A THz Tomography Imaging System

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Abstract — **Imaging of internal contents of a multilayer material, organic tissue, or just structural properties of an object behind a barrier is commonly desired in many aspects of the medical field or industry. THz waves have the ability to penetrate into many materials and therefore enable the observation of the object's interior. In this paper, a 3D THz imaging system is presented, and a method for the tomographic imaging is described. The properties of the material layers can be determined through observation of amplitude and the phase of the reflected THz wave with the obtained images.**

I. INTRODUCTION

THz waves are already used in many imaging applications, especially in the case of hidden, stand-off object observation under different shielding materials that include mostly textile, cardboard, and plastic. The THz detector used in the system described in this paper is based on a room temperature-operated microbolometer structure with a dual dipole antenna [1]. It was designed and fabricated in the Laboratory of Microelectronics as a THz stand-off system for a technology demonstrator. The system is based on a solid state THz source with a 300GHz central frequency, and operates in a continuous wave mode [2]. The detector consists of 32 pixels assembled in two lines. The system operates in a 2D reflection/transmission mode for the stand-off images, and is upgraded to a 3D system using the FM radar principle [3]. The block diagram of the system is presented in Fig. 1.

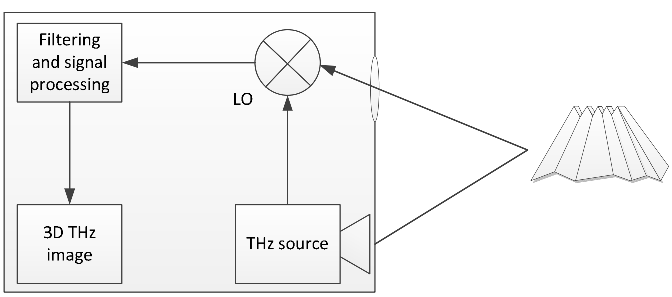


Fig. 1: The block diagram of 3D THz system.

The electronic FM modulated CW THz source illuminates the object of interest, then the reflected THz signal from the object continues to the THz detector, which also operates as a mixer. The filtering and signal processing is done on a raw signal to obtain relevant frequency components. Since the 3D THz system has opened a new variety of usage, one of the possible applications is the observation of layers in multilayer materials [4]. The method used gives a detailed image of a certain internal plane (slice) in the hidden or visually nontransparent object.

II. PRINCIPLE OF OPERATION

Different techniques were used to perform the THz tomography [5], however in this paper an efficient method based on 3D THz imaging using frequency modulated CW THz target illumination is presented. It is based on the observation of 3D image slices, or layers in the chosen direction. The latest version of the THz system produces the imaging data organized as a set of information for each detector pixel. The set consists of information about the frequency, amplitude, and phase of the received signal. The equation which describes the single pixel data is

$$P_{i,k} = I_{i,k} \cdot e^{j(\omega_{i,k} t + \varphi_{i,k})} \tag{1}$$

where $P_{i,k}$ is a pixel with amplitude $I_{i,k}$, frequency $\omega_{i,k}$, and phase $\varphi_{i,k}$. In the system, a THz array was used, therefore a total 32x32 imaging matrix was created.

For imaging, open source 3D graphics and animation software were used. This software allows the import of data from the sensor array and provides the possibility of detailed observation of the specific frequency component, which corresponds to the depth or distance in the 3D THz image. With some additional data processing techniques and some boundaries set, the tomographic image of a multilayer object can be captured and analyzed. An important attribute of the program is also the possibility of merging a visual and THz image. In Fig. 2, one such artificially composed scene was scanned. Individual layers can be clearly defined, and also some additional reflections and object properties are determined.

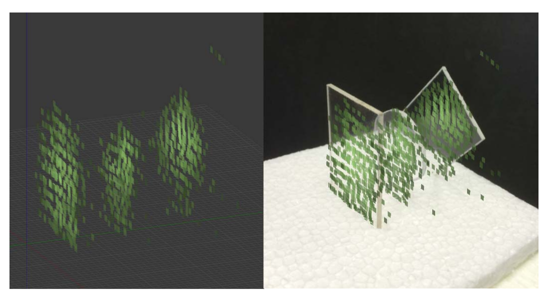


Fig. 2: The left image presents a THz scan result with three dominant layers, and on the right a fusion with a photograph in visual light is done.

From the obtained images, some physical data can be determined, e.g. relative permittivity, thickness, surface roughness, tilt of the surface, etc.

The image in Fig. 2 presents only the amplitude part of the imaging. Also, more detailed shifts and other material properties can be obtained with phase observation.

III. DETAILED OPERATION AND RESULTS

The main interest of research is in multilayer materials or structures with foreign objects, and so a special structure was made including a few kinds of materials in different shapes incorporated in multilayer object, using 4mm sponge material.

The container's circular opening (diameter 100mm), contained multilayers that were covered with textile. The top view of box with layers including pieces on different locations is shown in Fig. 3.

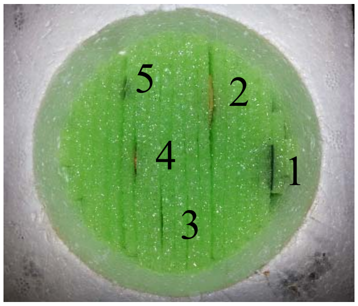


Fig. 3: The image presents multilayer material with different foreign materials

In Fig. 3 the first piece of material (marked with 1) is a part of silicon wafer, and the second piece is PCB partly metalized with Copper. The third and fourth piece are two circular metal plates with different radii. The last object is another piece of silicon wafer. The objects are positioned in different heights, but some in the same axis. The THz tomography imaging result is shown in Fig. 4.

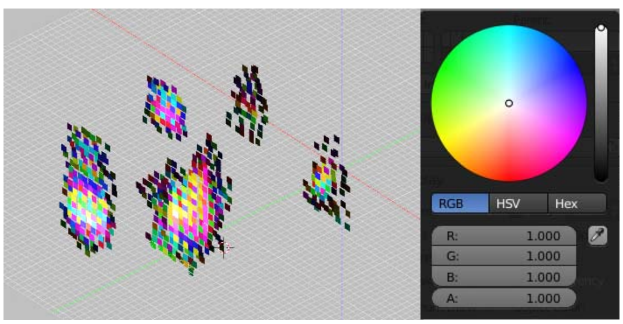
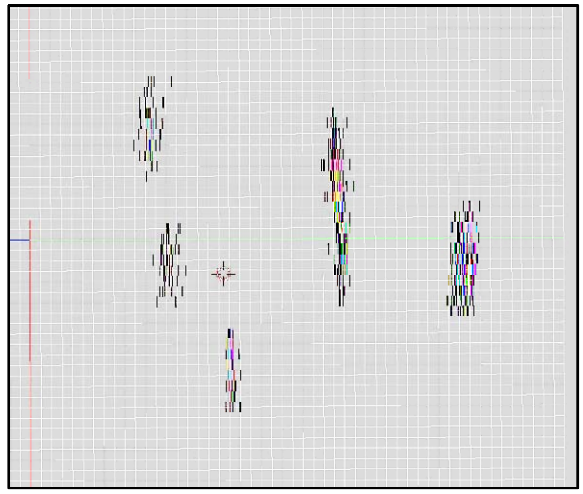


Fig. 4: The image presents result of THz scan of multilayer material with different foreign materials and color code for phase

The planes on Fig.4 show the exact locations of objects in multilayer material. The distance of each object is calculated separately using the FM radar principle. The first layer is 830mm from the THz imaging system. The value of amplitude and phase is obtained from the normalized complex number which corresponds to the pixel value. The pixel color presents the phase value and the pixel brightness the amplitude. The color code is initialized at each location with regard to the palette given in right part of Fig 4. The primary color code position is in the center of the circle. The phase information of each pixel together with surrounding pixels, determines the precise information about the position of object and how it is tilted or bent. An important fact is that the foreign object material properties such as density, transparence for THz, water continence, etc. can be studied.

One of the important results are objects distances – a FM radar result where all objects distances are included. The main distances are calculated from the received frequency and then the distance is corrected depending on the phase value at each pixel. In Fig.5 one of the imaging results is presented (top view). All layers can be defined; one can also detect several reflections called "micro" layers. Many of those micro layers belong to reflections between other layers, and also to reflections in material itself. The objects which are behind other objects (the last two objects) show a larger dispersion due to multi-reflections, and also a lower signal value – the signal-to-noise ratio is lower than in the first layers. One of the important parameters is the transparence of the observed material and the object in the THz frequency region. This defines the maximum possible depth of the tomographic imaging and resolution of the imaging result.



The precise analysis of layers in several different views and their merge gives a good approximation of the position and size of the objects in the material.

IV. SUMMARY

With the tomographic method described and the THz system used, many further applications development or material properties investigations can be carried out. The presented THz system was proven to be mature enough to support and upgrade research and development in the THz region. The obtained results are promising, they confirm THz tomography as having high potential, and one that should open new research and development opportunities.

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