INVESTIGATION OF THE EFFECT OF ULTRASONIC WAVES ON THE ELECTROPHYSICAL CHARACTERISTICS OF RADIATION RECEIVERS

Abdumalik Gaibov
Tashkent State Technical University, Tashkent, Republic of Uzbekistan,
E- mail: gaibov.1954@mail.ru

Kutbiddin Vakhobov
Tashkent State Technical University, Tashkent, Republic of Uzbekistan

ABSTRACT

The physical processes of capture and ejection of charge carriers in Si-n-p radiation receivers affecting their electrophysical characteristics (voltage-current) are investigated. It is shown that after ultrasonic treatment of Si receivers, there was a decrease in the height of the potential barrier of p-n junctions formed by the presence of local clusters of impurity atoms. The result of the decay process of local clusters of impurity atoms is the smoothing of the potential relief and the uniformity of the distribution of the electric pulling field in the sensitive area of the detector.

Keywords: Si radiation receivers, large-scale and small-scale local clusters of impurity atoms, ultrasound.

1. INTRODUCTION

It is currently known that ultrasonic irradiation affects the defective structure and electrophysical characteristics of semiconductors [1,2,3]. The paper analyzes the currents of n-p junctions caused by the capture processes of diffusive Si-receivers (detectors) of radiation exposed to ultrasound. The structure of Si-radiation receivers (Si-PI) were manufactured on the basis of p-silicon with orientation (111) doped with phosphorus to a concentration of $N \approx 10^{15} cm^{-3}$ and $N \approx 10^{16} cm^{-3}$ for different batches of Si-PI, according to standard technology.

Studies of the causes of polarization effects and low values of the functional characteristics of radiation receivers were selected Si-PI into 2 groups (recall that the effect of polarization is that while in the operating mode, the radiation receiver gradually degrades its functional characteristics due to the strong capture of charge carriers by traps. After heating to room temperatures, the radiation receiver restores its characteristics).

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

b) The effects of Si-PI-W polarization of this group were manifested most vividly and quickly for the values of 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.

2. RESULTS AND THEIR DISCUSSION

The dependences of the current on the reverse bias voltage at temperatures T = 300K were studied for two groups of Si receivers: with a strong effect of capturing charge carriers Si-PI-P and with a weak effect Si-PI-W, respectively. Figure 1 shows the measured dependences of the current on the reverse bias voltage V_b at a temperature T = 300K for two

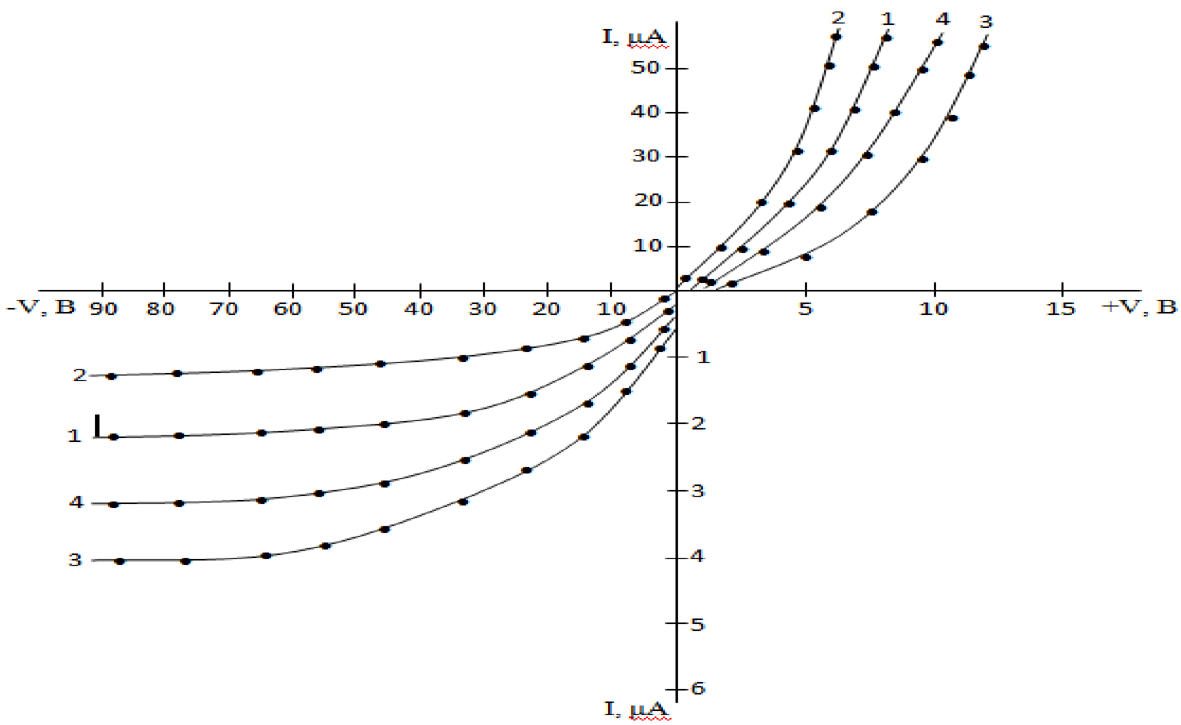

Figure 1. Dependences of current on reverse voltage for Si-Peaks of Si-PI-P radiation receivers, T =300K. a) Si-PI-W-curve 1 before ultrasound irradiation, curve 2- after irradiation; b) Si-PI-P - curve 3 before ultrasound irradiation, curve 4 – after irradiation. Ultrasound parameters I*=0.4W/cm^2, f=15MHz, t=45min, T=300K.

Si-PI-P and Si-PI-W radiation receivers containing, respectively, large-scale and small-scale local clusters of impurity atoms. It can be seen from the graph that a sharp rise in current (deterioration of characteristics) of Si-PI-P and Si-PI-W begins at a voltage of $V_b \approx$ 1,5V (curve 4 Figure 1.) and $V_b \approx$ 3.0V, (curve 1 Figure 1.), respectively. In addition, it was found that the reverse current Si-PI-P almost does not depend on temperature in the temperature range T = 77 ÷ 300 K, but at the same time there was a noticeable temperature dependence of the reverse current in Si-PI-W.

The application of the Fowler-Nordheim model makes it possible to calculate the dependence of the reverse current density on the reverse bias voltage I(V_b) based on the equation of the following form:

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

where A(T,E^1) is a function describing the process of transfer of charge carriers to the barrier surrounding a local accumulation of impurity atoms, D(E,E^1) is the transmission coefficient describing the probability of tunneling charge carriers through the barrier. This position is valid, since the barrier becomes repulsive after the capture of carriers by a local cluster of impurity atoms, or the barrier is such initially due to the nature of the atoms forming the cluster. Then, as calculations and calculations show, the functions $A(T,E^1)$ and $D(E,E^1)$ can be written as follows:

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

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

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

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

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

It is natural to assume that near a local cluster of impurity atoms, the electric field increases by a factor of β, since the presence of the cluster causes the occurrence of a local p-n junction, the electric field of which determines processes of carrier drift in a given location of the active element (sensitive area) of the radiation receiver [4, p.1191]. That is, the expression for the electric field in this case will have the following form:

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

where N_D is the concentration of donors; ε_s is the dielectric constant of the semiconductor; V_i is the built-in voltage; V_b is the reverse bias voltage. The calculation is based on the model of a sharp p-n transition, assuming that local clusters of impurity atoms are located near the region of the maximum field of the p-n transition of the Si radiation receiver. Taking into account the above, the electric field gain can be calculated as follows.

First, by numerical integration of equation (1), dependences $I(V_b)$ are calculated for various values of the effective barrier height $\Phi=(m^*/m_o)^{1/3}\Phi_B$ at temperatures T = 77K and T = 300K. These dependences for the values qΦ = 0,31; 0,52 и 0,72 eV at $N_D=1{,}2\cdot10^{15}$ см$^{-3}$ and $V_i=0$ were calculated, measured and given as an example for the value qΦ = 0.31 in Figure 2.. Then the experimental dependences $I(V_b)$ were compared with the calculated dependences $I(V_b)$ until they completely coincide and the coefficient β was determined from the simple ratio (7) :

$$\beta = [V_b\ (\text{theoretical value})/\ V_b\ (\text{experiment.value})]^{1/2} \qquad (7)$$

It is easy to see that the values of the coefficients β for radiation detectors Si-PI-P and Si-PI-W is $\beta_1 \approx 128$ и $\beta_2 \approx 13$, respectively. The effective height of the barriers is also determined using the matching procedure described in [4, p.1192]. It was found that the value of Φ for Si-PI-P and Si-PI-W is $\Phi_p \approx$ 0.62eV and $\Phi_w \approx$ 0.67eV, respectively.

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

As noted, for Si-PI-P, the reverse current density weakly depends on temperature. This is explained by the fact that 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 strongly depends on the temperature due to the low the values of the parameter are $\beta_2 \approx 13$, which is due to the smaller values of local accumulations of impurity atoms in this type of Si-PI-W compared to the values of local clusters of impurity atoms existing in Si-PI-P type radiation receivers.

From the analysis of the data obtained, it is possible to determine the intensity of localized (internal) electric fields near local clusters of impurity atoms, the values of which are $E \approx 10^6$-10^7 V/cm, which is approximately two orders of magnitude higher than the maximum electric field in the p-n junction of Si radiation receivers. For example, if we take Si-PI-P with a p-n junction width W = 20 mkm, at a voltage of V_b=10V the value of E^{max}_{p-n}= 5000 V /cm, and for a receiver of type Si- PI-W the value of $E^{max}_{p-n} = 2{,}5 \cdot 10^4$ V/cm.

The figures (1,2.) show the changes in current characteristics after passing through Si receivers of ultrasonic wave radiation 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 Vb are shifted to the region of lower values of currents (Figure 1, Curve 2.4; Figure 2.

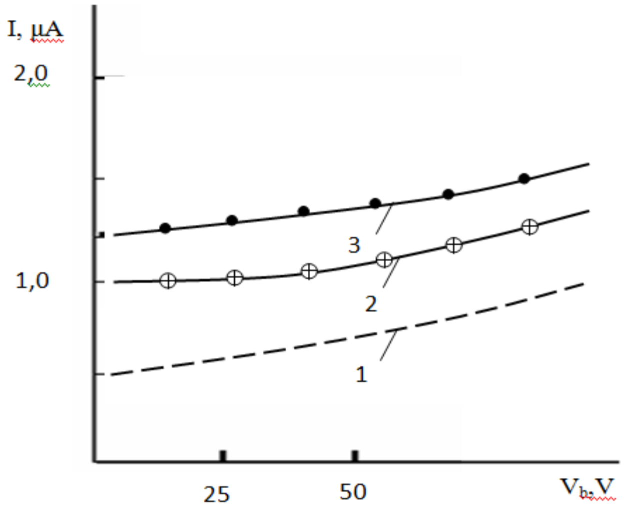

Figure. 2. Current-voltage characteristic of the Si-n-p detector up to (curve 1-theory; curve 2-experiment) and after (curve 3- experiment) ultrasonic treatment at I *= 0.4 W/cm^2, f =15 MHz, t =125min. at T = 300K.

Curve 3). After ultrasonic treatment of Si receivers, there was a decrease in the value of qΦ [5, p.36], that is, there was a decrease in the height of the potential barrier of p-n junctions formed by the presence of local clusters of impurity atoms, which is reflected in Table 1.

Table 1. The effect of ultrasonic treatment on the qΦ value

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

The decrease in the return currents of Si – p-n receivers after passing through them is probably due to the decay of local clusters in ultrasonic fields [6,p.3].

4. CONCLUSION

In diffusive Si radiation receivers, the passage of ultrasonic waves with a frequency of f≤25 MHz and an intensity (power) of $I^* \leq 0.5$ W/ cm^2:

a) Leads to the disappearance of the ”polarization” effect and

b) Causes an increase in the efficiency of collecting nonequilibrium charge carriers on electrical contacts as a result of the decay of local clusters of impurity atoms having in in its composition, gold atoms and those that acted before ultrasonic processing as effective centers for capturing drifting charge carriers.

The result of the local clusters of impurity atoms decay process is the smoothing of the potential relief and the uniformity of the distribution of the electric pulling field in the sensitive area, which provides a more efficient and faster collection of charge carriers on electrical contacts and thereby improving the functional characteristics of diffusion Si receivers.

LIST OF LITERATURE

1. Zaveryukhin B.N., Krevchik V.D., Muminov R.A. Features of ultrasonic exposure to Si(Li)-p-i-n detectors with an uneven distribution of the electric field.// Physics and technology of semiconductors, 1986, vol.20, v.3, pp.525-528
2. Gaibov A.G., Zaveryukhin B.N., Krevchik V.D., Muminov R.A. Acoustically stimulated processes in Si(Li)-p-i-n detectors // Letters to the Journal of Technical Physics, 1984, Vol.10, V.10, pp.616-620.
3. Zaveryukhina E.B., Zaveryukhina N..N., Lezilova L.N., Zaveryukhin B.N., Volodarsky V.V., Muminov R.A. Acoustically stimulated expansion of the short-wave range of spectral sensitivity of AlGaAs/GaAs-solar cells // // Letters in JTP, 2005, Vol.31, V.1, pp.54-66.
4. Eremin V.K., Strokan N.B., Danengirsh S.S. On the nature of large-scale traps in high-purity germanium // Physics and technology of semiconductors, 1977 vol.11, v.6, pp.1191-1193.
5. Zaveryukhina N.N., Zaveryukhina E.B., Vlasov S.I.,Zaveryukhin B.N. Acoustically stimulated change in density and energy spectrum of surface states in single crystals of p-silicon // Letters to the Journal of Technical Physics, 2008, 34, No. 6, pp.36-42
6. Mirsagatov Sh.A., Sapaev I.B., Nazarov Zh.T. Ultrasonic annealing of surface states in the heterojunction of the injection photodiode p-Si/n-CdS/n+-CdS. //Inorganic Materials, 2015, Volume 51, No. 1, pp.3-6.