THE RELATION BETWEEN THE EVEN PHOTOMAGNETIC EFFECT AND THE PHOTO-HALL EFFECT

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The paper discusses the scope for using the even photomagnetic effect PME in examining the properties of semiconductor materials in cases where one usually employs the photo-Hall PH effect. One of the components of the even PME involves the same mechanism as the PH, and therefore similar information is provided by the even PME and PH regarding the properties of the semiconductor material. This is confirmed by measurements on the even PME and PH, and also on the odd PME in the same geometry for p-type Ge and Si.

The odd photomagnetic effect (PME) is sometimes used [1] to determine the carrier mobility in a semiconductor material, along with data on the Hall effect or the photo-Hall effect (PH), particularly with bipolar conductivity. Here it is shown that one can use the even PME for the same purpose as the PH. This related to the mechanism responsible for the even PME: it has been shown for p-Ge [2] that one of the components of the even PME can be interpreted as the PH EMF due to the potential difference from the odd PME.

To compare the data on the even PME and PH, it is necessary to consider them under identical conditions. We assume that one of the planes in the specimen is illuminated with strongly absorbed light, and the specimen is in a magnetic field such that the field strength H forms an angle $\alpha \neq 0$ with the illuminated plane. The odd PME is measured in a direction perpendicular to the charge-carrier concentration gradient and to the projection of the vector H on the plane of the specimen, while the even effect is measured along this projection. To measure the PH, one uses the contacts for the even PME, while the current contacts are provided by the odd PME ones.

We assume that the shape of the specimen and the dimensions satisfy the usual requirements in PH measurement [3]. Then the following formula applies for the PH EMF:

$$V_{PH} = V\mu_H H \sin\alpha\, a/l, \qquad (1)$$

where μ_H is the photo-Hall mobility, V is the potential difference between the contacts separated by a distance l along the current direction, and l is specimen width (the distance between the measurement contacts for the even PME). If it is possible to neglect the terms proportional to h to the second and higher powers in the kinetic equation, we have as follows [4] for the photo-Hall mobility:

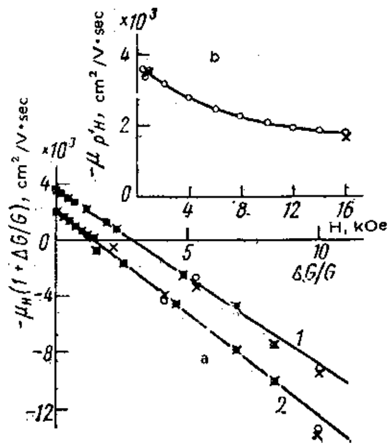

Fig. 1

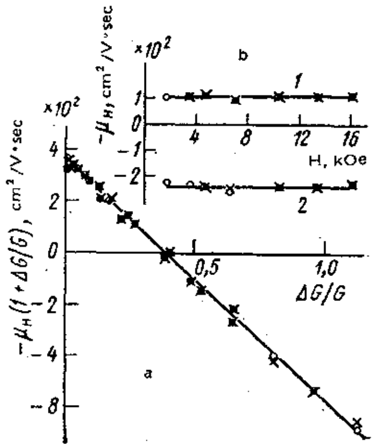

Fig. 2

Fig. 1. a) Dependence of the product $\mu_H(1+\Delta G/G)$ on ΔG/G for p-Ge at 293 K: H = 1 kOe (1) and 16.1 kOe (2); b) field temperature of $\mu_{p'H}$ for p-Ge at 293 K; o) from PH data and Hall effect (see formula (1)), ×) from PME data (see formula (3)). Figure 1b gives PME data corresponding to a low injection level, ΔG/G ~ 0.1.

Fig. 2. a) Dependence of the product $\mu_H(1+\Delta G/G)$ on ΔG/G for p-Si at 293 K for H = 16 kOe; b) field dependence of μ_H for p-Si at 293 K: ΔG/G = 0.26 (1) and 0.65 (2); o) from PH data; ×) from PME data.

$$\mu_H = \int_0^d (n\mu_n\mu_{nH} - p\mu_{p'}\mu_{p'H})\,dx \Big/ \int_0^d (n\mu_n + p\mu_{p'})\,dx. \qquad (2)$$

Here $n=n_0+\Delta n$ and $p=p_0+\Delta p$ are the electron and hole concentrations, equilibrium and nonequilibrium ones, while μ_n and μ_{nH} are the drift and Hall electron mobilities, and $\mu_{p'}$ and $\mu_{p'H}$ are the corresponding hole mobilities (with allowance for the presence of light and heavy carriers [5,6]), and d is specimen thickness.

Formula (2) for the photo-Hall mobility which defines the PH EMF, is the same as the formula for μ_H, which defines one of the components of the even PME (see formulas (4)-(6) in [5]). This is an additional confirmation of the interpretation for the even PME given in [2,5]. According to [5],

$$\mu_H = (V_{e0} - V_{ec})l/(aV_{od}H\sin\alpha), \qquad (3)$$

where V_{e0} and V_{ec} are the EMF's from the even PME correspondingly in the open-circuit and closed-circuit states for the odd effect, while V_{od} is the EMF from the odd PME.

One can therefore obtain information on the properties of the semiconductor related to μ_H in the absence of data on the pH if measurements on the odd PME are supplemented with ones on the even PME.

Data on μ_H can be used for example to determine the carrier mobilities.

If these mobilities and $c = \Delta n/\Delta p$ are identical throughout the thickness of the specimen, then μ_H can be expressed in terms of the relative conductivity change on illumination $\Delta G/G$. For a specimen of p type, for example, we get

$$\mu_H = -(\mu_{p'H} - \mu_i \Delta G/G)/(1 + \Delta G/G), \quad (4)$$

where μ_i is the photo-Hall mobility corresponding to a high injection level ($\Delta G/G \gg 1$). For $c = 1$, μ_i is equal to the Hall mobility for a semiconductor with inherent conductivity:

$$\mu_i = (\mu_n \mu_{nH} - \mu_{p'} \mu_{p'H})/(\mu_n + \mu_{p'}). \quad (5)$$

We see from (4) that data on the dependence of the PH on $\Delta G/G$ can be used to determine $\mu_{p'H}$ and μ_i, and therefore μ_{nH} if the ratios μ_{nH}/μ_n and $\mu_{p'H}/\mu_{p'}$, are known.

In view of the above analogy between the even PME (more precisely, one of its components) and the PH, we performed experiments on the dependence of the PME and PH on the injection level under identical conditions in order to compare the values of μ_H obtained by two different methods. We used specimens of p-type Ge and Si with specific resistances correspondingly of 29 and 13 Ω·cm.

Figures 1 and 2 show the results as the dependence of the product $\mu_H\ (1+\Delta G/G)$ on $\Delta G/G$. In both cases, the PME measurements for p-Ge and p-Si give the same results as the PH. This shows directly that one can use the PME, including the even effect, for the purposes for which one usually employs the PH.

We processed the data on the $\Delta G/G$ dependence of $\mu_H(1+\Delta G/G)$ in accordance with (4) using least squares in order to derive $\mu_{p'H}$ and μ_i. There was good agreement between the values of these found from the PME and PH measurements. For example, for p-Ge at H = 16.1 kOe, the two methods gave $\mu_{p'H}$ correspondingly of 2090 and 1980 $cm^2/V\cdot sec$, while the μ_i were 1390 and 1330 $cm^2/V\cdot sec$, which corresponds to the published data [6]; with H = 1 kOe, $\mu_{p'H}$ was 3420 and 3680 $cm^2/V\cdot sec$ and μ_i was 1130 and 1220 $cm^2/V\cdot sec$ [6]. We note the difference in the mobilities found for different values of H, the difference being particularly large for $\mu_{p'H}$. This discrepancy is naturally ascribed to the field dependence of the light-hole mobility [7]. Direct evidence for a major role for the light holes is given by the Hall mobility for the same specimen (Fig. 1b).

Similar results were obtained for p-Si: $\mu_{p'H}$ was correspondingly 360 and 355 $cm^2/V\cdot sec$, while μ_i was 920 and 915 $cm^2/V\cdot sec$. On the basis that the ratio of the Hall factors for electrons and holes in Si is 1.6 [8], one can use [5] to determine μ_{nH}, which was 1420 $cm^2/V\cdot sec$ on the basis of the PME data [8,9]. In the experiments with p-Si, we did not find any effect from H on the mobilities with low or high injection levels (Fig. 2b) because the mobilities of the light and heavy holes in p-Si differ much less than they do in p-Ge.

These measurements thus show that the physical reasons for the relation between the even PME and the PH make it possible in principle to choose either of these effects to supplement the odd PME in examining the properties of semiconductor materials.

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