Journal of Engineering Physics and Thermophysics, Vol. 80, No. 3, 2007

INFLUENCE OF THE THICKNESS OF THE BASE REGION OF STRUCTURES WITH A SCHOTTKY BARRIER ON THEIR CURRENT AND PHOTOELECTRIC CHARACTERISTICS

D. M. Edgorova

UDC 621.383.4/5.029.674:621.315.592.2

The influence of the thickness of the base region with deep impurity levels of diode Ag–nGaAs–n^+*GaAs structures with a Schottky barrier on their photoelectric characteristics has been investigated. It was established that, on illumination of these structures by an integral light with* $\lambda_{max} = 0.55$ *μm, in some of them the quenching effect appears — the back light current becomes lower than the dark current, and in the other the light current predominates over the dark current under the direct-bias conditions. In this case, the decrease in the light current is explained by the trapping of light carriers and their recombination with dark carriers under the conditions where the voltage drop across the Schottky barrier exceeds the voltage drop across the base region, and vice versa the increase in the light current is due to the larger voltage drop across the base region.*

Introduction. Diode structures with a Schottky barrier are improved constantly for the purpose of giving them new properties. On the basis of these structures, field-effect transistors, photodetectors, and photoelectric converters are made [1–3].

Among the photoelectric converters with a Schottky barrier, those that are based on Au–*n*AlGaAs–*n*GaAs structures with a controlled photosensitivity have attracted major attention [1]. In such structures, having an energy-gap width of 1.8 eV, the thin *n*AlGaAs layer and a part of the *n*GaAs region near the heterojunction are subjected to the action of a strong electric field, which makes it possible to control the spectral sensitivity of these structures by changing the thickness of the AlGaAs layer. An analogous effect can be obtained by changing the back bias in solar cells containing a thicker heterolayer since the difference between the energy-gap widths of the *n*AlGaAs and *n*GaAs regions decreases with increase in the blocking voltage. Photodetectors based on structures with a Schottky barrier can work under different conditions and in different optical ranges. Their performance is especially high in the visible and short-wave regions of the spectrum. The use of high energy-gap semiconductors, such as GaAs, for production of photodetectors makes it possible to obtain corresponding devices with a high working temperature, a high stability, and a high radiation resistance [3–5]. However, the deep impurity levels contained in the base region of structures with a Schottky barrier influence their photoelectric characteristics [6]. In particular, on illumination of such structures by light with $\lambda = 0.7$–1.2 μm, there arises in them a quenching of the direct current (its decrease) [7]; in [8] optical quenching of the photocurrent of these structures by an integral light was detected. It should be noted that the majority of works [3–5] on the study of structures with a Schottky barrier were devoted to the selection of a material for the base region and the determination of the dependence of its properties on the switching regime. However, the dependence of the photoelectric properties of the indicated structures on the thickness of their base region containing deep impurity levels has not been adequately investigated.

In the present work we investigated the dependence of the photocurrent of structures with a Schottky barrier on the thickness of their base region and the working voltage.

Obtaining of Experimental Samples and Investigation of Their Photoelectric Characteristics. The structures being investigated were made on the basis of epitaxial layers with *n*GaAs–n^+GaAs transitions by growing from the liquid phase of *n*GaAs. Their thicknesses varied from 3 to 12 μm, and the carrier concentration in them was equal

---

Physical-Technical Institute, "Physica–Sun" Scientific-Production Association, Academy of Sciences of the Republic of Uzbekistan, 26 Mavlyanov Str., Tashkent, 700084, Uzbekistan. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 80, No. 3, pp. 188–192, May–June, 2007. Original article submitted July 21, 2005; revision submitted June 27, 2006.

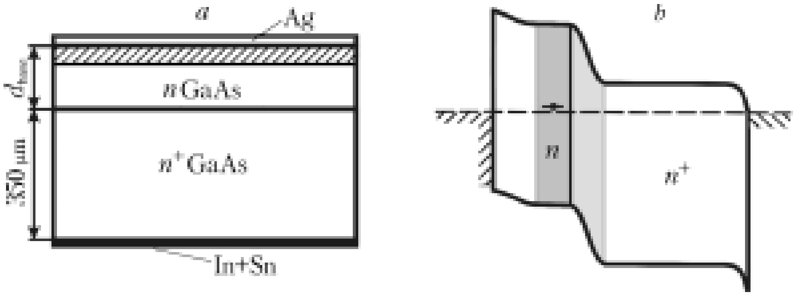


Fig. 1. General diagram (a) and energy-band diagram (b) of the Ag–*n*GaAs–n^+GaAs structure.

to ~$2 \cdot 10^{15}$ cm^{-3}. The alloys (Ga + GaAs), from which the epitaxial *n*GaAs layers were grown, were saturated with a monocrystalline gallium arsenide containing oxygen impurities and forming donor levels with a depth of ~0.7 eV in the upper half of the forbidden zone [9]. The refined oxygen concentration, determined by the gamma-photon activation, was equal to $4 \cdot 10^{15}$ cm^{-3} [10]. As substrates, we used monocrystalline n^+GaAs plates of thickness 350–400 μm with a carrier concentration $N \sim 3 \cdot 10^{18}$ cm^{-3}, dopped with tellurium. Semitransparent rectifying Ag contacts of thickness ~100 Å were formed on the surface of the epitaxial layer by vacuum deposition, and ohmic In + Sn contacts of thickness 200–300 Å were formed on the back side of the substrate. The general diagram of the structures obtained with a Schottky barrier is shown in Fig. 1. We investigated the current and photoelectric parameters of these structures.

On illumination of the Ag–*n*GaAs–n^+GaAs structures being investigated by an integral light of intensity 300 lx with $\lambda_{\max} = 0.55$ μm, the negative light current in their reverse bias region changed, depending on the thickness (3–12 μm) of the base region, to a positive one (in the forward bias region). In this case, an increase in the reverse voltage applied caused a nonlinear increase in the photocurrent and, as a result, there appeared a difference between the light (I^{light}) and dark (I^{d}) currents ($I^{\text{ph}} = I^{\text{light}} - I^{\text{d}}$). Accordingly, the current photosensitivity S_I changed under illumination by a definite light depending on the voltage applied:

$$S_I = \frac{I^{\text{ph}}}{\Phi}.$$

For example, as the volt-ampere characteristics of Ag–*n*GaAs–n^+GaAs structures with a high-ohmic region of thickness smaller than 3–4 μm show, in the reverse-bias region of these structures there arises a negative photosensitivity under illumination, while their forward-bias region does not react to the luminous radiation (Fig. 2a). The photosensitivity of the indicated structures was equal to 0.074 A/lm at a photocurrent $V_{\text{rev}} = 2$ V.

In structures with an active region of thickness 6–8 μm, the photosensitivity (0.296 A/lm) appeared in both the reverse and forward bias regions (volt-ampere characteristics in Fig. 2b). In this case, the light current in the forward-bias region was positive and the light current in the reverse-bias region was negative.

A further increase in the thickness of the *n*GaAs layer to 10–12 μm led to the suppression of the photosensitivity of the reverse-bias region of the structures and to the appearance of a photocurrent in their forward-bias region (0.014 A/lm) (Fig. 2c). In this case, the conductivity of the base region was modulated. As is seen from the volt-ampere characteristics obtained, a decrease in the thickness of the epitaxial layer with oxygen impurities, located under the barrier, leads to an enhancement of the negative-photosensitivity effect in the blocking regime (Fig. 2a). The photocurrent increases in direct proportion to the voltage applied to the structures. This can be due to the redistribution of this voltage between the potential barrier and the high-ohmic base layer, i.e., the increase in the photocurrent is caused by the increase in the electric field of the metal–semiconductor potential barrier.

The photoelectric characteristics of the structures being investigated (Fig. 2) allow the conclusion that the impurity oxygen levels become active when they are acted upon by the strong electric field of the depletion layer.

The decrease in the reverse light current detected (in samples No. 3 and 7) on illumination of the structures by visible light with $\lambda_{\max} = 0.55$ μm is explained by the trapping of minority light carriers by oxygen levels and their recombination with dark current carriers. As a result, the light current becomes lower than the dark current.

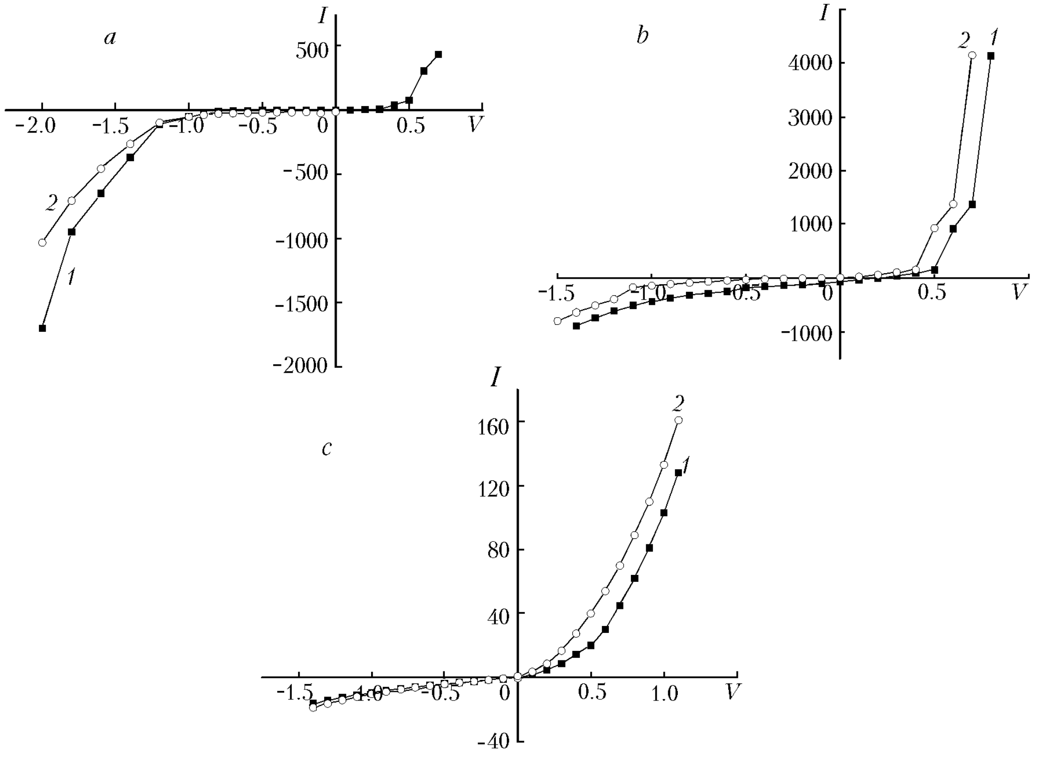


Fig. 2. Volt-ampere characteristics of the Ag–nGaAs–n^+GaAs structure with d_{base} = 4 μm, S = 0.3 cm^2 [a) sample No. 3], 8 μm, 0.09 cm^2 [b) No. 7], 10 μm, 0.08 cm^2 [c) No. 9]: 1) dark; 2) light. I, μA; V, V.

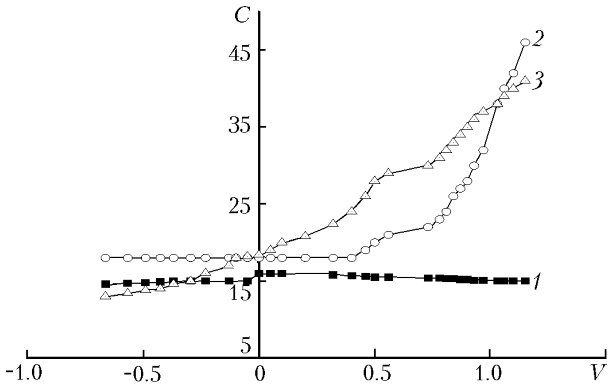
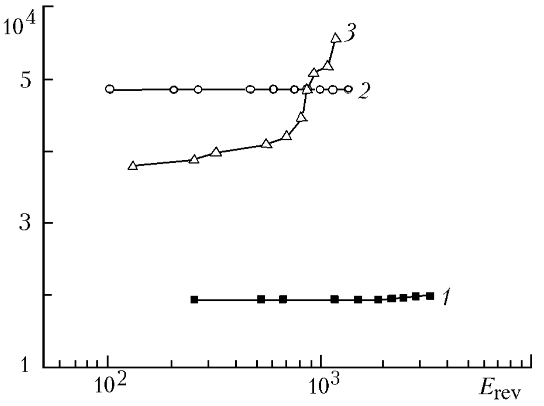


Fig. 3. Volt-ampere characteristics of samples with bases of different thickness: d_{base} = 4 (1), 8 (2), and 12 μm (3). C, pF; V, V.

As the thickness of the active region decreases (<3–4 μm), the electric field of the potential barrier increases and the oxygen levels more actively influence the process of formation of photocarriers. Therefore, under a direct bias, the influence of the recombination oxygen centers decreases and the positive light current increases with increase in the thickness of the base (sample No. 9). In this case, the photocurrent in the reverse bias region takes minimum values.

Analysis of the Negative Photosensitivity in Diode Ag–nGaAs–n^+GaAs Structures in the Blocking Regime. As the volt-capacitance characteristics of the structures being investigated show, these structures have close initial capacitances (16–18 pF) (Fig. 3). In this case, since the carrier concentrations in the base region of all the samples are equal, the samples with a thin base region had a higher electric-field strength. The capacitance of the



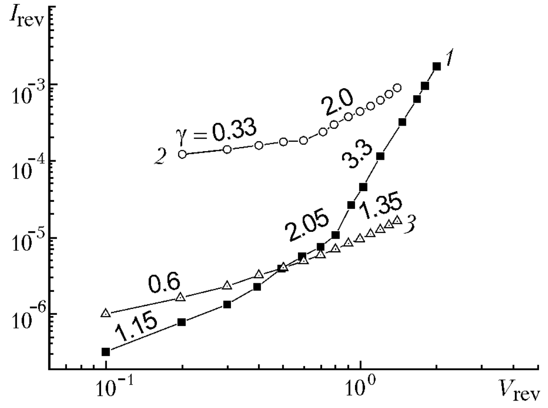


Fig. 4. Dependences of the thicknesses of space-charge layers on the strength of the barrier electric field: d_{base} = 4 (1), 8 (2), and 12 μm (3). W, cm; E_{rev}, V/cm.

Fig. 5. Back volt-ampere characteristics in the log-log scale of samples with bases of different thickness: d_{base} = 4 (1), 8 (2), and 12 μm (3). I_{rev}, A; V_{rev}, V.

samples with a thick base region increased to 46 pF with increase in the voltage applied to 1.1 V, which is explained by the decrease in the thickness of the space charge located under the barrier and the increase in the drop voltage across the base region.

Thus, the behavior of the volt-ampere characteristics of the structures being investigated is explained by the redistribution of the voltage applied between the space-charge layer and the base region. For example, in structures with a thin base (Fig. 2a), the voltage drop across the metal–semiconductor transition should be largest because of the low resistance of the base, i.e., the voltage drop across the space-charge layer should be higher than the voltage drop across the base: $V_b > V_{\text{base}}$. As the thickness of the base region further increases to 6–8 μm, the voltage drop across the metal–semiconductor transition should become practically equal to the voltage drop across the base region: $V_b \cong V_{\text{base}}$. In the samples with a thick base region, operating in the direct-bias regime, the voltage drop across the base should be largest: $V_b < V_{\text{base}}$.

As the photoelectric characteristics of the structures being investigated show, a distinguishing feature of these structures is that, when their thickness is equal to 3–8 μm, there appears in them a negative photocurrent under a reverse bias. In [7], a decrease in the current of such structures under illumination was detected in the direct-bias regime, which is explained by the double injection of carriers under conditions where the voltage drop across the base region is largest. In our case, in the regime of blocking of the barrier, all the processes occurring in the structures being investigated are determined by the changes in the depletion layer depending on the voltage and the changes in the deep donor oxygen impurity level contained in the base region of *n*GaAs.

For the purpose of analysis of the negative photocurrent arising in the indicated structures, we will consider the physical processes occurring in the space-charge layer of these structures in the regime of blocking of the barrier.

As our investigations have shown, the dependences of the capacitance of the metal–semiconductor transition in the structures being considered on the voltage of their regions with a negative photocurrent remain unchanged when the electric-field strength changes, which is explained by the fact that the thickness of the space-charge layer is independent of this parameter (Fig. 4, curves 1, 2). As for the volt-ampere characteristics, the dependence $I \sim V^{\gamma}$ includes portions with an exponent $\gamma = 2$ (Fig. 5), characteristic of the mechanism of tunneling of electrons from the metal to the semiconductor with the participation of a deep center [6]. In this case, the first portions of the dependence of the current on the voltage are due to thermoelectron ($\gamma = 1.15$, curve 1) and generation ($\gamma = 0.33$, curve 2) processes.

As is shown in Fig. 4, the thicknesses of the space-charge layers depend on the thickness of the base region of *n*GaAs. For a base region of thickness 4 and 8 μm, the thickness of the space-charge layer is independent of the blocking voltage. This invariability of the thickness of the space-charge layer is explained by the fact that the positive charge generated by the blocking voltage is compensated by the oxygen impurity level. On illumination of the blocked barrier, photocarriers are generated in the space-charge region under the barrier, where the deep oxygen levels located in the upper half of the forbidden region should possess, naturally, a large cross section of trapping of minority carriers; these levels have a high concentration and are most active in the process of recombination. On excitation of the structures being considered by an integral light, the nonequilibrium holes in their base are thermalyzed and the electrons generated are trapped by the effective recombination centers in the base. Under these conditions, a high rate of recombination of light nonequilibrium carriers with dark carriers is attained, which leads to a decrease in the light current. It should be noted that, in this case, the negative photosensitivity increases with decrease in the thickness of the base region (sample No. 3), i.e., it increases in proportion to the strength of the electric-field in the space-charge layer of the blocked transition.

When the thickness of the base region becomes larger than 10 μm (sample No. 9), the field in the blocked barrier decreases and the rate of recombination of nonequilibrium light carriers decreases, with the result that the effect of quenching of the light current is suppressed and a positive photocurrent appears under the direct-bias conditions.

Conclusions. On illumination of nGaAs–n^+GaAs structures by an integral light with $\lambda_{max} = 0.55$ μm, in some of these structures the reverse light current becomes lower than the dark current, and in others the light current predominates over the dark current under the direct-bias conditions. In this case, the decrease in the light current is explained by the trapping of light carriers and their recombination with dark carriers under the conditions where the voltage drop across the Schottky barrier exceeds the voltage drop across the base region and, vice versa, the increase in the light current is due to the predominance of the voltage drop in the base region.

NOTATION

C, capacitance, pF; d_{base}, thickness of the base region; E_{rev}, electric-field strength, V/cm; I, current, μA; I_{rev}, reverse current, A; I^{light}, light current, μA; I^{d}, dark current, μA; I^{ph}, photocurrent, A; $I \sim V^{\gamma}$, dependence of the reverse current on the voltage; S_I, current photosensitivity, A/lm; S, area of a sample, cm^2; V, voltage, V; V_b, voltage drop across the space-charge layer of the n-, m-transition, V; V_{base}, voltage drop across the base, V; V_{rev}, reverse voltage, V; W, thickness of the space-charge layer, cm; $\gamma = \Delta \log I/\Delta \log V$, exponent; λ_{max}, maximum wavelength of an integral light, μm. Subscripts: rev, reverse; light, light; d, dark; ph, photocurrent; base, base; b, barrier; max, maximum.

REFERENCES

1. A. L. Fahrenbruch and R. H. Bube, *Fundamentals of Solar Cells. Photovoltaic Solar Energy Conversion* [Russian translation], Énergoatomizdat, Moscow (1987).
2. S. M. Sze, *Physics of Semiconductor Devices* [Russian translation], Vol. 2, Mir, Moscow (1984).
3. M. Shur, *GaAs Devices and Circuits* [Russian translation], Mir, Moscow (1991).
4. V. N. Godovanyuk and Yu. G. Dobrovol'skii, State and prospects of the microphotoelectronic complex in the Chernovitsy region of Ukraine, *Prikl. Fiz.*, No. 3, 72–83 (2003).
5. N. L. Dmitruk, O. Yu. Borkovskaya, R. V. Konakova, I. B. Mamontova, S. V. Mamykin, and D. I. Voitsikhovskii, Influence of a gamma-irradiation on the phototransformation of metal–gallium arsenide barrier structures with a textured interface, *Zh. Tekh. Fiz.*, **72**, No. 6, 44–49 (2002).
6. S. V. Bulyarskii and A. V. Zhukov, Analysis of the mechanisms of current transfer determining the character of inverse volt-ampere characteristics of metal–GaAs barriers, *Fiz. Tekh. Poluprovodn.*, **35**, Issue 5, 560–563 (2001).
7. S. V. Slobodchikov, Kh. M. Salikhov, E. V. Russu, and Yu. G. Malinin, Quenching of the current of pSi–n^+ZnO–nZnO–Pd diode structures by light, *Fiz. Tekh. Poluprovodn.*, **35**, Issue 4, 479–481 (2001).
8. S. V. Slobodchikov, Kh. M. Salikhov, and B. E. Samorukov, Current transfer in Fe–p–InP diode structures, *Fiz. Tekh. Poluprovodn.*, **37**, Issue 2, 92–195 (2003).
9. V. I. Fistul', *Introduction to the Physics of Semiconductors* [in Russian], Vysshaya Shkola, Moscow (1984).
10. *GaAs FET, Principles and Technology* [Russian translation], Radio i Svyaz', Moscow (1988).