EFFECT OF DOPING ON THE ANISOTROPIC FREE CARRIER ABSORPTION IN n-Ge

By A. E. Belyaev, O. P. Gorodnichii

Institute of Semiconductors, Ukrainian SSR Academy of Sciences, Kiev*

Z. A. Demidenko and P. M. Tomchuk

Institute of Physics, Ukrainian SSR Academy of Sciences, Kiev**.

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An anomalously small value of the degree of the frequency dependence of parallel component of the free carrier absorption (FCA) coefficient observed experimentally in the heavily doped n-Ge⟨Sb⟩ crystals is reported. This effect is explained by existence of the inelastic electron-phonon interaction which has an influence on dependencies $\tau(\varepsilon)$ and $\alpha(\omega)$.

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Information about scattering mechanisms was, so far, obtained by measuring of FCA coefficient dependence on frequency $\alpha(\omega)$ [1]. The use of an uniaxial elastic deformation in many valley semiconductors opens new opportunities because free carriers can be transfered into one or two valleys by the large enough deformation. In this case the contributions of various scattering mechanisms to $\alpha_{\parallel}$ and $\alpha_{\perp}$ components of FCA coefficient have proved to be very different ($\alpha_{\parallel}$, $\alpha_{\perp}$ are the FCA coefficients for light polarized longitudinally and transversally to the long axis of the lowered ellipsoid)

$$\alpha_{\parallel}(\omega) = B\beta^{-1} \sum_j A_j^2(\omega) L_j^{\parallel}(\beta),$$

$$\alpha_{\perp}(\omega) = B \sum_j A_j^2(\omega) L_j^{\perp}(\beta), \tag{1}$$

* Address: Institute of Semiconductors, Academy of Sciences of the Ukr. SSR, Prospect Nauki 115, 252028 Kiev, USSR.

** Address: Institute of Physics, Academy of Sciences of the Ukr. SSR, Prospect Nauki 144, 252028 Kiev, USSR.

where $\beta = m_{\parallel}/m_{\perp}$, j labels the scattering mechanism, $A_j^2(\omega)$ are the scattering intensities, $L_j^{\parallel,\perp}(\beta)$ are the anisotropy factors for every scattering mechanisms and $B = 4\sqrt{2m_{\parallel}}e^2 N_{el}/[3cn\hbar^2(\hbar\omega)^{3/2}]$.

Values K_j,

$$K_j = L_j^{\perp}(\beta)/L_j^{\parallel}(\beta), \tag{2}$$

which characterize the degree of anisotropy for each scattering mechanism can be greater (for traditional intra-valley scattering mechanisms such as electron-phonon and ionized--impurity ones) or less (e.g., anisotropic intervalley scattering) than unity [1, 2]. This fact leads to the ratio $\alpha_{\perp}^j/\alpha_{\parallel}^j$ greater or less than β.

Hence, FCA anisotropy investigation gives more reliable information about contributions of various scattering mechanisms. FCA anisotropy calculation for traditional scattering mechanisms and for the lightly doped semiconductor crystals within quantum frequency region $\hbar\omega \gg kT$ was carried out in [1]. Impurities play double role in the heavily doped semiconductors. First, they change spectrum of phonons and of carriers (the local phonon states and impurity band appear). Secondly, the carriers are scattered by the impurities. In the latter case the electron impulse can be transmitted to impurities at the electron-phonon interaction making it inelastic [3] and resulting in a change of the dependence $\alpha(\omega)$.

FCA coefficients in Eq. (1) were obtained from the general formula of the second-order perturbation theory describing two-quantum process of the electron-photon and electron--crystal imperfection interactions:

$$\alpha(\omega) = \frac{2\pi}{\hbar}\iint\sum_m \frac{|H_{fm}^{\text{cr imp}}|^2\,|H_{mi}^{\text{phot}}|^2}{(E_m - E_i)^2} f_k(1-f_{k'})/(E_f - E_i)\,\frac{2dkdk'}{(2\pi)^6}, \tag{3}$$

where i, m, f are initial, intermediate and final electron states, respectively, and $f_k(1-f_{k'})$ points to the existence of electron in the initial and final states.

The square of the matrix element for intraband electron-photon interaction is

$$|H_{kk}^{\text{phot}}|^2 = \frac{2\pi e^2}{\hbar\omega cn}(\boldsymbol{l}_{\omega}\cdot\nabla_k\varepsilon_k), \tag{4}$$

where n is optical index of refraction, c is the light speed, $\boldsymbol{l}_{\omega}$ is the ort of light polarization, ε_k is electron energy.

The square of the matrix element correspondent to the inelastic electron-phonon interaction is given by

$$|H_{kk'}^{\text{add}}|^2 = \frac{D_{\text{add}}^2\hbar}{2\varrho\omega_{\text{add}}}|\boldsymbol{l}_q(\boldsymbol{k}'-\boldsymbol{k})|^2, \tag{5}$$

where D_{add} is the constant of interaction proportional to the potential difference between the host and impurity atoms, ω_{add}, $\boldsymbol{l}_q$ are the frequency and polarization ort of phonons, respectively.

Substitution of Eqs (4), (5) in Eq. (3) and its subsequent integration result in frequency dependence of $\alpha_{add} \sim \omega^{-1/2}$. The value of power is notably lower than for usual scattering on the long-wavelength acoustic phonons ($\alpha_{ac} \sim \omega^{-3/2}$).

Effect of doping on the carrier scattering may be manifested (except usual ionized-impurity scattering) by increase of the resonant type of local vibrations when impurity concentration becomes large enough. These local vibrations may form additional phonon

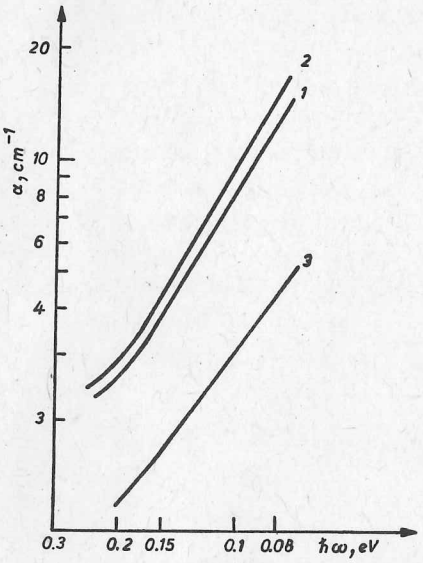

Fig. 1. Dependence of the FCA coefficient vs. absorbed photons energy in unstressed (unpolarized light) (*1*) and uniaxially stressed (linearly polarized light) (*2*, *3*) n-Ge. *2* — $\alpha_{\perp}$, *3* — $\alpha_{||}$

subband. Then, electron-phonon interaction is described in the framework of the additional deformation potential. Calculation performed analogously to the above-mentioned gives $\alpha \sim \omega^{-1/2}$ in this case, also. The value of anisotropy for these scattering mechanisms was found to be lower than unity. Therefore, interactions taken into account contribute mainly to parallel component of FCA coefficient resulting in decrease of exponent in power law $\alpha \sim \omega^{-r}$. It should be noted that the both considered scattering mechanisms depend on the impurity kind.

The investigation of FCA performed in the heavily doped n-Ge⟨Sb⟩ ($N_{el} = 10^{17} - 10^{18}$ cm^{-3}) crystals can be considered as the experimental confirmation of the effect under discussion. Measurements were conducted at 300 K in unstressed Ge crystals and crystals uniaxially stressed in the direction $\boldsymbol{P}\|$ [111] ($P = 8 \times 10^3$ kgf/cm^2). In the last case, the light was linearly polarized along or across the deformation axis. The measured frequency dependence of the FCA coefficient parallel component is proportional to ω^{-r}, with $r = 1.35$ (Fig. 1) that well agrees with our calculations. Furthermore, substantially low ratio of the normal ($\alpha_{\perp}$) and parallel ($\alpha_{||}$) components of the FCA coefficient can be explained correctly only when allowing for the considered additional scattering mechanisms.

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