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Thermo- and galvanomagnetic technique for semiconductors testing at high pressure up to 30 GPa

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Abstract

The thermoelectric power (S), magnetoresistance (MR) and thermomagnetic (TM) effects were measured at high pressure (P) in the vicinity of semiconductor–metal phase transitions for Te, Se and S micro-samples. From longitudinal and transverse Nernst–Ettingshausen (N–E) effects for Te and Se, the scattering parameter (r) of holes was estimated and under the closing of semiconductor gap (E_g) the decreasing of their effective mass (m) was found. S of Sulphur also decreased with pressure up to 40 GPa and the negative MR effect observed indicates low mobility (μ) of holes. The technique developed seems to be suitable for use in micro-device technology.
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1. Introduction

Using diamond anvils, the S- [1,2] and MR- [3] techniques at high pressure P up to $\sim$ 40 GPa have been developed [3,4]. They allow to determine the type and μ of charge carriers for high pressure phases [1–5]. Similar MR technique is applicable for fabricated micro-devices [6]. Combining S- and MR-techniques the TM-measurements were started up to 30 GPa [7] (the former limit was 3 GPa [8,9]). Contrary to Hall- and MR effects, not only the values but also the signs of longitudinal and transverse N–E effects depend on the r value [8]. In the present paper the results of TM measurements of micro-samples (single crystal Te with hole concentration of 3×10^{17} cm^{-3} at 4.2 K, grey amorphous Se, rhombohedral S) at ultrahigh P are discussed.

2. Experimental technique and results

For high pressure generation in solid medium (catlinite) the synthetic diamond (conducting) and boron nitride (insulating) anvils of Bridgman's type with work diameters 0.6–1.0 mm were used [10]. The diamond anvils served as a heater and a cooler for creation of thermal gradient along a sample [1,7]. Thin (5 μm) Pt–Ag ribbons served as electrical leads to a sample [1,7]. Samples were disc-shaped, with thickness (0.02–0.05 mm) much less than the diameter (0.3 mm), so the geometrical factor of MR was close to that of the Corbinaux disk [6].

The automated set up used allowed to record the parameters of the medium and signals from a sample

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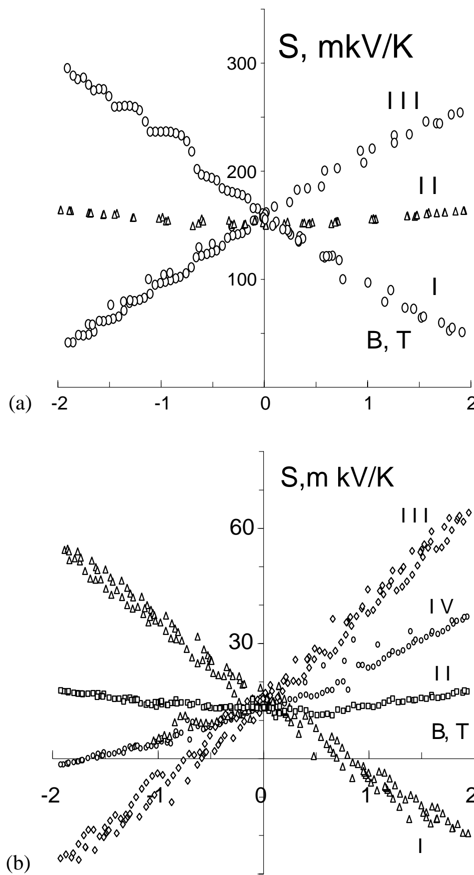

Fig. 1. The dependencies of thermoelectric power on B at $T = 295$ K for Te (at $P = 2.5$ GPa) (a) and Se (at $P = 13.6$ GPa) (b) samples at various turns of high pressure chamber around axis in B: (a): **I**—0°, **II**—90°, **III**—180°; (b): **I**—0°, **II**—90°, **III**—180°, **IV**—135°. **I** and **III** positions correspond to transverse, **II**—to longitudinal N–E effects and **IV**—to mixture of both effects. The platinum–silver ribbons for Boron nitride anvils (a) and synthetic diamond anvils (b) were used as an outputs to a sample.

simultaneously [5,7]. Due to asymmetrical position of the electrical probes the contribution of Hall effect usually existed in MR data, and vice versa. In our case, to separate transverse and longitudinal effects the measurements in magnetic field B (perpendicular to thermal gradient) were performed by turning the chamber around the axis [7].

The electrical resistance R and S of Te, Se and S samples decreased with P below the semiconductor–metal phase transitions at $\sim$ 4, 25 and 40–90 GPa [1,3,11,12]. The measurements of R and S at various B revealed the MR and N–E effects (Fig. 1) correspondingly.

The dependencies of S on B for Se and Te (Fig. 1) show strong variation with turning of a sample. The B-dependent linear signal was attributed to transverse (analogous to Hall) while the weak quadratic one—to longitudinal N–E effect (analogous to MR) [8,9]. The reason for the occurrence of transverse N–E effect was non-zero distance Δy in the Hall direction between the electrical probes to a sample mentioned above [7].

The equations for N–E effects in weak B ($B < 1/\mu$) are similar to $MR = A_1(\mu B)^2$ [8]:

$$\Delta S_{\|}(B) = A_2\left(\frac{k}{e}\right)(\mu B)^2, \quad Q = A_3 r\left(\frac{k}{e}\right)\mu, \qquad (1)$$

where $\Delta S_{\|}$ is the longitudinal N–E effect, Q is the coefficient of transverse N–E effect [8,9], e the electron charge; k the Boltzmann's constant; $\mu = e\tau(\varepsilon)/m$ the mobility of charge carriers; $\tau(\varepsilon) \approx \varepsilon^r$ the relaxation time; ε the hole energy [8]. A_1, A_2 (dependent on r) and A_3 are constants ~ 1 [9].

The values measured in experiments were voltages $\Delta U_{\|}(B) = \Delta S_{\|}(B)\cdot\Delta T$ and $\Delta U_{\perp}(B) = Q\cdot B\cdot\Delta T\cdot\Delta y/\Delta x$ (Δx—thickness of a sample). So the longitudinal N–E effect obtained ought to be independent of the sample dimensions, while the transverse one is proportional to $\Delta y/\Delta x$ ratio.

Positive longitudinal N–E effect (the increasing of $\Delta S_{\|}$ with B) observed for Te and Se (Fig. 1) suggested acoustic phonons scattering mechanism for holes ($r = -\frac{1}{2}$) [9] in accordance with ambient P—data for Te [8]. The increase of μ on P observed from the N–E and MR effects indicated the direct gap in Te and Se near $E_g \to 0$ ($m \sim E_g$) [10]. In contrast, Sulphur at 30–40 GPa has probably indirect E_g. Negative MR observed for Sulphur at 30 GPa suggested low mobility of holes, which is consistent with the amorphous crystal structure [12].

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