

**Features of temperature dependences electrical resistance of
Bi88.08Mn11.92 in magnetic fields**

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Electrical resistance temperature dependences features of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ in magnetic fields.

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Abstract

The temperature dependences of the electrical resistance of the solid solution of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ in the temperature range of 2-300 K and magnetic fields up to 90 kOe for both $\mathbf{H} \perp \mathbf{I}$ and $\mathbf{H} \parallel \mathbf{I}$ are studied. It has been shown that in a magnetic field, the temperature dependences of the electrical resistance of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ show maxima (insulator-metal transition) for both the $\mathbf{H} \perp \mathbf{I}$ and $\mathbf{H} \parallel \mathbf{I}$ orientations. The temperatures of the maxima increase with increasing field. The appearance of a noticeable difference between the temperature dependences of the electrical resistances of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ and the compound $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ with a lower manganese content and pure bismuth is discussed. It has been established that the magnetoresistance of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ is positive over the entire temperature range studied and reaches a value of 3290% in a magnetic field of 90 kOe for $\mathbf{H} \perp \mathbf{I}$, which is approximately 400% higher than in the

$\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ compound with lower Mn content. A suggestion has been made that the peculiarities temperature dependences behavior of the electrical resistance of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ without a magnetic field and in the field, are largely due to the influence of internal magnetism of the αBiMn phase and can be explained within the framework of the multiband theory.

Introduction

Bismuth is known as a material with unique electronic properties. Among them, the following can be distinguished: small Fermi energy (E_F) - of the order of only a few hundredths of an electron volt; long electron mean free path (up to several millimeters); small effective masses of charge carriers (of the order of 10^{-2} - 10^{-1} of the free electron mass) and reduced density of charge carriers (of the order of 10^{-5} electrons per atom). It also has a large dielectric (about 10^5) and large diamagnetic (approximately 100) permeability, and a g-factor as high as 200. For the first time, it has been experimentally discovered a large positive magnetoresistance, cyclotron resonance in metal, Shubnikov–de Haas and de Haas-van Alphen effects, oscillating magnetostriction, undamped microwave waves, and a number of dimensional effects [1,2]. It was recently suggested that some of the electrons in bismuth could be regarded as massive Dirac fermions [3–7]. In addition, it was shown, that bismuth [6] can be used in a relatively new field of modern electronics – valleytronics [8–13], which is related to the control of local maxima/minima in the valence band or conduction band of multivalley semiconductors and semimetals, which include bismuth [6]. The authors [6,13,14] found that bismuth can undergo full valley polarization in strong magnetic fields. It is assumed that in the future quantum qubits based on valleys can be created [15].

There is no doubt that not only bismuth, but also its compounds, to which bismuth can partially transfer its unique electronic properties, are of great interest from an applied and scientific point of view. Among a large number of such materials, BiMn alloys have a special place. BiMn is a ferromagnetic with a high ferromagnetic transition temperature $T_C \approx 633$ K [16]. Bi-Mn solid solutions are interesting because they have high values of coercivity at room temperature. With increasing temperature, it grows to values exceeding the coercive force in permanent magnets based on rare-earth elements [17,18]. This, as well as the low cost of the materials under consideration compared to rare-earth magnets, makes them attractive for practical use in high-temperature applications.

It should be noted that electrical transport in these materials has been practically unstudied, but its behavior may be no less interesting than the magnetic properties.

Research by our group have shown that the compound $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ with a small amount of manganese has colossal positive anisotropic magnetoresistance and anomalies in the temperature dependence of electric resistance $R(T)$ in magnetic field [19,20]. The purpose of this work is to show what happens to $R(T)$ in a magnetic field if the manganese content is increased. The features of the temperature dependences of the $\text{Bi}_{88.08}\text{Mn}_{11.92}$ compound in magnetic fields up to 90 kOe will be examined in detail.

Samples and experimental method

Bismuth and manganese of $> 99.999\%$ purity were the starting components for the samples. Containers for synthesis and growth of the material were graphitized quartz ampoules \varnothing 16-18 mm, vacuumed to a residual pressure of $\sim 10^{-2}$ Pa. The samples were obtained by crystallization using the Bridgman method at a growth rate of 1.5 mm/hour. This growth method can produce single-crystalline or large-crystalline textured samples. Stabilization of the temperature in the furnace (especially at the crystallization front) is necessary for the growth of high-quality materials, which was maintained with the help of temperature regulating devices of RIF-101 type with the accuracy of $\pm 0.5^\circ\text{C}$.

The final ingots were obtained in the form of cylinders. To measure the electrical resistance along the base of the cylinder (conditionally perpendicular to the c -axis), samples in the form of parallelepipeds with dimensions of approximately $2.5 \times 1.4 \times 1.1$ mm were cut out. A fully computerized setup (PPMS, Quantum Design) utilizing the four-point probe technique with stabilized measuring alternating current ($I = 15$ mA, $f = 19$ Hz) directed along the larger sample size, was used to measure the samples resistance $R(T)$. Silver epoxy contacts were glued to the surface of the parallelepiped in order to produce a uniform current distribution in the central region where voltage probes in the form of parallel stripes were placed. The distance between the potentiated contacts was approximately 1.5 mm. Contact resistances below 1Ω were obtained. Measurements have been performed both without field and in transverse and perpendicular to the current magnetic fields up to 90 kOe in the temperature range $2 \div 300$ K. For these measurements, the constant magnetic field was supplied by a superconducting solenoid.

Quantitative elemental composition determination were carried out using a Philips 515 scanning electron microscope with an EDAX PV9800 spectrometer. According to the results of this study, the average quantitative elemental composition by volume of the material was as follows: 88.08 at% Bi, 11.92 at% Mn. Deviations from this composition did not exceed $\pm 2\%$ at

different points of the sample surface (usually about 8 measurements were taken). At the same time no other elements except bismuth and manganese were detected. According to the phase diagram [21] in this range of manganese concentrations, the sample is a bismuth matrix with inclusions of the α -BiMn magnetic phase. In this work, the results obtained were compared with the results obtained on a compound with a lower concentration of manganese $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$, as well as on pure bismuth, which were prepared using the same method as the test sample $\text{Bi}_{88.08}\text{Mn}_{11.92}$.

Since the $\text{Bi}_{88.08}\text{Mn}_{11.92}$ had a small distance between potential contacts (1.5 mm) compared to its cross-section ($\sim 1.4 \times 1.1 \text{ mm}^2$) and a small distance between current contacts ($\sim 2.5 \text{ mm}$) recounting electrical resistance to electrical resistivity will be inaccurate, so it was decided not to recalculate electrical resistivity.

Results and discussion

Temperature dependences of electrical resistance without a magnetic field

For the convenience of comparing the temperature dependences of the electrical resistance of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ with $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ and pure bismuth, the electrical resistance was plotted in relative units $R(T)/R(300 \text{ K})$. Figure 1 shows the temperature dependence $R(T)/R(300 \text{ K})$ of the textured polycrystalline $\text{Bi}_{88.08}\text{Mn}_{11.92}$ (black squares), which is metallic in the entire temperature range (electrical resistance decreases with decreasing temperature). However, several regions with different slope can be distinguished at $R(T)/R(300 \text{ K})$. Thus, a linear dependence is observed from the room temperature and down to about 200 K, then the slope strongly deviates from linearity and at a temperature $T_{infl} \approx 70 \text{ K}$ a kink is observed at $R(T)/R(300 \text{ K})$, below which the function decreases more rapidly. Ultimately, in the temperature range 4–14 K (inset in Fig. 1), a quadratic dependence typical for bismuth is observed [21].

In Fig. 1 we also plotted $R(T)/R(300\text{K})$ for a sample with a lower concentration of manganese, $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ (green circles), and pure bismuth (blue triangles). The temperature dependence of the electrical resistance of bismuth was measured in the temperature range 8–300 K and is linear from room temperature to 15 K.

A comparison of the temperature dependences of the electrical resistance of pure bismuth and the tested $\text{Bi}_{88.08}\text{Mn}_{11.92}$ solid solution shows that they differ greatly, especially below 200 K (Figure 1). At the same time, the temperature dependence of the electrical resistance of the solid solution with a lower concentration of manganese (3.69 at.%) (green circles) is almost the same

as that for pure bismuth. Thus, the dependences almost coincide up down to about 120 K. Below this temperature, the temperature dependence for a solid solution with 3.69 at.% Mn deviates upward from linearity. Thus, it can be stated that the temperature dependence of the electrical resistance changes significantly with increasing manganese concentration and, as a consequence, inclusions of the α -BiMn magnetic phase.

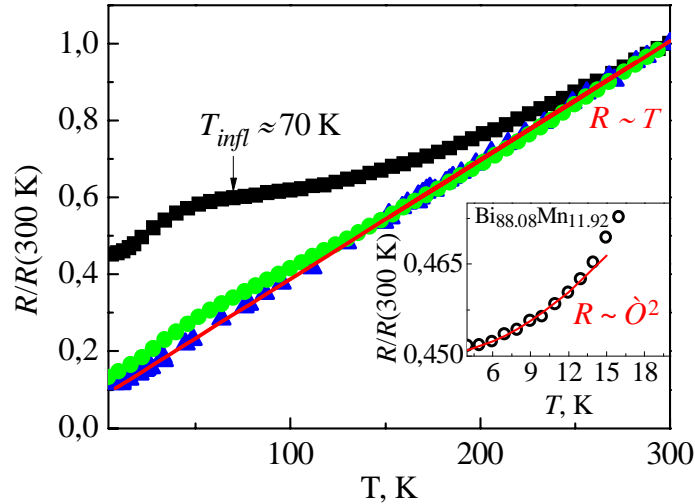


Fig. 1. (Color online) The temperature dependence of resistivity in relative units $R/R(300\text{ K})$ for $\text{Bi}_{88.08}\text{Mn}_{11.92}$ (■), $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ (●), pure bismuth (▲). The inset shows the low-temperature dependence of the electrical resistivity of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ in the temperature range 4–18 K. The red curve is $R \sim T^2$.

Temperature dependences of electrical resistance in magnetic fields

Let us consider the results of experimental studies of the temperature dependences of the electrical resistance $R(T)$ of the textured polycrystal $\text{Bi}_{88.08}\text{Mn}_{11.92}$ in magnetic fields up to 90 kOe for two directions $\mathbf{H} \perp \mathbf{I}$ (Fig. 2a) and $\mathbf{H} \parallel \mathbf{I}$ (Fig. 2b). At zero field, $R(T)$ is almost linear (lowest black lines in both figures). However, when a magnetic field is applied, a large positive magnetoresistance immediately appears which has a specific temperature dependence. With decreasing temperature, the temperature dependences of electrical resistance in magnetic fields, both for the configuration $\mathbf{H} \perp \mathbf{I}$ and $\mathbf{H} \parallel \mathbf{I}$, show an increase in ohmic losses, followed by a maximum (insulator-metal transition) and a noticeable subsequent decrease in resistance. Moreover, as the field increases, the maximums shift towards higher temperatures. Note that in contrast to $\text{Bi}_{88.08}\text{Mn}_{11.92}$, no maxima on $R(T)$ in magnetic fields were observed in the sample

with lower manganese concentration - $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ for configuration $\mathbf{H} \parallel \mathbf{I}$, but they occurred for configuration $\mathbf{H} \perp \mathbf{I}$ [20].

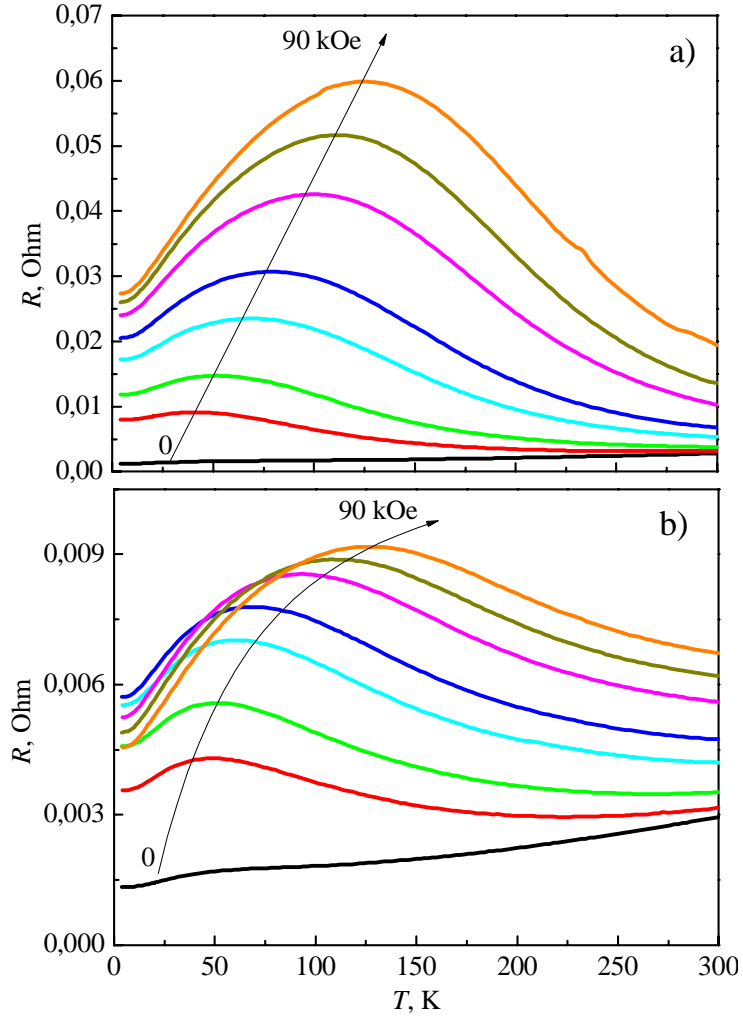


Fig. 2. (Color online) The temperature dependences of the electrical resistance of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ for the configuration $\mathbf{H} \perp \mathbf{I}$ (a) and $\mathbf{H} \parallel \mathbf{I}$ (b) without field (black lines) and at fixed magnetic fields, kOe: 5, 10, 20, 30, 50, 70 and 90.

Figure 3 shows the dependences of the maximum temperatures on the magnetic field, which are plotted for the configuration $\mathbf{H} \perp \mathbf{I}$ and $\mathbf{H} \parallel \mathbf{I}$ for $\text{Bi}_{88.08}\text{Mn}_{11.92}$ (black open and closed circles, respectively) and $\mathbf{H} \perp \mathbf{I}$ for $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ (red closed squares). The figure shows that the temperatures of the maxima at the same field values in the case of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ are slightly higher for the $\mathbf{H} \perp \mathbf{I}$ configuration than for $\mathbf{H} \parallel \mathbf{I}$. Comparison of $T_{max}(H)$ for $\text{Bi}_{88.08}\text{Mn}_{11.92}$ and

$\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ shows that at the same field values, the temperature of the maxima is significantly higher for the compound with lower manganese concentration, $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$.

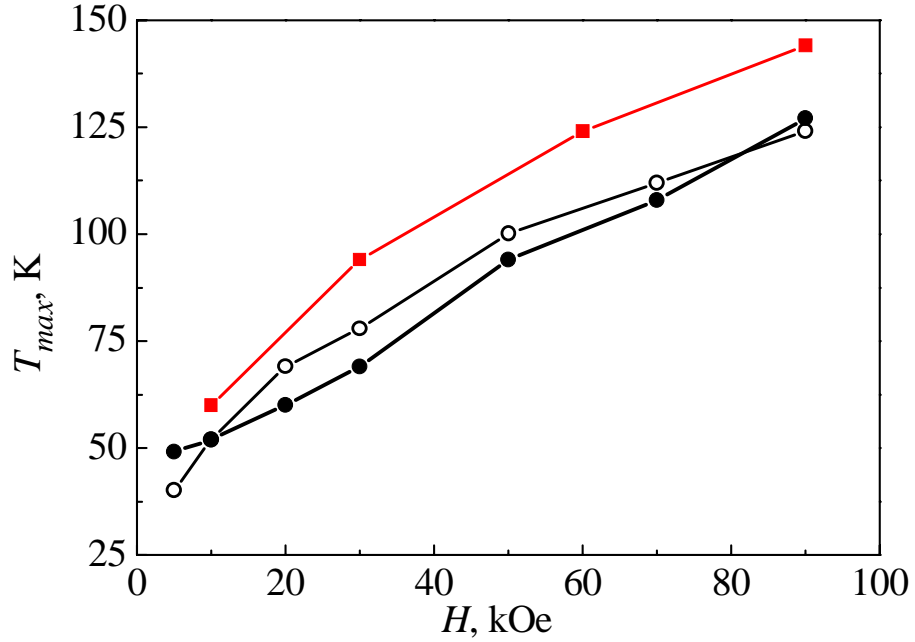


Fig. 3. (Color online) The magnetic-field dependencies of the maximum temperatures of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ for the configuration $\mathbf{H} \perp \mathbf{I}$ (\circ) and $\mathbf{H} \parallel \mathbf{I}$ (\bullet) and $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ for the configuration $\mathbf{H} \perp \mathbf{I}$ (\blacksquare).

We had the measurements results of $R(T)$ of pure bismuth for the $\mathbf{H} \perp \mathbf{I}$ configuration in a field of 30 kOe, and it was decided to compare them with the dependences for $\text{Bi}_{88.08}\text{Mn}_{11.92}$ and $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ (Figure 4). It is clearly seen in the figure that the temperature dependences for $\text{Bi}_{88.08}\text{Mn}_{11.92}$ (Fig. 4, red triangles) and $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ (Fig. 4, blue squares) are qualitatively very similar and differ only in the maxima temperature, which is higher in the compound with a lower manganese concentration - $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$. The dependence of $R(T)$ for pure bismuth (Fig. 4, black circles) is fundamentally different. There is no maximum and the semiconductor behavior of electrical resistance (growth of ohmic losses with decreasing temperature) is observed in a wide temperature range with subsequent saturation below 16 K. It is possible that the maximum and electrical resistance drop will appear at temperatures below liquid helium temperature.

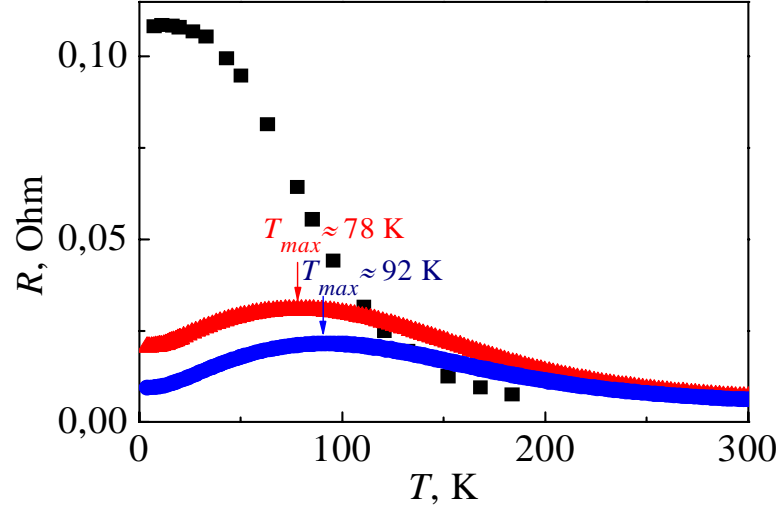


Fig. 4. (Color online) The temperature dependences of electrical resistance of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ (\blacktriangle), $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ (\bullet) and pure bismuth (\blacksquare) for the configuration $\mathbf{H} \perp \mathbf{I}$ (a) in the magnetic field 30 kOe.

Magnetoresistance temperature dependences.

Fig. 5 shows the temperature dependences of the relative magnetoresistance $\Delta R/R_0 = [R(H) - R(H=0)] / R(H=0)$ of solid solution $\text{Bi}_{88.08}\text{Mn}_{11.92}$ for configurations $\mathbf{H} \perp \mathbf{I}$ (a) and $\mathbf{H} \parallel \mathbf{I}$ (b) in magnetic fields up to 90 kOe. Magnetoresistance is positive at all temperatures and magnetic fields. At the same time, with growing magnetic field, the magnetoresistance increases as expected at all temperatures for the $\mathbf{H} \perp \mathbf{I}$ configuration (Fig. 5a). Clearly expressed maxima on $\Delta R/R_0(T)$ appear starting from fields of 20 kOe. For weaker fields $\Delta R/R_0(T)$ increases with decreasing temperature and these dependences are practically saturated below 25 K. Temperature dependences of magnetoresistance for configuration $\mathbf{H} \parallel \mathbf{I}$ (Fig. 5b) behave in a similar way as for $\mathbf{H} \perp \mathbf{I}$ in fields of 5, 10, 20 and 30 kOe, namely, the magnetoresistance increases with increasing field for all temperatures. Above the maximum temperatures, the magnetoresistance also increases with increasing field at all temperatures. However, for stronger fields of 50, 70 and 90 kOe below maximum temperatures, an inverse relationship is observed, namely: the magnetoresistance decreases with growing field (Fig. 5b).

For comparison, Table 1 presents the maximum values of the relative magnetoresistance $\Delta R/R_0$ of the $\text{Bi}_{88.08}\text{Mn}_{11.92}$ и $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ for configurations $\mathbf{H} \perp \mathbf{I}$ and $\mathbf{H} \parallel \mathbf{I}$ in a field of

90 kOe. It can be seen that the value of $\Delta R/R_0$ is noticeably higher in the material with a higher concentration of manganese - $\text{Bi}_{88.08}\text{Mn}_{11.92}$ for both one and the other magnetic field configuration.

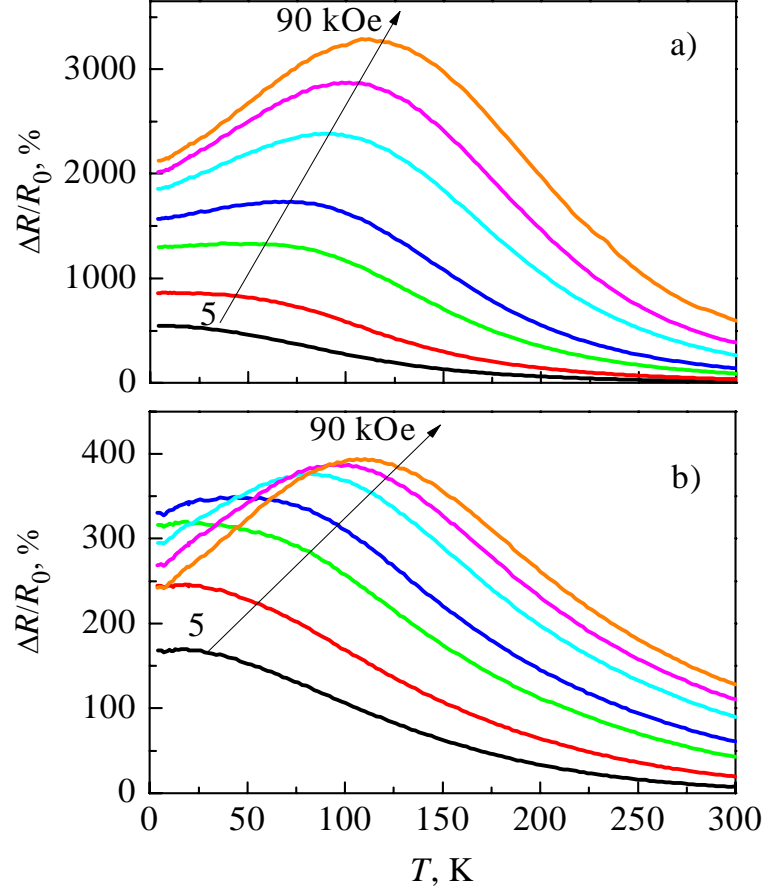


Fig. 5. (Color online) The temperature dependences of the relative magnetoresistance $\Delta R/R_0 = [R(H) - R(H=0)] / R(H=0)$ of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ for the configuration $\mathbf{H} \perp \mathbf{I}$ (a) and $\mathbf{H} \parallel \mathbf{I}$ (b) at fixed magnetic fields, kOe: 5, 10, 20, 30, 50, 70 and 90.

Table 1. Maximum values of the relative magnetoresistance $\Delta R/R_0$ of the $\text{Bi}_{88.08}\text{Mn}_{11.92}$ and $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ for configurations $\mathbf{H} \perp \mathbf{I}$ and $\mathbf{H} \parallel \mathbf{I}$ in a field of 90 kOe.

Material	$\Delta R/R_0$, $\mathbf{H} \perp \mathbf{I}$ 90 kOe	$\Delta R/R_0$, $\mathbf{H} \parallel \mathbf{I}$ 90 kOe
$\text{Bi}_{88.08}\text{Mn}_{11.92}$	3290	390
$\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$	2880	235

Discussion

To date, there is no generally accepted theory of electrical conductivity in Bi-Mn solid solutions. However, we will try to present an explanation of the processes taking place in this compound, at least at the level of phenomenology.

The appearance of maxima (insulator-metal transition) in the temperature dependences of electrical resistance in a magnetic field can be explained within the framework of a multi-band model [22]. This model considers the presence of several channels of charge carriers (electrons and holes), competition between which leads to the appearance of either semiconductor or metallic behavior of the temperature dependences of electrical resistance in a magnetic field. We believe that the existence of such a mechanism in our samples is highly probable. Let us discuss it in detail. According to modern concepts, bismuth has a rather complex band structure. The Fermi surface of bismuth consists of one hole pocket at the T-point and three electron pockets at the L-points in the first Brillouin zone of the rhombohedral cell [6]. These three equivalent electron pockets can be considered as triply degenerate electron valleys in a zero magnetic field. Due to the strongly anisotropic shape of the electron pockets, the threefold degeneracy of the valleys can be removed in a rotating magnetic field [13,14]. At L-points, bismuth has narrow gap ($E_g \sim 15.3$ meV) between the conduction band and the valence one. At the same time, Bi is a heavy element with a strong spin-orbit splitting at the atomic 6p-levels (the atomic $p_{3/2} - p_{1/2}$ splitting in Bi is 1.5 eV [23]). Bands close to the Fermi level are strongly affected by spin-orbit interaction. The existence of the hole Fermi surface at T-point is due to the strong spin-orbit interaction [24]. Another consequence of the spin-orbit interaction is the so-called projection spin-orbit gap in the Γ -T direction, which corresponds to the normal direction of Bi (111). This projection gap is formed between the p-band, which creates a hole pocket in the T-point, and the p-band with higher binding energy. The strong spin-orbit interaction also leads to the fact that the electrons in the L-point show almost linear dispersion dependence and can be considered as massive Dirac fermions. At the same time, the application of a magnetic field in certain directions can first reduce the gap at the L-points [14], and then cause level crossing as the field increases [25]. As the field increases further, the hole and electron subbands will shift in opposite directions, and eventually an insulator-metal transition will occur [26,27]. Thus, a magnetic field of a certain magnitude and direction can lead to changes in the band structure, which initiate the predominance in some temperature intervals of the contribution to conduction from hole charge

carriers, and in others from electronic ones. Consequently, either semiconductor or metallic nature of the temperature dependence of the electrical resistance in a magnetic field appears.

The material $\text{Bi}_{88.08}\text{Mn}_{11.92}$ studied in this work is a bismuth matrix with magnetic αBiMn phase inclusions. The internal magnetism of this phase in solid solutions $\text{Bi}_{88.08}\text{Mn}_{11.92}$ and $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ has an additional effect on the zone structure of the bismuth matrix and, as a consequence, leads to the appearance of specific temperature dependences of electrical resistance in magnetic field, which differ significantly from those observed in pure bismuth. At the same time, the scattering of charge carriers on magnons itself does not cause the metal-insulator transition, but can only slightly change the dependence in the temperature region, where the metallic behavior of electrical resistance exists. Magnon scattering often leads to the appearance of the $R \sim T^2$ dependence in the low temperature region [28]. In the absence of a magnetic field in pure bismuth and in $\text{Bi}_{88.08}\text{Mn}_{11.92}$, as discussed above also at low temperatures $R \sim T^2$ (Fig.1). The power law dependence of $R \sim T^2$ in pure bismuth is explained either by the appearance of a specific mechanism of electron-phonon scattering characteristic of bismuth and some other semimetals (the so-called intervalley electron-phonon scattering) [29] or by electron-hole scattering [21,30,31]. That is, the dependencies can differ only in the coefficient at T^2 and they are difficult to separate. It is interesting to compare the temperature dependences of electrical resistivity that were plotted in the absence of magnetic field for pure bismuth and $\text{Bi}_{88.08}\text{Mn}_{11.92}$ (Figure 1). These dependences differ significantly from each other, which may be a consequence of the presence of magnetic αBiMn phase inclusions in $\text{Bi}_{88.08}\text{Mn}_{11.92}$. The temperature dependences of the electrical resistivity of bismuth and $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ compound with a low magnetic phase content are very similar down to 120 K (have a similar linear dependence). The $R(T)$ dependences are very different for the compound with high αBiMn content - $\text{Bi}_{88.08}\text{Mn}_{11.92}$ and for the compound with low magnetic phase content - $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$. Comparison of temperature dependences of electrical resistance and magnetoresistance of these compounds in magnetic field also shows a significant difference in the temperatures of maxima, the form of dependences and the magnitude of relative magnetoresistance. All this confirms a noticeable influence of magnetic inclusions of the αBiMn phase on the electrical conductivity of Bi-Mn solid solutions.

Note that there are also more exotic mechanisms that can lead to the appearance of the metal-insulator transition in pure bismuth and in Bi-Mn solid solutions. Thus in [32] it was shown that in bismuth even in relatively small field (up to 30 kOe), phenomena similar to

magnetic breakdown (quantum tunneling of charge carriers in a magnetic field between different energy bands) can be observed when measuring along selected directions. In [33–35], the insulator-metal transition in a magnetic field is associated with the manifestation of the so-called Bose metallic state in which exciton and superconducting instabilities coexist. It is also not excluded that a change in the magnetic structure of the α BiMn phase, below 100 K, can lead to the appearance of appreciable magnetostriction and, as a consequence, to a change in the conductive properties of the whole compound $\text{Bi}_{88.08}\text{Mn}_{11.92}$ or $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$.

The presence of strong anisotropy of the temperature dependences of the electrical resistivity of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ can be explained in the same way as it was done for pure bismuth. As it was shown in [33], the behavior of electrical resistance changes most of all in a transverse magnetic field when $\mathbf{H} \perp \mathbf{I}$. In this case, the magnetic field distorts the trajectory of the charge carriers (orbital effect) and, at the same time, spin-dependent scattering of the carriers is observed. In the case of $\mathbf{H} \parallel \mathbf{I}$, the orbital effect is significantly suppressed and practically only the magnetoresistance associated with spin-dependent carrier scattering is observed. Although the main mechanism of the anisotropy of the temperature dependence of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ is the same as in pure bismuth, the internal magnetism that occurs in $\text{Bi}_{88.08}\text{Mn}_{11.92}$ can also affect the anisotropy. The nature of this effect is not yet known and we plan to study it thoroughly.

In the near future, it is also planned to study the magnetic field dependences of electrical resistance at different temperatures for a better understanding of the mechanisms influencing the behavior of magnetoresistance in $\text{Bi}_{88.08}\text{Mn}_{11.92}$. It is important to study the Hall effect, which can provide answers to a number of questions related to the interaction of charge carriers from different subbands in a magnetic field [22,36]. Of great interest is also the theoretical and experimental study of changes in the band structure of bismuth (using ARPES) occurring in Bi-Mn solid solutions.

Conclusions

For the first time, a comprehensive analysis of the behavior of the resistance of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ in a magnetic field of up to 90 kOe was carried out in comparison with $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ and pure bismuth.

It was found that the temperature dependency of the electrical resistance without a magnetic field for the solid solution of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ differs significantly from that for pure bismuth and the compound $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$ with a lower manganese content.

It has been shown that in a magnetic field, the temperature dependences of the electrical

resistance of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ show maxima (insulator-metal transition) for both the $\mathbf{H} \perp \mathbf{I}$ and $\mathbf{H} \parallel \mathbf{I}$ orientations. The temperatures of the maxima increase with increasing field.

It has been established that the magnetoresistance for $\text{Bi}_{88.08}\text{Mn}_{11.92}$ is positive in the entire temperature range studied. At the same time, in a magnetic field of 90 kOe, it is significantly higher than in a solid solution with a lower manganese content $\text{Bi}_{95.69}\text{Mn}_{3.69}\text{Fe}_{0.62}$.

There is anisotropy of temperature dependences of electrical resistance and magnetoresistance of $\text{Bi}_{88.08}\text{Mn}_{11.92}$ in a magnetic field for $\mathbf{H} \perp \mathbf{I}$ and $\mathbf{H} \parallel \mathbf{I}$.

It is suggested that the peculiarities temperature dependences behavior of the electrical resistance $R(T)$ in $\text{Bi}_{88.08}\text{Mn}_{11.92}$ without magnetic field and in the one, are largely due to the influence of the internal magnetism of the αBiMn phase and can be explained within the framework of the multiband theory.

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