"HOT" OPTICAL PHONONS IN POLAR SEMICONDUCTORS

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In a strong electrical field, longitudinal optical phonons (LOP) draw energy from the heated electrons and become heated themselves. The degree of heating, i.e., the form of the phonon distribution function, depends on the relation between the phonon-phonon and phonon-electron collision frequencies ($\nu_{ff}$ and $\nu_{fe}$). An experimental investigation of this phenomenon makes it possible to determine $\nu_{ff}$.

We are interested in a situation wherein the electron density n is sufficiently high ($n \approx 10^{16}$ cm$^{-3}$) so that the symmetrical part of the electron distribution function $n_p^{(0)}$ is a Fermi (or Maxwellian) distribution with effective temperature $T_E$. It is assumed that the LOP limiting energy $\hbar\omega_0$ greatly exceeds the temperature $T_E$ and the Fermi energy $\xi$ (if the electrons are degenerate).

LOP with momenta q interact with electrons with momenta p and mass m in the interval

$$\sqrt{p_0^2 + p^2} - p \lesssim q \lesssim \sqrt{p_0^2 + p^2} + p, \text{ where } p_0 = \sqrt{2m\hbar\omega_0} \gg p.$$

The frequency of the phonon-electron collisions is

$$\nu_{fe}(q) = \frac{2}{(2\pi\hbar)^3} \int d^3p\, W_q (n_p^{(0)} - n_{p+q}^{(0)})\, \delta(\epsilon_{p+q} - \epsilon_p - \hbar\omega_0) = \tag{1}$$

$$= \frac{2e^2m^2\omega_0 T_E}{\hbar q^3} (\kappa_\infty^{-1} - \kappa_0^{-1}) \ln[1 - n^{(0)}(\epsilon_1)]^{-1},$$

where $\epsilon_1(q) = (q^2/8m)[1 - (p_0^2/q^2)]^2$, and $\kappa_\infty$ and $\kappa_0$ are the high-frequency and static dielectric constants. The dispersion of the optical phonons is neglected. The last factor in (1) ensures an exponential decrease of $\nu_{fe}(q)$ at momenta q outside the interval $q_1 \equiv \sqrt{p_0^2 + p^2} - p \leq q \leq \sqrt{p_0^2 + p^2} + p \equiv q_2$, where p is the average electron momentum.

If the electron gas is not degenerate, then

$$\nu_{fe}(q) = \frac{(2\pi)^{3/2}\hbar^2 m^{1/2} e^2 \omega_0 n}{q^3 T_E^{1/2}} (\kappa_\infty^{-1} - \kappa_0^{-1})\, e^{-(\epsilon_1(q)/T_E)}. \tag{2}$$

At high concentration of ionized impurities ($N_i = n$) and at low temperatures, the electrons give up their momentum essentially to the impurities. Therefore the phonon distribution function contains only the symmetrical part, for which we have

$$N_q = \frac{\nu_{ff}\, e^{-(\hbar\omega_0/T)} + \nu_{fe}\, e^{-(\hbar\omega_0/T_E)}}{\nu_{ff} + \nu_{fe}}. \tag{3}$$

Slight heating of the phonons takes place when $\nu_{fe} > \nu_{ff}$. Then we have in the interval

$q_1 \leq q \leq q_2$

$$N_q = e^{-(\hbar\omega_0/T_E)}\left\{1 - \frac{\nu_{ff}}{\nu_{fe}}\left[1 - e^{-\hbar\omega_0\left(\frac{1}{T} - \frac{1}{T_E}\right)}\right]\right\}. \quad (4)$$

On the other hand, if $\nu_{fe} < \nu_{ff}$, heating becomes difficult, but then the phonon equilibrium is greatly disturbed if the electrons are sufficiently heated, so that $\exp\{\hbar\omega_0[(1/T) - (1/T_E)]\} \gg \nu_{ff}/\nu_{fe}$. With this, we have in the interval $q_1 \leq q \leq q_2$

$$N_q = \frac{\nu_{fe}}{\nu_{ff}} e^{-(\hbar\omega_0/T_E)}. \quad (5)$$

The power transferred by the electrons to the optical phonons is

$$P = \frac{\hbar\omega_0}{2\pi^2\hbar^3}\left(e^{-(\hbar\omega_0/T_E)} - e^{-(\hbar\omega_0/T)}\right)\int \frac{q^2 dq}{\nu_{fe}^{-1} + \nu_{ff}^{-1}}. \quad (6)$$

In the case of slight heating, when $\nu_{fe} \gg \nu_{ff}$,

$$P = \frac{\hbar\omega_0\nu_{ff}}{\pi^2}\frac{p_0^2 p}{\hbar^3}\left(e^{-(\hbar\omega_0/T_E)} - e^{-(\hbar\omega_0/T)}\right). \quad (7)$$

The non-ohmicity coefficient [1] is $\beta = [(d\sigma/dT_E)(dP/dT_E)^{-1}]_{T_E=T} \approx \nu_{ff}^{-1}$, i.e., by measuring $\beta$ we can determine directly the damping frequency of the LOP with momenta $q = p_0$.

Let us estimate the density n at which the inequality $\nu_{fe} > \nu_{ff}$ is satisfied. According to [2-6] the damping of transverse optical phonons with $q = 0$ at room temperature is $(2.2 - 3.9) \times 10^{11}$ sec$^{-1}$ for GaP, AlSb, and GaAs, $1.7 \times 10^{12}$ for ZnSe, and $1.9 \times 10^{12}$ for ZnO. Assuming $\nu_{ff}$ to be of the same order and correcting for the temperature dependence, we should expect $n \gtrsim n_0 \approx 10^{16}$ cm$^{-3}$ at $T_E \approx 40°$K.

Under conditions of difficult heating, when $n < n_0$ and when $N_q$ is given by (5), we can investigate the heating of optical phonons and find the frequency $\nu_{ff}$ by determining the cross section for elastic scattering of neutrons with absorption of LOP. The cross section is proportional to $N_q$ [7], and therefore has a maximum that increases with the field and is inversely proportional to $\nu_{ff}$ when the neutron scattering vector coincides with $p_0/\hbar$ (accurate to within the reciprocal lattice vector). For the substances listed above $p_0/\hbar = (2.5 - 4) \times 10^6$ cm$^{-1}$.

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[1] Sh. M. Kogan, FTT 4, 2474 (1962), Soviet Phys. Solid State 4, 1813 (1963).

[2] D. A. Kleinman and W. G. Spitzer, Phys. Rev. 118, 110 (1960).

[3] W. I. Turner and W. E. Reese, Phys. Rev. 127, 6126 (1962).

[4] S. Iwasa, I. Baslev, and E. Burstein, Proc. 7th Internat. Conf. Phys. Semicond., Paris, 1964.

[5] S. Mitra, Proc. Internat. Conf. Phys. Semicond., Kyoto, 1966.

[6] P. J. Collins and D. A. Kleinman, J. Phys. Chem. Sol. 11, 190 (1959).
[7] Yu. A. Izyumov, UFN 80, 41 (1963), Soviet Phys. Uspekhi 6, 359 (1963).

## ANOMALOUS DISPERSION OF THE FARADAY EFFECT IN FERRIMAGNETIC $RbNiF_3$

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We investigated the Faraday effect in $RbNiF_3$ in the wavelength interval from 0.35 to 1.1 μ and observed a strong spectral dependence of the rotation of the plane of polarization of light. Hexagonal $RbNiF_3$ goes over into the ferrimagnetic state below 145°K [1]. The crystallographic symmetry is described by the space group $D_{6h}^4$ [2]. The investigated sample was a plate 0.6 mm thick perpendicular to the hexagonal axis. The measurements were made in magnetic fields up to 16.5 kOe using a single-beam installation with linear dispersion 32 Å/mm at 77 and 295°K.

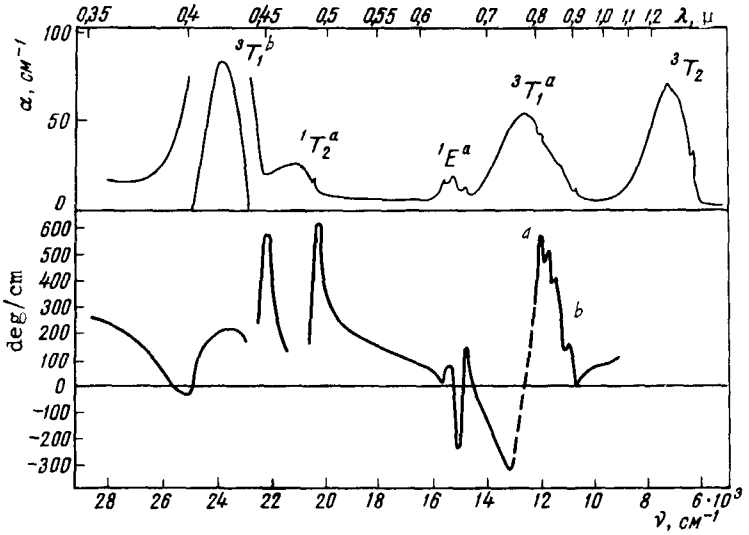


Fig. 1. Faraday effect in $RbNiF_3$ at T ≈ 77°K in a 16.5 kOe magnetic field (section ab was measured in a 13.25 kOe field). The upper part of the figure shows the absorption spectrum of the crystal at the same temperature.

The obtained spectral dependence of the specific rotation $\alpha_F$ at 77°K and in a 16.5 kOe field is shown in Fig. 1, which shows also the optical absorption of $RbNiF_3$ along the optical axis [3]. The Faraday rotation reverses sign several times and its magnitude changes greatly in the investigated spectral interval. This complicated behavior can be explained by examining the connection between the rotation and the absorption. When the absorption lines are approached from the sode of the long-wave edge, the rotation of the plane of polarization of