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FUNCTIONAL POSSIBILITIES OF Ag–N^0AlGaAs–n^+GaAs–n^0GaInAs–Au STRUCTURES WITH AN ISOTYPE BASE REGION

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We have considered the spectral characteristics of two-base structures with isotype heterojunctions and with Schottky and Mott barriers to the base regions and explained the features of the impurity and photovoltaic effects in two-base structures containing deep impurity levels of oxygen and intrinsic defects.

Introduction. Structures with a metal–semiconductor junction find wide application in various fields and in electronic circuits of information-telecommunication systems. Due to the development of various modified structures with a Schottky, Mott, and Bardeen barrier [1], new functional properties of structures with a metal–semiconductor junction are realized. By now low-barrier structures intended for creating microwave bias-free detectors have been developed, and high working frequencies have been attained on Mott-barrier structures. The modified structures with low potential barriers (~0.2 eV) presented in [2] are based on epitaxially grown GaAs layers obtained by gaseous-phase epitaxy from organometallic compounds on gallium arsenide substrates with a carrier density of $2 \cdot 10^{18}$ cm^{-3}. The carrier density in an epitaxial layer of thickness 0.1 μm is $2 \cdot 10^{16}$ cm^{-3}. On the surface of the epitaxial layer a potential barrier from Al is formed. The possibility of controlling the effective barrier height in Schottky diodes was attained by varying the thickness of the *delta*-doped layer introduced between the metal and the semiconductor. A decrease in the effective barrier height provided dominant tunneling of carriers through the barrier.

In the case where the base region is formed from a high-resistance material and is completely covered with a space-charge layer and the value of the barrier capacitance (C_{bar}) is equal to the geometric capacitance

$$C_{\text{bar}} = S \left(\frac{q\varepsilon\varepsilon_0 N}{2\,(U_{\text{k}} \pm U)} \right)^{1/2} = \frac{\varepsilon\varepsilon_0 S}{d_{\text{base}}}\,,$$

we will have a Mott barrier. In its base region, electrons are absent even under direct bias, and the current transfer is defined by the diffusion mechanism: $I = I_{\text{s}}[\exp\,(qU/kT) - 1]$, where I_{s} weakly depends on temperature but more strongly depends on voltage. Low values of the barrier capacitance permit achieving higher frequencies than in the Schottky barrier [3].

In Schottky-barrier structures, due to their use as a base region of isotype heterojunctions containing deep impurity levels, large photocurrent values are attained in the long-wave region of the spectrum. The development of structures with two potential barriers [4–6] has made it possible to obtain bilateral photosensitivity and photocurrent amplification. At the same time, the realization of structures based on photovoltaic effects began to attract the attention of researchers. Such interest is due to the absence from the structures of dark currents, which makes it possible to process optical and other signals without distortion. Researchers began to study intensively the possibilities of using semiconductor structures for other purposes, in particular, solar cells as nuclear radiation detectors [7] and diodes and transistors as temperature sensors [8]. The production of photovoltaic optrons was launched [9], i.e., a new trend in the physics of semiconductor devices based on photovoltaic effects was formed. In this aspect, of interest was the devel-

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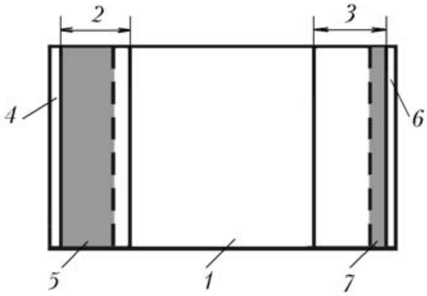


Fig. 1. Geometry of the two-base Ag–N^0AlGaAs–n^+GaAs–n^0GaInAs–Au structure: 1) n^+GaAs:Te substrate with a concentration of $3\cdot10^{18}$ cm^{-3}; 2) wide-band heteroepitaxial N^0AlGaAs layer of thickness 2 μm doped by oxygen with a concentration of $4\cdot10^{15}$ cm^{-3}; 3) narrow-band heteroepitaxial n^0GaInAs layer of thickness 3 μm doped by oxygen with a concentration of $4\cdot10^{15}$ cm^{-3}; 4) Mott barrier of thickness 70 Å from Ag created on the N^0AlGaAs layer; 5) space charge created with an N^0AlGaAs layer; 6) Schottky barrier of thickness 70 Å from Au created on the n^0GaInAs layer; 7) space charge created with an n^0GaInAs layer.

opment of various special-purpose structures based on photovoltaic effects, since the physical fundamentals of any device are specific.

At present, of interest are noiseless structures sensitive in the infrared (IR) region of the spectrum intended for use in various information systems. The search for ways of increasing the efficiency of IR photodetectors is continuing, and much consideration is given to the investigations of the photoelectrical characteristics of blocked-conductivity structures [10] and structures with isotype junctions [11]. However, the photosensitivity in the long-wave region of the spectrum (1–2 μm) in them is attained only under certain working voltages (0.8–1.0 V), which causes the appearance of noise currents. BIB (Blocked Impurity Band) structures with blocked conductivity of p^+–i–p–p^+ structures were proposed in [8] as an impurity band photodetector of the far IR range operating at helium temperatures. Its chief advantage over the classical impurity band photodetector is a combination of a high quantum efficiency at a high doping level of the photosensitive layer with a lower noise level due to the presence of the blocking layer, which made it possible to create photodetectors (PhD) operating in the 0.4–40 μm spectral range. Certainly, in this aspect of interest is the realization of photovoltaic detectors in which noise current is practically absent.

The present paper analyzes the functional possibilities of the modified two-base isotype Ag–N^0AlGaAs–n^+GaAs–n^0GaInAs–Au structure with a metal–semiconductor junction.

Production of Modified Ag–N^0AlGaAs–n^+GaAs–n^0GaInAs–Au Structures. The realization of the advantages of the narrow-band and broad-band regions in a single structure is problematic when they are positioned immediately one under the other, since in this case we will have the photoeffects of one of these regions instead of their integration. And in the proposed case where the base regions are situated on either side of one substrate, they will appear to be mutually independent as to their reaction to the optical radiation but electrically controlled. In so doing, new properties will manifest themselves: bilateral photosensitivity, decrease in dark currents, improvement of the frequency band. Therefore, the structure under investigation has been created by joining technologically a kind of two independent structures with a different base region through the common highly doped region — the substrate. Since the base heteroregions (N^0AlGaAs, n^0GaInAs) have a carrier density three or more orders lower compared to the low-resistance n^+GaAs substrate, the influence of the substrate on the physical processes is excluded independent of its thickness. The geometry of the modified Ag–N^0AlGaAs–n^+GaAs–n^0GaInAs–Au structure is given in Fig. 1, where it is shown that on different surfaces of the highly doped n^+GaAs:Te substrate (1) with a carrier density $n \sim 3\cdot10^{18}$ cm^{-3} isotype heterolayers of N^0AlGaAs (2) and n^0GaInAs (3) have been grown by the method of liquid-phase epitaxy. The carrier density in oxygen-doped heterolayers is $4\cdot10^{15}$ cm^{-3}, and the thicknesses are 2–3 μm. On the N^0Al$_{0.2}$Ga$_{0.8}$As surface, a rectifying semitransparent (70 Å) potential Mott barrier creating a space-charge layer (5) has been formed form Ag (4). On the surface of the narrow-band n^0Ga$_{0.9}$In$_{0.1}$As heterolayer, a Schottky barrier from Au (6) with a space-charge layer (7) has been formed.

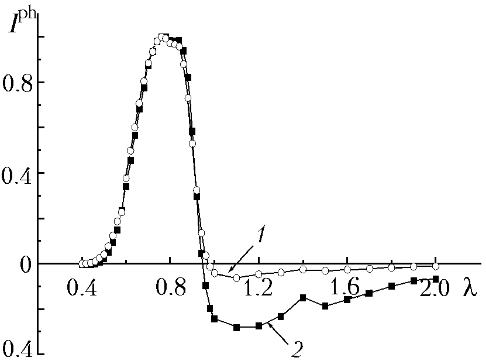


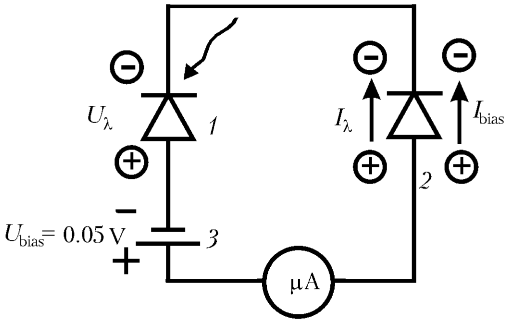
Fig. 2. Spectral characteristic of the Ag–N^0AlGaAs–n^+GaAs–n^0GaInAs–Au structure: 1) in the blocking regime of the Ag–N^0AlGaAs junction; 2) in the short circuit regime. I^{ph}, rel. unit; λ, μm.

Thus, the investigated structure contains two opposing potential barriers which are alternately blocked when the external voltage polarity is changed ((–)m–N^0 junction, and in the other case n^0–m(–) junction).

Investigation and Comparative Analysis of the Photoelectrical Characteristics of Ag–N^0AlGaAs–n^+GaAs–n^0GaInAs–Au Structures Depending on the Switching Regimes. As was shown in [12], in one-base Ag–n^0GaAs–n^+GaAs structures with a thick (12 μm) homoisotype base illuminated by the integral light, a positive photocurrent is generated, and in the case of a thin base (4 μm), the photocurrent is negative, i.e., quenching (decrease) of the light current occurs. In two-base structures, in the photodiode regime the signs of the photocurrent and back current coincide, and when positive polarity of the bias voltage is applied to the Ag–N^0AlGaAs junction, there is a spectrally dependent decrease in the current traversing the structure. These effects of decreasing current in one- and two-base structures are similar in appearance, but in principle they differ considerably from one another. For instance, in the one-base Ag–n^0GaAs–n^+GaAs structure with a Schottky barrier photocurrent appears only in the presence of reverse voltage, and in two-base Ag–N^0AlGaAs–n^+GaAs–n^+GaInAs–Au structures with an isotype heterobase region photocurrents are generated without bias voltage, which points to a different nature of the physical processes in two-base structures.

Photovoltaic Regime. Characteristic of the spectral characteristics of the Ag–N^0AlGaAs–n^+GaAs–n^0GaInAs–Au structure in the short-circuit current regime under illumination from the side of Ag–N^0AlGaAs is the fact that as the monochromatic radiation wavelength increases from 0.4 to 2 μm, the photocurrent traverses the maximum (0.74 μm) and zero at 0.9 μm and then changes sign, generating a photocurrent of negative polarity in the range up to 2 μm with peaks at 1.1 and 1.55 μm (Fig. 2).

Photodiode Regime. When the negative polarity of the bias voltage is applied to the illuminated (–)Ag–N^0Al$_{0.2}$Ga$_{0.8}$As heterolayer, the photocurrent traverses the maximum (at 0.74–0.75 μm) and, decreasing, begins to cover the long-wave region up to 2 μm. An increase in the bias voltage does not influence the photocurrent value in the intrinsic absorption region, and in the long-wave region (0.96–1.4 μm) the photocurrent sign changes to negative. The curves of the dependences of short-circuit photocurrent and the spectral sensitivity in the intrinsic absorption region in the blocking regime of the broad-band Ag–N^0Al$_{0.2}$Ga$_{0.8}$As barrier coincide (Fig. 2), and an increase in the blocking voltage does not change the photocurrent value, i.e., the processes of generation of photocarriers both in the regime of short-circuit current and at Ag–N^0Al$_{0.2}$Ga$_{0.8}$As barrier blocking remain unaltered. This points to the fact that the thickness of the space-charge layer as a function of the blocking voltage remains unchanged, peculiar to the Mott barrier. In the regime of (–)Ag–N^0–n^+–n^0Au(+) connection of the modified Ag–N^0AlGaAs–n^+GaAs–n^0GaInAs–Au structure to the voltage source (Fig. 3), illumination of the structure from the side of the Ag–N^0Al$_{0.2}$Ga$_{0.8}$As junction leads to the appearance of a photocurrent whose direction coincides with the direction of the current generated by the external source. This current falls off in the directly connected nonilluminated n^0GaInAs–Au junction and freely traverses the circuit. However, in the long-wave region of the spectrum of 0.94–2 μm the processes of photogeneration of carriers weaken significantly, which is due to the negative sign of the photocurrent and the (twice) larger values of the dark current (at a voltage of –0.05 V) compared to the photocurrent generated by the Ag–N^0Al$_{0.2}$Ga$_{0.8}$As junction.



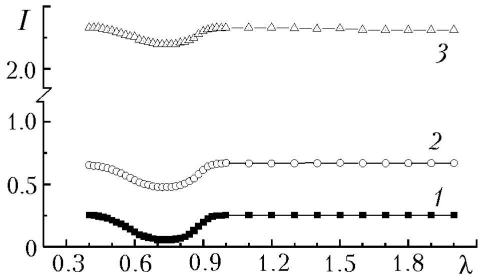


Fig. 3. Model inclusion of the Ag–N^0AlGaAs–n^+GaAs–n^0GaInAs–Au structure in the regime of (–)Ag–N^0–n^+–n^0–Au(+): 1) Ag–N^0AlGaAs Mott barrier as a photogenerator; 2) n^0GaInAs–Au Schottky barrier as a load; 3) bias source. I_λ, photogalvanic current; I_{bias}, bias current from the source.

Fig. 4. Spectral dependence of the current traversing the (+)m–N^0–n^+–n^0–m(–) structure at various voltages: 1) U = +0.05 V; 2) +0.1 V; 3) U = +0.2 V. I, μA; λ, μm.

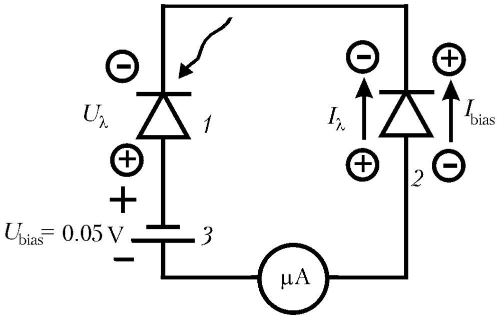


Fig. 5. Model inclusion of the Ag–N^0AlGaAs–n^+GaAs–n^0GaInAs–Au structure in the regime of (+)Ag–N^0–n^+–n^0–Au(–): 1) Ag–N^0AlGaAs Mott barrier as a photogenerator; 2) n^0GaInAs Schottky barrier as a load; 3) bias source. I_λ, photogalvanic current; I_{bias}, bias current from the source.

As the bias voltage polarity of the illuminated (+)Ag–$N^0Al_{0.2}Ga_{0.8}As$ heterolayer is changed by +0.05 V, a spectrally dependent decrease in the current traversing the structure is observed (Fig. 4). The quantity of the current half-fall gives a value of 1.67 eV (0.74–0.75 μm), i.e., the energy gap width of $N^0Al_{0.2}Ga_{0.8}As$. This process can be explained by the compensation of the intrinsic dark bias current generated by the external source by the photocurrent of the opposite sign generated by the Ag–$N^0Al_{0.2}Ga_{0.8}As$ barrier, i.e., by the interaction of the voltages generated by the source and the illuminated Ag–$N^0Al_{0.2}Ga_{0.8}As$ junction. An increase in the bias voltage together with an increase in the generated minory carriers (dark currents) decreases the photocurrent value (Fig. 4, curve 3). In this regime of connection to the blocked n^0GaInAs–Au junction, two voltage sources turn out to be switched on; one of them is the power unit and the other is the Ag–$N^0Al_{0.2}Ga_{0.8}As$ photogenerator (Fig. 5). As is seen from the figure, from the applied bias voltage with a fixed value, e.g., U_{bias} = 0.05 V, without illumination we obtain a reverse current of the n^0GaInAs–Au junction. However, illuminating the Ag–$N^0Al_{0.2}Ga_{0.8}As$ junction by monochromatic radiation of wavelength from 0.4 to 0.94 μm corresponding to the intrinsic absorption, we obtain in the given junction a photocurrent with a maximum at an energy equal to the energy gap width of the $N^0Al_{0.2}Ga_{0.8}As$ heterolayer whose emf sign is opposite to the direction of the reverse current of the blocked n^0GaInAs–Au junction. As a result, the difference of these voltages turns out to be applied to the blocked n^0GaInAs–Au junction. Precisely the voltage generating current in the circuit will be equal to the difference between the bias voltage U_{bias} = const and the voltage U_λ of the photocurrent generated by the illuminated Ag–$N^0Al_{0.2}Ga_{0.8}As$ junction: $I^{\text{light}}R = U_{\text{bias}} - U_\lambda$. Here U_λ has a dependence analogous to the spectral photocurrent. Its value will reach a maximum without bias voltage and, as the blocking voltage is increased, it will decrease in the form of reflection of the fall of the dependence of the light current on the monochromatic radiation wavelength (Fig. 4). Such structures are of interest for fiber-optical system as noiseless photodetectors and switches.

Conclusions. A change in the geometric and electrophysical parameters of structures with a metal–semiconductor junction leads to a changes in their functional properties. The modified two-base Ag–N^0AlGaAs–n^+GaAs–n^0GaInAs–Au structures containing oxygen impurity levels in the isotype base region with Schottky and Mott barriers exhibit photosensitivity in a wide spectral range (0.4–2.0 μm) in both the short circuit current regime and the photodiode regime.

NOTATION

C_{bar}, barrier capacitance, pF; d_{base}, thickness of the base region, μm; i, overcompensated high-resistance layer; I^{light}, illumination light current, μA; I^{ph}, photocurrent; I, direct bias current, A; I_{s}, saturation current, A; I_λ, monochromatic radiation current, A; I_{bias}, bias voltage current, A; k, Boltzmann constant, $1.38 \cdot 10^{-23}$ J/K; m_1, metal creating a barrier with a wide-band AlGaAs layer; m_2, metal creating a barrier with a narrow-band GaInAs layer; N, charge carrier density, cm^{-3}; n^+, highly doped GaAs layer with n-type conductivity; N^0AlGaAs, wide-band high-resistance epitaxial layer; n^0GaInAs, narrow-band high-resistance epitaxial layer; p, layer with p-type conductivity; p^+, highly doped layer with p-type conductivity; q, electron charge, C; R, resistance, Ω; S, area of the sample, cm^2; T, temperature, K; U, voltage, V; U_{c}, contact potential difference, eV; U_{bias}, bias voltage, V; U_λ, photogalvanic voltage, V; ε, dielectric constant of the semiconductor; ε_0, dielectric constant of vacuum, $8.85 \cdot 10^{-12}$ F/m; λ, monochromatic radiation wavelength, μm. Subscripts: bar, barrier; base, base; light, light; bias, bias; c, contact; ph, photo; s, saturation.

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