Investigation of Low-Frequency Photocurrent Oscillations in GaAs Irradiated by Electrons

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Abstract:
The paper presents the results of investigation of impurity photoconductivity of GaAs irradiated by the accelerated electrons (3 MeV) at temperature T=77 K. After irradiation there are a lot of levels of radiation origin in crystal, which changed there relative contribution photoconductivity with the annealings. The shape of photocurrent kinetics indicates unambiguously to the presence of adherence levels in the forbidden gap of GaAs. It was established, that after annealing at temperature T=423 K, by selection of incident light intensity (the quantum energy $h\nu \geq 0{,}9$ *eV) and field intensity applied to the sample it is possible to obtain such a state, when in the impurity photoconductivity kinetics curve regular low-frequency photocurrent oscillations are observed (2-10 Hz). These oscillations are explained by a nonuniform distribution in the sample of defects which are responsible for adherence levels. The intensive filling and devastation of these levels by nonequilibrium current carriers result in photocurrent oscillations.*

Keywords*: radiation, annealing, oscillations, photoconductivity.*

Despite considerable amount of publications on investigation of radiation defects (RD) nature in GaAs this problem remains actual till now. Among numerous publications, only small number of papers are dedicated to the study of RD created in GaAs, at low room temperature [1-65]. However, just the investigations of the properties of RD, created at low temperatures (T ≤ 100 K) allow to study nature crystal defects [1,6]. The restricted amount of such publications is due to complication of carrying out experiments.

In the present paper the results of investigation of the properties of RD appearing in n-type GaAs ($n = 10^{15}$ cm^{-3}), irradiated by the accelerated electrons at temperature T=77 K are given. The irradiation was carried out by the accelerated electrons with the energy of 3.5 MeV and the integrated electron current $\Phi = 6.10^{15} e/cm^2$. The impurity photoconductivity spectra were studied before and after irradiation and after each isochronous annealing up to temperatures T=450 K. The impurity photoconductivity spectra were measured on the infrared spectrometer at temperature T=77K.

The investigations show, that immediately after irradiation there are numerous levels of radiation origin in the crystal: the E_c - 0,45±0,02 eV, E_c - 0,52±0,02 eV, E_c - 0,57±0,02 eV, E_c - 0,66±0,02 eV, E_c - 0,72±0,03 eV, E_c - 0,98±0,04 eV, E_c - 1,26±0,04 eV, with the level E_c - 0,72 eV being much more intensive then the other ones. These levels are retained at the subsequent annealings; however the red boundary of the spectrum is shifted to smaller energies detecting new levels. So, after annealing at temperature T=203 K the level E_c - 0,20±0,02 eV is revealed, and after annealing at temperature T=343 K - E_c - 0,14±0,02 eV. Simultaneously the relative contribution of the level E_c - 0,72 eV to the photoconductivity decreases and reaches its minimum after annealing at temperature T=343 K. The further annealing increases the contribution of this level and the red boundary of the spectrum is again moved in the opposite direction. The level E_c - 0,52 eV is maintained before annealing at T=293 K, though its contribution diminishes with annealing and the effect of photoconductivity quenching is observed. The subsequent annealings do not result in essential changes in this area of the spectrum before annealing at temperature T=423 K, after which the level E_c - 0,52 eV appears again.

Simultaneously with the the investigation of impurity photoconductivity spectra the kinetics of photocurrent increase and relaxation was studied. The shape of curves of the photoconductivity kinetics depends on the voltage, applied to the sample, intensity and energy of incident infrared light and time of presence of the sample in dark. Immediately after the irradiation and subsequent annealings, under action of quanta with the energy $h\nu < 0.8$ eV, the kinetics of type I (see fig. 1) was observed.

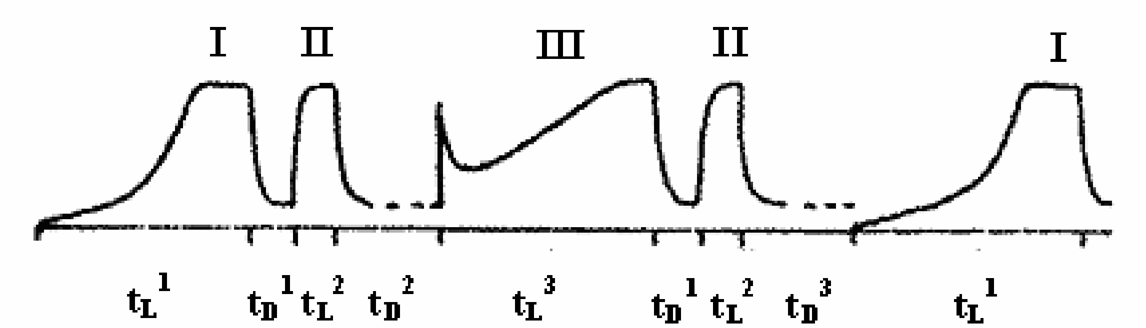
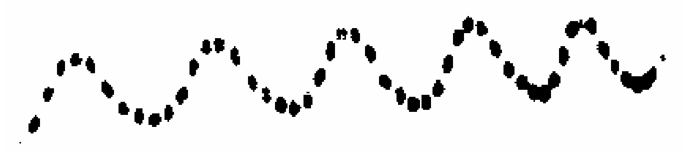


Fig. 1. Typical photocurrent kinetics of GaAs irradiate with accelerated electrons at different annealing stages

From the figure it is clear, that the photocurrent kinetics is S-shaped, i.e. at the beginning of illumination a slow increase in the photoconductivity is observed which, gradually comes to saturation (in our experiment this time was ~ 9-10 sec.). If immediately after switching off the light (delay time in dark t_D^1) we will illuminate a sample again, we obtain a kinetics of type II, and after staying in dark for a long time (t_D^2) a kinetics of type I occurs again. Beginning from the quantum energy of $h\nu \geq 0.9$ eV the kinetics of type III is observed, however such shape depends on delay time in dark $t_D^1 < t_D^2 < t_D^3$. If $t_D^2 = t_D^3$, we obtain the kinetics of type I. The shape of kinetics of type III appears before annealing at temperature T=293 K, however with annealing the value of outburst diminishes, and after outburst the increase of the photocurrent is accelerated (~1-2 sec.). The shape of kinetics of type III again occurs after annealing at temperature T=423 K and is maintained after the subsequent annealings. The shape of the above mentioned kinetics indicated unambiguously the presence of adherence levels in the forbidden gap of a semiconductor, the intensive filling and devastation of which are responsible for the change of the shape of the photoconductivity kinetics [7]. Apparently these changes can be connected with the change in the concentration of levels E_c – 0.52 eV and E_c – 0.72 eV, taking place at the same temperatures. In the process of investigations it was established, that after annealing at temperature T=423 K by selection of incident light iIntensity (the quantum energy $h\nu \geq 0.9$ eV) and voltage, applied to the sample, it is possible to obtain such a state, when in the impurity photoconductivity kinetics (section of the photocurrent increase) regular low-frequency photocurrent oscillations are observed (fig. 2). When a constant field intensity is applied to the sample (~50 V/cm) the enhancement light intensity leades to the change of the shape and frequency of oscillations (from 2 up to 10 Hz). Further intensity increase results in disappearance of oscillations and photocurrent increase. It should be noted, that to obtain similar current oscillations with an increase of the field intensity applied to the sample it is also necessary to increase the light intensity and vice versa. The study of I-U characteristics at different light intensities, causing current oscillations (1.2 eV), has shown, that the photocurrent oscillations are not caused by contact phenomena. These oscillations might result from a nonuniform distribution of defects over the crystal thet are responsible for adherence levels (presumably for the level E_c – 0.52 eV), the intensive filling and devastation of which by nonequilibrium current carriers, results in photocurrent oscillations.

a)



b)

Fig. 2. low-frequency photocurrent oscillations (~2 Hz) at different intensity of a light: $I_a<I_b$ (of quantum energy - $h\nu \geq 0.9$ eV, Intensity of an electric field - 50 V/sm)

The carried out investigations allow to conclude the folowing. As is known, under irradiation with the accelerated electrons at temperature 77K, both point lattice defects such as Frenkel pairs, and composite complexes of defects are formed in GaAs, annealed at high temperatures. The annealing at low temperatures results in release and migration of simple defects, which is expressed by the shift of the red boundary of the spectrum to lower energies. When migrating in the crystal a part of simple defects annihilates, and the other part, coming up to the composite complexes of defects, transforms them in to electrically inactive centers, which results in diminution of the contribution of deep levels (E_c - 0,.2 eV and E_c – 0.72 eV) to the photoconductivity. The further annealing at high temperatures results in decay of generated inactive complexes, again forming the defects responsible for these levels, and their contribution to the photoconductivity begins to increase.

Simultaneously the adherence levels appear in the forbidden gap and photocurrent oscillations arise. Proceeding from this fact it is possible to assume, that these levels (probably related with the level E_c – 0.52 эВ), being agglomerated together create inhomogeneities in different parts of a crystal, the intensive filling and devastation of which by nonequilibrium current carriers result in photocurrent oscillations. As it is known, in the irradiated samples the GaAs mobility of carriers strongly decreases [8], which probably is the reason for low oscillation frequencies, since all the studied samples had a very high resistivity (high level of compensation). In our case, for charge accumulation in the inhomogeneities, nonequilibrium charge carriers must be created and with the increase in the illumination intensity (i.e. with the increase in the nonequilibrium carrier concentration) the oscillation frequency increases. The annealing of these complexes apparently takes place at temperatures above 450K.

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