INFLUENCE OF ULTRASONIC WAVES ON PHOTOELECTRIC CHARACTERISTICS OF SI-PHOTO RECEIVERS

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ABSTRACT:

The paper considers the influence of ultrasonic fields on the photoelectric and spectral characteristics of diffusion Si-n-p receivers of electromagnetic radiation. It was found that ultrasonic irradiation increases the lifetime, diffusion length of carriers and, as a consequence, increases the efficiency of collecting carriers on the electrical contacts of Si-n-p-receivers. As a result of these processes, an increase in the value of the short-circuit current is observed, which causes an increase in the no-load voltage and the efficiency of such a diffusion Si-n-p-structure operating in the photo reformation mode.

Keywords: Si-photo receiver, ultrasound, short-circuit current, solar cell photovoltaic cells, solar lighting, fill factor, no-load voltage, electrically active centers, electrically inactive centers.

INTRODUCTION:

In [1-3], for the first time, the existence of local inhomogeneities with a concentration of N <10^{10} sm^{-3} in "ultra-pure" semiconductor materials, which do not allow reaching the ultimate functional characteristics of radiation detectors, was demonstrated. Intensive scientific research has led to the discovery of the decay of some local inhomogeneities in ultrasonic fields [4,5].

A characteristic feature of the study of acoustically stimulated effects in silicon detectors conducted at the time of the present studies is that they were made exclusively for detectors made of silicon compensated by lithium (Li), the so-called Si (Li) pin detectors - drift Si (Li) - detectors.

It seemed interesting to us to analyze in detail the behavior of the photoelectric characteristics of Si-n-p optical receivers before and after ultrasonic exposure. Si photodetectors belong to the class of radiation detectors and the results of their research will provide valuable information that can be used to improve the functional characteristics of semiconductor photoelectronic devices (photodiodes, photoresistors, etc.) and

THE MAIN PART:

In these experiments, np structures from low impedance were studied silicon, which had an area of S = 5x5mm^2 and a thickness of d = 250÷50μm. The p-Si base layer had a resistivity of 1.8 Om·sm<ρ<3 Om·sm. Phosphorus was used as a dopant to create a diffusion n^+ layer with a thickness of 0.15÷5μm in the base. The concentration of dopant N for various Si samples ranged from $7\cdot10^{18}$ sm^{-3} to $5.5\cdot10^{19}$ sm^{-3}. The concentration N was determined by four probe methods. As a frontal contact, we used a deposited gold layer with a density of K = 30 ÷ 50 μg / sm^2. The back contact was a layer of sprayed aluminum (Al).

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Electrophysical, photovoltaic and spectral characteristics were measured in a standard way, using spectrophotometers SF-4 and SF-20, as well as light sources in the form of xenon lamps with power from 100 W to 150 W and infrared filters. Ultrasonic processing of the Si-p-p-photodetector was carried out in a standard way by using a liquid sound duct located between the Si photodetector and an ultrasonic emitter.

Fig. 1. demonstrates the family of current-voltage characteristics of a Si photodetector obtained and studied by us when the latter is illuminated with light with different levels of illumination before and after ultrasonic exposure. The studied Si photodetectors worked as photoconverters and had an open-circuit voltage V_{xx} at T = 300K within 0.5V ÷0.53V. (photoconverters of solar cells).

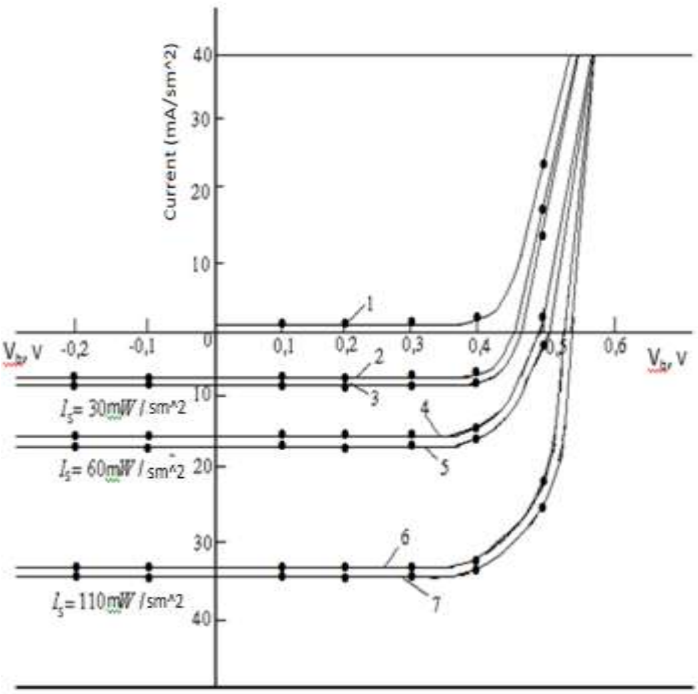

Fig. 1. The current-voltage characteristics of the Si-np photodetector at various lighting levels I_S before (curves 2, 4, 6) and after (curves 3, 5, 7) of ultrasonic irradiation of the photodetector with ultrasonic waves of intensity I * = 0.25 W / sm², f = 25 MHz for t = 40 min, at T = 300K. Curve 1 – Dark

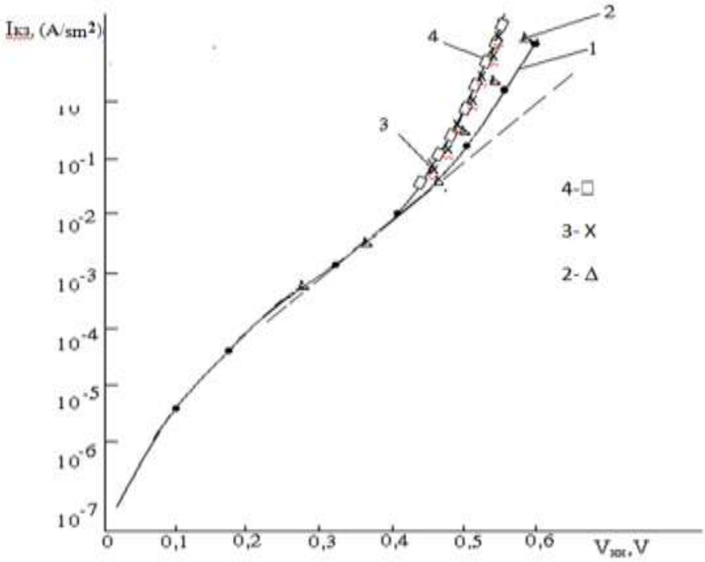

Fig. 2. The dependence of the short circuit current on the open circuit voltage under single and ten-fold sunlight, measured before and after ultrasonic processing of the Si-n-p photodetector at T = 300K. Before ultrasonic treatment: • Curve 1 (single exposure to sunlight); Δ - curve 2 (10-fold solar illumination). After ultrasonic treatment (I* = 0.25W / sm², f = 25MHz, t = 40min): x -curve 3 (single exposure to sunlight); □-curve 4 (10x solar illumination). The dashed line is theory.

The usual I (V) dependences for a Si photodetector are shown in Fig. 2. The fill factor ff, determined by the ratio of the maximum specific power Pm to the product value $V_{xx} \cdot I_{kz}$ (Ikz is the short-circuit current) for this photodetector, has the following value: ff "≈ 0.72. It should be noted that the dependence of I_{kz} on the power of the illumination level is linear throughout the measurement interval, and the dependence of V_{xx} on the illumination power is almost logarithmic.

Thus, it can be shown that the $\log I_{kz}$ (V_{xx}) dependence approaches linear, this is observed from Fig. 2. A theoretical analysis of the behavior of the main characteristics V_{xx}, I_{kz}, ff depending on the influence of external factors (temperature, illumination) is quite well described in various works, for example

[6], but the effect of ultrasonic fields on these characteristics has not been studied in detail.

In these studies, we use Si photodetectors as models of solar energy photoconverters subjected to ultrasonic irradiation.

An analysis of the experimental dependence of I_{kz} (V_{xx}) presented in Fig. 2 shows that the coefficient "n"≈1.51÷1.52 and A ≈25.8V^{-1}÷26V^{-1} for the value of the short-circuit current I_{kz} ≈ (1,2÷1.4) 10^{-3}A / sm^2 and I_0 ≈1.2·10^{-7} A / sm^2.

It is also clearly seen that an increase in the illumination power already at 10 times solar illumination leads to a deviation of the dependence of the current-voltage characteristics on linearity in the region of large bias voltages V_b> 0.45 V (Fig. 2). This effect is explained by saturation of the recombination centers by carriers, an increase in the lifetime, and, as a result, leads to an increase in the efficiency of the collection of nonequilibrium charge carriers on the collector contacts of the Si photodetector. In the same figure 2, curves 3.4 of the dependence I (V_b), measured after the passage of an ultrasound through a Si photodetector, are shown.

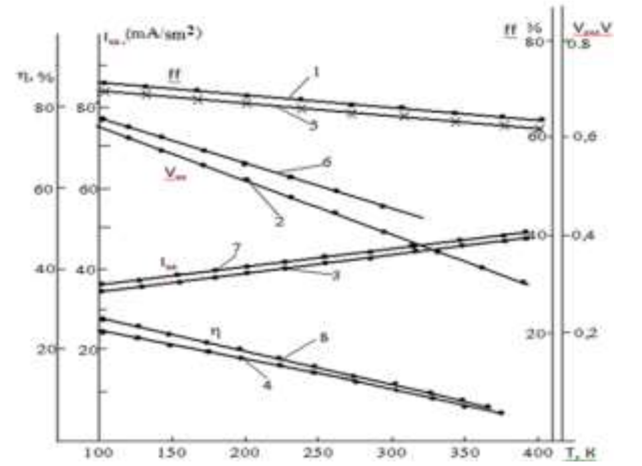

Fig. 3. Temperature dependences of the parameters of the Si-np photodetector (ff, V_{xx}, I_{kz}., η), measured at illumination intensity I_S = 130 mW / sm^2 before (curves 1, 2, 3, 4) and after (curves 5, 6, 7, 8). Ultrasound irradiation with intensity I* = 0.25 W / sm^2 and frequency f = 25 MHz for t = 40 min at T = 300K.

The temperature dependences of the main characteristics of the studied Si photodetector, as well as the spectral dependence of the photoresponse before and after ultrasonic processing, are presented in Figs. 3 and 4, respectively. It is of interest to us to explain the observed acoustically stimulated changes in these

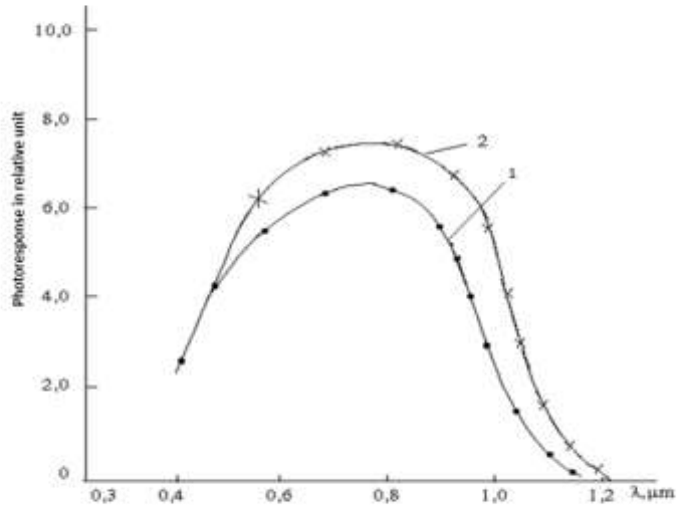

Fig. 4. Spectral dependence of the photoresponse of a Si-n-p photodetector before (curve 1) and after (curve 2) the action of ultrasound with I* = 0.25 W / sm^2 and frequency f = 25 MHz for t = 40 min at T = 300K.

CHARACTERISTICS:

The fact thatthat all the studied characteristics to one degree or another experienced a slight increase in their values. Since all characteristics are interconnected by known relations, they are all determined by the collection efficiency of nonequilibrium charge carriers, which crucially depends on the degree of perfection of the crystal lattice of the Si photodetector.

So, it is known that the degree of perfection of the crystal lattice is determined by the concentration of defects. Defects can be electrically inactive and active. The latter affect the lifetime of minority carriers in sensitive areas of photodetectors. As you know, when considering the processes of transfer of charge carriers (electrons), the diffusion equation is used:

$I_n = qD_n [(\partial(n_p - n_{po})/\partial x]$, (1)

where D_n is the electron diffusion coefficient associated with the carrier mobility μ_n by the Einstein relation $D_n = kT\mu_n/q$. The value of D determines the diffusion length of charge carriers L through the equation:

$L = (\mu кT\tau/q)^{1/2}$, (2)

Thus, the dependence I_{kz} (V_c) is mainly due to an increase in the lifetime τ, which is influenced by the mutual arrangement of the energy levels of the capture and recombination centers. The theory gives the following well-known expression for the quantity τ see for example [1]:

$\tau = 1/(N\sigma_n V_t)$, (3)

where N is the concentration of capture and recombination centers; σ_n -section of the capture centers; V_t is the thermal velocity of the carriers.

The presence of the dependence of the concentration N on the influence of the ultrasonic field leads to the fact that τ increases with a decrease in the concentration of electrically active centers and their transition to an electrically inactive state by acoustic diffusion of previously existing or acoustically generated donors and acceptors, as well as their further combination into electrically inactive complexes and processes decay of local clusters of impurity atoms [7,8]. These acoustically stimulated processes lead to smoothing of the potential relief of the sensitive region of the photodetector and, as a result, to an increase in the diffusion length L, an increase in the efficiency of carrier collection and radiation detection. It must be borne in mind that under certain conditions, such as, for example, in the case of the introduction of gold atoms into the sensitive region [9], уменьшение decreases. A similar decrease in τ can also occur at threshold powers I* of ultrasound ≥ 2÷5W/sm^2, when there is an intense generation of defects that reduce τ.

The increase in V_{xx} and η (efficiency) after the passage of megahertz ultrasonic waves through the Si-n-p-photodetector occurs through acoustically-stimulated increase in I_{kz}, which are associated with the latter relations [6]:

$V_{xx} = (kT/q)\ln(I_{кз}/I_o)$ (4)

And

$\eta = V_{xx} I_{xx} ff/P_s$ (5)

The presented spectral dependence of the photoresponse after sonication (Fig. 4, curve 2) in the region λ_0 = 0.6 μm ÷ 0.8 μm shows its increase compared to the initial curve. This indicates that surface recombination has a low speed and it is suppressed by ultrasound in the surface layers of the n-p junction of the Si photodetector. An increase in the photoresponse is also clearly manifested in the longer wavelength range λ_0 ≥ 0.8 μm ÷.2 μm, i.e., the collection of nonequilibrium charge carriers formed upon absorption of lower-energy photons is facilitated due to the acousto-stimulated increase in the diffusion length L of carriers in silicon.

CONCLUSION:

It has been established that ultrasonic irradiation of receivers by radiation from the “input” window leads to a change in the concentration of electrically active centers in the sensitive region of the receiver, smoothing the relief of the impurity by the mechanism of acoustically stimulated diffusion. A positive change in the defective structure of the sensitive region leads to a change in its transport properties, which determine the collection processes of nonequilibrium charge carriers. In this case, there is an increase in the lifetime, diffusion length of the carriers and, as a result, an increase in the efficiency of collecting carriers on the electrical contacts of Si-n-p receivers. As a result of these processes, an increase in the short-circuit current is observed, which causes an increase in the open circuit voltage and the efficiency of such a diffusion Si-n-p structure operating in the photoconversion mode. It is noted that surface carrier recombination decreases in the surface layers of a Si-n-p photodetector under the influence of ultrasonic waves**.**

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