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Abstract

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ON THE ISOTROPIC AND ANISOTROPIC COMPONENTS OF THE EVEN PHOTOMAGNETIC EFFECT

In (^{1}) it was shown that in semiconductors, along with the odd photomagnetic effect, which has now been studied many times, an even photomagnetic effect is also observed. It consists in the fact that, when a semiconductor placed in a magnetic field is illuminated, an electric field and the corresponding emf arise in it, the sign of which does not change when the sign of the magnetic field is changed. Usually the odd photomagnetic emf is measured in the direction perpendicular to the magnetic field, and the even photomagnetic emf—in the direction parallel to the magnetic field (the light falls perpendicular to the magnetic field).

From the elementary theory (^{2}) it follows that the magnitude of the even photomagnetic emf E_q

$$E_q = E_l \mu H \sin 2\theta, \tag{1}$$

where E_l is the odd photomagnetic emf; μ is the mobility of the carriers; H is the magnetic field; θ is the angle between the normal $\mathbf{n}$ to the plane of the sample and the magnetic field, or, taking into account that the odd photomagnetic emf E_l is proportional to H:

$$E_q \sim H^2 \sin 2\theta. \tag{1a}$$

In the work (^{3}) it was shown that in germanium single crystals the even photomagnetic effect is anisotropic and formula (1) is inapplicable. On this basis, in (^{4}) a phenomenological equation was obtained for the photomagnetic emf,

$$E = L_1 e_{ikl} n_k H_l + L_2 H_i n_k H_k + L_3 n_{\underline{i}} H_{\underline{i}}^2. \tag{2}$$

Here L_1, L_2, L_3 are constants characterizing the semiconductor; e_{ikl} is the unit completely antisymmetric tensor of the third rank; $\mathbf{n}$ is the internal normal to the illuminated surface of the semiconductor; $\mathbf{H}$ is the magnetic field. No summation is performed over the underlined indices.

Fig. 1

Figure 1: Fig. 1

The last term of this equation describes the anisotropy of the even photomagnetic effect. It follows from it that the even photomagnetic emf must be observed not only in the direction of the magnetic field **H** or of its component along the sample, but also in any other direction, in particular in the direction perpendicular to the magnetic field (along which the odd photomagnetic emf is usually measured). In addition, from (2) it follows that the even anisotropic photomagnetic effect can be observed in a sample whose plane is parallel to the magnetic field, i.e., at $\theta = \pi/2$, when, according to the elementary formula (1), $E_q = 0$. Such a case is realized when the normal to the illuminated plane of the crystal coincides with the [111] axis. This was in fact found in (3).

The experiments we have carried out fully confirmed the conclusions of the phenomenological theory. The even photomagnetic emf is indeed observed

in a direction perpendicular to the magnetic field; this is manifested in the fact that the odd photomagnetic emf is asymmetric with respect to reversal of the direction of the magnetic field. The experiments were carried out on a sample of single-crystal germanium, cut in the form of a circular disk (3), the normal to whose plane coincided with the [111] axis.

In this particular case the expression for the even photomagnetic emf E_q has the form

$$E_q = L_2 H^2 \sin 2\theta \cos \varphi_0 + + L_3 H^2 \left[\frac{1}{3} \sin 2\theta \cos \varphi_0 + \frac{1}{3\sqrt{2}} \sin^2 \theta \cos(3\varphi - 2\varphi_0) \right], \tag{3}$$

where φ_0 is the angle between the projection of H onto the plane of the sample and the direction along which the even photomagnetic emf is measured; φ is the angle of rotation of the sample about the normal n.

Fig. 1

Figure 1 presents the anisotropy curves of the even photomagnetic emf $E_q(\varphi)$, obtained on p-Ge when it was measured along the direction of the magnetic field ($\varphi_0 = 0$) and perpendicular to it ($\varphi_0 = \pi/2$). In both cases the plane of the sample is parallel to the field. The anisotropy curves for both cases proved to be identical.

In the general case the even photomagnetic emf E_q must be composed of isotropic E_i and anisotropic E_a components:

$$E_q = E_i + E_a.$$

Fig. 2

Figure 2: Fig. 2

Both components can be separated experimentally and the coefficients L_1 and L_2 determined from equation (3). This can be done most simply on samples for which the normal to the plane is the [111] axis. In this case the even photomagnetic emf is described by equation (3), in which the first term on the right-hand side is the isotropic component, and the second is the anisotropic component of the even photomagnetic emf. It follows from equation (3) that the isotropic and anisotropic components of the even photomagnetic emf depend differently on the angle θ. Therefore, by measuring the dependence of the photomagnetic emf on θ, one can determine the coefficients L_1 and L_2 separately.

Fig. 2

Figure 2 presents the results of measurements of the extreme value of the even photomagnetic emf ($\varphi = 0,\ 2/3\pi,\ 4/3\pi$) as a function of the field H for $\theta = 90^\circ$ and $\theta = 120^\circ$. The emf was measured in the direction of the projection of the magnetic field onto the plane of the sample ($\varphi_0 = 0$).

To obtain qualitative results we assumed that equation (2) is applicable not only at small magnetic fields, for which an expansion accurate to quadratic terms is valid, but also for

large fields, while regarding the coefficients L_1 and L_2 as depending on the magnitude of the magnetic field. Proceeding from this and using (3), we determined the values of L_1 and L_2. In Fig. 2 the dotted curves show the dependences of the expressions

$$\frac{E_i}{\sin 2\theta \cos\varphi_0} \quad \text{(curve } a\text{)}, \qquad \frac{E_a}{\frac{1}{3}\sin 2\theta\cos\varphi_0 + \frac{1}{3\sqrt{2}}\sin^2\theta\cos(3\varphi - 2\varphi_0)} \quad \text{(curve } b\text{)}$$

on the magnitude of the magnetic field H. It is evident from the curves that the isotropic and anisotropic components of the photomagnetic e.m.f. depend differently on the magnetic field H and may differ in sign. This also explains the change in sign of the total even photomagnetic e.m.f. ($\theta = 120^\circ$), which was also observed in (^{5}).

Photomagnetic effects, as is known, owe their origin to the diffusion of carriers from the illuminated surface of the specimen to the unilluminated one. It was therefore to be expected that corresponding e.m.f.'s would arise when an electric current from an external e.m.f. source is passed through the specimen in the same direction. Such an experimental arrangement corresponds to the so-called "planar" (even) Hall effect (^{6}).

To test this assumption, electrodes were deposited (at the center) on the same specimens on which the photomagnetic e.m.f. had been measured, and an electric current was passed through them. The even e.m.f. arising in the magnetic field was measured in the same way as the photomagnetic e.m.f. The measurements showed that the even "Hall effect" likewise consists of isotropic and anisotropic parts and is described by the same equation (2).

A detailed description of the experiments will be given later.

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