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Research of the photo-voltaic effect in the two-base Ag-N^0AlGaAs-n^+GaAs-n^0GaInAs-Au structure with various thicknesses of a base

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Abstract. The results of research of photoelectric phenomena in the two-base Ag-N^0AlGaAs-n^+GaAs-n^0GaInAs-Au structure are presented. The photo-voltaic effect observable in a wide range of the spectrum (0.4-2 μm) is explained by different signs of the photo EMF created by the separation of photocarriers in the energy barrier and from the levels of intrinsic defects as well as deep impurities of oxygen in the quasineutral base. A mechanism of photosensitivity of thin base structures with Schottky-Mott's barrier under photovoltaic conditions is offered.

Keywords: iso-type junction, heterolayer, two-base structure, barrier, photovoltaic effect.

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1. Introduction

The structures with a metal-semiconductor junction are used very much in various spheres, e.g., in electronic schemes of information-telecommunication systems. New functional possibilities of the structures with a metal-semiconductor junction are realized by the creation of various modified structures with Schottky barrier, Mott barrier, and Bardin barrier [1, 2]. Using the iso-type heterojunctions containing impurity levels in the base of there structures allows one to get high photocurrents in the long-wave range of the spectrum. Two-side photosensitivity and photocurrent's amplification are reached by the creation of structures with two potential barriers [3, 4]. Research of structures with photo-voltaic effects in which there are no dark currents quickens the pace, because they allow one to transform optical and other signals without distortions. The more attention is given to researches of the photoelectric characteristics of structures with iso-type junctions [5]. However, these structures' photosensitivity in the long-wave range of the spectrum (1–2 μm) is reached only at a definite working voltage, which causes the appearance of noise currents. In this aspect, the development of photo-voltaic receivers, in which the noise currents are practically absent, is undoubtedly interesting.

This work presents the results of research of photo-voltaic effects in the modified two-base Ag-N^0AlGaAs-n^+GaAs-n^0GaInAs-Au structure with various thicknesses of the base, as well as the analysis of electronic processes.

2. Manufacturing the researched structures and investigation of the spectral characteristics under conditions of the photo-voltaic effect

Beginning the consideration of two-base structures, it is necessary to note that, as distinct from the technology of manufacturing of one-base structures [6], the fabrication of the two-base Ag-N^0AlGaAs:O-n^+GaAs-n^0GaInAs:O-Au structure was realized by the alternate growing of heterolayers in various processes of liquid epitaxy. In the first process, the epitaxy heterolayer $N^0Al_{0.2}Ga_{0.8}$ was grown on one side of the n^+GaAs substrate, and, in the second process, the epitaxy heterolayer $n^0Ga_{0.9}In_{0.1}$ was grown on the other side of the same n^+GaAs. As a result of the repeated thermal influence in the flow of hydrogen on the hetero-epitaxial N^0AlGaAs layer, the gettering of defects takes place, so that a metal-semiconductor junction created on its surface gets properties of Mott's barrier. Short-circuit current's conditions are fulfilled by the switching of the researched structure directly to an ammeter. Epitaxial layers of the base of the researched structure grown by liquid epitaxy from the source single crystal nGaAs:O (with a concentration of carriers of $4\cdot10^{15}$ cm^{-3}) doped by oxygen under industrial conditions in a technological process are destined for the manufacturing of modulators [7]. As the substrate, a single crystal n^+GaAs doped with tellurium (with a concentration of carriers of $(2–3)\cdot 10^{18}$ cm^{-3}) was used. The base thicknesses were equal 4 and 12 μm. In the structures with the base thickness of 4 μm at room temperature, the photo-voltaic effect was found [8]. It is accompanied by the change of the photocurrent sign at the transition from the area of intrinsic absorption to that of impurity one in a large range of the spectrum (0.4 up to 2 μm). The photo-voltaic effect (see Fig. 1) is observed under the short-circuit current conditions. That is, without any working voltage, the photocurrent is created in a closed circuit at the excitation by monochromatic and integrated radiation. A special feature of the discovered photo-voltaic effect for the Ag-N^0AlGaAs is the change of its sign at the illumination with increase in the monochromatic radiation wavelength from 0.4 up to 2 μm. At the intrinsic absorption (0.5–0.9 μm), the photocurrent has positive sign; while, at the impurity absorption (0.96 up to 2 μm), the photocurrent gets negative polarity with peaks at 1.1 and 1.55 μm (see Fig. 1). The observed peaks at 1.1 μm can be identified as those corresponding to the energy levels of intrinsic defects' centers of the base epitaxial layers; whereas the peaks at 1.55 μm are related to levels of oxygen (0.8–0.82 eV). At the excitation of the nGaInAs-Ag structure, the short-circuit photocurrent has maximum at 0.94 μm (curve 5); it is conformed with the band gap of GaInAs (1.32 eV). However, at impurity absorption, photocurrents have low values. At increasing the temperature from room one to 80 °C, values of photocurrents remain constant the intrinsic absorption, but their values increase proportionally to the temperature increase at the impurity absorption (curves 2 and 4, Fig. 1). It is possible to explain the invariance of the photocurrent at the intrinsic absorption by the independence of physical processes on temperature, first of all, the independence of the thickness of the Ag-N^0AlGaAs barrier's space charge layer on temperature.

It is possible to explain the change of the sign of a spectral photocurrent by a change of the region of carriers' photogeneration with the variation in the wavelength of optical radiation. So, the radiation with wavelengths from 0.4 till 0.94 μm generates photocarriers from the surface and from the irradiated barrier space charge. Then the radiation reaches the quasineutral part of the base and the heterojunction of N^0AlGaAs-n^+GaAs, the direction of photocarriers has an opposite sign, when the photoexcitation of carriers occurs from the levels of intrinsic defects of the heterolayer and from the oxygen impurity levels. As a result, we have change of the sign of a photocurrent under short-circuit conditions depending on the wavelength of exciting optical radiation. With increase in the temperature, the creation of the given photocurrent needs a smaller energy of photon radiation.

In the two-base Ag-N^0AlGaAs-n^+GaAs-n^0GaInAs-Au structure with a base thickness of 12 μm, the photoelectric phenomena are manifested differently. Under short-circuit conditions, photocurrent has a positive sign (Fig. 2) at the whole spectral range unlike structures with a thin base. Both at the intrinsic and impurity absorption, there are the appropriate peaks related to the gap width, intrinsic defects (1.2 μm), and oxygen impurity (1.5 μm).

The difference between photogeneration processes in this case and those in the thin-base case is that radiation is absorbed by not reaching the iso-type N^0AlGaAs-n^+GaAs junction border, and photogenerated carriers move in the same direction. So we have positive photocurrent on the spectral characteristics.

Thus, in the Ag-N^0AlGaAs-n^+GaAs-n^0GaInAs-Au structure with the base containing the deep impurity levels of oxygen at room temperature, the photo-voltaic effect is discovered in a wide range of the spectrum (0.4 up to 2 μm). It is accompanied by the change of the sign of photocurrents at the transition from the intrinsic absorption to the impurity one in structures with a base thickness smaller than 4 μm, and it has positive sign at a thickness of 12 μm.

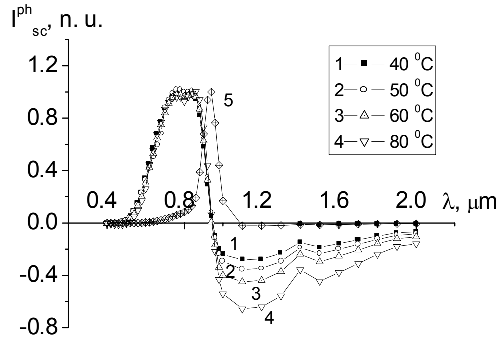

Fig. 1. Spectral characteristic of the Ag-N^0AlGaAs-n^+GaAs-n^0GaInAs-Au structure with base's thickness ~ 4 μm at various temperatures under short-circuit current conditions at the illumination from the Ag-N^0AlGaAs-side.

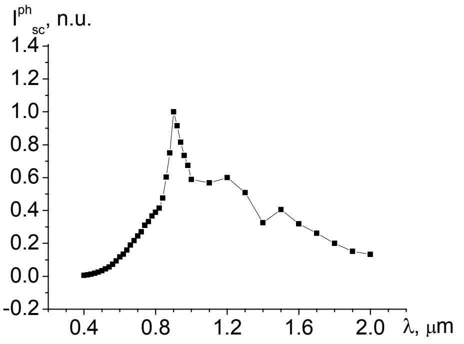

Fig. 2. Spectral characteristic of the Ag-N^0AlGaAs-n^+GaAs-n^0GaInAs-Au structure with base's thickness ~ 12 μm at 50 °C under short-circuit current conditions at illumination from the Ag-N^0AlGaAs side.

3. Models of mechanisms of photosensitivity of thin-base structures with Schottky-Mott's barriers under photo-voltage conditions

At the illumination from the wide-gap side, the photogeneration takes place on the Ag-N^0AlGaAs-n^+GaAs barrier, and the dark n^0GaInAs-Au junction becomes a load resistance. On the other hand, at the illumination from the narrow-gap side, the dark wide-gap barrier becomes a load. Hence, the process of photogalvanic current's formation is caused by dark barriers taking place of a load resistance and the barrier as a photogalvanic element. Therefore, at the change of one illuminated surface by another one, we have already the photogalvanic current of other junction. In the process of increase in the wavelength of exciting optical radiation, we have firstly a photocurrent of one sign which is generated directly under a barrier. With the further increase in the wavelength of radiation, the photocurrent with the other sign is generated due to the penetration of light radiation in the quasineutral heterolayer of the base, which has a beam in the band of conductivity of the isotype junction as a reflecting metal-semiconductor junction. Approaching the direction of generated photocarriers results in the change of the sign of the photocurrent. It is necessary to note that the photosensitivity of the two-base structure to photo-voltaic conditions is operated not only by the base thickness, but also by the difference of concentrations on the iso-type heterobarrier as a weekly doped heterolayer – a highly doped heterolayer. The mechanism of photosensitivity of the two-base structure can be explained as follows.

In two-base structure from the side of the illuminated wide-gap heterobarrier, electrons are excited and then are transferred into the base, as shown in Fig. 3 (position 1). Then the light radiation from the intrinsic absorption region excite electrons and holes in the depletion layer, and they move in the base and the contact (position 2). Then the radiation with the wavelength which is more than that of the intrinsic absorption reaches the quasineutral part of the base near the border with the space charge layer and excites carriers (position 3). When the wavelength is equal to the depth of bedding of the impurity levels of oxygen, photocarriers begin to be generated from impurity levels (position 4).

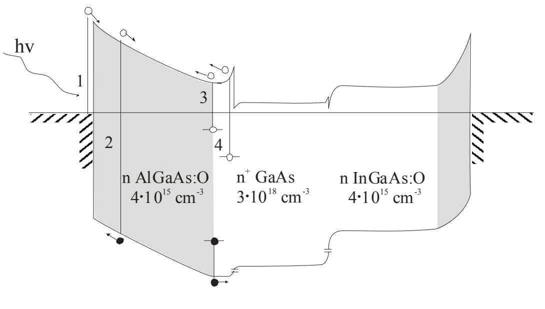

Fig. 3. Gap diagram of the two-base Ag-$N^0Al_{0.2}Ga_{0.8}$As-n^+GaAs-$n^0Ga_{0.9}In_{0.1}$As-Au structure in equilibrium under illumination of Ag-$N^0Al_{0.2}Ga_{0.8}$As Mott's barrier.

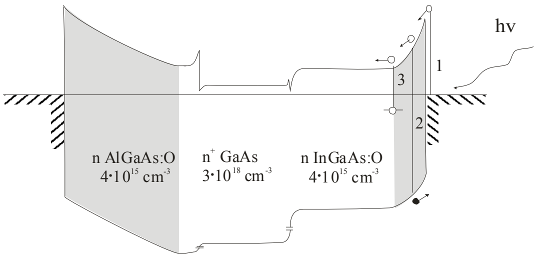

Fig. 4. Gap diagram of the two-base Ag-$N^0Al_{0.2}Ga_{0.8}$As-n^+GaAs-$n^0Ga_{0.9}In_{0.1}$As-Au structure in equilibrium under illumination of $n^0Ga_{0.9}In_{0.1}$As-Au Schottky's barrier.

In the case of illumination of the two-base Ag-$N^0Al_{0.2}Ga_{0.8}$As-n^+GaAs-$n^0Ga_{0.9}In_{0.1}$As-Au structure from the side of narrow-gap indium containing a heterolayer, electrons are excited from the metal as well (Fig. 4, position 1). Then, at the intrinsic absorption of photons, electrons and holes from the space charge region are separated (position 2). Then the generation of carriers from the levels of intrinsic defects takes place (position 3).

4. Conclusion

The photo-voltaic effect observed in the two-base Ag-N^0AlGaAs-n^+GaAs-n^0GaInAs-Au structure is determined by signs of the photo EMF created at the separation of photocarriers in the energy barrier and from the levels of intrinsic defects, as well as the levels of deep oxygen impurities in the quasineutral base. The temperature invariance of the spectral photocurrent in the range of intrinsic absorption in a thin base-structure can be explained by a fixed value of space charge layer's thickness independent of these factors in Mott's barrier. In the impurity range of the spectrum, the generation of carriers occurs in the quasineutral base, where, with increase in the temperature, a smaller energy of photon radiation is necessary to generate the given photocurrent.

In the two-base Ag-N^0AlGaAs-n^+GaAs-n^0GaInAs-Au structure with thin base, the photocarriers generated in the Ag-N^0AlGaAs barrier are directed towards to each other in the metal-semiconductor junction and in the weekly doped semiconductor – highly doped semiconductor heterojunction. The structures with photovoltaic effect are interested as noiseless photodetectors for optical fiber systems.

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