BWO based THz imaging system

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Abstract. Terahertz (THz) imaging is a relatively new field of optical engineering and physics. Despite it has been already used in such directions as biomedical imaging, non-destructive evaluation of materials, and security detection of concealed objects, there are many problems in the development of them, connected with low efficiency of imaging sources and detectors. A new type of THz imaging system was implemented, based on backward wave oscillator THz source. Its efficiency of detecting concealed objects was shown.

1. Introduction

As THz radiation has high penetration depth in dielectric materials [1],[2],[3]), it can be used for detection of different concealed objects, especially within the security problems. This idea was developed during the last several years [4]-[11]. Depending on the source of THz radiation there are two promising types of imaging: using pulse source within time of light imaging scheme (see for example [12],[13]) as it is usually utilized in THz time-domain spectroscopy, and continuous THz systems [12],[14],[15]].

In pulse imaging systems, there is a big disadvantage of low power efficiency [16]-[18]. Other negative factor is long time of scanning (depended on the desirable resolution). In continuous imaging systems, as a source of THz radiation Gunn diode, photomixing scheme or backward wave oscillator (BWO) are often used [12],[19]. Unfortunately, detectors used in these systems have low sensitivity. Thus it is essential to use more powerful THz sources.

In this work, we suggest a new THz imaging system scheme, based on BWO 0.25THz source and heterodyne Schottky diode detector module. For increasing a source power input, we have studied BWO output beam profile and deviation and have implemented beam correction module.

The suggested imaging system was tested during a set of experiments. Estimation of the obtained images of concealed metal objects shows the ability of this system to detect such objects under different types of fabric and clothes.

2. THz imaging system description

The suggested scheme of active THz imaging system (figure 1) uses BWO continuous source of 0.25 THz radiation with average output power 50 mW. BWO generates a THz beam with rather complicated profile (figure 2). Arbitrary peaks, inhomogeneity, and ring-structure are well noticed. To increase illumination power, it is necessary to reduce inhomogeneity and make divergence of output beam more smooth. For this purpose a special beam integrator was developed (figure 3).
**Figure 1.** BWO based THz imaging system scheme.

**Figure 2.** BWO beam registered by pyroelectrical matrix beam profiler: a) is the result of scanning in lateral direction, b) 3D beam profile.
Figure 3. Beam integrator: internal surfaces are reflecting plane mirrors; beam divergence increases in $k$ times; partially internal space is filled by the scattering nonabsorbent medium.

The internal surface of this integrator is reflecting. The ratio between input and output apertures is $\alpha = a/b$. Integrator is placed close to the BWO output hole, and thus the beam divergence increases in $k = \alpha$ times. Partially the internal integrator space is filled by dielectric scattering medium for making output beam homogeneous. Right after the integrator, an attenuator is placed for reducing output illuminating power. The THz detector is based on the Schottky diode heterodyne scheme with optical mechanical scanning system. In heterodyne detector, the radiation reflected from the object is mixed with radiation from the reference heterodyne source – Gunn diode. The resulted signal is visualized on the PC monitor. Image of the object is normalized to the brightest object point. If the BWO illuminating beam is reflected from highly reflecting object, then it is possible to obtain only one bright point on the image. To prevent this situation, attenuator is used.

3. Experimental results
During the experiment, images of the test-objects were obtained by the suggested THz imaging system. We used aluminum foil stripes on paper: paper is highly transparent at 0.25 THz, while foil is highly reflecting. This set consisted of 6 objects with different stripes frequency 0.031, 0.050, 0.0625, 0.083, 0.125, 0.250 cm$^{-1}$ (figure 4).

Figure 4. Set of the test-objects.

The described test-objects were observed on man under different clothes: coat, jacket, and synthetic fabric. The distance between the object and the imaging system was 3.5 meters. From the figure 5 it can be clearly seen, that all these objects were detected by our visual system, but the resolution is limited for the last test-object due to the scattering properties of clothes.
Figure 5. Images of test-objects: (a) without covering, (b) under synthetic fabric, (c) under jacket, (d) under coat.
4. Conclusion

THz imaging system based on BWO source and heterodyne detector was developed. The BWO beam quality was increased without significant power losses. This system can be effectively used for finding concealed objects: metal things, weapon, knives. Results of the experiment show the ability to resolve little parts of objects under thin fabric up to 0.250 $\text{sm}^{-1}$ and under thick clothes (coats) up to 0.125 $\text{sm}^{-1}$.

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