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Abstract. *The photosensitivity of a three-barrier photodiode m-n-p-m-structure, where the m-n- and p-m-junctions are formed as rectifying, are studied. It is shown the significant increasing of quantum efficiency during exciting of structure from the substrate side when n-p-heterojunction is direct biased. It is found the condition which leads to a state with a constant sensitivity in a wide range from 0,95 to 1,3 eV that can be interested for telecommunication and fiber-optic systems. It is shown the availability in structure of internal photoelectric gain.*

Keywords: *heterostructure, photodiode, highest photosensitivity, photoemission, n-p-heterojunction, quantum efficiency, potential barriers*

ТРЕХБАРЬЕРНЫЕ ФОТОДИОДНЫЕ Au/AlGaAs(n)/GaAs(p)/Ag - СТРУКТУРЫ

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Аннотация. *Исследована фоточувствительность трехбарьерной фотодиодной m-n-p-m-структуры, в которой m-n- и p-m-переходы сформированы как выпрямляющие. Показано значительное увеличение квантовой эффективности при возбуждении структуры со стороны подложки при прямом смещении n-p-гетероперехода. Найдены условия, которые приводят к состоянию с постоянной чувствительностью в широком диапазоне от 0,95 до 1,3 эВ, что может быть интересным для телекоммуникационных и волоконно-оптических систем. Показано наличие в структуре внутреннего фотоэлектрического усиления.*

Ключевые слова: *гетероструктура, фотодиод, высокая фоточувствительность, фотоэмиссия, n-p-гетеропереход, квантовая эффективность, потенциальные барьеры*

1. Introduction

Nowadays, there is a tendency of intensive transition to more economical and high-speed information transmission and storage systems [1,2]. The wire cables are replaced with optical cables that do not respond to electromagnetic and magnetic radiations. Receiving modules of optical systems gradually begin to cover the long-wave region of the spectrum 1,55 microns [3]. In this aspect, leading firms conduct intensive research on the development of low-cost and high-speed modules, improve the photodetectors, solve the problems of increasing the volume and speed of information transmitted and processed [4]. In particular, data streams, as well as their speed, increase continuously, due to which telecommunication systems become more efficient and at the same time more complex and require ever higher-quality and high-speed devices that process, transmit and store information.

Among the commercially available photodetectors used in receiving modules, it should be noted p-i-n- and avalanche photodiodes based on silicon and InGaAs, which belong to photodetectors with internal gain of the photocurrent due to avalanche multiplication of charge carriers in the breakdown mode [5].

However, in these structures, large values of dark currents limit their widespread use. Therefore, to reduce their dark currents, different approaches are used. Thus, in the manufacture of avalanche p-i-n-photodiodes, in order to reduce the dark current, a protective ring was used in [6], which prevents the p-n junction from reaching charge carriers generated at the periphery of the crystal. However, they were not able to reduce the capacity of the structure (<130 pF). In [7], to reduce the photodiode capacitance, a semiconductor wafer was fabricated with a GaSb / GaInAsSb / GaAlAsSb heterostructure with separated sensitive (diameter 50 μm) and contact mesas, connected by a bridging frontal contact. The main directions in the research and development of photodetectors are outlined. These are planar two-barrier photodiode structures based on gallium arsenide and indium gallium arsenide with metal-semiconductor rectifying barriers [8], as well as a sandwich two-three barrier structures based on homo and heterojunctions [9,10].

This paper is devoted to the study of the photosensitivity of a three-barrier photodiode m-n-p-m-structure, where the m-n- and p-m- junctions are formed as rectifying.

2. Experimental Samples

The three-barrier photodiode structure was obtained on the basis of a p-n-junction, in which the p-type region is a bulk gallium arsenide crystal doped with chromium (GaAs:Cr), and the n-type region consists of an epitaxial layer with $N_D = 2\cdot10^{16}$ cm^{-3}, of aluminum-gallium arsenide (AlGaAs). The thickness of the n-type region obtained by liquid phase epitaxy is 1,5 μm.

A rectifying translucent (100 Å) Ag contact is formed on the surface of the p-type region, and a rectifying Au contact layer is applied on the surface of the n-type region.

The structure area is 2 mm^2, and the specific capacitance is ~0,2 pF / mm^2.

The dark current-voltage characteristic of these structures in the forward-biased heterojunction mode, when both metal-semiconductor junctions are reverse biased, has some rise after 70 volts, and in the opposite direction when the heterojunction is reverse biased up to 100 volts the current is monotonous and close to linear.

It should be noted that the observed increase in current is due to the approach of breakdown at the reverse biased metal-semiconductor junction.

3. Experimental results and discussion

When Au-n$Al_{0.1}Ga_{0.9}$As-pGaAs-Ag structures are excited in the heterojunction direct biased mode from a tungsten lamp with an emission maximum of 860 nm and an illumination of 100 lux, both from the film side and from the substrate side, the light currents have similar values (Fig. 1a, curves 2 and 3), but as the breakdown at the junction (substrate) approaches, the pGaAs-Ag current becomes more than 22 μA versus 18 μA.

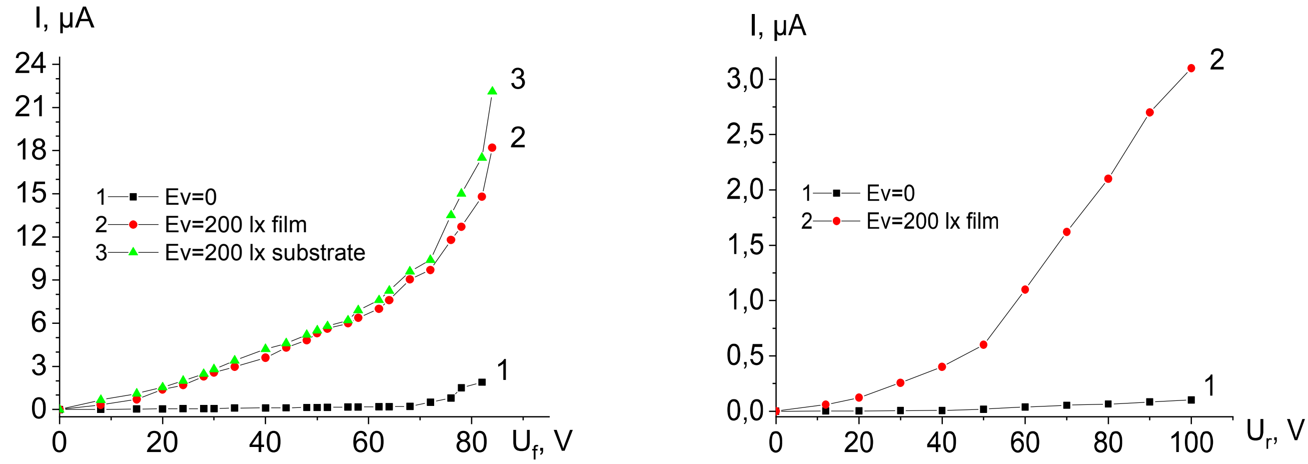

Fig. 1. Volt-ampere characteristics of the Au-n$Al_{0.1}Ga_{0.9}$As-pGaAs-Ag structure in the mode of (a) direct and (b) reverse bias of the heterojunction

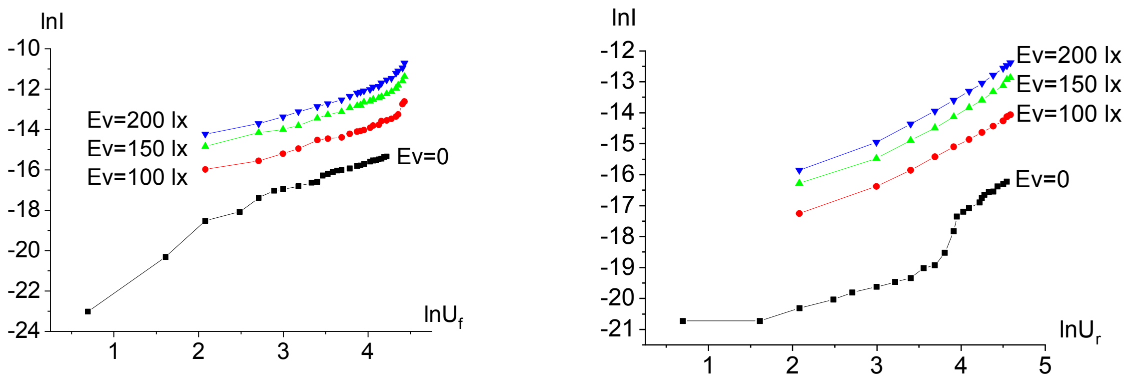

Fig. 2. Volt-ampere characteristics of Au-n$Al_{0,1}Ga_{0,9}$As-pGaAs-Ag-structure in double logarithmic scale in the mode of (a) direct and (b) reverse bias of the heterojunction

In the reverse bias of the heterojunction and when illuminated from the heterolayer side, the light current reaches 3 μA, which is seven times less than in the other mode. At the same time, the light current from voltage up to 50 volts increases close to nonlinear, and then the growth becomes more steep, that is, the region where photocarriers are generated is modulated according to the same law. The exponent is 1.0.

Studies of the spectral characteristics showed that the quantum efficiency when the structure is excited from the substrate in the mode of direct bias of the n-p-heterojunction is almost an order of magnitude larger (Fig. 3). At a voltage of the order of 25 volts in a wide range from 0,95 to 1,3 eV, the sensitivity is unchanged. This region of the spectrum is of interest for telecommunication and fiber-optic systems.

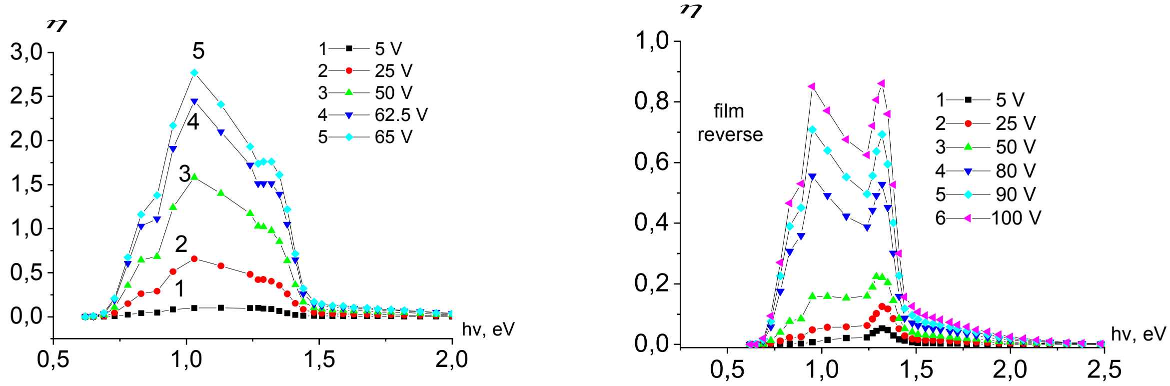

Fig. 3. Spectral sensitivities with illumination from the side of a reverse biased heterojunction (a) and from the side of a forward biased heterojunction (b)

When the heterojunction is reverse biased with a voltage of 50 volts and the structure is illuminated from the heterolayer (Fig. 3), the quantum efficiency reaches up to 0,22, and in a wide band from 0,95 to 1,23 eV, the sensitivity is almost unchanged. As the applied voltage increases to 65 volts with a radiation power of 0,2 mW/cm^2, the quantum efficiency of the structure increases to 2.77, that is, there is an internal photoelectric gain.

4. Conclusion

On the basis of the observed dependences of the light and spectral characteristics, it can be concluded that the highest photosensitivity in the Au-n$Al_{0.1}Ga_{0.9}$As-pGaAs-Ag structure is achieved in the forward biased mode of the heterojunction under excitation from the heterolayer.

In this mode, when metal-semiconductor junction is reverse biased, the internal gain of the photocurrent takes place, that is, the quantum efficiency is greater than one. However, in the mode of direct bias of potential barriers, the photocurrent has smaller values.

This indicates that the effective separation of photocarriers occurs in the space charge region of the reverse biased metal-semiconductor junction and when the polarity of the operating voltage is changed, a small part of the photons reach the space charge region of the reverse biased heterojunction.

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