Study of the Influence of Ultrasonic Waves on Electro-physical Characteristics of Radiation Receivers

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Abstract--- *The physical processes of capture and ejection of charge carriers in Si-n-p radiation detectors, affecting their electro-physical characteristics (current-voltage), are investigated. It was shown that after ultrasonic treatment of Si detectors, the height of the potential barrier of p-n junctions formed by the presence of local clusters of impurity atoms decreased.*

Keywords--- *Si Radiation Detectors, Large-scale and Small-scale Local Clusters of Impurity Atoms, Ultrasound, Height of the Potential Barrier of the PN Junction.*

I. INTRODUCTION

Currently, it is known that ultrasonic irradiation affects the defective structure and electro-physical characteristics of semiconductors [1, 2,3]. The paper analyzes currents of n-p junctions due to capture processes of diffusion Si radiation detectors (detectors) subjected to ultrasound. The structure of Si radiation detectors (Si-PI-P) was made on the basis of p-silicon with an (111) orientation doped with phosphorus to a concentration of $N \approx 10^{15}$ cm^{-3}и $N \approx 10^{16}$ cm^{-3} for different batches of Si-PI, using standard technology.

Studies of the causes of polarization effects and low values of the functional characteristics of radiation detectors were selected by Si-PI into 2 groups (recall that the polarization effect is that, when in operation, the radiation detector gradually worsens its functional characteristics due to the strong capture of charge carriers by traps.After heating to room temperature, the radiation receiver restores its characteristics).

a) In Si-PI-P of this group, capture effects were observed (field dependences $\lambda(1/E)$ had a nonlinear shape in the low-level range of $E \leq 1000$V/cm), which is associated with shallow capture centers. Detectors of this group had average spectrometric characteristics. The spectral lines in this case had a long decline from the low-energy side, which is due to the presence in the sensitive layer of a certain number of local accumulations of impurity atoms (LSPA).

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b) The polarization effects of Si-PI-W, of this group, manifested themselves most vividly and quickly for the values of the radiation registration times t_p<2 hours. The spectral lines of this Si-PI group had doublets and have significant sizes of local clusters of impurity atoms.

II. MATERIALS AND METHODS

The applied technique for manufacturing silicon diffusion detectors is based on the known methods for manufacturing detectors from silicon [4].

For the manufacture of Si PDD detectors, p-type single-crystal silicon ingots with specific resistance $\rho=(10\div14)\cdot10^3\Omega$cm and minority carrier lifetimes $\tau=450\div650\mu$s, as well as lower-resistance p- ingots, were used Si with p-Si c$\rho\leq(2\div5)\cdot10^3\Omega$cm and $\tau=800\div1000\mu$s. The oxygen concentration No. 2 was no more than 10^{16} $cm^{-3}$and the dislocation density N_D~10^4cm^{-2}.Cylinder-shaped ingots were cut into plates up to 0.5 mm thick. The plates had an area S from 0,25 $cm^2$to 2,0cm^2. Si-plates were ground on both sides with M15 abrasive powder. After appropriate chemical treatment, aluminum (Al) with a thickness of $l\approx0{,}45\mu m\div 0{,}5\mu m$ was sprayed onto one of the sides of the Si wafers; in this technological procedure, the edges of the Si wafer were protected by a mask. After that, a solution of phosphorus pentoxide P_2O_5 was deposited on the other side of the Si plate and this coating was dried.The next technological step was the diffusion of phosphorus into the Si wafer. Samples located in quartz cassettes were placed in a diffusion furnace. Diffusion of phosphorus was carried out at a temperature of T = 1073K in an inert gas stream for a time t = 60 minutes. Then the temperature slowly dropped to room temperature. The aluminum deposited on the Si wafer is fused with it at T≈820K and then, diffusing from the melt into the bulk of the Si wafer, forms a heavily doped p^+- silicon layer. After cooling, the Si-plate undergoes a series of chemical-technological operations for cleaning and removing phosphor silicate glass on the n^+- layer obtained by diffusion of phosphorus. Gold with a density of about 30÷50μgramm/$cm^2$was sprayed onto the entrance window of the Si-n-p structure. Electrical contacts to the n- and p-layers were made in the form of clamping or by attaching thin metal wires using conductive silver pastes. Then the structure was mounted in the housing. Large-area Si-n-p structures can be cut into smaller plates and PDD detectors can also be made from them for specific purposes. It also provides for the protection and sealing of the edges of the semiconductor detector with special protective coatings.

III. RESULTS AND DISCUSSIONS

The dependences of current on the reverse bias voltage were studied at temperatures T = 300 K for two groups of Si detectors: with a strong capture effect of Si-PI-P charge carriers and with a weak Si-PI-W, respectively. Figure 1 shows the measured current versus reverse bias voltage Vb at a temperature of T = 300K for two Si-n-p radiation detectors Si-PI- and Si-PI-W, containing, respectively, large-scale and small-scale local clusters of impurity atoms. The graph shows that a sharp rise in current (deterioration) of Si-PI-P and Si-PI-W begins at a voltage of $V_b\approx$ 1,5V(curve 4 of Fig. 1.) and $V_b\approx$ 3,0V (curve 1 of Fig..1.) respectively. In addition, it was found that the Si-PI-P reverse current is almost independent of temperature in the temperature range T = 77 ÷ 300 K, but at the same time, a noticeable temperature dependence of the reverse current was observed for Si-PI-W.

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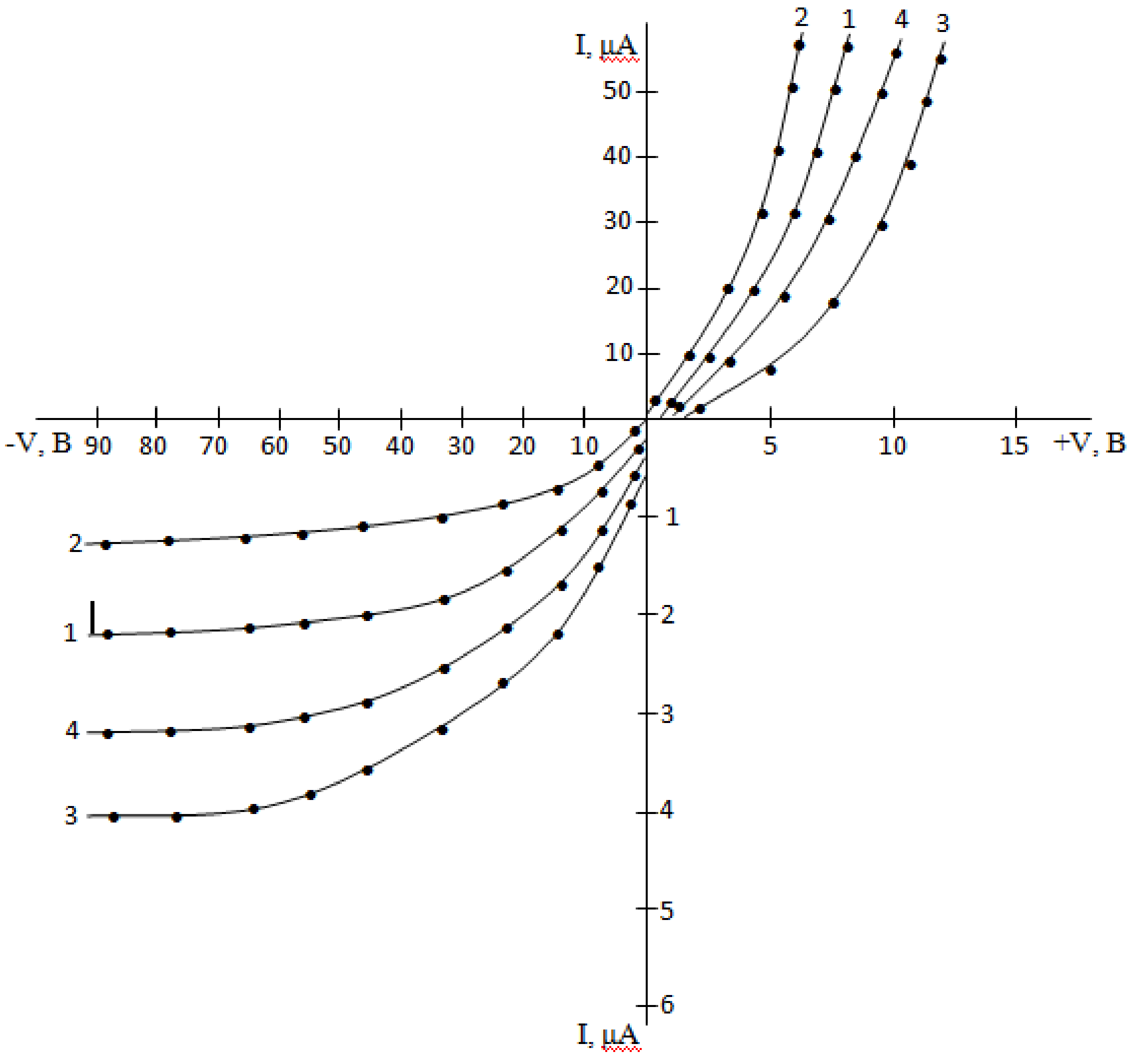

Figure 1: Dependence of Current on Reverse Voltage for Si-PI-W-and Si-PI-P-radiation Detectors, T = 300K.

a) Si-PI-W-curve 1 before irradiation with ultrasound, curve 2 - after irradiation;

b) Si-PI-P-curve 3 before irradiation with ultrasound, curve 4 after irradiation.

Ultrasound parameters I*=0,4W/cm^2, f=15MHz, t=45min, T=300K.

Application of the Fowler-Nordheim model allows us to calculate the dependence of the reverse current density on the reverse bias voltage I(V_b) based on an equation of the following form [5]:

$$I(T,E) = \int_{-\infty}^{-\infty} A(T,E^1) D(E,E^1) dE^1 \quad (1)$$

whereA(T,E^1) is a function that describes the process of transfer of charge carriers to the barrier surrounding a local cluster impurity atoms, D(E,E^1)is the transmission coefficient describing the probability of tunneling charge carriers through the barrier.

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This situation is true, since the barrier becomes repulsive after the capture of carriers by a local accumulation of impurity atoms, or the barrier is initially such due to the nature of the atoms forming the cluster. Then, as calculations and calculations show [5], the functionsA(T,E^1) and $D(E,E^1$ can be written in the following form:

$$(T,E^1) = (4\pi m^* \cdot kT/h^3)\ln[1+\exp(-E^1/kT) \quad (2)$$

$$D(E,E^1) = \exp(-4(2m^*)^{1/2}(q\Phi_B-E^1)^{3/2}\cdot V(y))/2h^*qE, \quad (3)$$

$$\text{where} y = (q^3\cdot E)^{1/3}/q\Phi_B \quad (4)$$

The following notation is used in the equations: m * is the effective mass of charge carriers; Boltzmann k-constant; T-absolute temperature; h * is the Planck constant; q is the electron charge; F_v-barrier height; E-electric field strength; E1 is the energy of carriers (electrons or holes); V (y) is the Fowler-Nordheim function. In the calculations, it is assumed that V (y) = 1. At a value of $T\rightarrow 0$, equation (1) will have the following form:

$$I(0,E) = q^3E^2\exp(-4(2m^*)^{1/2}(q\Phi_B)^{3/2}/3h^*qE)/16\pi^2h^{*2}q\Phi_B \quad (5)$$

It is natural to assume that, near a local cluster of impurity atoms, the electric field is amplified by a factor ofβ, since the presence of the cluster causes the appearance of a local p-n-junction, the electric field of which determines the processes of carrier drift at a given location of the active element (sensitive region) of the radiation receiver [6]. That is, the expression for the electric field in this case will have the following form:

$$E= \beta(2qN_D/\varepsilon_s)^{1/2}(V_i+V_b)^{1/2} \quad (6)$$

where ND is the concentration of donors; ε_s- is the dielectric constant of the semiconductor; V_i- built-in voltage; V_b is the reverse bias voltage. The calculation performed is based on the model of a sharp pn junction, assuming that local accumulations of impurity atoms are located near the region of the maximum pn junction field of the Si radiation receiver. In view of the above, the electric field gain can be calculated as follows.

Firstly, by numerically integrating equation (1), the dependences I (V_b) are calculated for various values of the effective barrier height $F=(m^*/m_0)^{1/3}F_v$at temperatures T = 77K and T = 300K. Dependence data for qΦ = 0,31; 0,52 и 0,72eV and $N_D=1{,}2\cdot 10^{15}$см$^{-3}$и V_i=0 and Vi = 0 were calculated, measured and presented as, for example, for qF = 0.31 in Figure 2.. Then, the experimental dependences I (V_b) with the calculated dependences I (V_b) until they completely coincide and the coefficient $\beta$was determined from a simple relation (7):

$$\beta = [V_b \text{ (theoretical meaning)}/ V_b \text{ (excremental meaning.)}]^{1/2} \quad (7)$$

It is easy to see that the values of the coefficients $\beta$for the Si-PI-P and Si-PI-W radiation receivers are $\beta_1 \approx 128$ and$\beta_2 \approx 13$, respectively. The effective height of the barriers Φ is also determined using the matching procedure described in [4]. It was found that Φ for Si-PI-P and Si-PI-W is $\Phi_p \approx 0{,}62$eV and$\Phi_w \approx 0{,}67$eV, respectively.

A feature of the presented model of the current transport mechanism is that the temperature dependences of the reverse currents of Si radiation detectors are calculated without introducing any special approximations. For this, as noted earlier, the numerical integration of equation (1) is carried out for various values of β, Φ_B and the reverse bias voltage V_b.

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As noted, for Si-PI-P, the reverse current density weakly depends on temperature. This is because the temperature-independent coefficient D in equation (1) significantly exceeds the temperature-dependent function A (T, E^1) due to the very small width of the barrier. The decrease in the barrier width is caused by a significant increase in the local field near the local accumulation of impurity atoms. In the Si-PI-W radiation receiver, the reverse current density is strongly dependent on temperature due to the low value of the parameter $\beta_2 \approx 13$, which is associated with smaller values of local accumulations of impurity atoms in this type of Si-PI-W in comparison with the existing LSPA in radiation receivers of the type Si-PI-P.

From the analysis of the data obtained, it is possible to determine the magnitudes of the localized (internal) electric fields near local clusters of impurity atoms, the values of which $E \approx 10^6$-10^7V/ cm, which is approximately two orders of magnitude higher than the maximum electric field in the pn junction of Si radiation detectors. For example, if we take Si-PI-P with

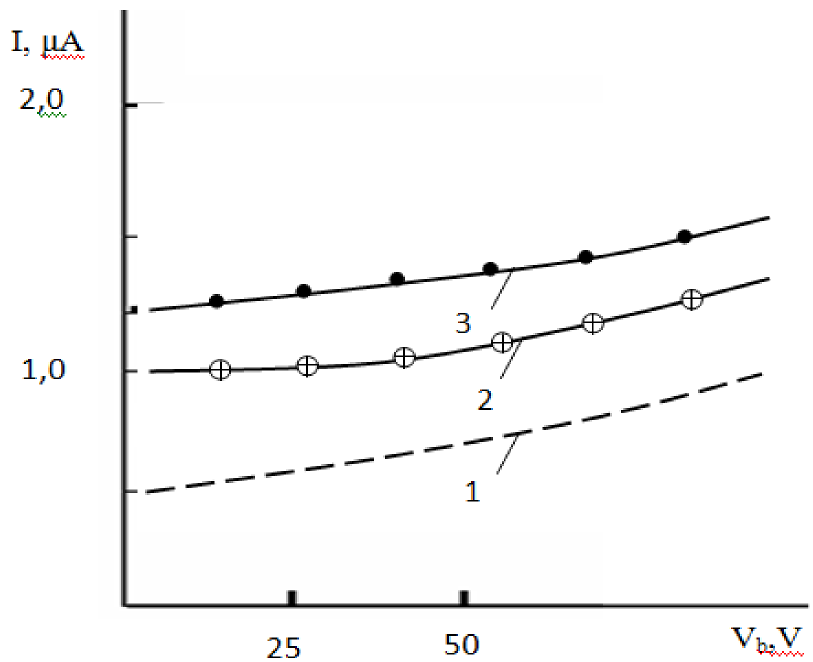

Figure 2: Current-Voltage Characteristic of the Si-np Detector before (curve 1 theory; curve 2 experiment) and after (curve 3 experiment) Ultrasonic Treatment at I*=0,4W/cm^2, f =15MHz, t=125minприT=300K

with a p-n-junction width W = 20 μm, with a voltage of V_b=10V, it is E^{max}_{p-n}= 5000V/ cm, and for a Si-PI-W receiver, it is $E^{max}_{p-n} = 2{,}5 \cdot 10^4$ V/cm.

Figures (1.2.) Show changes in current characteristics after ultrasonic waves emitted through Si detectors with a frequency of f = 15 MHz with an intensity of I* = 0,4 W/cm^2.

It is clearly seen that the curves of the dependence of the reverse current on the bias voltage V_b are shifted to the region of lower currents (Fig. 1 curves 2.4; Fig. 2. Curve 3). After ultrasonic treatment of the Si detectors, qΦ

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decreased [7], that is, the height of the potential barrier of pn junctions formed by the presence of local clusters of impurity atoms decreased, as shown in Table 1.

Table 1: The Effect of Ultrasonic Treatment on qΦ

qΦ,eV, before ultrasonic treatment	qΦ, eV, after ultrasonic treatment
0,31	0,25
0,52	0,45
0,72	0,66

Decrease in reverse currents of Si - p - n - receivers after passing through them the protective shutdown device (PSD)is connected with - apparently, with the decay of local clusters in ultrasonic fields. [8]

IV. CONCLUSION

In diffusion Si radiation detectors, the passage of ultrasonic waves with a frequency of f≤25 MHz and intensity (power) $I^{*} \leq 0.5$ W/cm^2:a) the polarization effect disappears and b) increases the collection efficiency of non-equilibrium charge carriers to electrical contacts as a result of the decay of atomic local accumulations of impurities containing gold atoms and acting before ultrasonic treatment as effective centers of capture of drifting charge carriers.The result of the decay process of local clusters of impurity atoms is the smoothing of the potential relief and the uniform distribution of the electric pulling field in the sensitive region, which provides a more efficient and faster collection of charge carriers to electrical contacts and thereby improving the functional characteristics of diffusion Si detectors.

V. CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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