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Generation of Terahertz Pulsed Radiation with Photoconductive Antennas Based of Low-Temperature-Grown Gallium Arsenide and Its Applications

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Abstract

The design and technological conditions for manufacturing photoconductive antennas based on low-temperature-grown gallium arsenide (LT-GaAs) have been developed. An optimized photoconductive THz antenna based on LT-GaAs with flag geometry of the contacts was fabricated. LT-GaAs samples were obtained by molecular-beam-epitaxy at temperatures of 230 °C on GaAs (100) substrates. On an optical setup with a femtosecond titanium-sapphire laser, a volt (watt)-ampere characteristics and photocurrent efficiency of the photo-conductive antenna measured by the pyroelectric sensor. The optimum annealing temperature of LT-GaAs was determined for generation of intense THz radiation. PCA have been tested in the terahertz radiation generation. The substantial effect of water vapor in the air and the environment of transparent objects is THz. The useful terahertz bandwidth extends from 0.1 to 2.7 THz and the source of terahertz wave is the most commonly used nonlinear crystal ZnTe in the biomedicine applications. However, in comparison PCA on LT-GaAs with ZnTe have better results in the intensity and the power of the THz response. Therefore, it will be possible to detect a lower concentration of biological objects.

Keywords: Photoconductive antennas; low-temperature grown gallium arsenide.

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1. Introduction

The area of the electromagnetic spectrum of terahertz (THz) radiation with wavelengths of about 0.1 to several millimeters used: new devices are being intensively created to ensure life safety; medical diagnostics; nondestructive technological and operational control. Because of the innocuous action on natural objects and sufficiently high penetrating power [1-3].

Terahertz (THz) technology find many applications in security screening, spectroscopy, communications, medical, imaging and so on. The main feature of THz radiation is the small energy of quanta of terahertz radiation (10 meV), and this THz radiation is non-ionizing and safe for humans, unlike X-ray radiation. Also, THz radiation has a high penetrating power unlike visible and IR radiation. There are great interest in applying THz spectroscopy to probe and characterize various biomaterials in recent decades because most low-frequency biomolecular motions, including vibration and rotation of the molecular skeleton, lie in the same frequency range as THz radiation. Therefore, various biomolecules can be effectively recognized and characterized according to their distinctive spectral fingerprints. Due to the weak interactions including hydrogen bonds and van der Waals lying in the THz range, the low-frequency vibration and rotation of biomolecules could be probed by THz spectroscopy. that the excess arsenic on the surface does not depend on the annealing temperature.

There is great interest in applying THz spectroscopy to probe and characterize various biomaterials because most low-frequency biomolecular motions, including vibration and rotation of the molecular skeleton, lie in the same frequency range as THz radiation. Therefore, various biomolecules can be effectively recognized and characterized according to their distinctive spectral fingerprints. Additionally, by sensitively probing the fast hydration dynamics around biomolecules whose key large-amplitude motions coincidently occur on the picosecond timescale of THz frequencies, THz spectroscopy has demonstrated unique advantages for detecting the coupling between biomolecules and their hydration shells.

One of the most important applications of THz PCA in medicine is the early detection and diagnosis of diseases. Successful examples are the identification of caries [4], the assessment of the degree of skin burns [5], the control of wound healing and scarring, the detection of subdermal carcinoma [6].

The low-frequency molecular motions that originate from the hydrogen bonds of nucleic acid base pairs and nonbonded interactions are sensitive to the base composition and conformational state of nucleic acids; this phenomenon can be utilized as the basis of THz spectroscopy for nucleic acid detection. The four nucleobases [adenine (A), cytosine (C), guanine (G), and thymine (T)] have distinct absorption coefficients in the THz range and, thus, can be clearly profiled. THz spectroscopy will help to identify and content nucleic acids in DNA by the difference in the absorption coefficients and the positions of the THz radiation peaks.Various cultured human cancer cells can be distinguished by their different complex dielectric constants (Figure 2D). Notably, the THz system has demonstrated greater sensitivity in measuring tiny structural changes in cultured cell monolayers than conventional optical phase contrast microscopy and electric cell-substrate impedance sensing. Differences in the complex dielectric constant in the THz region of frequencies of pure water and water containing cancer cells, including DLD-1, HEK293, HeLa allows them to be identified, which is an important task in the treatment of cancer [7].

2. Experimental Setup

The average power and the THz spectrum of the PCA radiation were investigated on the created stand (Figure 1), and images formed by reflection and transmission.

A femtosecond laser with a wavelength of 800 nm with a repetition rate of 70 MHz and an average power of 1.8 W used as the radiation source for exciting the PCA. The femtosecond laser acts on the PCA then the generated THz radiation is resolved into a spectrum using a Fourier spectrometer based on a Michelson interferometer, then it is detected by a pyroelectric detector.

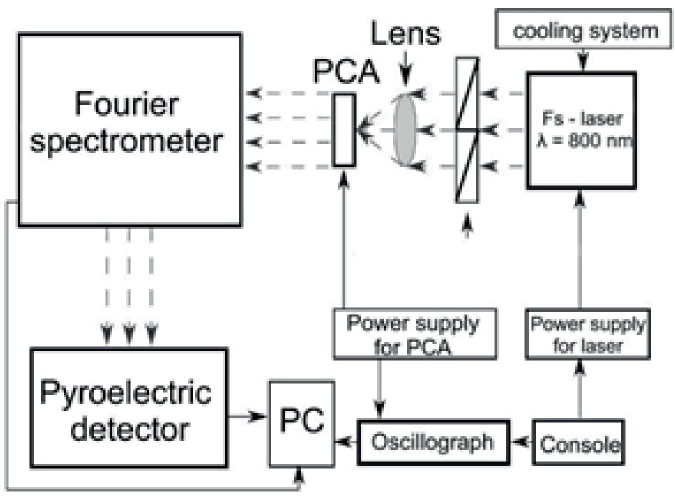

Figure 1: The scheme of the developed stand: power supply unit FPA (10 -200 V, 10 - 300 mA).

When replacing the pyroelectric detector with a THz camera, it is possible to obtain 2D images of objects with the registration of the spectrum of the terahertz radiation transmitted and reflected from these objects. Such a scheme showed in Figure 2.

3. Results

In the present work, Zomega and BATOP antennas used as standard radiators for obtaining transmission spectra and for capturing images of objects in the THz spectral region.

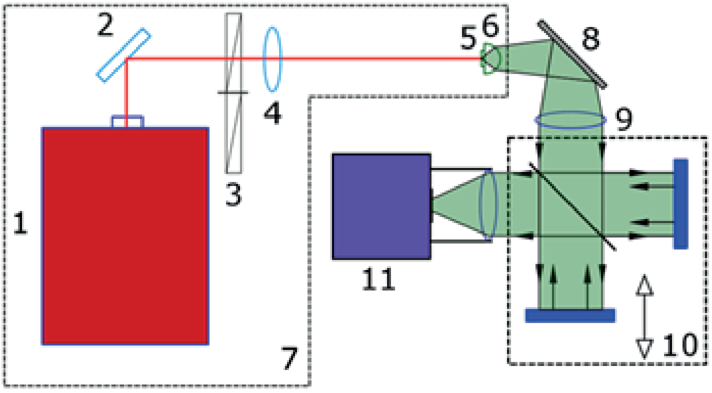

Figure 2: The scheme of the stand of the spectral terahertz radio image. 1- laser, 2- rotating mirror, 3-optical interrupter of the spectrometer, 4- lens, 5- emitter, 6- hyperspherical THz lens made of high-resistance silicon, 7- THz radiation generation unit, 8- sample, 9- THz lens, 10- Michelson interferometer with Fourier spectrometer, 11- THz video camera with lens.

Using the ZOMEGA PCA and the scheme shown in Figure 2, experiments conducted to determine the transmission spectra of THz radiation through a dry paper, wet paper (Figure 7).

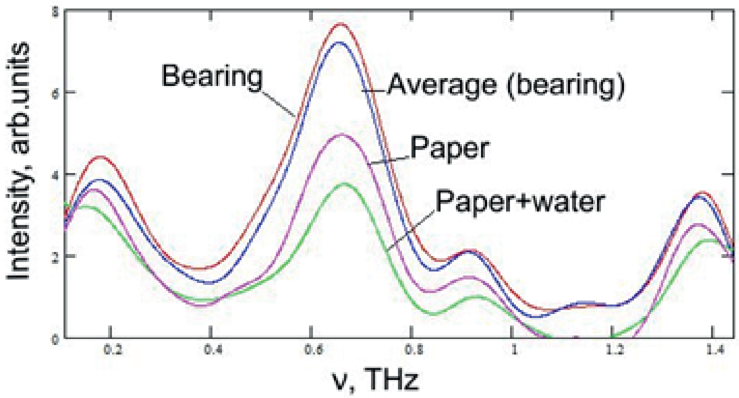

Figure 3: The spectrum of PCA Zomega. The THz path through the air (humidity 50%) is 35 cm. Transmission spectra for three cases: 1) there is no sample (reference); 2) dry paper; 3) paper + water. Here the blue curve is the mean (reference) spectrum as the average of the two reference spectra, i.e. measurements were made without barriers.

The spectral characteristics of THz radiation measured by time domain spectroscopy method. These graph shows the THz waveforms and their Fourier-transformed spectra. The graph (Fig.1) shows a comparison between the radiation waveforms for the antennas and crystal ZnTe (Zinc Telluride). The intensity of THz radiation from the PCA on LT-GaAs is 2 orders of magnitude greater than the intensity of the THz radiation from a nonlinear crystal of ZnTe.

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The characteristics of an optimized photoconductive antenna made it possible to establish that the design of a photoconductive THz antenna based on LT-GaAs low-temperature gallium arsenide with the flag type geometry of the contacts developed by the method of molecular beam epitaxy has a high THz response power. Figure 1 shows that the main part of THz radiation is concentrated in a rather narrow spectral range from 0 to 2 THz.

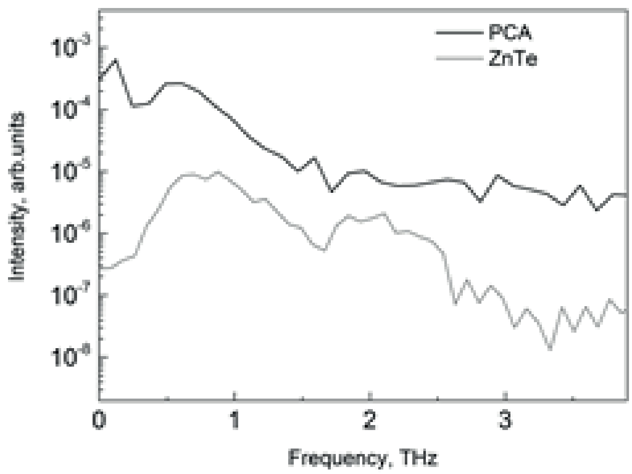

Figure 4: The intensity of the THz response of the PCA as a function of frequency in the interval 0-4 THz, the bias voltage of 100 V, the pump power is 300 mW and the probe power is 150 mW.

4. Summary

Thus, in the course of research, various photoconductive antennas based on LT-GaAs tested, including those manufactured in NRNU MEPhI. Measurements of the average power and spectrum of the generated THz radiation. Manufactured PCA in NRNU MEPhI has great characteristics. When the PCA is pumped by a femtosecond laser with a total power of 200 mW at a voltage of 160 V, the resulting photocurrent with an amplitude of 14 mA and an average THz power of 5 μW. A low value of dark current (24 nA) for PCA 8U makes it possible to use a higher bias voltage (140V) compared to ZOMEGA (90V), thereby increasing the maximum potential power generated by the antenna 8U. All PCA were tested in the terahertz radiation generation with the registration of the spectrum of the transmitted and reflected THz radiation. The substantial influence of water vapor in the air and the humidity of transparent objects is noted both for the integrated power of the transmitted THz radiation and on the shape of the spectrum of this radiation, especially at frequencies above 1 THz.

The useful terahertz bandwidth extends from 0.1 to 2.7 THz and the source of terahertz wave usually used nonlinear crystal ZnTe in the biomedicine applications. However, in comparison PCA on LT-GaAs with ZnTe have better results in the intensity and the power of the THz response. Therefore, it will be possible to detect a lower concentration of biological objects.

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