Electrophysical Characteristics of Sub-THz Diode with Schottky Barrier

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***Abstract* – In the paper, the results of research of the electrophysical and frequency characteristics of semiconductor structure with a Schottky barrier based on n-GaAs are presented. Current-voltage characteristic and frequency characteristic at the range 115-257 GHz are given. The possibility of using such semiconductor structures as a detector of Sub-THz radiation is shown.**

***Index Terms* – Sub-THz, Schottky barrier, detector, semiconductor structures.**

I. Introduction

THE PRODUCTION AND DEVELOPMENT of modern technical devices requires complex and accurate measurements. Semiconductor structures are actively used to create a wide range of appliance and devices of functional electronics elements and converters of power pulse electronics, photodetectors, quantum-sensitive detectors of ionizing radiation, matrix image receivers in X-rays and gamma rays. Semiconductor detectors are widely used in the ultrahigh frequency (microwave) range [1 – 5]. In particular, in the sub-terahertz (Sub-THz) range (100-300 GHz), the use of Schottky barrier diodes is promising due to the development of new generation communication standards, contactless security systems, as well as medical technologies and devices for the research of the environment, natural and artificial materials [6 – 11].

Semiconductor detectors are based on the principle of measuring voltage pulses that occur as a result of increasing the conductivity of a crystal under the action of incoming particles or photon radiation. One of the main materials of semiconductor detectors is gallium arsenide (GaAs). Due to a number of properties, it is considered a promising material for microelectronics [12, 13]. GaAs has a large value of band gap Eg=1.428 eV, a wide range change of parameters with the introduction of various dopant, and high mobility of charge carriers. The mobility value for electrons is μ_n=8500 $cm^2/(V\cdot s)$, and for holes, μ_p=400 $cm^2/(V\cdot s)$.

A mandatory part of any semiconductor device is the contact of the metal with the semiconductor. There are two types of contacts: non-rectifying ohmic contact and rectifying junction, which is also called the Schottky barrier. Semiconductor structures that use a metal-semiconductor junction as a barrier are called diodes with Schottky barrier (DSB).

II. Problem Statement

Currently, a huge number of different types of detectors have been developed. For example, some of them: bolometers, pyrometers, Mott diodes, Si MOSFET [14], acousto-optical (Golay cell). These detectors are very sensitive, but have difficulty in operation, for example, necessity of cooling with liquid helium (astronomy usually uses bolometers cooled to the temperature of liquid helium, which can improve the sensitivity of the device) or limited performance due to the inertness of physical processes (Golay). All this affects the complexity of the use process and the high cost of equipment.

One of the distinctive features of diodes with Schottky barrier is the absence of minority carriers during operation. The current flowing in the forward bias (throughput mode) is caused by electrons moving from the semiconductor to the metal. Due to this, the processes of accumulation and dissolution of charge carriers are practically absent, and therefore Schottky diodes have a high speed. In addition, unlike other types of diodes, DSB have a low voltage drop, which allows less heat dissipation and less heating.

In view of these features, it is necessary to research the characteristics of semiconductor structures with a Schottky barrier that are promising for use as a Sub-THz radiation detector, which will significantly reduce the cost of measuring equipment and reduce weight and size parameters, and increase performance.

III. Experimental Technique

A. Test sample

For research of electrophysical and frequency characteristics, an experimental sample of a Schottky barrier diode was prepared (Fig.1).

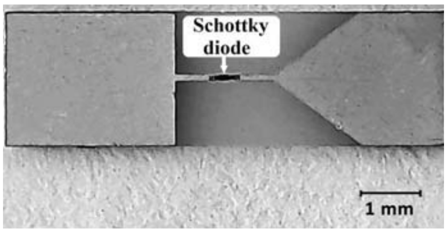

Fig.1. Microphotograph of a test sample of a diode with Schottky barrier.

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To create the detector structures, n-type gallium arsenide was used, located on a semi-insulating substrate made of ceramic. Sulfur (S) with an atomic concentration of $N_d = 10^{18}$ cm^{-3} was used as a doping impurity. Metal contacts were made by spraying a metal film with a thickness of 30 nm.

B. Static characteristics of a Schottky diode

Measurements of the current-voltage characteristics (CVC) were carried out using the Keithley 2611 meter source. With the help of a measuring device, a specified offset voltage was applied to the test sample in the range from -0.998 to 0.998 V. Current and voltage were measured using an ammeter and a voltmeter, respectively and automatic recorded on the personal computer (PC).

C. Frequency characteristics of the Schottky diode

Frequency characteristics of the Schottky diode were measured using quasi-optical measuring equipment (Fig.2) [15].

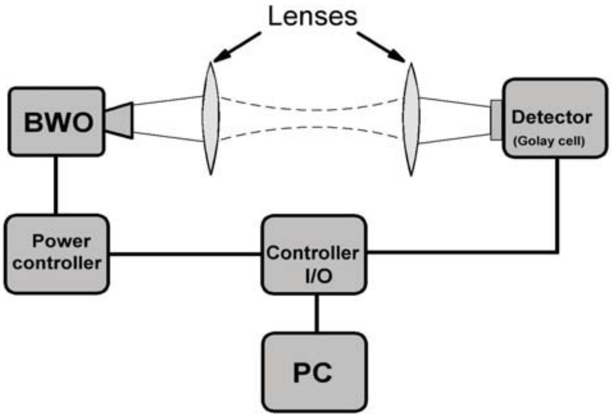

Fig.2. Configuration of the experimental setup for studying the frequency properties of the Golay detector.

As a source of continuous monochromatic terahertz radiation, a backward wave oscillator (BWO) was used, which allows generating electromagnetic radiation in the frequency range of 115-257 GHz. To focus the divergent beam, a Teflon lens with a focal length of 120 mm was used. The second lens was placed directly in front of the detector for maximum localization of radiation on the Schottky diode itself, which was placed in the housing. With a step frequency change at 5 GHz were measured the current through the detector with the help of microammeter. In the same environmental conditions, the frequency response was measured using a Golay cell and data was recorded using a PC. Fig.2 and Fig. 3 show the configuration of the measuring device for studying the frequency properties of the Golay cell (Fig.2) and the Schottky detector (Fig.3).

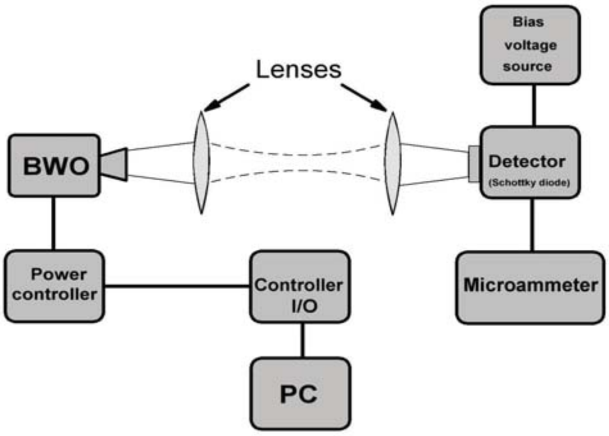

Fig.3. Configuration of the experimental setup for studying the frequency properties of the Schottky detector.

In addition, microwave film attenuators that transmit a certain amount of radiation were used to measure current sensitivity in the installation. Fig. 4 shows a diagram of an experimental quasi-optical system for studying the frequency characteristics of detectors Sub-THz range. The attenuators were made of films with different bandwidth: 10%, 30%.

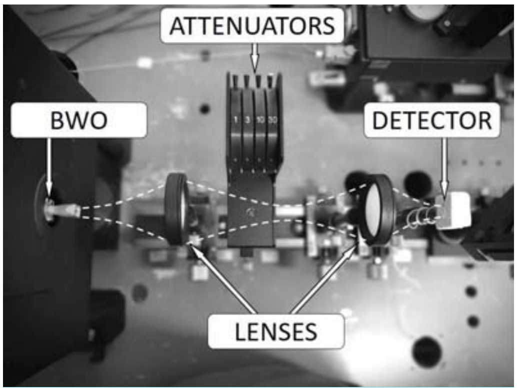

Fig.4. Image of a quasi-optical system for studying the current sensitivity of a Sub-THz radiation detector based on diode with Schottky barrier.

The intensity of the electromagnetic wave was changed by mechanical insertion of attenuators into the quasi-optical path. By changing the offset voltage at a fixed frequency of 249 GHz corresponding to the maximum radiation intensity, the current-voltage characteristics of the diode were obtained: when the radiation passes without weakening, when it weakens by 70%, when it weakens by 90%, and when there is no radiation. Further, assuming the passage of radiation without weakening for 100% of the power, which corresponds to 25 mW (the average power that the source produces), the values of the current sensitivity of the diode are obtained. Three intervals of power values are selected from the graph, and the dependence of current sensitivity on the bias voltage is constructed.

IV. Experimental Results

Fig.5 shows the current-voltage characteristic of a sample of a diode with Schottky barrier based on n-GaAs. Measurements were made at positive and negative bias voltages. However, in this case, only the positive bias voltage is of interest for determining the threshold value of the U_b.

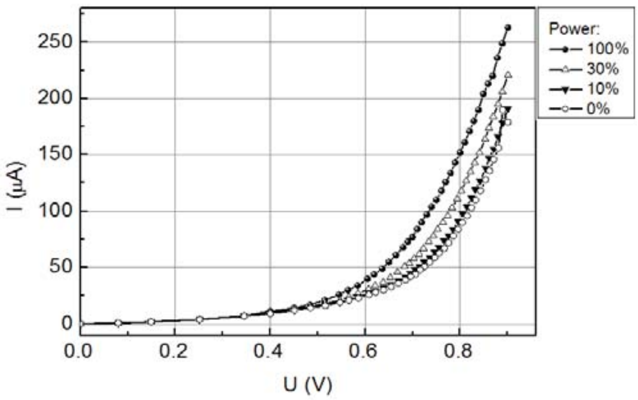

Fig. 5. Current-voltage characteristic of a diode with Schottky barrier based on n-GaAs depending on the relative power of the incident Sub-THz radiation (25 mW correspond to 100% of the power).

Fig. 6 shows the frequency response of the Golay cell in the range of 115-257 GHz. From this dependence, 30 values of fixed frequencies were selected, at which the current increment on diode with Schottky barrier was measured under the influence of Sub-THz radiation.

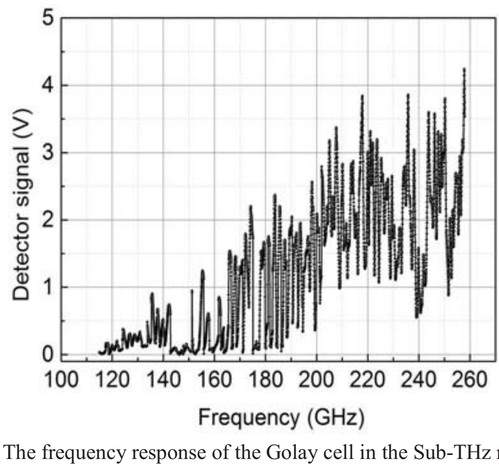

Fig.6. The frequency response of the Golay cell in the Sub-THz range.

Fig.7 shows a comparative graph of the frequency characteristics of a diode with Schottky barrier and the Golay cell.

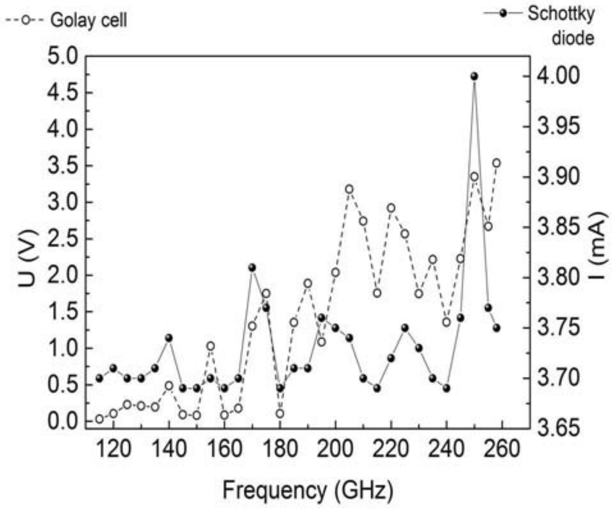

Fig.7. Frequency response of a diode with Schottky barrier and a Golay cell in the Sub-THz range.

Assuming that radiation passes without weakening for 100% of the power, which corresponds to 25 mW (the average power that the source gives out), the percentage values of the radiation power were converted to milliwatts. The transmission of one tenth of the radiation corresponds to a power of 2.5 mW. The transmission of the one thirtieth of the radiation corresponds to a power of 7.5 mW.

The following shows the dependence of the current through the diode with Schottky barrier on the power of the incident electromagnetic radiation at fixed values of the bias voltage (Fig.8) at a frequency of 249 GHz.

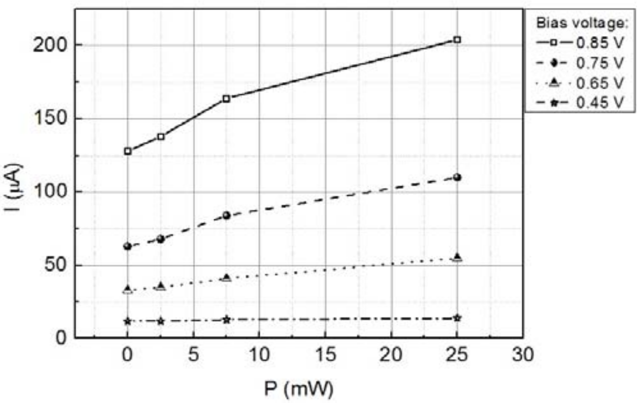

Fig.8. Dependence of current on the power of a diode with a Schottky barrier at a frequency of 249 GHz depending on the bias voltage in the range of 0.45-0.85 V.

Fig.9 shows the dependence of the current sensitivity of the diode on the bias voltage.

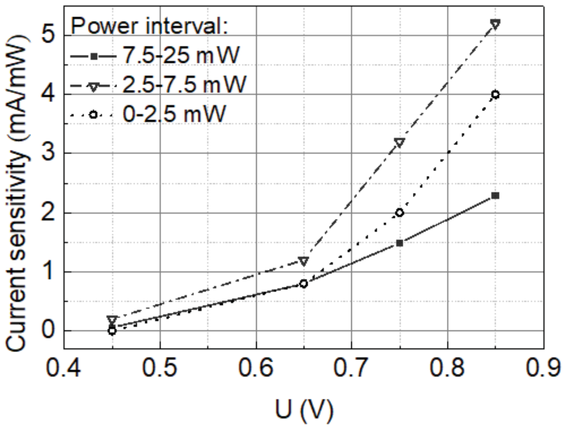

Fig.9. Dependence of the current sensitivity of the diode on the bias voltage at a frequency of 249 GHz.

V. DISCUSSION OF RESULTS

Analyzing the current-voltage characteristic of a diode with Schottky barrier (Fig.4), the threshold opening voltage is determined using a linear approximation. When the radiation transmit without weakening, U_b = 0.623 V, and in the absence of radiation, U_b = 0.706 V. Decrease in the threshold voltage in the presence of radiation can be explained by the presence of interaction of carriers with each other, for example, electron-hole scattering (EHS)[16, 17]. Threshold voltages exceed the typical value for detectors based on gallium arsenide [18]. This may be due to a number of factor m s that change the type of current-voltage characteristic of the diode [19]. For example, depending on the methods of metal deposition, the deposited film may introduce additional defects in the near-surface region of the semiconductor [20]. These defects lead to a solid-phase reaction involving contacting materials or to mutual diffusion of metal and semiconductor atoms [21]. Another reason may be the presence of an intermediate oxide layer associated with the oxidation of the semiconductor surface before applying the metal. Removing these layers is a technologically complex task, so in most cases, the oxide layer is always present on the surface of the semiconductor. Analysis of the current dependence on power at a fixed offset voltage (Fig.8) determined the following pattern: an increase in the radiation power leads to an increase in the current through the diode. From Fig. 9 it can be seen that the current sensitivity has a pronounced nonlinear dependence on the bias voltage. As the offset voltage increases, the detector current increment increases at a fixed power. The power range of 2.5-7.5 mW corresponds to the highest current sensitivity of the diode.

The frequency response of a diode with Schottky barrier was measured in the range of 115-257 GHz with an offset of 0.797 V (Fig.7). To assess the applicability of a diode with Schottky barrier in the terahertz range, the same characteristic was removed, but using a Golay cell. The correlation observed (Fig.7) allows us to confirm the assumption that the presented DSB can be used as a Sub-THz radiation detector.

VI. CONCLUSION

This article describes the properties of a diode with a Schottky barrier based on gallium arsenide, its features, the principle of operation and the prospects for using it as a Sub-THz radiation detector. Due to the specific structure of the diode, measurements made in the terahertz range using it allow one to quickly get high-quality results. The possibility of replacing the device in the installation will reduce the cost of measuring equipment and reduce the weight and size parameters.

ACKNOWLEDGMENT

The authors are grateful to Gennady Fedorovich Kovtunenko, an employee of the Research Institute of Semiconductor Devices Problems" (Tomsk, Russia) for the provided samples of diodes with a Schottky barrier and to Kirill Valerievich Dorozhkin, a Junior researcher at the Terahertz Research Laboratory of the National Research Tomsk State University for his assistance in conducting the experiment.

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