PHOTOELECTRON DIFFUSION IN A STRONG MAGNETIC FIELD

V. F. Elesin and Yu. A. Bykovskii
Moscow Engineering-Physics Institute
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1. It is customary to assume that photoelectrons having an energy exceeding the energy $\hbar\omega_0$ of the optical phonon make a negligible contribution to the photocurrent, inasmuch as the energy and momentum relaxation times τ_{op} are exceedingly small for optical phonons.

We shall show that in strong magnetic fields ($\Omega\tau_{op} \gg 1$, Ω = Larmor frequency) high-energy photoelectrons of this kind can play a predominant role in the diffusion current, and this leads in turn to spectral singularities of the photocurrent, in particular, a change in the sign of the Kikoin-Noskov photoelectromagnetic effect (PEM).

2. We consider a semiconductor at low temperatures ($kT \ll \hbar\omega_0$). Assume that photoelectrons of energy $\hbar\omega_0$ are produced under the influence of a monochromatic source and interact with optical phonons, recombining with a time τ_e. Here we are interested in photoelectrons having high energies, $\omega \gg \omega_0 > \Omega$, so that even in a quantizing magnetic field ($\Omega \gg kT$) it is legitimate to use the quasiclassical kinetic equation (large quantum numbers). Furthermore, for simplicity let us assume that the phonon frequency and the matrix element of the electron-phonon interaction do not depend on the quasimomentum, and that a quadratic dispersion law holds for the electrons. The problem was considered in this approximation in [1], where the photoelectron energy distribution function $f_0(\varepsilon)$ was determined. Substituting $f_0(\varepsilon)$ from (4) into the expression for the transverse-diffusion coefficient ($\vec{H} \parallel Z$)(see [2]) we get, under the condition $\tau_{op}\Omega \gg 1$, $\tau_{op} \ll \tau_e$,

$$D_{xx}(\omega) = [2(n-1)(\omega - \frac{n-2}{2}\omega_0)]/3m\Omega^2\tau_e,$$

$$n = \text{integer}\{\omega/\omega_0 + 1\}$$

or at high frequencies, $\omega \gg \omega_0$,

$$D_{xx}(\omega) \approx \frac{\omega}{3m\Omega^2\tau_e}\frac{\omega}{\omega_0}. \qquad (1)$$

3. Expression (1) can be derived from the following considerations: The coefficient of diffusion with energy ω in a strong magnetic field is equal to $2\omega/3m\Omega^2\tau_{op}$. Multiplying it by the fraction $\omega\tau_{op}/2\omega_0\tau_e$ of such electrons we obtain (4). Let us compare $D_{xx}(\omega)$ with the diffusion coefficient of thermalized photoelectrons:

$$\frac{D_{xx}(\omega)}{D_{xx}(T)} = \frac{\omega}{kT}\frac{\omega}{2\omega_0}\frac{\tau_{im}}{\tau_e}.$$

For example, for InAs at T = 4°K this ratio becomes of the order of unity when $\omega \approx 10^{-8}$ sec, and the momentum relaxation time $\tau_{im} \approx 10^{-12}$ sec [3].

We note that in the case of nonmonochromatic light $D_{xx}(\omega)$ must be averaged over the source spectrum $F(\omega)$ in the following manner:

$$\bar{D}_{xx}(\omega) = (\Delta\omega)^{-1}\int_0^{\Delta\omega} F(\omega)D_{xx}(\omega)\,d\omega\,, \tag{2}$$

inasmuch as the employed $f_0(\varepsilon)$ is the Green's function, in particular:

$$F(\omega) = \begin{cases} 1, & 0 < \omega < \Delta\omega \\ 0, & \omega > \Delta\omega, \end{cases} \qquad \bar{D}_{xx}(\omega) = \frac{1}{3}D_{xx}(\Delta\omega)\,.$$

4. Let us analyze the frequency dependence of the PEM. Assume that strongly absorbed light is incident in the x-axis direction and generates nonequilibrium electrons and holes that diffuse to the inside of the sample. A PEM field is then produced in the y direction ($\vec{H} \parallel Z$) [4] (see [5]):

$$E_y = -\{e\int_0^d \frac{dn}{dx}[D^n_{yx} + D^p_{yx} - (\sigma^n_{yx}+\sigma^p_{yx})(D^n_{xx} - D^p_{xx})(\sigma^n_{xx}+\sigma^p_{xx})^{-1}]dx\}\cdot$$
$$\{\int_0^d [(\sigma^n_{yy}+\sigma^p_{yy}) + (\sigma^n_{yx}+\sigma^p_{yx})^2(\sigma^n_{xx}+\sigma^p_{xx})^{-1}]dx\}^{-1} \tag{3}$$

where $D^{n,p}_{ik}$ and $\sigma^{n,p}_{ik}$ are the diffusion coefficients and the conductivities of the electrons and the holes, respectively.

Let us consider an n-type semiconductor in which $n_0 \gg \Delta n$, Δp, p_0 and $m_n \gg m_p$, so that $\sigma^n_{ik} \approx en_0\mu^n_{ik} \gg \sigma^p_{ik}$. The diffusion is due to the thermalized and high-energy photoelectrons

$$D^n_{ik} = D^n_{ik}(T) + D^n_{ik}(\omega) \tag{4}$$

and to the thermalized nondegenerate photo-holes, with the thermalized carriers satisfying the Einstein relations. Calculation shows that the coefficient $D^n_{xy}(\omega)$ can be neglected if $\tau_{op} \ll \tau_{im}$.

Gathering the results and recognizing that $\sigma^n_{xx} \ll \sigma^n_{xy} \approx en_0c/H$ in a strong magnetic field, we obtain in lieu of (6):

$$E_y \approx \frac{kT}{e}\frac{H}{cd}\frac{\Delta n(0) - \Delta n(d)}{n_0}[\mu^n_{xx} + \mu^p_{xx} - \frac{e}{kT}D^n_{xx}(\omega)]\,. \tag{5}$$

We see thus that the field E_y reverses sign at a certain frequency and becomes negative. The physical interpretation is as follows:

The equilibrium electrons are deflected in the y direction by the magnetic field and by the Dember electric field E_x due to the difference in the diffusion coefficients of the holes and electrons [6]. This deflection is opposite in direction to the deflection of the photoelectrons by the magnetic field and by the gradient, and makes a negative contribution to the PEM, which is described by the second term in the numerator of (6) or by the term $D^n_{xx}(\omega)$ in (8). A rise in ω causes $D^n_{xx}(\omega)$ and hence E_x to increase (σ_{xx} = const), and this leads to the reversal of the sign of the PEM. Estimates similar to those presented above show that such an effect can be observed in InAs and InSb when $\omega \approx 0.3 - 0.5$ eV and $T \approx 4°K$.

5. Let us consider now the situation in which the equilibrium electrons are degenerate. In this case μ^n_{xx} experiences Shubnikov - de Haas oscillations [7] (see [5, 8]). If now eD^n_{xx}/kT becomes of the same order as μ^n_{xx}, then the PEM emf begins to undergo sign-reversing oscillations with increasing magnetic field.

We propose that the periodic reversal of the sign of the PEM emf in n-type InAs with change in the magnetic field, observed by Kikoin and Lazarev [9], is connected with the mechanism described above.

We note that the analysis of the concrete cases calls for allowance for a number of factors and requires a separate study.

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*We put $\hbar = 1$ throughout, and the phonons referred to are optical phonons.

STIMULATED RAYLEIGH SCATTERING OF LIGHT IN SOLUTIONS OF LIQUIDS

V. I. Bespalov and A. M. Kubarev
Radiophysics Research Institute
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A number of papers [1] have reported observation of stimulated scattering of the Mandel'shtam-Brillouin component (SMBS) and stimulated scattering of light of the wing of the Rayleigh line (SRWS) in liquids. We report in this note some results of observations of SMBS and SRWS as well as of stimulated scattering of the central Rayleigh component (SCRS) in liquid mixtures.

The experimental setup was similar to that described in [2]. A light flash (λ = 0.6943 μ, spectrum width < 10^{-2} cm^{-1}) of duration $\sim$ 20 nsec and power $\sim$ 5 MW was focused (F = 15 cm) inside a cell containing the investigated liquid. A Faraday valve was used to eliminate feedback between the cell and the laser. The spectrum of the light passing through the cell and backscattered was analyzed with the aid of a Fabry-Perot interferometer.

2. Since the initial purpose of the experiment was to investigate the possibility of obtaining a specified frequency shift by selecting the solution concentration, we chose for the mixtures such liquid pairs (quinoline C_9H_7N and ethyl alcohol C_2H_5OH, nitrobenzene $C_6H_5NO_2$ and carbon tetrachloride CCl_4), in which the shift due to SMBS is appreciably different. The results of the investigation of the light-frequency shift following SMBS in the backward direction is shown in Fig. 1. The horizontal axis represents the concentration of the quinoline and nitrobenzene in

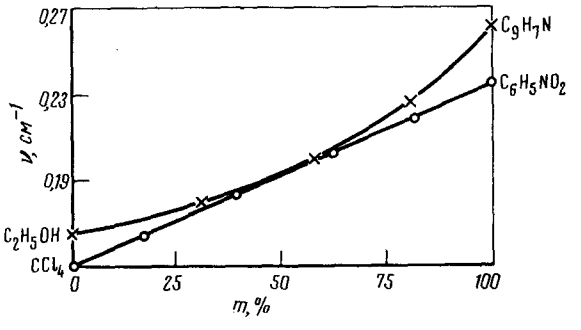

Fig. 1