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INFLUENCE OF ELECTRON IRRADIATION ON CHARACTERISTICS OF p-InSb INJECTION PHOTODIODES

The characteristics of infrared photosensitivity for injection photodiodes on *p*-InSb base were investigated. It is shown that as a result of electron irradiation at electron energy $E = 225$ MeV and integral dose $\Phi = 10^{14}$ sm^{-2} the carrier lifetime practically does not change. The change of diodes parameters corresponds to the scheme for the formation of Frenkel defects in *p*-InSb: shallow donors — interstitial site In and Sb, shallow acceptor — Sb-vacancy, deep donor — In-vacancy. The threshold beam of light-irradiation for the diodes practically does not change.

The injection photodiodes (IPhD) on the base of *p*-InSb, doped by germanium, with heavy holes concentration $p_0 = 10^{12}...10^{13}$ sm^{-3} were studied. The technology of the samples production was described in [1]. The length of the diodes base was $d = 0.5...5$ mm. The properties of the similar photo resistors (PhR) were studied simultaneously. The measurements of the volt-current characteristics (VCC) and photosensitivity were executed at the temperature $T = 77$ K and below. The Hall constant and electrical conductivity were measured within the temperature range $T = 55...300$ K to determine the material parameters. The lifetimes of charge carriers were determined by measurements in photoconductivity and photo magnetic effects.

The samples were irradiated by the electrons with energy $E = 2.5$ MeV. The integral doses of the irradiation were $\Phi = 10^{14}$ cm^{-2}. The *p-n*-conversion of InSb-conductivity, as in the case under the greater doses [2], at such doses did not yet occur. The temperature of the samples in process of irradiation was $T \geq 300$ K.

The VCC for one in the IPhD with $d = 0.5$ mm and the equivalent PhR are presented in Fig. 1. They are linear in wide range of voltages. The direct branch of the VCC of IPhD has several sections of current dependence on voltage: the ohmic in the area of low currents, practically coincided with VCC for photo resistor; the super linear section ($I \sim V^n$, where $n = 2...3$). The super exponential section, the area of negative differential resistance and the section of the strong current increase after switching follow herein. Only two first sections ($I = qp_0\mu_p V/d$) and ($I = (9/8)q\mu_n\mu_p p_0 \tau_n V^2/d^3$) are shown in Fig. 1, since namely they in this case present the most interest with standpoint of injection amplification. In the main ways, VCC of the diodes corresponds to the work data [3], in which the presence of *S*-characteristics is explained on the base of the injection breakdown theory for high-resistance compensated semiconductors in suggestion that recombination occurs through two independent levels with energy $E_1 = E_v + 0.071$ eV and $E_2 = E_v + 0.11$ eV.

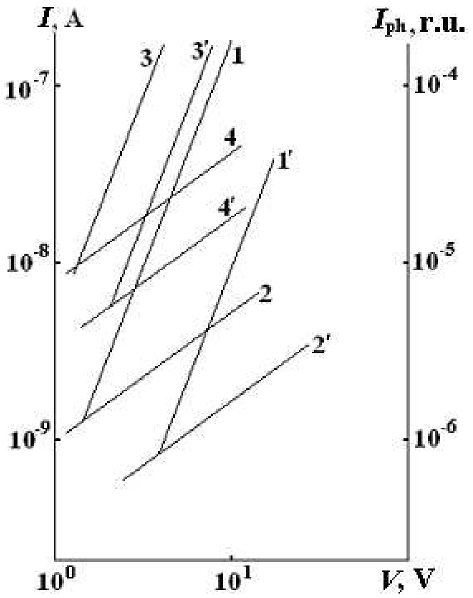

Fig. 1. The dark *I-V*-characteristics of the diode (*1*, *1'*) and resistor (*2*, *2'*), the dependence $I_{ph}(V)$ for IPhD (*3*, *3'*) and PhR (*4*, *4'*) before and after (the figures with touch) the irradiation. $T = 60$ K, $\lambda = 10.6$ mm

Practically repeating the variation of dark VCC before irradiation, the graphs $I(V)$ for IPhD and PhR as the result of irradiation were shifted differently. After irradiation the value of holes concentration p for the given IPhD and PhR decreased from $5 \cdot 10^{12}$ up to $3 \cdot 10^{12}$ cm^{-3}, i. e. velocity of holes removal was $\Delta p/\Phi = 2 \cdot 10^{-2}$ cm^{-1}. The electron mobility μ_n changed from $2 \cdot 10^5$ up to 10^5 cm^2/V·s, the mobility of the holes μ_p changed from $5 \cdot 10^3$ up to $2.8 \cdot 10^3$ cm^2/V·s. The decrease of the difference concentrations of shallow acceptors and donors ($N_a - N_d$) with velocity $\frac{\Delta(N_a - N_d)}{\Phi} = 1.8 \cdot 10^{-2}$ cm^{-1} as the result of irradiation took place. Simultaneously the concentration of deep acceptor levels with activation energy $E_c - 0.05$ eV is observed to increase with approximately the same velocity. This corresponds to data for *p*-InSb-resistors [4]. In this work it was shown that concentration of recombination levels does not change as the irradiation result for the case of one-level model of the recombination.

In accordance with equations for VCC, the dark current of resistor changed accordingly to decrease in the values μ_p and p_0 but the diode current on the square section — according to decrease in the values μ_n, μ_p, p_0. This means that the electron lifetimes as the result of irradiation remained practically invariable, that was shown by the direct τ_n measurements. Such conclusion is confirmed that transition voltage from ohmic section of VCC to the square region section $V_{12} = d^2/\mu_n\tau_n$ changed accordingly with μ_n decrease. The invariability in τ_n means that for the model of carriers recombination in InSb through two independent levels, the concentration of these levels and their charge condition under irradiation practically does not change.

The described in [5] scheme of formation and localization of Frenkel radiation defects on the grounds of the given experimental data gets the confirmation: shallow donors — interstitial site In and Sb, shallow acceptor — Sb-vacancy, deep donor — In-vacancy (E_c — 0.05 eV). As the result of the irradiation, the additional concentration of shallow donors is appeared. It leads to decrease in the difference (N_a — N_d) when the concentration N_a (germanium dopant) is invariable. In this case the velocity $\frac{\Delta(N_a - N_d)}{\Phi}$ must approximately comply with the velocity for introduction of deep acceptors and the value $\Delta p/\Phi$, that was observed by us.

The decrease in the values μ_n and μ_p as irradiation result is connected, probably, with appearance of mutually compensating, unlikely-charged radiation defects, similarly the case of carriers scattering in strongly doped crystals. As the result of irradiation for IPhD, the increase in transition voltage to the section of the negative differential resistance took place. This is possible to explain namely by decrease in charge carriers mobility, i. e. by decrease in their drawing depth.

The dependencies of photo-response for IPhD and PhR on voltage (Fig. 1) repeat the variation of dark VCC. The values of voltage V_{12} before and after of irradiation approximately coincide. The diode photocurrent for the certain voltage changed in accordance with decrease in the product $\mu_n\mu_p$, the resistor photocurrent — in accordance with change in the μ_p value. The concentration of photo carriers p_{ph} under one and the same power of illumination was alike before and after of the irradiation. The threshold beam of light-irradiation for IPhD after electron irradiation does not change practically.

It is shown, that injection photodiodes on InSb-base after electron irradiation keep rather high photosensitivity and show photoelectric injection amplification under action of light with $\lambda = 10.6$ μm. There is the possibility to increase voltage failure by electron irradiation. The irradiation does not change the concentration of the deep levels.

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ВПЛИВ ЕЛЕКТРОННОГО ОПРОМІНЕННЯ НА ХАРАКТЕРИСТИКИ ІНЖЕКЦІЙНИХ ФОТОДІОДІВ З p-InSb

Досліджено характеристики інфрачервоної фоточутливості інжекційних фотодіодів на основі p-InSb. Показано, що в результаті електронного опромінення при енергії електронів $E = 225$ МеВ і інтегральній дозі $\Phi = 10^{14}$ $см^{-2}$ час життя електронів практично не міняється. Зміна параметрів ІФД відповідає схемі утворення дефектів Френкеля в p-InSb: дрібні донори — міжвузельні In і Sb, дрібний акцептор — вакансія Sb, глибокий донор — вакансія In. Пороговий потік для ІФД у результаті опромінення практично не змінюється.

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ВЛИЯНИЕ ЭЛЕКТРОННОГО ОБЛУЧЕНИЯ НА ХАРАКТЕРИСТИКИ ИНЖЕКЦИОННЫХ ФОТОДИОДОВ ИЗ p-InSb

Исследованы характеристики инфракрасной фоточувствительности инжекционных фотодиодов на основе p-InSb. Показано, что в результате электронного облучения при энергии электронов $E = 225$ МэВ и интегральной дозе $\Phi = 10^{14}$ $см^{-2}$ время жизни электронов практически не меняется. Изменение параметров ИФД соответствует схеме образования дефектов Френкеля в p-InSb: мелкие доноры — межузельные In и Sb, мелкий акцептор — вакансия Sb, глубокий донор — вакансия In. Пороговый поток для ИФД в результате облучения практически не изменяется.