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CHANGING OF THE ANISOTROPY PARAMETER OF MOBILITY IN n-Ge SINGLE CRYSTALS WITH HETEROGENEOUS DISTRIBUTION OF DOPING IMPURITY

The influence of illumination with different intensity on changing parameter's anisotropy of mobility $K=\frac{\mu_\perp}{\mu_{||}}=\frac{m_{||}}{m_\perp}\cdot\frac{\langle\tau_\perp\rangle}{\langle\tau_{||}\rangle}$ in γ-irradiated by the chosen dose examples n-Ge with heterogeneous distribution of doping impurity in crystal volume is analyzed. On the basis of experimental and theoretical calculations it is shown that in γ-irradiated n-Ge the longitudinal component of mobility $\mu_{||}$ in the separate isoenergetic ellipsoid does not practically depend on illumination intensity. The essential change of transversal mobility component $\mu_\perp$ at the increase of illumination intensity is defined by the change in anisotropy parameter of relaxation times $K_\tau=\frac{\langle\tau_\perp\rangle}{\langle\tau_{||}\rangle}$.

Keywords: semiconductor, irradiated, anisotropy, mobility.

Introduction

The presence of the periodic distribution of impurity in semiconductor crystals under research of the transfer phenomena leads to the appearance (under the definite conditions) of several specific effects. The directed appearance of heterogeneities in crystal volume makes it possible to create the samples with the new properties, for example, with the given stage of anisotropic mobility. Recently there were a number of publications on studying the influence of doping impurity concentration and the dose of γ-irradiated to the exchange of the anisotropy parameter of mobility $K=\frac{\mu_\perp}{\mu_{||}}$ in n-Ge single crystals with heterogeneous distribution of doping impurity [1 - 5]. A great interest has arisen to make a research on light influence of different intensity to the exchange of K parameter for these single crystals.

Problem statement

During the analysis of possibilities to control the influence of layered periodic heterogeneities on electro-physical effects in n-Ge samples, irradiated by the chosen dose, in particular by action of the different intensity illumination, the changing of anisotropy parameter of mobility $K=\frac{\mu_\perp}{\mu_{||}}=\frac{m_{||}}{m_\perp}\cdot\frac{\langle\tau_\perp\rangle}{\langle\tau_{||}\rangle}$ was observed, where $K_m=\frac{m_{||}}{m_\perp}$ – parameter of the effective masses anisotropy; $K_\tau=\frac{\langle\tau_\perp\rangle}{\langle\tau_{||}\rangle}$ – parameter of the anisotropy for relaxation times tensor.

Main results of the research

For measurements of n-Ge single crystals, two groups of samples were cut out along the crystallographic direction [111] (in which the maximum strain-sensing for the germanium was realized) that growth layers were placed differently in the relation to current direction J and mechanical tension X: samples of group I are cut out along the crystal growth in the direction [111] (thus growth layers are perpendicular $\vec{J}\parallel\vec{X}$); samples of group II are oriented under the angle 70° concerning the growth axis, but also in the direction [111] (thus growth layers are approximately parallel $\vec{J}\parallel\vec{X}$). The measurements of piezoresistance and piezo-hall-effect for the different illumination intensities were realized at T = 77 K on the primary samples n-Ge ($\rho_{300\,K}$ = 0,42 Om·m) and on the samples irradiated with Co^{60} by the dose 1,1 · 10^{21} quantum/m^2. The lightning of the explored crystals was carried out through the filters CdSb to break band-to-band transitions. Experimental results for the longitudinal piezoresistance and piezo-hall-effect measurements are presented in Table 1. As shown in the Table, for the samples from different groups with the increase of lighting intensity, the parameter of anisotropic mobility increases $K=\frac{\mu_\perp}{\mu_{||}}$, which is defined by the ratio

Table 1. **Basic characteristics of explored crystals n-Ge at the different levels of lightning**

Samples of group I (at $\vec{J} \parallel \vec{X} \perp [111]$)				
ρ_D/ρ_L, arb. units	ρ_∞/ρ_0, arb. units	ρ_0, Om·m	K, arb. units	n, m^{-3} (X = 0,8 GPa)
1	5,6	2,63	7,9	$2{,}34 \cdot 10^{18}$
1,5	7,7	1,76	11,05	$2{,}65 \cdot 10^{18}$
2	8,7	1,32	12,55	$3{,}25 \cdot 10^{18}$
3	13,5	0,88	19,75	$3{,}38 \cdot 10^{18}$
5	15,3	0,53	22,45	$5{,}02 \cdot 10^{18}$
10	22,58	0,26	33,37	$6{,}87 \cdot 10^{18}$
Samples of group II (at $\vec{J} \parallel \vec{X} \parallel [111]$)				
ρ_D/ρ_L, arb. units	ρ_∞/ρ_0, arb. units	ρ_0, Om·m	K, arb. units	n, m^{-3} (X = 0,8 GPa)
1	8	0,18	11,5	$2{,}1 \cdot 10^{19}$
1,5	11,5	0,12	16,75	$2{,}25 \cdot 10^{19}$
2	13	0,09	19	$2{,}4 \cdot 10^{19}$
3	14,5	0.06	21,25	$3{,}01 \cdot 10^{19}$

$$K = \frac{3}{2}\frac{\rho_\infty^{[111]}}{\rho_0} - \frac{1}{2}, \qquad (1)$$

where ρ_0 – specific resistance at $X = 0$; $\rho_\infty^{[111]}$ – at $X = 0{,}8$ GPa when piezoresistance gets to the satiation.

It is significant, that for the samples of group I the change of values K, specific crystal resistance and concentration of charge carriers essentially differ then for samples of group II. It can be explained by the sharp increase of layered periodic heterogeneities amplitude in the group I of samples, where the current direction and strain ($\vec{J} \parallel \vec{X}$) is perpendicular to the crystal growth layers [3].

In the case of deformations, which provide the full migration of charge carriers into minimums of the conduction band energy, the longitudinal $\mu_{||}$ and transversal $\mu_\perp$ mobility component in the separate isoenergetic ellipsoid are defined according to:

$$\mu_{||} = \frac{1}{en_e\rho_\infty^{[111]}}, \qquad (2)$$

$$\mu_\perp = K\mu_{||}. \qquad (3)$$

Based on the experimental data and using the correlations (2) and (3), the dependence $\mu_\perp$ and $\mu_{||}$ on the level of lighting ρ_D/ρ_L (where ρ_D and ρ_L are the values of specific resistance in darkness and under illumination) for samples oriented differently in the relation to the growth layers are constructed (Figs. 1 and 2) [6, 7].

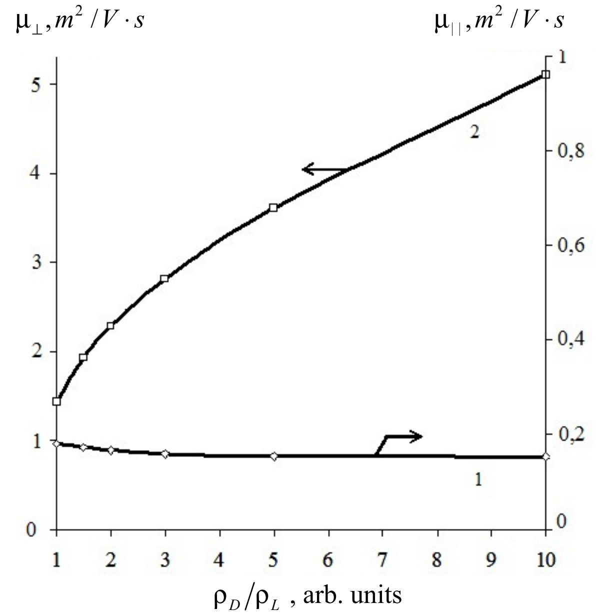

Fig. 1. Dependences $\mu_{||} = f(\rho_D/\rho_L)$ and $\mu_\perp = f(\rho_D/\rho_L)$ at T = 77 K in irradiated n-Ge with Co^{60} by the dose $1{,}1 \cdot 10^{21}$ quantum/m^2 for the samples at $\vec{J} \parallel \vec{X} \perp [111]$.

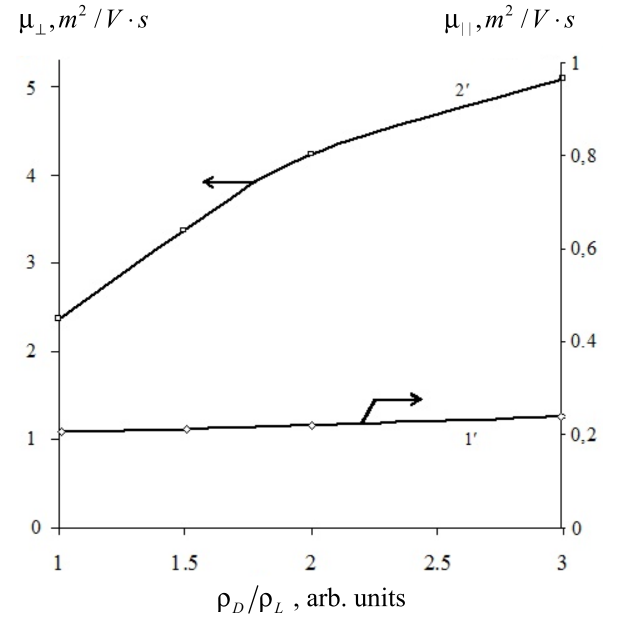

Fig. 2. Dependences $\mu_{||} = f(\rho_D/\rho_L)$ and $\mu_\perp = f(\rho_D/\rho_L)$ at T = 77 K in irradiated n-Ge with Co^{60} by the dose $1{,}1 \cdot 10^{21}$ quantum/m^2 for the samples at $\vec{J} \parallel \vec{X} \parallel [111]$.

By the dependences $\mu_{||} = f(\rho_D / \rho_L)$ (see curves *1* and *1′* in Figs. 1 and 2) for two samples groups almost the invariability of mobility component $\mu_{||}$ from illumination value is observed. As to mobility component $\mu_{\perp}$ (see curves *2* and *2′* in Figs. 1 and 2), it can increase sharply for the indicated current direction and strain in the relation to the crystal growth layers at the illumination intensity increase. As the data of cyclotron resonance show for the effective masses, the electron size $K_m = \frac{m_{||}}{m_{\perp}} = 19.3$, as far as $m_{\perp} = 0.082 m_0$ and $m_{||} = 1.58 m_0$. From the independence $\mu_{||}$ of the illumination intensity it is possible to conclude that the obtained increase of $\mu_{\perp}$ at the illumination intensity rise can be defined by the decrease in anisotropy parameter of relaxation times K_{τ}, because $\mu_{\perp} K_{\tau} = \mu_{||} K_m = const$.

Besides the mass $m_{||}$ is «more» inert to the different type of crystal changes, and that is why $\left\langle \tau_{||} \right\rangle$ practically does not change that follows from the equation

$$\mu_{||} = \frac{e}{m_{||}} \left\langle \tau_{||} \right\rangle . \tag{4}$$

Accordingly $m_{\perp}$ in 19,3 times less than $m_{||}$. This indicates that the perpendicular constituent is considerably sensitive to the different influence types. In accordance to the ratio

$$\mu_{\perp} = \frac{e}{m_{\perp}} \left\langle \tau_{\perp} \right\rangle \tag{5}$$

the relaxation time $\left\langle \tau_{\perp} \right\rangle$, which describes the impulse relaxation for $m_{\perp}$, will change more essentially than $\left\langle \tau_{||} \right\rangle$ that is confirmed experimentally. In is necessary to note, that the observed anisotropy of mobility for n-Ge agrees with the results of theoretical and experimental works [4], where in the diffusive approach the theoretical model of the free heterogeneous semiconductor is constructed, which describes the experimental results and takes into account thin layered periodic heterogeneities structure.

Conclusion

On the basis of experimental and theoretical calculations it is shown that in γ-irradiated n-Ge the longitudinal component of mobility $\mu_{||}$ in the separate isoenergetic ellipsoid does not practically depend on illumination intensity. The essential change of transversal mobility component $\mu_{\perp}$ at the increase of illumination intensity is defined by the change in anisotropy parameter of relaxation times K_{τ}.The study of the given features creates the pre-conditions to consider the mentioned effects in different construction types of semiconductor sensors, and also will secure real ways of the displays minimization of these effects where they can turn out enough undesirable.

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ЗМІНА ПАРАМЕТРА АНІЗОТРОПІЇ РУХЛИВОСТІ В МОНОКРИСТАЛАХ n-Ge З НЕОДНОРІДНИМ РОЗПОДІЛОМ ЛЕГУЮЧОЇ ДОМІШКИ

Аналізується вплив освітлення різної інтенсивності на зміну параметра анізотропії рухливості $K=\frac{\mu_{\perp}}{\mu_{||}}=\frac{m_{||}}{m_{\perp}}\cdot\frac{\langle\tau_{\perp}\rangle}{\langle\tau_{||}\rangle}$ в γ-опромінених монокристалах n-Ge з неоднорідним розподілом легуючої домішки в об'ємі кристала. На основі експериментальних і теоретичних розрахунків показано, що в γ - опроміненому n-Ge поздовжня складова рухливості $\mu_{||}$ в окремих ізоенергетичних еліпсоїдах практично не залежить від інтенсивності освітлення. Істотна зміна поперечної складової рухливості $\mu_{\perp}$ при збільшенні інтенсивності світла визначається зміною параметра анізотропії часів релаксації $K_{\tau}=\frac{\langle\tau_{\perp}\rangle}{\langle\tau_{||}\rangle}$.

Ключові слова: напівпровідник, опромінення, анізотропія, рухливість.

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ИЗМЕНЕНИЕ ПАРАМЕТРА АНИЗОТРОПИИ ПОДВИЖНОСТИ В МОНОКРИСТАЛЛАХ n-Ge С НЕОДНОРОДНЫМ РАСПРЕДЕЛЕНИЕМ ЛЕГИРУЮЩЕЙ ПРИМЕСИ

Анализируется влияние освещения различной интенсивности на изменение параметра анизотропии подвижности $K=\frac{\mu_{\perp}}{\mu_{||}}=\frac{m_{||}}{m_{\perp}}\cdot\frac{\langle\tau_{\perp}\rangle}{\langle\tau_{||}\rangle}$ в γ-облученных монокристаллах n-Ge с неоднородным распределением легирующей примеси в объеме кристалла. На основе экспериментальных и теоретических расчетов показано, что в γ-облученном n-Ge продольная составляющая подвижности $\mu_{||}$ в отдельных изоэнергетических эллипсоидах практически не зависит от интенсивности освещения. Существенное изменение поперечной составляющей подвижности $\mu_{\perp}$ при увеличении интенсивности света определяется изменением параметра анизотропии времен релаксации $K_{\tau}=\frac{\langle\tau_{\perp}\rangle}{\langle\tau_{||}\rangle}$.

Ключевые слова: полупроводник, облучение, анизотропия, подвижность.

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