ELECTRO-OPTICAL KERR EFFECT ON HOT ELECTRONS IN n-InSb

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In semiconductors with strong low-temperature carrier scattering by optical phonons, the distribution function of the hot carriers in strong electric fields becomes highly anisotropic[1], and the ratio of the drift velocity v_{dr} to the random velocity v_r can reach values 0.6 - 0.7 [1 - 3]. This gives rise to anisotropy of the absorption [2, 4] and of the intraband emission [5] of light by the hot holes in p-Ge, and also of the absorption and recombination radiation of the hot carriers in n-InSb [6, 7].

1. Theory. We shall show that the anisotropy of the distribution function and of the non-parabolicity of the conduction band leads to anisotropy of the refractive index in strong electric fields. Assume that besides the strong electric field $\vec{F}_0 \parallel Oz$ the semiconductor is acted upon by a weak high-frequency electromagnetic field $F_1\exp(i\omega\tau)$, with $\omega\tau \gg 1$ (τ is the momentum relaxation time). Then, on the basis of a solution of the Boltzmann kinetic equation, we obtain for the imaginary part of the electric-conductivity tensor

$$\sigma_{ij} = -i\frac{e^2}{\omega}\int \frac{1}{\hbar^2}\frac{\partial^2\epsilon}{\partial k_i \partial k_j} f(\mathbf{k})\,d\mathbf{k}, \tag{1}$$

where $\vec{k}$ is the electron wave vector and $f(\vec{k})$ is the hot-electron distribution function. The susceptibility is $\chi_{ij} = -i\sigma_{ij}/\omega$. If $F_0 = 0$, then the distribution function f is in equilibrium and (1) is equivalent to the expression obtained in [8] for χ. Assume an isotropic non-parabolic band of the Kane type, so that $(\varepsilon + \varepsilon_g)(\varepsilon/\varepsilon_g) = \hbar^2/k^2/2m_0^*$ (ε_g is the width of the forbidden band). Assume also a biased Maxwellian distribution function[2] $f = A\exp[-(\varepsilon(\vec{k}) - \hbar\vec{k}\cdot\vec{v}_{dr})/kT_e]$ (T_e is the temperature of the hot electrons)[3]. In this case the electric-conductivity tensor (1) is diagonal (its components are σ_{zz} and $\sigma_{xx} = \sigma_{yy}$) and the dielectric constant is an ellipsoid of revoltuion. The crystal becomes optically anisotropic with an optical axis parallel to the field $\vec{F}_0$. The difference between the refractive indices for the two polarizations of the light $\vec{F}_1 \parallel \vec{F}_0$ and $\vec{F}_1 \perp \vec{F}_0$ equals, accurate to terms kT_e/ε_g and $m_0^* v_{dr}^2/kT_e$,

$$n_\parallel - n_\perp = -i\frac{2\pi}{\omega n_0}(\sigma_{zz} - \sigma_{xx}) \approx \frac{2\pi e^2 N}{\omega^2 m_0^* n_0}\frac{2m_0^* v_{dr}^2}{\epsilon_g} \times\left(1 - \frac{mv_{dr}^2}{2kT_e} - g\frac{kT_e}{\epsilon_g}\right) \tag{2}$$

[1] Under the condition that the average carrier energy $\langle\varepsilon\rangle$ is smaller than the energy of the optical phonon $k\theta$.

[2] Which is valid, as shown by estimates and experiments on the Faraday effect on hot electrons in n-InSb [9], at $N > 5 \times 10^{15}$ cm^{-3} for the passive ($\varepsilon < k\theta$) and active ($\varepsilon > k\theta$) regions.

[3] The authors are grateful to I.B. Levinson for remarks concerning the form of the distribution functions.

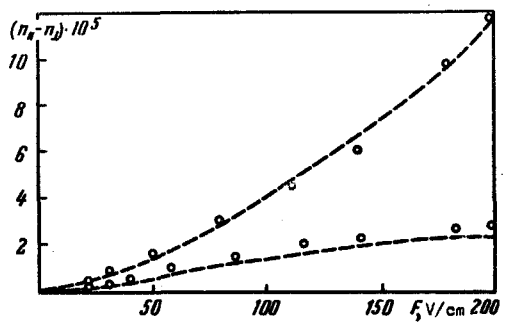

Fig. 1. Anisotropy of the refractive index as a function of the field for two samples: 1 - $N = 6.5 \times 10^{14}$ cm^{-3}, $\mu_r = 4.4 \times 10^5$ cm^2/V-sec; 2 - $N = 4.7 \times 10^{15}$, $\mu_r = 1.8 \times 10^5$. Circles - experiment, dashed line - theory; n-InSb, $T_0 = 80°K$, $\langle\lambda_0\rangle = 12$ μ.

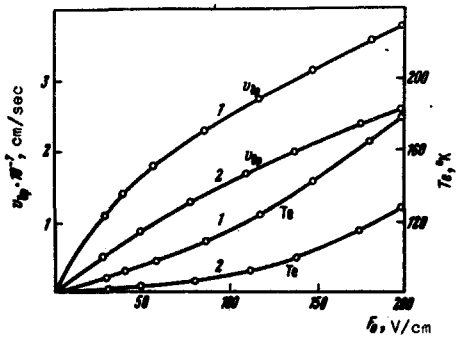

Fig. 2. Drift velocity and temperature of the hot electrons for two samples. The notation is the same as in Fig. 1. n-InSb, $T_0 = 80°K$.

(N is the electron density and n_0 is the refractive index of the lattice), and the phase shift is $\delta\phi = 2\pi L(n_\parallel - n_\perp)/\lambda_0$ (L is the length of the crystal in the direction of light propagation and λ_0 is the wavelength of the light in vacuum).

2. Experiment. Plane-polarized light was converted into circularly polarized with the aid of a germanium total internal reflection prism and passed through the n-InSb crystal (the directions of propagation and the strong field $\vec{F}_0$ were perpendicular to each other) and then through the analyzer. The strong-field pulse duration was 1.2 μsec and the repetition frequency was 2 Hz.

The light-modulation pulse ($M = \delta\phi$ with $\delta\phi \ll 1$) was registered with a photoamplifier (Ge + Zn photoreceiver at $T_0 = 50°K$) and a synchronous detector, and could also be observed with an oscilloscope. The waveform of the modulation pulse coincided with the waveform of the strong-field pulse, and the depth of modulation reached 16% at $N = 6.5 \times 10^{14}$ cm^{-3} and L = 8 mm. The light source employed was either a CO_2 laser ($\lambda_0 = 10.6$ μ) or a graphite emitter. In the latter case, the short-wave part of the radiation was cut off with a filter of bleached indium antimonide ($T_0 = 300°K$), so that the wavelength averaged over the spectrum was $\langle\lambda_0\rangle = 12$ μ.

The experimental results are shown in Fig. 1, which gives also the calculated value of $n_\parallel - n_\perp$. T_e was estimated from the Faraday effect on the hot electrons, and v_{dr} was estimated from the current-voltage characteristic (Fig. 2). We see that the agreement between the calculated and experimental values of $n_\parallel - n_\perp$ is good, so that the Kerr effect is indeed due to the action of two factors, the anisotropy of the distribution function (the terms of the expansion of $f(\vec{k})$ which are quadratic in v_{dr}) and the non-parabolicity of the conduction band.

It should be noted that in [9 - 10] they also calculated the anisotropy of the refractive index in strong electric fields for semiconductors with a spherical band. However, the reason for the appearance of the anisotropy is different. According to [9], its occurrence is possible in semiconductors with parabolic dispersion if the anisotropy of the distribution function is neglected. In the region of "warm" carriers $n_\parallel - n_\perp \sim N\omega^{-4}F_0^2$, and the sign of $n_\parallel - n_\perp$ depends on the scattering mechanism. For $F_0 = 50$ V/cm, the values of $n_\parallel - n_\perp$ are smaller by a factor 6×10^4 than those obtained by us in the experiments.

In [10] it was found for a parabolic band that

$$n_{\parallel} - n_{\perp} = \frac{2\pi N e^2}{m^* \omega^2 n_0} \frac{3\delta}{5-\delta}; \quad \delta = \frac{1}{\langle \epsilon \rangle} \left\langle \frac{f_2(\epsilon)}{f_0(\epsilon)} \epsilon \right\rangle,$$

where f_0 and f_2 are the first and third terms in the expansion of the distribution function in Legendre polynomials. Using the values of $f_2(\varepsilon)$ and $f_0(\varepsilon)$ determined experimentally for hot holes in p-Ge, we can find that δ is equal to 0.4, 0.48, and 0.5 for v_{dr}^2/v_r^2 equal to 0.18, 0.44, and 0.5, respectively. Assuming that the same ratio of δ and v_{dr}^2/v_r^2 is maintained for the electrons in n-InSb with $N = 6.5 \times 10^{14}$ cm^{-3}, we can calculate $n_{\parallel} - n_{\perp}$ in accordance with [10]. For $F_0 > 140$ V/cm, the value of $n_{\parallel} - n_{\perp}$ is 6 - 7 times larger than that obtained by experiment.

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RELAXATION PHENOMENA IN FERRITES OF THE SYSTEM $NiFe_{2-x}Cr_xO_4$

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In the investigation of hyperfine interactions in ferrites of the $NiFe_{2-x}Cr_xO_4$ system [1, 2], we observed violations of the equidistant distribution of the components of the Mossbauer line of the Fe^{57}. These violations were manifest in the fact that the temperature dependence of the effective magnetic field, determined from the distance between the external and internal components of the spectrum, turned out to be different. Figures 1 and 2 (the spectra obtained with samples with x = 1.2 and x = 1.4 were identical) show the results of the reduction of the Mossbauer spectra for the compositions x = 1.2 and x = 1.4. The spectra were reduced by least squares with a computer (using a Lorentz approximation for the line shape)[1]. We took into account the fact that the Fe^{3+} ions occupy predominantly tetrahedral sites (A sites) in the crystal lattice [1, 2].

Such an ambiguity in the determination of the values of the magnetic field (it is seen in Fig. 2 at temperatures starting with $T/T_c \approx 0.7$) can be

[1] The program for reducing the Mossbauer spectrum with the computer was graciously supplied by Yu.M. Ostanevich (JINR).