Spectroscopic terahertz imaging with the InGaAs-based bow-tie diode

Irmantas Kašalynas, Rimvydas Venckevičius, Dalius Seliuta, and Gintaras Valušis
Center for Physical Science and Technology, Semiconductor Physics Institute, A. Goštauto 11, Vilnius, LT-01108, Lithuania

***Abstract*—Spectroscopic terahertz imaging with the InGaAs-based bow-tie diode as room temperature THz detector was proposed. Images were recorded in transmission mode from 0.5 THz up to 2.5 THz applying an optically-pumped molecular THz laser. The content of compounds in test samples was studied and discriminated from the spectroscopic imaging results along with Fourier spectroscopy data.**

I. Introduction

THE terahertz (THz) region of the electromagnetic spectrum lying between 0.1 THz and 10 THz is very attractive due to non ionizing radiation character and feature to penetrate many packaging materials like paper, plastic, lather, etc. Moreover, some substances have spectral features in this region; hence, spectroscopic data is a way for their identification.

The main tool for THz spectroscopy and imaging is assumed to be the coherent THz time-domain spectroscopy systems[1]. However, for practical implementation it requires to reduce strongly their size, eliminate rather expensive femtosecond laser and optical components in the setup. A compact continuous wave THz spectroscopy system can be assembled using discrete electronic sources[2] and quantum cascade lasers[3] as THz emitters; on the other side, such approach also requires a compact, broadband, robust, rather sensitive THz sensor with fast response time.

In this work, we propose the InGaAs-based bow-tie (BT) diode for spectroscopic THz imaging at room temperature. Optically-pumped molecular THz laser delivering averaged power above 1 mW was used as the source. Images in transmission geometry in frequency range of 0.5 - 2.5 THz were recorded with the BT diode operating in a photovoltaic mode. The samples of different composition were prepared for the experiments. The additives homogeneity was screened and the average content was estimated using imaging results together with transmittance spectra recorded by Fourier transform spectrometer (FTS).

II. Experimental setup and Samples

The setup for active spectroscopic THz imaging is shown in Fig. 1. A silicon lens coupled InGaAs-based BT diodes were used as the reference (D1) and the signal (D2) detectors, while as the THz source served tuneable THz laser operating in continuous wave mode. Objects were placed on a computer-driven XY translation stage and raster scanned in the focal plane of parabolic mirror. Transmitted through the sample THz beam was collected and focused on the detector D2. THz transmittance images were recorded using a lock-in technique and the position-synchronized measurements sampling axis (X-axis) with the resolution up to tens of microns. An X-axis sampling rate was of about 2 times higher compared to the time constant of the lock-in amplifier in order to preserve THz images undistorted due to quantization errors. Employment of high speed linear stage (Aerotech PRO115) in the setup enabled us to scan areas up to 20 cm wide with up to one micron resolution using X-axis scan speed up to 300 mm/s.

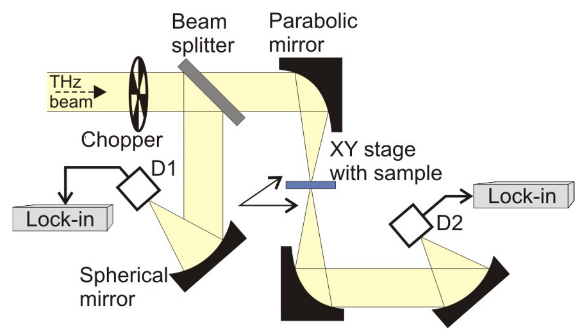

Figure 1. Setup for spectroscopic THz imaging.

The BT diode operation principle relies on non-uniform electrons heating in shaped semiconductor layer resulting in THz radiation detection in photovoltaic mode[4]. The principle of operation is free from any intra-subband transitions and hence does not exhibit temperature restrictions. Taking into account the BT diode response band, one can note that the sensitivity is nearly independent on frequency up to 1 THz[5]. The sensitivity further decrease is due to limitations defined by electrons energy relaxation time[5] and coupling efficiency due to the antenna properties of the detector contacts[6].

The samples under test were explosive simulators prepared of sucrose and tartaric acid mixing them with polytetrafluoro-ethylene (PTFE) powder and forming cylindrical form pellets under pressure. Three pellets consisting of 10% sucrose (SC), 10% tartaric acid (TA), and mixture of 5% SC and 5% TA (TA&SC), respectively, and one pellet - of pure PTFE were fabricated. The transmittance of each sample was measured by the FTS with 1 cm^{-1} resolution in vacuum environment at room temperature. The measured data is shown in Fig. 2. Low energy vibration modes was observed in the spectra only for the samples with SC and TA compounds but not for references made of PTFE and high-density polyethylene (HDPE). The THz laser lines used for spectroscopic THz imaging are indicated in Fig. 2.

We performed the spectroscopic THz imaging of unpacked samples and shielding them with plastic, textile, and paper. Unpacked samples transmission image at selected frequency is shown in Fig. 3. In comparison with pure PTFE pellet the samples with TA and SC compound demonstrated relatively

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larger absorption, the value of which was in good agreement with FTS data (see also Fig. 2). Note that the component clusters appearing as different transmission spots in the pellet area can be easily distinguished.

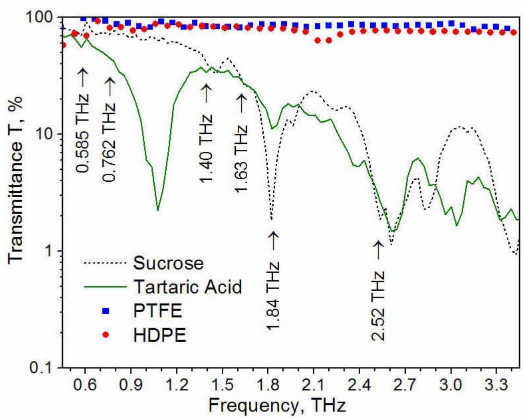

Figure 2. The transmittance of sucrose (SC), tartaric acid (TA), polytetrafluoroethylene (PTFE), and high-density polyethylene (HDPE) samples at room temperature.

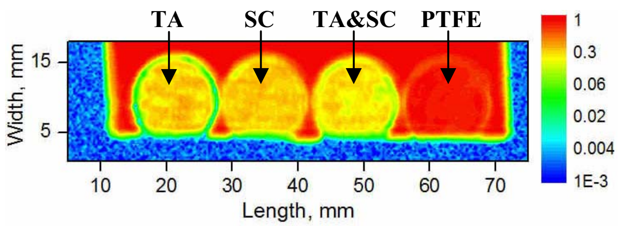

Figure 3. The THz transmission image of the explosive simulator samples at 1.40 THz frequency.

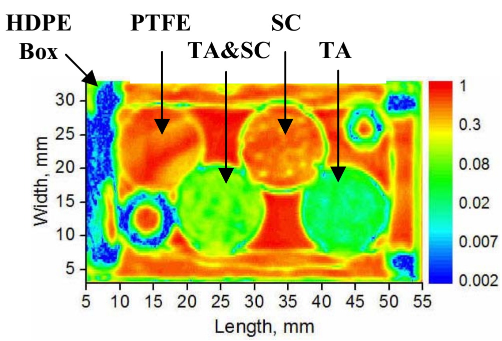

Figure 4. The same samples as in Fig. 3 but now they were packed inside a HDPE box. Additionally metallic washer (left bottom) and hexagon nut (top right) were enclosed. The THz transmission image was recorded at 1.40 THz frequency.

Later all four pellets were enclosed in the box made of HDPE sheets of 2 mm thickness. Additionally two metallic rings (washer and hexagon nut) which block the THz laser beam were packed inside. The transmission image at the same THz laser frequency is shown in Fig. 4. Again the component clusters are obvious but absolute absorption value for the pellets with TA and SC can not be reconstructed reliably due to presence of HDPE box interference.

Finally, the content of the TA and SC in each pellet was estimated using the spectroscopic THz images and the sample absorbance spectra as described in Ref. 7. It was found TA and SC values of 10±1 % and 11±1 %, respectively for single component pellets what well agreed with the respective known content. The TA and SC content in the mixture pellet was found to be 9±1 % and 3±1 %, respectively. Such disagreement from known 5 % content for both was attributed to surface scattering issues and selected THz frequencies incompatible with compounds native absorption lines.

III. Conclusions

The spectroscopic THz imaging of the explosive simulators was performed using the BT diode as room temperature THz detector. The samples absorbance at discrete THz laser frequencies was found in good agreement with the Fourier spectroscopy data. The content of sucrose and tartaric acid in test samples was discriminated.

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