THE INFLUENCE OF DEFORMATION AND LIGHT ON THE P-N-JUNCTION I-V CHARACTERISTIC IN AN ELECTROMAGNETIC FIELD

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Abstract

In this work, we studied the effect of deformation and light on the I-V characteristic of a p-n-junction located in a strong microwave field. Shown, the availability of the ability to control the I-V characteristic p-n-junction located in the microwave field using light and deformation. Changes in the coefficient of light absorption by deformation due to changes in the band gap of the conductor have been studied.

Keywords: p-n-junction; strong electromagnetic field; deformation; light; absorption coefficient.

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1. Introduction

It is known that in inhomogeneous semiconductors, when a temperature gradient appears between the boundaries of a semiconductor, a thermoelectromotive force (TEMF) arises. In a semiconductor, it is possible to create an inhomogeneous concentration of current carriers by artificial means, for example, by the action of light. If you heat the illuminated side of the semiconductor, leave the other side at the same temperature, EMF [1] will appear on the semiconductor boundary. This effect was first identified by Tauz and called the thermo-photoelectric effect [2]. The results of the Tauz experiment showed that at ordinary temperature gradients this effect is very small, but it can be observed. If only the current carriers are heated with a microwave field, then even higher temperatures and high voltage values can be achieved. Such an effect was observed by Repshas and Ashmontash, but they received not very high voltage and called it the electromotive force of the photogradient of heated current carriers. This name was adopted for the volumetric photo EMF in some cases, when impurities are in homogeneously distributed in a semiconductor [3]. In work [4], the thermoelectric effect of heated charge carriers in n- and p-type germanium at lattice temperatures of 300K and 77K is considered theoretically and experimentally. The results showed that this effect of coupling with heating in weak fields is quadratic, in strong fields it is linear. In the experiment in strong fields, saturation and even a decrease in the effect were observed. In addition, it was found that this effect is sensitive to the form of the dependence of the pulse relaxation time of current carriers on the energy and potential at the surface. In work [5], the change in the photo EMF was investigated upon heating the charge carriers in the germanium p-n-junction. It is shown that the photo EMF grows in proportion to the temperature of minority current carriers. Measuring the photo EMF of heated charge carriers is a simple and accurate method for determining the temperature of heated minority carriers. The effect of light on the tensosensitivity of the p-n- junction is given in the work [6].

Models of generation and recombination in homogeneous semiconductor structures were created in fundamental works for microelectronics [7,8]. The results of these works perfectly describe the I-V characteristics of ideal structures with a depletion region and defects in this region, photoelectric processes involving defects, and other important phenomena in semiconductors. These works have numerous applications and an extensive bibliography of citations, for example [9]. Nevertheless, these works require refinement and development when disordering, strong electric fields, and electron-phonon interaction take place. Nanoscale disorder in diamond-like semiconductors can be caused by different factors. Artificial nanoscale disorder is obtained by forming an array of quantum wells, for example, in crystals based on III–V solid solutions and other complex semiconductors, including those based on oxides. This process can be initiated, for example, by irradiation or ion implantation of a semiconductor and silicon too. Natural nanoscale disorder can also be due to different factors: compensation, structural damage, glass formation, high defect concentration. Silicon contains a wide variety of defects, including vacancy -impurity complexes. Oxygen is an important impurity located at interstitial sites in the silicon lattice. Vacancies are easily trapped by oxygen atoms, leading to a formation of vacancy-oxygen (VO) complexes. Upon annealing, VO complex can combine with vacancy or interstitial oxygen to form more complicated complexes, such as V_2O, VO_2, VO_3, and so on [10]. Current-voltage characteristics of p-n-junctions with defects contain all information about defects and deep centers that they create. Disorders in semiconductors accompanied by spatial localization of electronic states. As a result, to recombine, charge carriers must overcome a potential barrier; barriers over come through tunnelling is referred to as the tunneling recombination. Transport models with allowance for disordering were proposed in [11,12]. Generation and recombination are accompanied by electronic transitions between localized states. A good description of the experimental results cannot be made without taking into account the electron-phonon interaction, which increases the probability of the mentioned transitions. The probabilities of such transitions have been investigated by many authors [13-18], however, results that are easy to compare with experiment were obtained in [19] and they successfully explained various experimental results [20-26].

However, in the above studies, the effect of deformation and light on the I–V characteristic of the p-n junction in microwave fields has not been sufficiently studied from the theoretical point of view. The purpose of this work is to study the effect of deformation and light on the I–V characteristic of a p-n-junction in a microwave field, the possibility of controlling the I–V characteristic of a p-n- junction in a microwave field using light and deformation, and changing the absorption coefficient due to a change in the semiconductor band gap by deformation.

Ii. The Effect Of Deformation On The Photocurrents Of The P-N-Junction Under The Influence Of Light Located In The Microwave Field.

It is known that a photocurrent occurs only when illuminated by light, the energy of a quantum is sufficient to obtain an electron-hole pair. Light of such a long wavelength is absorbed strongly, therefore electron-hole pairs are formed in the vicinity of the boundary.The total photodiode current is written as follows [27]:

$$I = I_s\left[\exp\left(\frac{eU}{kT}\right)-1\right]-I_c \qquad (1)$$

Here, $I_s = e\left(\frac{D_h p_n}{L_h}+\frac{D_e n_p}{L_e}\right)$, $I_c = eI_0(1-\beta_0)$, $\beta_0 = \beta_s + \beta_v = \frac{d(2L_n^2 + dL_s)}{2L_n^2 L_s + d}$ - total losses for bulk and surface recombination, $\beta_c = \frac{d}{L_s + d}$ - relative losses for surface recombination, $\beta_v = \frac{L_s d^2}{2(L_s + d)L_n^2}$ - relative volumetric recombination losses, $L_s = D_n/s$, d – illuminated area thickness, $I_0 = (1-R)G\alpha$ – light intensity, α- light absorption coefficient [28]:

$\alpha = A(h\nu - E_g - \Delta\varepsilon)^r$, if $h\nu \approx E_g$ then $\alpha = A(\Delta\varepsilon)^r$

T- grate temperature, E_g- bandgap, ν- light frequency, h– Planck's constant, Δ- deformation potential, r- for a properly valid transition $r = 1/2$, correctly forbidden transition $r = 3/2$. A- coefficient for a correctly admissible transition $A = 2\cdot 10^4$ [29], $G = W_i/\hbar\omega$– the number of photons incident on a unit surface, W_i – total light energy, $R = \left(\frac{n-1}{n+1}\right)^2$– light reflectance, n – refractive index of the medium, $L = \left(\frac{2\varepsilon\varepsilon_0}{e}\frac{n_n + p_p}{n_n p_p}\right)\sqrt{(\varphi_0 + U)}$– space charge layer width, $L_s = D_e/s$, s — recombination rate.

Taking into account the higher value for the photocurrent, we obtain

$$I_c = -\frac{eI_0}{1+\frac{L}{L_s}} = \frac{eG(1-R)A(h\nu - E_g - \Delta\varepsilon)^r}{1+\sqrt{\left(\frac{2\varepsilon\varepsilon_0}{e}\frac{n_n + p_p}{n_n p_p}(\varphi_0 + U)\right)}\frac{s}{D_e}} \qquad (2)$$

Substituting (2) into (1), we obtain the expressions

$$I = I_s\left(\exp\left(\frac{qU}{kT}-1\right)\right)-\frac{eGL_s(1-R)A(\Delta\varepsilon)^r}{L_s + L} \qquad (3)$$

Using this expression for the current-voltage characteristic of the p-n-junction, we get the graph shown in Figure.1.In the absence of a microwave field, light and deformation, the reverse branch is almost close to the U axis; when light is applied and deformation to the p-n-junction, the reverse branch is shifted downward from the axis; with increasing deformation, proportionally without changing the light intensity, an even greater downward shift of the reverse I–V characteristic is observed.It can be seen from Figure.1 that deformation increases the photocurrent. This is of great practical importance, since the simultaneous action of light and deformation on semiconductor photocells makes it possible to control the photocurrent and photo electromotive force.

In the absence of warming up in weak fields [30]:

$$\bar{I}(U_B, I_c) = I_s\left[\exp\left(\frac{eU}{kT}\right)\int_0^{2\pi}\left(\exp\left(-\frac{eU_B\cos(\omega t)}{kT}\right)\right)\frac{d(\omega t)}{2\pi}-1\right]-I_c \qquad (4)$$

If we substitute (4) into (2), we get the expression:

$$I = I_s\left(\exp\left(\frac{eU}{kT}\right)\int_0^{2\pi}\left(\exp\left(-\frac{eU_B\cos(\omega t)}{kT}\right)\right)\frac{d(\omega t)}{2\pi}-1\right)-\frac{eGL_s(1-R)A(\Delta\varepsilon)^r}{L_s + L} \qquad (5)$$

Using expression (5), we can obtain the I–V characteristic of the p-n- junction located in the microwave field (Figure 2). Hence, it can be seen that the microwave wave increases the recombination current at the p-n-junction, and light and deformation increase the generation current.

At high-power UHF waves, the photo I -V characteristic of the p-n-junction (when, $I_c \neq 0;\ T_e \neq T_h > T;\ U_B \neq 0$) is determined using expression (1) by the following expression [29]:

$$\bar{I} = \frac{eD_e n_p}{L_e}\left\{\left(\frac{T_e}{T}\right)^{\frac{1}{2}} \exp\left(\frac{e\varphi_0}{kT} - \frac{e(\varphi_0 - U)}{kT_e}\right)\int_0^{2\pi} \exp\left(-\frac{eU_B\cos(\omega t)}{kT_e}\right)\frac{d(\omega t)}{2\pi} - 1\right\} +$$

$$+\frac{eD_h p_n}{L_h}\left\{\left(\frac{T_h}{T}\right)^{\frac{1}{2}} \exp\left(\frac{e\varphi_0}{kT} - \frac{e(\varphi_0 - U)}{kT_h}\right)\int_0^{2\pi} \exp\left(-\frac{eU_B\cos(\omega t)}{kT_h}\right)\frac{d(\omega t)}{2\pi} - 1\right\} - I_c$$

(6)

If we substitute (6) into (4), then we obtain

$$I = \frac{eD_e n_p}{L_e}\left\{\left(\frac{T_e}{T}\right)^{\frac{1}{2}} \exp\left(\frac{e\varphi_0}{kT} - \frac{e(\varphi_0 - U)}{kT_e}\right)\int_0^{2\pi} \exp\left(-\frac{eU_B\cos(\omega\omega t)}{kT_e}\right)\frac{d(\omega t)}{2\pi} - 1\right\} +$$

$$+\frac{eD_h p_n}{L_h}\left\{\left(\frac{T_h}{T}\right)^{\frac{1}{2}} \exp\left(\frac{e\varphi_0}{kT} - \frac{e(\varphi_0 - U)}{kT_h}\right)\int_0^{2\pi} \exp\left(-\frac{eU_B\cos(\omega\omega t)}{kT_h}\right)\frac{d(\omega t)}{2\pi} - 1\right\} - \frac{eAGL_s(1\text{-}R)(\Delta R)^{r}}{L_s + L}$$

(7)

Using (1) expressions, you can get the I–V characteristic of the p-n-junction in the microwave field.

It can be seen from it that a high-power microwave wave increases the recombination current at the p-n-junction, and light and deformation increase the generation current.

When electrons and holes are heated and the height of the potential barrier is perturbed, as well as the potential struggler is perturbed, and deformation is also applied (in strong microwave waves) $I_c \neq 0$; $T_e \neq T_h > T$; $U_B \neq 0$; $\varepsilon \neq 0$ [31].

$$\bar{I} = I_{se}(\varepsilon)\left\{\left(\frac{T_e}{T}\right)^{\frac{1}{2}} \exp\left(\frac{e\varphi_0}{kT} - \frac{e(\varphi_0 - U) + eU_B\left|\overline{\cos(\omega\omega t}\right|}{kT_e}\right) - 1\right\} +$$

$$+ I_{sh}(\varepsilon)\left\{\left(\frac{T_h}{T}\right)^{\frac{1}{2}} \exp\left(\frac{e\varphi_0}{kT} - \frac{e(\varphi_0 - U) + eU_B\left|\overline{\cos(\omega\omega t}\right|}{kT_h}\right) - 1\right\} - \frac{eAGL_s(1\text{-}R)(\Delta R)^{r}}{L_s + L} \qquad (8)$$

where for silicon p-n-junctions

$$I_{se}(\varepsilon) = \sqrt{\frac{ek}{\tau_e}T^{4,4}\cdot 10^9}\,\frac{3\cdot 10^{33}}{p_p}\exp\left(-\frac{\varepsilon_g(0) + \Delta\varepsilon}{kT}\right),$$

$$I_{sh}(\varepsilon) = \sqrt{\frac{ek}{\tau_h}T^{4,7}\cdot 2.5\cdot 10^9}\,\frac{1.5\cdot 10^{33}}{n_n}\exp\left(-\frac{\varepsilon_g(0) + \Delta\varepsilon}{kT}\right)$$

The volt-ampere characteristic is shown in Figure 4. It can be seen from it that a high-power microwave field increases the recombination current at the p-n-junction. Light and deformation increase the generation current if the number of photons per unit area is large.

2. Conclusions

- In the absence of light and deformation, the reverse branch of the I–V characteristic is close to the U axis, when light is applied and deformation is applied to the p-n-junction, the reverse branch of the I–V characteristic shifts down from the axis, if the deformation is proportionally increased without changing the light, which is observed even more downward displacement of the reverse branch of the I–V characteristic. From this it can be seen that the deformation increases the photocurrent.
- A microwave wave of low and high power increases the recombination current at the p-n-junction, and light and deformation increase the generation current.

A high-power microwave wave increases the recombination current at the p-n-junction.

3. References

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