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INVESTIGATION OF VOLT-CAPACITY CHARACTERISTICS OF SI-PHOTODETECTORS

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Abstract:

The behavior of the electrophysical characteristics of silicon Si-photodetectors before and after ultrasonic treatment is studied. It is shown that due to the acoustically stimulated diffusion of phosphorus at a low temperature (T≈300K), the p-Si base is compensated, which becomes more high-resistance, which leads to an increase in the drop in the applied bias voltage V_b on the depleted layer W_d and an increase in the electric field strength in it. As a result of these processes, an increase in the magnitude of 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.

Keywords: Ultrasound; Si radiation receivers; Si-photodetectors; C-V-characteristic.

1. INTRODUCTION. The choice of Si -n-p photodetectors in optical radiation as objects of research in this work is due to the fact that they have shallow p - n junctions, which are photoactive. In physical processes, generation, separation of electron-hole pairs occur in surface layers, in contrast to Si-n-p-diffusion receivers of nuclear radiation. In this regard, it is of scientific and practical interest to investigate the phenomena occurring under the action of ultrasound in such Si -n - p structures, which is presented below. 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 devices in photoelectronics (photodiodes, photoresistors, etc.) and photoenergetics (solar cell photoconverters).

2. MATERIAL AND METHOD. In these experiments, low-resistance silicon n-p structures were studied, which had an area $S=5\times5$ mm^2 and a thickness $d=250\div50$ μm. The p-Si base layer had a resistivity of 1.8 Ω·cm <ρ<3 Ω·cm. Phosphorus was used as a dopant to create a diffusion n+ layer in the base with a thickness of 0.15 ÷ 5 μm. The dopant concentration N for various Si samples ranged from $7\cdot10^{18}$ cm^{-3} to $5{,}5\cdot10^{19}$cm^{-3}. The value of N concentration was determined by the four-probe method. The structure of the Si photodetector is shown in Fig. 1. A sawn layer of gold with a density К = 30 ÷ 50 μg/cm^2 was used as a frontal contact. The rear contact was a layer of sawn aluminum (Al).

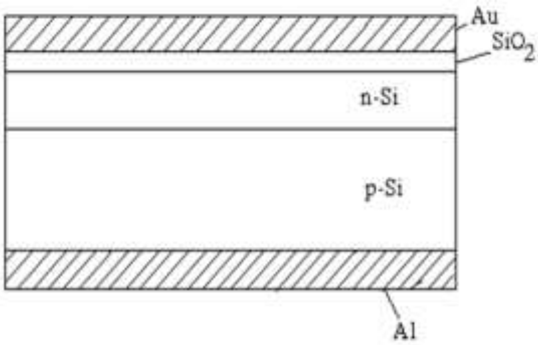

Fig.1. The structure of the Si-n-p-photodetector.

3. RESULTS AND DISCUSSION. Let us now turn to the dependence of capacitance on voltage (C-V-characteristic), presented in the coordinates $C^{-2} = f(V_b)$ Fig.2. As you know, the capacitance of the p-n

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junction is determined by the usual equation $C=S\varepsilon_s/W_d$, where S is the area of the n-p junction, ε_s is the permittivity of the semiconductor, W_d is the width of the depleted layer. The diffusion of phosphorus in p-Si forms a thin Si layer of n-type conductivity. Usually, donors and acceptors during diffusion are distributed unevenly in the diffusion layer, and analysis of the C–V dependence makes it possible to judge this [1]. For this, the well-known relation is used:

$$C^{-2} = [W_d/(\varepsilon_s S)]^2 = [2(N_A+N_D)/qS^2\varepsilon_s N_A N_D](V_d-V_b), \quad (1)$$

where V_d is the built-in or diffusion potential in the region of the n-p junction.

As shown in Fig.2. the experimental data of the $C^{-2}=f(V_b)$ dependence differ from linear ones, which indicates the absence of a sharp impurity concentration profile [2]. To a greater extent, the distribution profile is characteristic of diffusion transitions, which we have obtained. This indicates the coincidence of the theory of theoretical and experimental results. An analysis of the experimental characteristics I(V) = f(T) and C(V) = f(T) shows that the values of the built-in potential $V_v(T)$ determined from these data practically coincide. The value of $V_v(T)$ lies within ~ 0.56 V ÷ 1.13 V in the temperature range T = 100K ÷400 K, as can be seen from Figure 2. As is known, the value of the built-in potential VV is determined by the following equation [3]:

$$V_V=q(N_D x^2_n+N_A x^2_p)/(2\varepsilon_s)=E_{max}(x_n-x_p)/(2\varepsilon_s)=qW^2_d[N_A N_D/N_D+N_A]/2\varepsilon_s, \quad (2)$$

where E_{max} is the maximum field in the transition; x_n and x_p-boundary of the depleted layer in the n-region and p-region of the semiconductor; $W_d = x_n - x_p$ is the depleted layer width.

Let us now turn to the $C^{-2}V(T)$ dependences measured after exposure to ultrasonic waves (Fig. 2, curve 7). For example, only one curve 7 is shown and discussed, since otherwise the presence of other curves measured after the passage of ultrasonic waves I=0.25 W/cm^2, f=25 MHz, t=20 min, will complicate the understanding of Figure 2 and, accordingly , text. There is a clear tendency to reduce the capacitance and increase the value of the built-in potential. With sufficient confidence, we can assume that after the passage of ultrasonic waves through the structure of the Si photodetector, a change in the concentration of charge carriers occurred at the boundaries of the x_n and x_p depleted layer of the np junction, which is an active element in which electron-hole pairs are generated when it is irradiated electromagnetic radiation.

The observed change in the charge density at the boundaries of the depleted layer after ultrasonic exposure is associated with the effect of acoustically stimulated diffusion of phosphorus atoms, which was also previously observed in [4]. Equation (2) for V_v contains the parameter x_n, the value of which is determined by the penetration depth of phosphorus into the p-Si base. In contrast to [4], where the effect of acoustically stimulated phosphorus diffusion was determined by layer-by-layer etching of the sample, in this work it was revealed by analyzing the electro physical characteristics of the sample without destroying it, which allows the latter to be used for further studies, for example, photovoltaic, which is presented below. In addition, in contrast to [5, 6], here a “softer” mode of ultrasonic processing of samples is carried out at lower powers of ultrasonic waves. In this mode (I*<1 W/cm^2), no other acoustically stimulated phenomena occur (for example, generation of defects, dissociation of complexes, etc.), which can be competing processes and sharply change the behavior of the electro physical and other characteristics of the sample.

Thus, due to the acoustically stimulated diffusion of phosphorus at a low temperature (T ≈ 300 K), the p-Si base is compensated, which becomes more resistive. As a result, the applied bias voltage drop V_b on the depleted layer W_d and the electric field strength E increase in it. These acoustically stimulated effects lead to an increase in the built-in (diffusion potential, see equation (2) for V_v).

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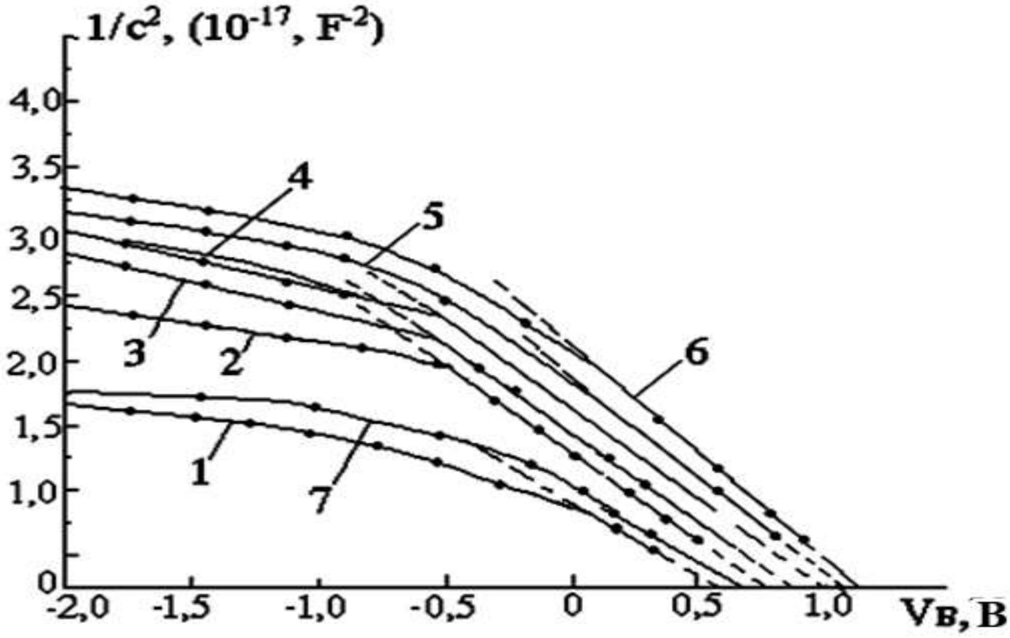

Fig.2. Dependences of C-2 on the reverse voltage Vb curve 1- differ from linear, which indicates the absence of a sharp impurity concentration profile.

IN CONCLUSION of this section, we can say that as a result of the ongoing changes in the structure of the Si photodetector, which affected the behavior of the I(V) and C(V) characteristics, one should expect a clear change in the spectral and photoelectric characteristics of the Si photodetector. As a result of these processes, an increase in the magnitude of 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 observed that the surface recombination of carriers decreases in the near-surface layers of the Si-n-p photodetector under the action of ultrasonic waves.

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