves. According to [2] these photoconductive emitters are capable of relatively large average THz powers of 40 μW and bandwidths as high as 4 THz. This source operates with comparatively low power, but the beam is stable and coherent with well known temporal characteristics. Hence it is used for spectroscopy with high spectral resolution and excellent signal-noise ratio and for imaging technologies.

Typical emitted THz radiation power from EKSPLA Company is around 10 µW when pumped by mode-locked ultrafast laser with 100 mW output power and 150 fs pulse duration. The Fourier transform of waveform gives the spectral content of THz radiation.

In brief, in this system (fig.1) the pulsed optical beam created by an ultrafast laser is spitted into a probe beam and a pump beam. The pump beam is incident on the THz emitter (the THz source) to generate picoseconds terahertz pulses. The terahertz radiation is collimated and then focused on sample using a teflon lenses. After transmission through the target the beam is collimated and refocused on the THz detector. This detector can measure the electric field coherently. The optical probe beam is used to gate the detector and to measure the THz electric field instantaneously. At this the optical delay stage (computer controlled) is used to measure the transmitted terahertz pulse profile at a discrete number of time points to provide temporal information.

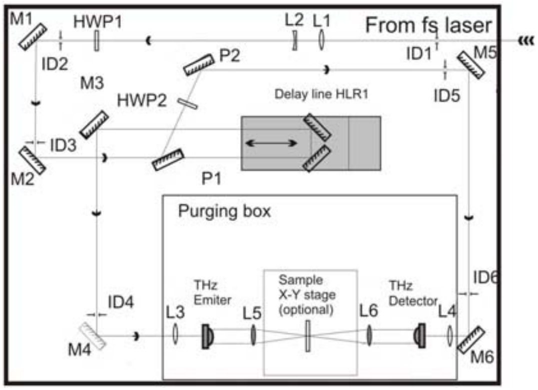


Fig.1. Optical layout

3. Experimental

3.1 THz Spectroscopy

Different wrapped chemical substances (or mixtures) have unique spectral “fingerprint” when using the THz spectroscopy. The convolution spectrum in the THz domain otained from scanning a wrapped substance has three contributions to the absorption spectrum: one from the atmospheric air, one from the wrapping and one from the substance of interest. The first two contributions form what is known as “the reference spectrum”. Knowing the reference spectrum, a pure individual spectrum can identify the substance of interest.

Using THz-TDS spectroscopy from EKSPLA Company we obtain THz power spectra of some commercial materials of interest. The power spectra are obtained from 0.1 to 5 THz with a resolution of 0.05 THz and scanning time of two minutes. A comparison of the spectra with and without sample inserted into THz beam path gives the power spectra of the sample under investigation. Using Bert-Lambert law (1) we obtain absorption spectra for different materials:

$$Abs_{spectra} = -2\ln\cdot\frac{P}{P_0} \qquad (1)$$

P = *power spectra radiation*
P_0 = *spectra power reference*

Using THz-TDS spectroscopy, we obtained absorption spectra for poppy seeds wrapped in paper or polyethylene foil ones given the reference spectrum for the wrapping we obtain the same spectrum for the hidden material (fig. 2). The experiments were carried out at normal atmospheric pressure and room temperature. In the scanning process with T-ray the power spectrum depends of thickness and absorption proprieties of the materials. The poppy seeds were selected in our experiment because is commercial substance and used in food and pharmacy.

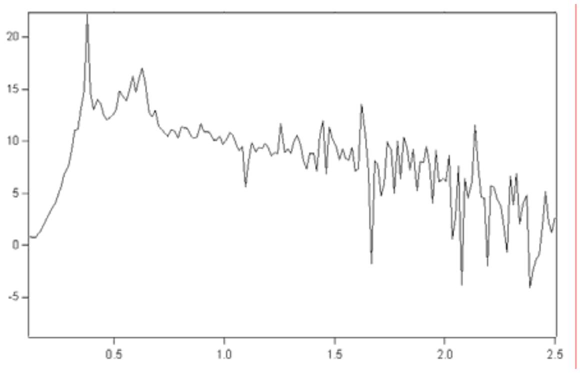
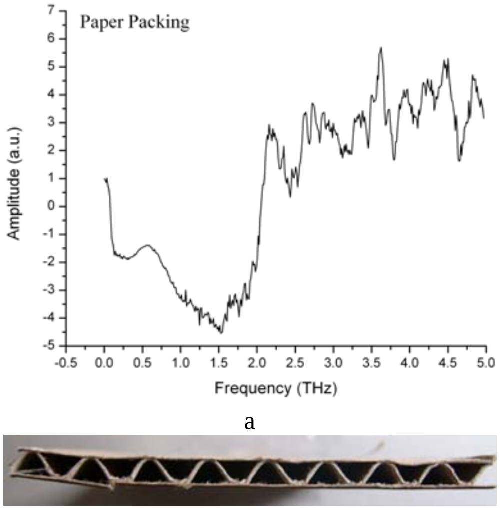


Fig. 2. Absorption spectra of poppy seeds wrapped in paper envelope.

In Figure 3 are shown THz absorption spectrum of packaging paper and the picture of the scanned material.



a

b

Fig.3a. THz absorption spectra for paper packaging, b. Photograph of paper packaging

Polyethylene is the most popular plastic in the world used as wrapping. The polyethylene absorption spectrum is presented in Fig. 4. Polyethylene foil having 0.5mm thickness was used to obtain the THz reference spectrum.

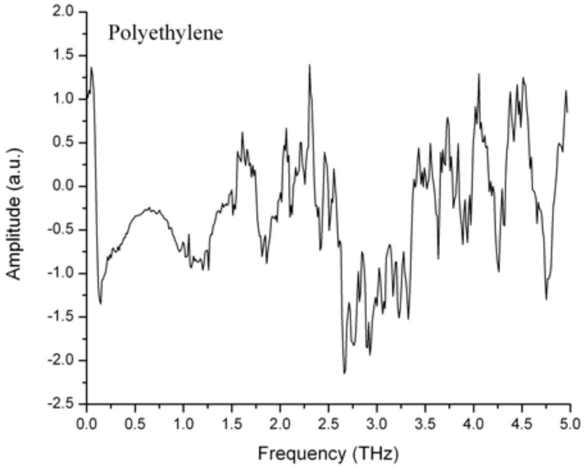


Fig. 4. THz absorption spectra of polyethylene foil

3.2 THz Imaging

Obtaining images through X-ray scanning is well known technique on airports or medicine, but it produces damages to the human body or generally to biological objects. Lately, the focus in scanning research shifted to systems that scan objects or human body without damaging their structure. A radiation domaine fulfilling this goal is THz. With this technolgy, one can control crowded regions through permanent scanning without affecting the subjects. For example, in security, T-rays can penetrate through clothes or plastic to discover at distance concealed metallic weapons.

T-rays are of interest also in fields like medicine and biology.

This work presents a detection experiment and the reconstruction of the images obtained from metallic objects wrapped in paper cardboard. The same kit was used, but adapted to imagistic by adding mechanical components that allow for movement of the scanned object in front of the beam. The object of interest can be moved in the X-Y plane. This way, on can obtain bidimensional images of different samples (such as metal objects, semiconductors, and substances that absorb THz radiation strongly).

The system can obtain images at different frequencies between 100 GHz and 5 THz with a resolution of 50 THz. This experiment emphasizes the penetrating properties of the THz radiation for different substances. We obtained images of a metallic object (Al 30mm x 30 mm), wrapped in paper (thickness 0.1 mm) and cardboard having 4 mm thickness

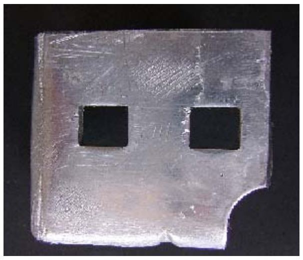


Fig.5-Metallic Object

Fig.6-Metallic object from paper warpper

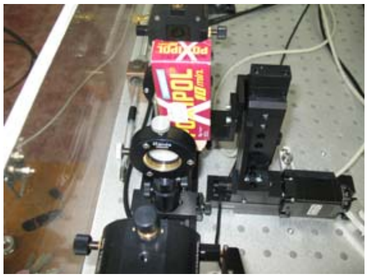


Fig.7. Photograph of emitter/detector system and X-Y sample manipulator.

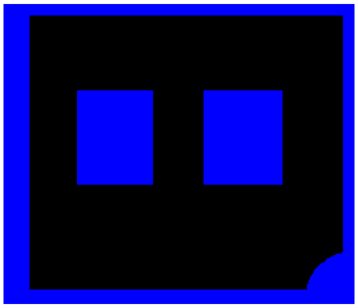


Fig. 8. THz transmission image of a metallic object wrapped in paper packaging

Reconstruction of the objects from the scanned images is done by obtaining a matrix of spectra in the 0.1-5 THz frequency domain. Each pixel in those images contains information from that frequency domian. In this way, the recontruction of the images can be done for the entire frequency spectrum.

For example, the metallic object image (Fig. 8) have a better contrast between 0.4-0.8 THz domain.

THz domain while for the remaining frequencies the image is afected by the humidity of the air and the reduced emitting power of the THz source. The digital resolution of the picture is given by the size of the THz radiation beam. The narrower the beam, the higher the resolution of the object’s image. The binary image is an image containing only black or white pixels. In this experiment we obtained the image of a 30x30mm metallic object. Since the diameter of the beam we used was 3 mm, the resulting binary map of the object was 10x10 pixels. At this resolution, the image of the object appears distorted; in our case is unusual smooth as compared with the real object Fig.8.

4. Discution

Using THZ- spectroscopy it is possible to obtain both absorption spectra and image of hidden objects. With EKSPLA THZ-TDS spectroscopy kit we obtained information about metallic objects and spectral signature substances hidden substances through only one scanning. Air absorption could be o source of noise so it will be better to subtract the nitrogen spectrum from the spectrum obtained in air.

5. Conclusion

Using THz radiation we demonstrated on some commercial materials that any material have unique spectral fingerprint With EKSPLA THZ-TDS system is showed that we can obtain images of the metallic objects which are hidden. The applications mentioned here show that THz imaging is desired by many different parts of industry and research, so that it can be expected that much effort will go into this field. But despite the number of potential applications for THz imaging no technology is yet the ideal way, though the recent advances could lead to practicable and compact systems. Hence, research in this field is going to be very interesting in the future.

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