Formation of spectral characteristic of silicon differential photoreceivers.

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Abstract. The article provides information about the structure and technology of manufacturing of silicon differential photoreceivers having a selective spectral characteristic. The possibility was established of displacement of the longwave boundary of sensitivity $\lambda_{0.5}$ from 0.37 to 0.47μm at change of a dose of implantation of arsenic in the range of 200-5000 μC/cm^2 at constant short-wave border ($\lambda_{0,5}$ = 0.28μm). The effect of the implantation dose on the quantum yield of the differential channel was investigated.

1. Introduction.

Silicon-based photoreceivers are widely used in optoelectronics. This is due to the possibility of silicon devices to register optical radiation in wide spectral range, including ultraviolet, visible and near-infrared radiation. Besides, it is necessary to note the highly developed and comparatively low cost technology of silicon devices. However, the availability of wide spectral range is not always useful. If there is a problem of registration of radiation in the limited spectral range, for example in the UV area, the availability in IR and visible areas is parasitic and reduces noise immunity of the device. Using high-quality external filters for its deep suppression. increases the cost of devises and is not always effective. In addition, researchers note the tendency of filters to aging, especially when irradiated with UV light [1]. The method is of interest to form the spectral range of the photoreceiver by subtracting signals from a number of nearby photosensitive platforms with different spectral characteristics (differential photo receivers) [2.3]. This method allows to adjust the spectral characteristic by using only group technological operations of semiconductor manufacturing without application of the external filters. As a well-managed way to change the spectral characteristics, implantation can be applied to the surface layer, creating additional recombination centers and reduce sensitivity of photoreceiver in the shortwave range [4]. It was established, that it is effective for these purposes to use heavy ions, for example As [5]. The influence of the doping dose on the type of spectral characteristic of photoreceiver is shown. However, the known publications provide information for a limited interval of implantation doses. There is no information about the influence of the doping degree on the quantum yield of differential signal. The present article is devoted to solving these questions.

2. Photoreceiver structure.

The topology of differential photoreceiver is shown in Figure 1. Photoreceiver represents a system of 16 identical in size photodiodes divided into two groups. The technology of photodiodes of the first group provided high sensitivity in wide spectral range and the sensitivity of photodiodes of the second group was suppressed in the UV range by creating recombination centers in the surface area. The sensitive areas were positioned in checkered order, evenly filling the area of view of the photoreceiver. This provided improvement in the homogeneity of the sensitivity distribution on the area of photoreceiver.

For differential photoreceivers the necessary condition is the significant difference of spectral sensitivity in the working range of spectrum and at the same time nearness of spectral characteristics in the non-working area. The latter circumstance allows by subtracting the signals to practically eliminate the sensitivity in the nonworking part of spectrum. If one needs an ultraviolet photo receiver, the most important requirement for the main channel is to ensure maximum sensitivity in the shortwave range. Silicon photodiodes, obtained by the standard diffusion method, usually have a declining characteristic in the UV range. In Figure 2, the spectral sensitivity of the diffusion photodiode for equal flow of quanta with the depth of location of ***p-n*** barrier of 2.2 microns (curve 1) is given as an example. Decreasing the depth to submicron dimensions, such as 0.8-0.9μm is also insufficient (curve 2).

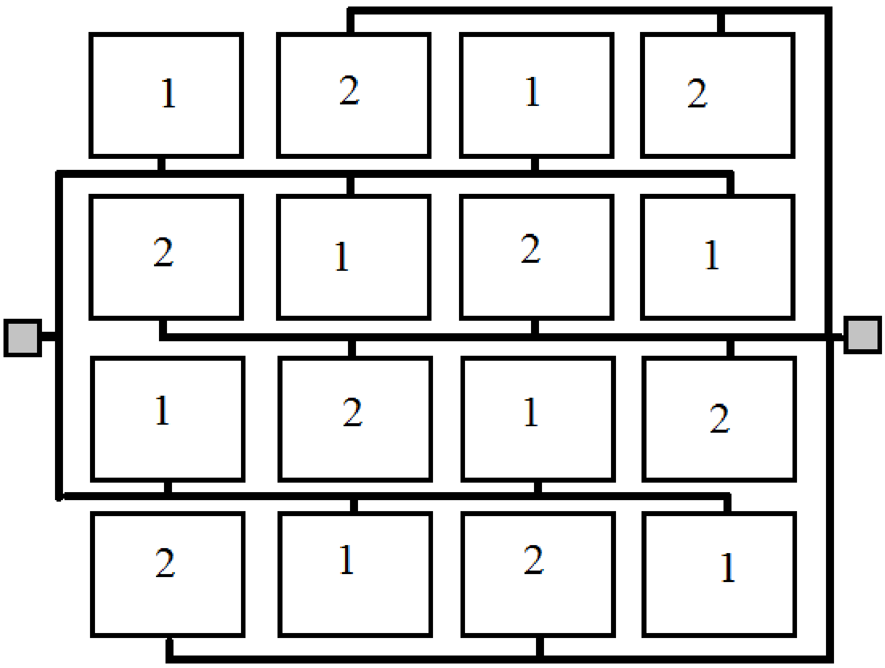

Figure 1. Photoreceiver topology.

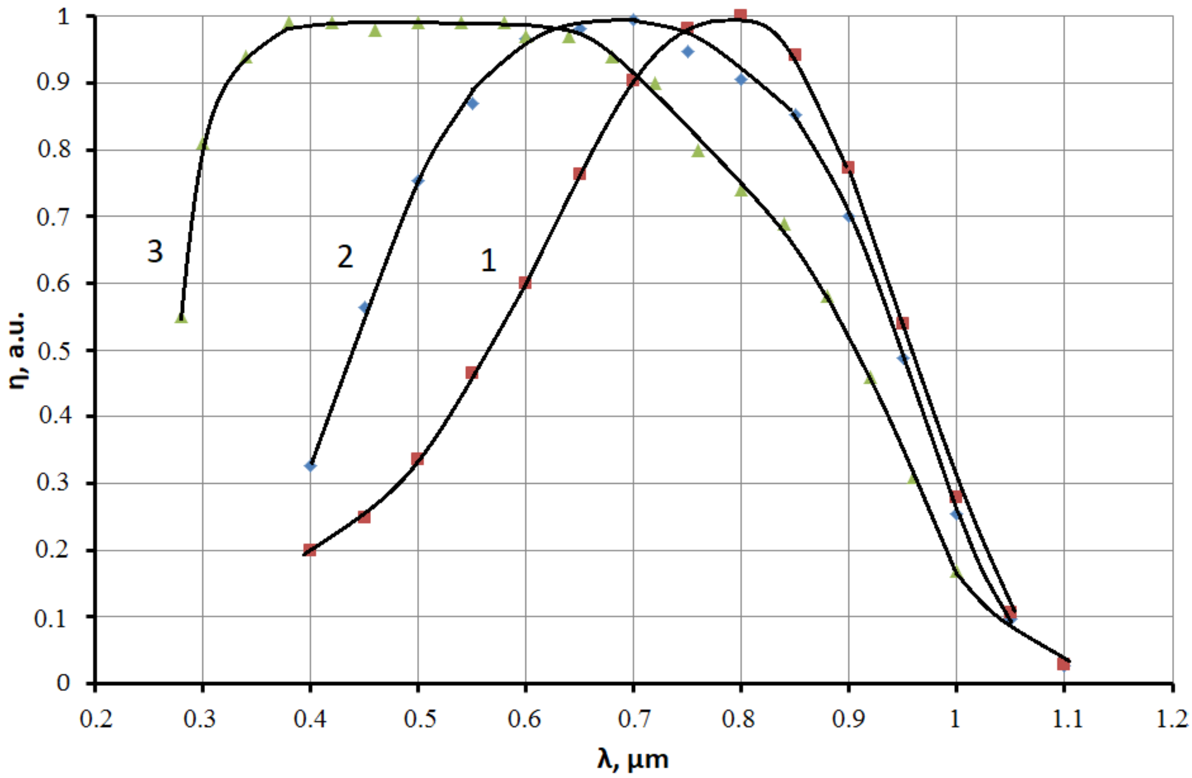

Figure 2. Spectral sensitivity of silicon photodiodes, obtained by deep (1) and shallow (2) diffusion and by implantation (3).

To increase the sensitivity of the main channel we used the photodiode structure created by implant doping of small dose of phosphorus of 30-70 μC/cm^2. After up-diffusion of the implanted layer necessary to form a barrier with good electrical characteristics, the ***p-n*** barrier with a sharp gradient of donor concentration at a depth of about 0.2μm was created. Using this method (curve 3) has significantly increased sensitivity in the shortwave range.

The second channel was formed simultaneously with the first, on the same wafer, with the use of combined technological operations, but with the addition at the final stage of the process of implantation of high dose of arsenic. This technique allowed to create additional recombination centers in the surface area of the second channel and reduce the sensitivity of the photodiode in the UV range. In addition, the presence of concentration maximum in the form of the impurities distribution during implantation created a decelerating electric field for photocarriers in the surface area. Thus, the formation of ion-implanted layer led to decreasing in the sensitivity of the auxiliary channel in the UV range, both due to recombination processes, and by creating a decelerating electric field. At the same time, the identity of the deep layers of both channels provided close spectral sensitivity in the longwave area, where the processes of collecting photocarriers were determined by the areas removed from the surface. Arsenic was chosen as intersitial impurity from the following considerations. This element has a small projected running, has low diffusion coefficient and high ultimate silicon solubility. Such properties allowed to form ***p-n*** barrier with high concentration of impurity at the minimum depth, poorly sensitive to the subsequent thermal treatments.

3. Spectral characteristic of photoreceiver.

One of the critical moments determining the type of spectral characteristic of the differential channel is the amount of the dose of arsenic implantation. In this connection series of photoreceivers with different degree of doping of auxiliary channel has been investigated. Figure 3 shows the normalized spectral characteristics of differential channels for the area of small doses, and in Figure 4 - for significant doses. As expected, with the increase in the implantation dose, expansion of the spectral range of sensitivity through the displacement of the longwave border was observed. Analysis of their relationship (Figure 5) showed that the infrared border on the level of $\lambda_{0.5}$ can be approximated by expression:

$$\lambda = \lambda_0 + k\ln\frac{Q}{Q_0},$$

where λ_0 = 0.347μm, k = 3,2 10^{-2} μm, Q_0= 100 μC/cm^2.

Thus, changing the doping dose within reasonable limits one can control the position of the longwave boundary sensitivity from 0.37 to 0.47μm. At that, the left boundary of the spectral range remained unchanged ($\lambda_{0,5}$ = 0.28μm).

Another important characteristic is the level of the signal of the differential channel, the value of which was also dependent on the doping dose of the auxiliary channel. Figure 6 shows the dependence of quantum efficiency of differential channel for different doses of As. Values are given as a ratio of the quantum yield of the differential channel to the value of the quantum yield of the main channel. As the dose increased, the differential channel signals increased. Figure 7 presents the analysis of the dependence of the quantum efficiency of the differential channel from the doping dose of As for the fixed wavelength λ = 0.34μm (in the range of maximum of spectral characteristic of the differential channel). As one can see, in the range of 500 to 2000 μC/cm^2 there was significant dose effect on the sensitivity of the differential channel. Starting from 2000 μC/cm^2 the quantum yield value slows.

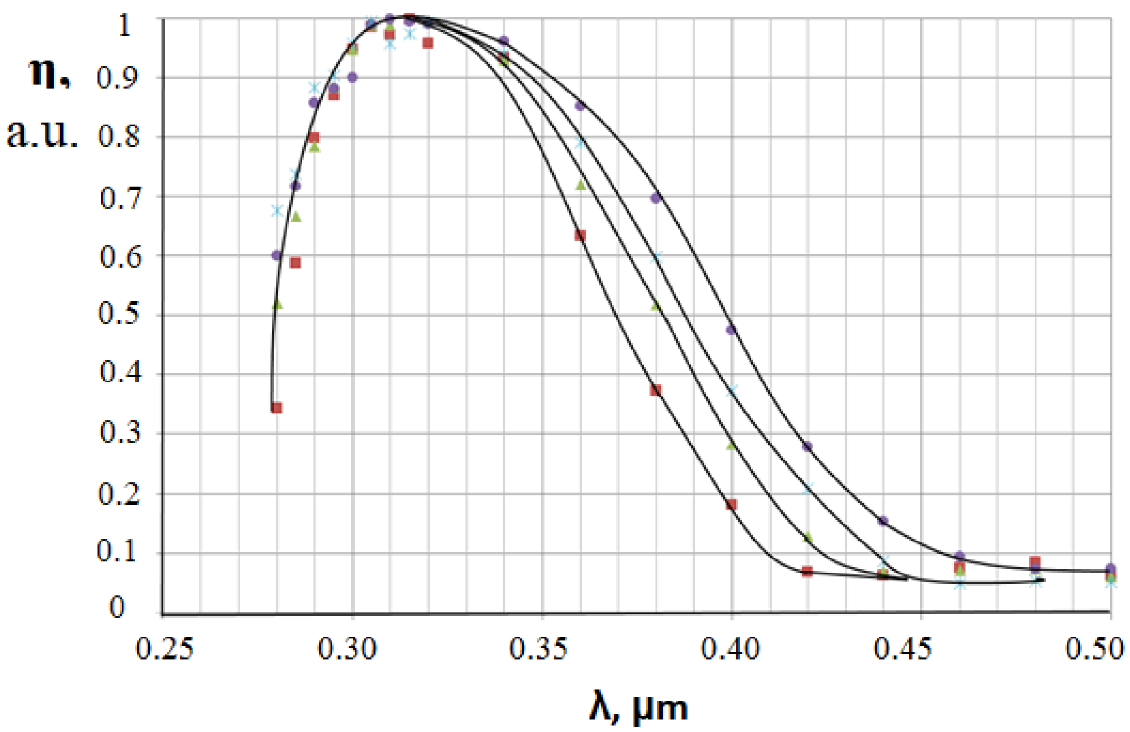

Figure 3. Dependence of spectral sensitivity of differential channel from doping dose in the area of small doses (200, 300, 400, 500 μC/cm^2).

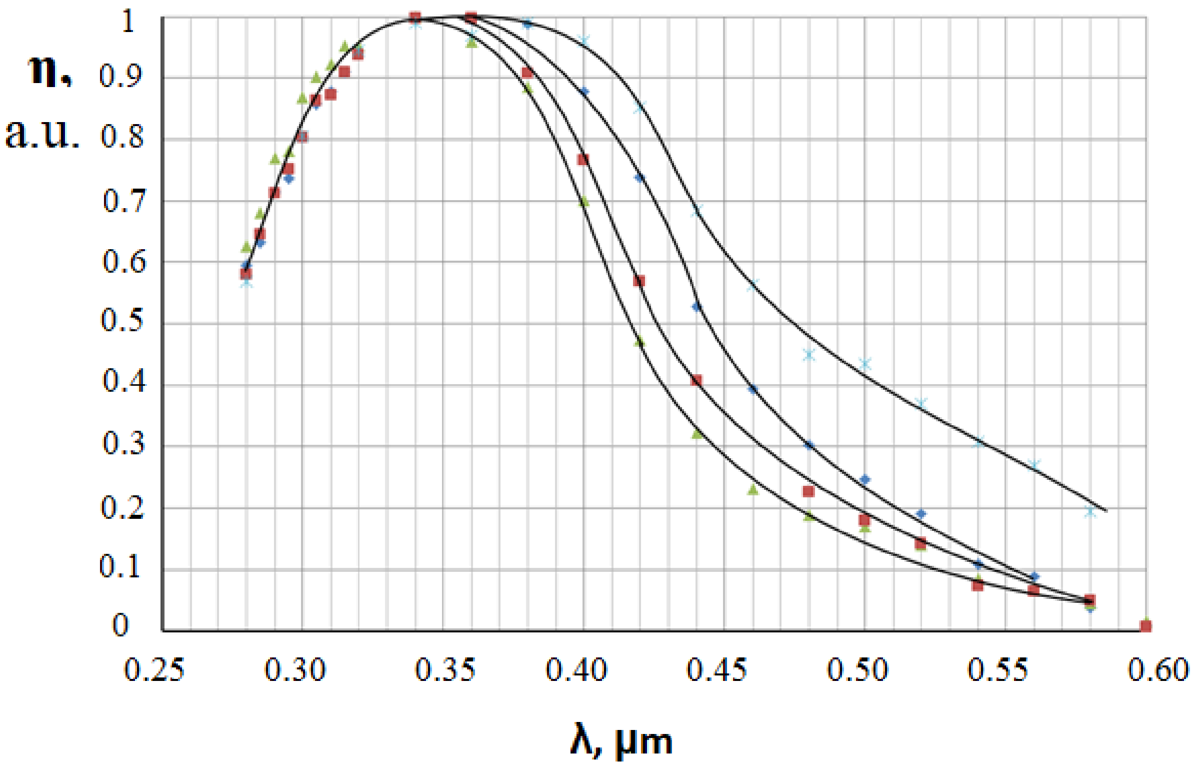

Figure 4. Dependence of spectral sensitivity of differential channel from doping dose in the area of large doses (700, 1000, 2000, 5000 μC/cm^2).

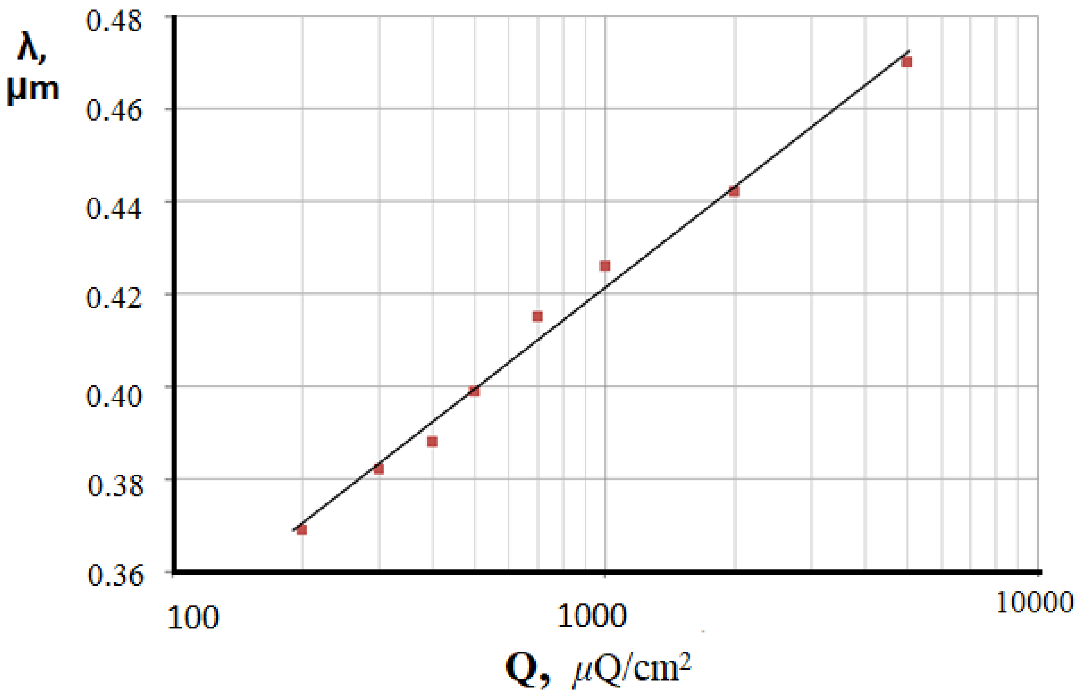

Figure 5. Longwave boundary dependence of the differential channel from As implantation dose.

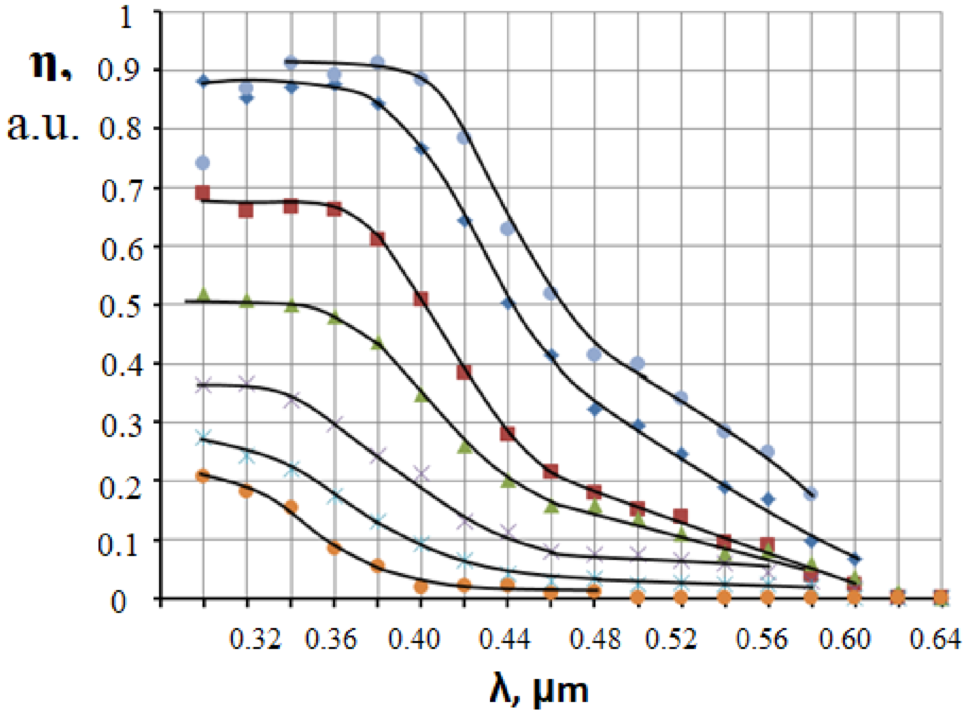

Figure 6. Spectral dependence of the ratio of quantum efficiency of the differential channel to the efficiency of the main channel from As implantation dose.

Doses: 200, 300, 500, 700, 1000, 2000, 5000 μC/cm^2.

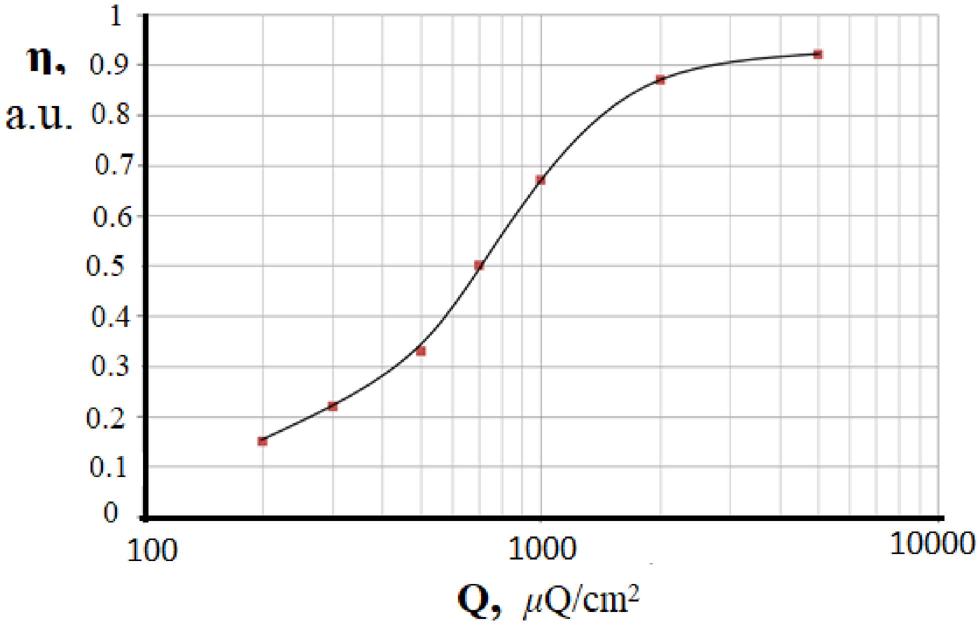

Figure 7. Quantum efficiency dependence of differential channel on As implantation dose for λ = 0.34 μm.

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Approaching to 90% and further, increase in dose has little effect on sensitivity. Thus, if the problem of maximally possible sharpening spectral range is not necessary, the doping doses of 1000 – 2000 μC/cm^2 should be considered as close to optimum. At the same time, a good selectivity of spectral characteristic and the high sensitivity of the differential photoreceiver remains.

4. Conclusion.

The important advantages of silicon differential photoreceivers is the ability to control spectral sensitivity using methods of group technological operations of semiconductor manufacturing. On the basis of the relationships obtained during this work it is possible to form the position of the longwave boundary of the spectral range of photoreceivers in the range from 0.37 to 0.47μm by controlling the implantation dose. At that, the left boundary of the spectral range remained unchanged ($\lambda_{0,5}$ = 0.28 μm). The study of the dependence of quantum yield from implantation dose gives the reason to consider for such photoreceivers arsenic doping dose of 1000-2000 μC/cm^2 as close to optimum .

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