POSSIBILITY OF TOTAL SEPARATION OF GALVANO- AND THERMOMAGNETIC EFFECTS IN SEMICONDUCTORS

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Methods of total separation of transverse and longitudinal galvanothermomagnetic (GTM) effects are considered in an experiment carried out by the method of variation of the action factors.

The standard scheme for determining kinetic coefficients is based on known representations of solid-state theory. Expressions by which the kinetic coefficients are calculated [1, 2] are ordinarily obtained under the assumption that the object of the investigation is either under isothermal or adiabatic conditions. If any of these conditions is not satisfied during conduction of the experiment, then, strictly speaking, it is impossible to use these expressions. Meanwhile, not one, but some combination of several physical actions (PA) acts simultaneously on the object under investigation in the practice of the physical experiment. In this case, all the other (uncontrollable external or induced by given) factors are undesirable — are parasitic. This results in the fact that the effects characterizing the direct connection between a given effective force field (or group of fields) and the flux (fluxes) they cause in the object under investigation either do not appear at all or if they are determined, then it is with a methodological error not subject to an exact quantitative estimate.

Therefore, the circumstances mentioned result in the appearance of significant difficulties or the impossibility, generally, of determining finer effects, less in absolute value than the effects being measured; the diminution in accuracy and the increase in the time to conduct the experiment specify a loss in additional physical information.

These difficulties can be overcome by using the principle of variation of the action factors proposed in [3, 4] and the methods of experimental investigation of the kinetic properties of solids developed on its basis. This principle is based on taking account of peculiarities in the physical nature of the particles forming the object of investigation and the variations in methods of imposing or removing the PA during conduction of the experiment. The peculiarities of the physical nature of the particles upon imposition (or removal) of a unit PA on the object of investigation are manifest in that different material energy, charge, and mass flux carriers are characterized by a distinct duration of the irreversible process of building up the stationary state. If the PA are given in the experiment and are controllable, then by variation of the order and duration of their imposition and removal in the object, all the fundamental, imposed, and prospective effects caused by the action of these factors can be produced and recorded successively in time.

Among the other variational methods in [3], a method of using the galvano- and thermomagnetic effects (GTME) by means of variations of the thermal, magnetic, and electric fields was proposed. Algorithms of the physical investigations (API) were presented there which permit determination of practically all the GTME. The external electrical field $\vec{E}$ resulting in the appearance of currents $\vec{j}$ in the object and the magnetic field $\vec{H}$ were subjected to variation with the external thermal field ∇T, an invariant quantity. In the general case, the total potential difference at the Hall (transverse) probes can be comprised of nine separate electromotive forces and voltage drops

$$V_{1-4} = V_\alpha + V_{\vec{N}E}^{\downarrow} + V_{RL} + V_H + V_E + V_{\vec{N}EP}^{\downarrow} + V_{RLP} + V_{\alpha P} + V_\rho. \quad (1)$$

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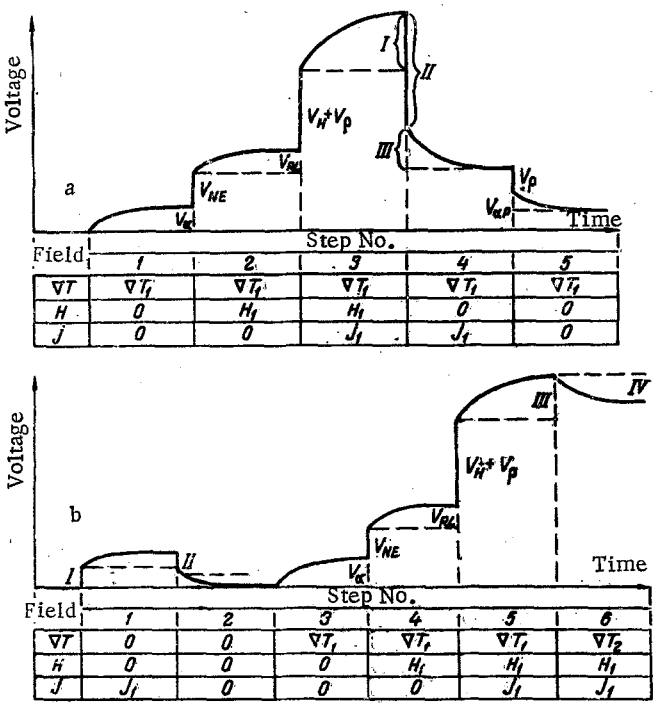

Fig. 1. Algorithm of the physical investigation (API-1) (a) and (API-2) (b) and general form of the emf and voltage drop diagram for transverse GTME: for a: I) $V_E + V_{\alpha P} + V_{NEP} + V_{RLP}$; II) $V_H + V_{NE}^{\perp} + V_{NEP}^{\perp}$; III) $V_E + V_{RL} + V_{RLP}$; for b: I) V_ρ; II) $V_{\alpha P}$; III) $V_E + V_{\alpha P} + V_{NEP}^{\perp} + V_{RLP}$; IV) $V_{\alpha P} + V_{NEP}^{\perp} + V_{RLP}$.

The sequence of the time assignment of the imposed force fields in the best API for separating the effects is presented in Fig. 1a, where the general form of the diagram of the transverse GTM effects realized by this algorithm, recorded on the diagram tape of a fast-acting instrument, is shown. This permits obtaining the following nine measurable values of the emf and the voltage drops:

$$V_\alpha;\ V_{NE}^{\perp};\ V_{RL};\ V_H + V_\rho;\ V_E + V_{\alpha P} + V_{NEP}^{\perp} + V_{RLP};$$
$$V_H + V_{NE}^{\perp} + V_{NEP}^{\perp};\ V_E + V_{RL} + V_{RLP};\ V_\rho;\ V_{\alpha P}.$$

All the separate emf's and voltage drops can be found from their comparison, with the exception of the Ettingshausen emf V_E, which is encountered only in the sum with V_{RLP}. It is easy to see that no other version constraining the variations of just the electric and magnetic fields will permit separation of V_E and V_{RLP}.

For the total separation of these effects, it is possible to turn to variations of the third, thermal field, in particular, to produce such a temperature gradient ∇T_2 wherein the thermal flux originating from the Peltier effect would be cancelled. The API-2 version is presented in Fig. 1b. It permits a separate determination of the magnitude of the four basic GTM effects and three (V_ρ, V_α, $V_{\alpha P}$) of the five superposed effects. To do this, it is necessary to calculate the value of the Peltier temperature gradient $\nabla T_P^{III} = \nabla T_1 V_{\alpha P} V_\alpha^{-1}$ during the experiment by means of the results of the first three steps of the measuring cycle and to introduce the thermal field variation cancelling the quantity ∇T_P in the sixth step. The algorithm in Fig. 1b assumes a very high level of automation of the experiment, which is not provided for in known experimental apparatuses. Let us also note that the time of carrying out the whole experiment grows considerably in the case of the variation of the inertial heat field.

Let us now consider another possible method of total separation of GTME, for which only the two factors E and H of the three (E, H, ∇T) are subjected to variation according to the API-1. This can be achieved if it is assumed that the ratios between the magnitudes of the thermomagnetic effects are independent of the nature of their generating heat field. In fact, $V_{NE} = A^{\perp}_{NE} H\nabla T$, $V_{RL} = \alpha A_{RL} H\nabla T$ and the superposed effects $V^{\perp}_{NEP}$ and V_{RLP} are described by the same formulas with the sole replacement of the temperature gradient ∇T superposed from outside by the temperature gradient ∇T_P caused by the parasitic Peltier effect. The obtained identity

$$\frac{V_{RL}}{V^{\perp}_{NE}} = \frac{V_{RLP}}{V^{\perp}_{NEP}} \tag{2}$$

relates the fundamental and imposed thermomagnetic effects and permits the calculation of the quantity V_{RLP} and, thereby, the Ettingshausen emf V_E also. In exactly the same way, by eliminating ∇T and ∇T_P, the second identity containing V_{RLP} can be obtained:

$$\frac{V_{RL}}{V_{\alpha}} = \frac{V_{RLP}}{V_{\alpha P}}. \tag{3}$$

An analogous situation holds to a great extent in measuring the longitudinal GTME. If $\nabla_x T$ is kept constant throughout the experiment, then the Peltier, Nernst, and Maggi–Righi–Leduc effects will yield no contribution to the measurable electrical signal. In this case, the total potential difference on the longitudinal probes 2-5 (V_{2-5}) includes six quantities:

$$V_{2-5} = V_{\alpha_0} + V^{\parallel}_{NE} + V_{\rho_0} + V_{\Delta\rho} + V_{E-t} + V_{RL-t}, \tag{4}$$

where V_{α_0} is the thermal emf for H = 0, V_{ρ_0} is the ohmic voltage for H = 0, $V_{\Delta\rho}$ and $V^{\parallel}_{NE}$ are the longitudinal magnetic resistance and Nernst–Ettingshausen GTME, and V_{E-t} and V_{RL-t} are the additional emf's in the longitudinal direction which appear from the transverse Ettingshausen and Righi–Leduc GTME (the coefficients A_E and A_{RL}) in terms of the thermomagnetic Nernst–Ettingshausen effect (the coefficient $A^{\pm}_{NE}$). Here V_{E-t} and V_{RL-t} are given by the formulas

$$V_{E-t} = H^2 A^{\pm}_{NE} A_E j_x \Delta x_{2-5}, \tag{5}$$

$$V_{RL-t} = H^2 A^{\pm}_{NE} A_{RL} \nabla_x T \Delta x_{2-5}, \tag{6}$$

where Δx_{2-5} is the spacing between the longitudinal probes.

The signals in (4) are easily separated in an experiment performed by means of the API-1.

If constancy of the heat flux w_x is assured, then in this case temperature gradients and their corresponding TE and TM emf's due to the Peltier ($\nabla_x T_P$; $V_{\alpha P}$, $V^{\parallel}_{NEP}$), Nernst ($\Delta_x T_N$; $V_{\alpha N}$ and $V^{\parallel}_{NEN}$) and Maggi–Righi–Leduc [$\nabla_x T_{MRL} = -\nabla_x T(\Delta\kappa(H)/\kappa_0)$; $V_{\alpha MRL}$, $V^{\parallel}_{NEMRL}$; here κ is the coefficient of thermal conductivity] effects will be added to the initial gradient $\nabla_x T$. The total potential difference hence includes 12 separate voltage drops and emf's. For total separation of the quantities mentioned, which are measured by means of the API-1, it is necessary to use the identity

$$\frac{V_{\alpha_0}}{V^{\parallel}_{NE}} = \frac{V_{\alpha P}}{V^{\parallel}_{NEP}} = \frac{V_{\alpha N}}{V^{\parallel}_{NEN}} = \frac{V_{\alpha MRL}}{V^{\parallel}_{NEMRL}}, \tag{7}$$

as well as to calculate the values V_{E-t} and V_{RL-t} by means of (5) and (6). The simultaneous determination of the transverse and longitudinal GTM effects by the method of variations of the PA in one experiment should be performed to evaluate the coefficients $A^{\perp}_{NE}$, A_E, AND A_{RL}.

A comparison between the methods of total separation and recording of transverse and longitudinal GTM effects presented above shows that the experiment is most simply realized technically in the variations of just the two fields $\vec{E}$ and $\vec{H}$ (API-1) with the identities (2), (3), (5)-(7) taken into account.

Total separation of all the GTM effects in one experiment permits posing the problem of calculating the maximal quantity of secondary parameters characterizing electronic models of semiconductors. In this connection, it is quite important to us to consider henceforth optimal methods of calculating these parameters under minimal a priori assumptions.

NOTATION

V_{1-4}, V_{2-5}, emf's on the transverse (Hall) and longitudinal probes; V_α, thermal emf; V_ρ, ohmic voltage drop; V_H, V_E, V_{RL}, $V_{NE}^{\perp}$, emf's of the transverse Hall, Ettingshausen, Righi–Leduc, and Nernst–Ettingshausen effects; $V_{\alpha P}$, $V_{\alpha N}$, and $V_{\alpha MRL}$, emf of the longitudinal Peltier, Nernst, and Maggi–Righi–Leduc effects; $V_{\Delta\rho}$ and $V_{NE}^{\parallel}$, emf of the longitudinal magnetic resistance and Nernst–Ettingshausen effects; $V_{\alpha P}$, $V_{NEP}^{\perp}$, and V_{RLP}, secondary thermal emf and TM effects caused by the Peltier heat; $A_{NE}^{\perp}$, A_{RL}, A_E, coefficients of the Nernst–Ettingshausen, Righi–Leduc, and Ettingshausen effects; E, H, electric and magnetic field intensities. Indices 0, H = 0.

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THERMAL CONDUCTIVITY OF RARE EARTH FLUORIDE CRYSTALS

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Thermal resistance of LaF_3 and HoF_3 monocrystals is linearly dependent on temperature. In LaF_3 crystals a deviation from the linear law was observed at $T > 170°K$ in the direction of higher thermal-conductivity values. In doped $LaF_3:Eu^{2+}$ in the region $T > 170°K$ thermal resistance is lower than in pure specimens.

Halogenides of the rare earth elements are used in electrochemical devices as solid electrolytes. This has stimulated study of their structure and physical properties [1, 2]. Most data have been gathered on lanthium fluoride LaF_3. The crystalline structure of LaF_3 and other similar rare earth fluorides of the tisonite series has remained a matter of discussion. Oftedal [3] established a hexagonal structure with spatial group $D_{3h}^3(P6_3/mcm)$ by the x-ray diffraction method. Nuclear magnetic resonance studies [4,5] indicated a hexagonal cell with group $C_{6v}^3(P6_3/cm)$. Optical measurements defined the trigonal space group $D_{3d}^4(P\bar{3}c1)$. Data on the isomorphic CeF_3 favor the trigonal structure [6, 7]. In pure LaF_3 crystals thermal resistance shows no anisotropy (just as electrical conductivity [8]) and changes by a linear law (measurements performed by the technique of [15] with error of 5%) $W = 1.9 \cdot 10^{-3}$ T (m·deg/W) up to 170°K. Above this temperature nonlinearity sets in in the direction of higher thermal-conductivity values (Fig. 1a, b). The Leibfried–Schlömann expression for thermal conductivity of pure crystals [9] with the Klemens correction [10] (decreasing the numerical coefficient of the Leibfried–Schlömann formula by a factor of 14) gives good agreement with ex-

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