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Comparison between magnetoresistivity and magnetothermopower in $Bi_{93.99}Mn_6Fe_{0.01}$

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For the first time magnetoresistivity $\Delta\rho/\rho$ and magnetothermopower $\Delta S/S$ in textured polycrystalline samples of $Bi_{93.99}Mn_6Fe_{0.01}$ were studied in a wide temperature range (300 ÷ 4.2) K and in magnetic field B=3 T. The peculiarities on the temperature dependencies of resistivity ρ, magnetoresistivity $\Delta\rho/\rho$, thermopower S and magnetothermopower $\Delta S/S$ were found. These peculiarities are likely due to modification of the band structure of the charge carrier energy spectrum and/or spin-dependent scattering of charge carriers under magnetic field. It is shown that the peculiarities on the temperature dependence of $\Delta\rho/\rho$ and $\Delta S/S$ correlate each other very well.

Keywords: magnetic field, resistivity, magnetoresistivity, thermopower, magnetothermopower

Впервые исследованы магнетосопротивление и магнетотермоЭДС в поликристаллическом образце $Bi_{93,99}Mn_6Fe_{0,01}$ в интервале температур 4,2-300К без магнитного поля и в поле 3Т. Обнаружены особенности на температурных зависимостях электросопротивления, магнетосопротивления, термоЭДС и магнетотермоЭДС при измерениях в магнитном поле 3Т, предположительно обусловленные изменением зонной структуры энергетического спектра носителей заряда и/или спин-зависимого рассеяния носителей заряда, происходящими под действием магнитного поля. Показано, что особенности на температурных зависимостях магнетосопротивления и магнетотермоЭДС хорошо коррелируют друг с другом.

Ключевые слова: магнитное поле, удельное электросопротивление, магнетосопротивление, термоЭДС, магнетотермоЭДС

Вперше досліджено магнетоопір і магнетотермоЕРС в полікристалічному зразку $Bi_{93,99}Mn_6Fe_{0,01}$ в інтервалі температур 4,2÷300К без магнітного поля і в полі 3Т. Виявлені особливості на температурних залежностях електроопору, магнетоопору, термоЕРС і магнетотермоЕРС при вимірах в магнітному полі 3Т, імовірно обумовлені зміною зонної структури енергетичного спектру носіїв заряду та / або спін-залежного розсіювання носіїв заряду, що відбуваються під дією магнітного поля. Показано, що особливості на температурних залежностях магнетоопору і магнетотермоЕРС добре корелюють один з одним.

Ключові слова:.магнітне поле, питомий електроопір, магнетоопір, термоЕРС, магнетотермоЕРС.

Introduction

Magnetic properties study of the materials based on Bi and Mn has shown that at room temperature some of such compounds possess the rather high value of the coercive force which increases with temperature. The fact makes these materials to hold much promise for creating of the permanent magnets for high-temperature applications [1,2]. However, there is a lack of the electrical transport study of these materials in magnetic fields. In our recent paper [3] we have partially filled up the gap and studied the temperature dependence of resistivity ρ(T) of the textured polycrystalline $Bi_{93.99}Mn_6Fe_{0.01}$ in the temperature range (300 ÷ 4.2) K in magnetic field B=6T. However, no experiments as for thermopower in such compounds have been performed so far. In the paper we report on results of the simultaneous measurements of the temperature dependencies of the resistivity ρ(T) and thermopower S(T) from room temperature down to 4.2 K in magnetic field B=3 T. The measurement results were used to calculate for the first time the temperature dependencies of magnetoresistivity Δρ/ρ and magnetothermopower ΔS/S.

Matherials and methods

The polycrystalline samples, whose properties have been measured, were prepared using analytical purity grade reagents of Bi, Mn and Fe. The quartz tubes of 16-18 mm long evacuated to the pressure $P \sim 10^{-2}$ Pa were used as containers for the synthesis and growth of the $Bi_{93,99}Mn_6Fe_{0,01}$ polycrystals. The synthesis has been performed in a horizontal tube furnace of the SUOL type. The crystals were grown using Bridgeman's method at temperature 630ºC with the sinking velocity of about 1.5 mm/h.

The process has resulted in textured polycrystalline $Bi_{93,99}Mn_6Fe_{0,01}$ of the cylindrical shape. Rectangular samples of about 7x2x2 mm were cut out along of the element of cylinder. A fully computerized setup on the bases of a Physical Properties Measurement System (Quantum Design PPMS-9T) utilizing the four-point probe technique was used to measure the longitudinal resistivity ρ(T) and magnetoresistivity Δρ/ρ. Silver epoxy contacts were glued to the extremities of the sample in order to produce a uniform current distribution in the central region where voltage probes in the form of parallel stripes were placed. Contact resistances below 1Ω were obtained. Resistivity was measured using alternative current (I = 30 mA, f =17 Hz) running along the largest sample dimension. The thermopower S was measured using the standard approach as described elsewhere [4]. Measurements were performed in a wide temperature range (300 ÷ 4.2) K both without magnetic field and in magnetic field applied perpendicularly to the measuring current. Magnetic field was produced by the superconducting solenoid.

Results and discussion

Figure 1 shows temperature dependences of resistivity ρ (curves 1,4) and thermopower S (curves 2,3) measured both without field (curves 1,2) and in magnetic field B=3 T (curves 3,4). It should be noted, that ρ(T) measured at B=0 demonstrates linear dependence in the whole temperature range from room temperature down to 4.2 K (curve 1). In magnetic field B=3T the positive magnetoresistive effect followed by appearance of noticeable maximum on the ρ(T) curve was observed. The magnitude and location of this maximum increases quickly with increase of the magnetic field.

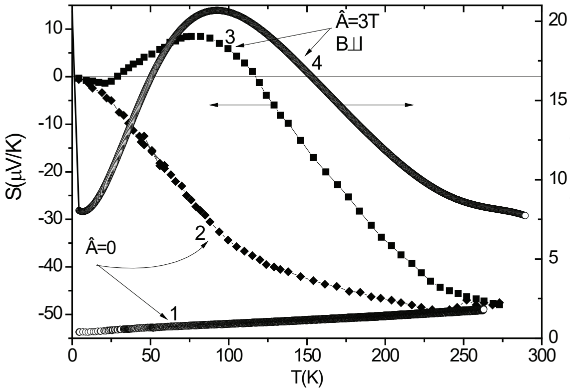

Fig.1. Temperature dependences of resistivity ρ(T) (curves 1,4) and absolute thermopower S(T) (curves 2,3) at B=0 (curves 1,2) and at B = 3 T (curves 3,4).

The specific behavior of ρ(T) in magnetic field, can be caused by different reasons. One of them is the possibility of the transformation of the Mn magnetic subsystem. It is well known that the transition from antiferro- or paramagnetic ordering to ferromagnetic one may be attended by strong changes in conductivity. Most likely it is due to the so-called spin-dependent scattering of the conduction electrons [5,6]. The spin-dependent scattering depends on the direction in which magnetic field is applied to the sample. There are preferred magnetic field directions along which the changes in magnetic subsystem occur more quickly and in more weak fields than it occurs in other directions. Evidently, particularities observed in magnetic field on the ρ(T) are also expected to appear on the temperature dependences of magnetization, thermopower and some other physical characteristics.

Figure 1 shows temperature dependences of the absolute thermopower S (curves 2) measured both without field (curves 2) and in magnetic field B=3 T (curves 3). It is seen that at B=0 measured thermopower has negative sign in the whole temperature range from room temperature down to 4,2 K. Accordingly, under applied field the thermopower S(T) increases much faster with decrease of temperature demonstrating transition from negative values of S to the positive ones at $T_1 \approx 117$ K followed by a distinct maximum at $T_{mS} \approx 80$ K. Below T_{mS} S(T) starts to decrease smoothly along with ρ(T) demonstrating transition from positive values to the negative ones at $T_2 \approx 30$ K. At $T_2 \approx 30$ K weak minimum is observed below which S(T) draws to zero. On the whole, the S(T) curve reminds the ρ(T) dependence in magnetic field (curve 4).

Observed change of the thermopower sign in studied $Bi_{93.99}Mn_6Fe_{0.01}$ can be caused by different reasons. First of all the change of the sign of the charge carriers is possible. This effect is often observed in semimetals which include Bi too. The next reason is the likely change of the charge

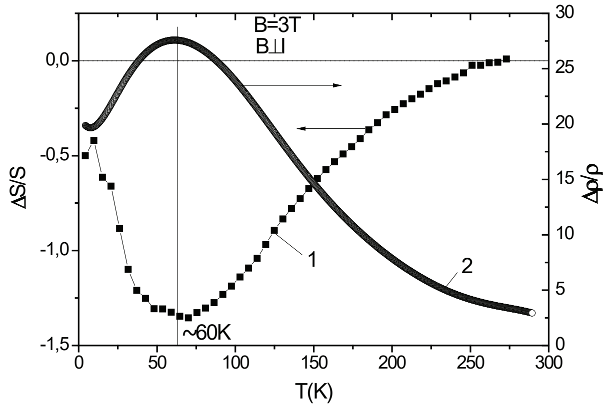

Fig. 2. Magnetoresistivity Δρ/ρ (curve 2) and magnetothermopower ΔS/S (curve 2) as a function of temperature in magnetic field B=3 T.

carrier concentration and their distribution between different isoenergetic surfaces under applied magnetic field [7]. The same physical mechanism can also account for the peculiarities of the ρ(T) behavior observed in magnetic field.

Very interesting result comes from the comparison between temperature dependences of magnetoresistivity Δρ/ρ = [ρ(B, T)-ρ(0, T)]/ρ(0, T) (Fig. 2, curve 2) and magnetothermopower ΔS/S = [S(B, T)-S(0, T)]/S(0, T) (Fig. 2, curve 1). The distinct correlation between both temperature dependences is observed. However, Δρ/ρ increases with temperature demonstrating maximum at $T_{max} \approx 60$ K, whereas ΔS/S noticeably decreases with T demonstrating minimum but again at the same temperature $T_{min} \approx 60$ K. Thus, both maxima observed in Fig. 1 shift towards the lower temperatures. However, if the shape of the Δρ/ρ (T) curve is in keeping with the curve of ρ(T) (Fig. 1), the temperature dependence of the ΔS/S (Fig. 2, curve 1) is completely different. Nevertheless, the minimum of the thermopower is in precise correspondence with the maximum of the thermoresistivity (Fig. 2). The result allows us to conclude that such unusual shape of the ΔS/S (T) dependence is most likely specified by the same physical mechanism (by the rearrangement of the magnetic structure and/or by the modification of the energy band structure). It should be emphasized that such temperature dependence of ΔS/S is observed for the first time. Evidently, the physical processes in $Bi_{93.99}Mn_6Fe_{0.01}$ which result in revealed correlation between the temperature dependencies of magnetoresistivity Δρ/ρ and magnetothermopower ΔS/S require further investigation.

Conclusion

1. It is shown, that textured polycrystalline $Bi_{93,99}Mn_6Fe_{0,01}$ demonstrates noticeable maximum on ρ(T) when magnetic field is applied in B⊥I configuration. The maximum can be connected with the change of the spin-dependent scattering and/or with modification of the changes of the band structure of the energy spectrum of the charge carriers in magnetic field.

2. For the first time maximum on the temperature dependence of the thermopower S(T) is revealed. In addition, below $T_1 \approx 117$ K S(T) demonstrates transition from negative values of S to the positive ones which can be attributed to the transformation of the energy bands structure under magnetic field.

3. For the first time temperature dependence of the magnetothermopower ΔS/S was studied. It is found, that ΔS/S demonstrates minimum at $T_{min} \approx 60$ K. Moreover, the minimum on ΔS/S exactly coincides with the maximum of the magnetoresistivity Δρ/ρ. The finding allows us to conclude that the reasons which result in appearance of peculiarities on both magnetothermopower and magnetoresistivity are caused by the similar physical mechanisms.

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