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CHANGE IN MAGNETORESISTANCE IN MANGANESE CHALCOGENIDES $MnSe_{1-X}Te_X$ FROM BULK TO THIN-FILM SAMPLES

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The electrical and optical properties of anion-substituted antiferromagnetic semiconductors MnSe1-XTeX ($0.1 \le X \le 0.4$) in the temperature range 77-300 K and magnetic fields up to 13 kOe in bulk samples and in polycrystalline thin films are investigated. Negative magnetoresistance was found in the MnSe1-XTeX solution in the neighbourhood with a Néel temperature for X = 0.1 and for a composition with X = 0.2 in the paramagnetic region up to 270 K. A correlation was established between the spin-glass state and magnetoresistance for X = 0, 1 and 0.2. The optical absorption spectra were measured in the frequency range 2000 cm-1 < ω < 12000 cm-1. A decrease in the gap in the spectrum of electronic excitations and a several of absorption peaks near the bottom of the conduction band were found. Coexistence of two crystalline phases was found in polycrystalline films of the MnSe1-XTeX system by X-ray diffraction analysis. Resistance maxima were established in the region of polymorphic and magnetic transitions. A model of localized spin-polarized electrons with a localization radius varying in a magnetic field as a result of competition between ferromagnetic and antiferromagnetic interactions is proposed. In the paramagnetic region, negative magnetoresistance is caused by tunneling of spin-polarized electrons during orbital ordering.

Keywords: manganese chalcogenides, magnetoresistance, conductivity, thin films, current-voltage curve.

ИЗМЕНЕНИЕ МАГНИТОСОПРОТИВЛЕНИЯ В ХАЛЬКОГЕНИДАХ МАРГАНЦА $MnSe_{1-X}Te_X$ ПРИ ПЕРЕХОДЕ ОТ ОБЪЕМНЫХ ОБРАЗЦОВ К ТОНКОПЛЕНОЧНЫМ

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Исследованы электрические и оптические свойства анион-замещенных антиферромагнитных полупроводников MnSe1-XTeX ($0,1 \le X \le 0,4$) в области температур 77–300 К и магнитных полей до 13 кЭ в объемных образцах и поликристаллических тонких пленках. В твердых растворах MnSe1-XTeX обнаружено отрицательное магнитосопротивление в окрестности температуры Нееля для X = 0,1 и для состава с X = 0,2 в парамагнитной области до 270 К. Установлена корреляция спин-стекольного состояния и магнитосопротивления для X = 0,1 и 0,2. Измерены спектры оптического поглощения в интервале частот 2000 см-1 < ω < 12000 см-1. Обнаружено уменьшение щели в спектре электронных возбуждений и ряд пиков поглощения вблизи дна зоны проводимости. В поликристаллических пленках системы MnSe1-XTeX найдено сосуществование двух кристаллических фаз методом рентгеноструктурного анализа. Обнаружены максимумы сопротивления в области полиморфного и магнитного переходов. Предложена модель локализованных спин-поляризованных электронов с радиусом локализации, меняющимся в магнитном поле в результате конкуренции ферромагнитных и антиферромагнитных взаимодействий. В парамагнитной области отрицательное магнитосопротивление вызвано туннелированием спин-поляризованных электронов при орбитальном упорядочении.

Ключевые слова: халькогениды марганца, магнитосопротивление, проводимость, тонкие пленки, ВАХ.

Introduction. To control spacecraft in extreme conditions with a temperature difference of two hundred or three hundred degrees, it is necessary to create elemental electronic microelectronics that operates in these conditions. Traditional electronics operates on silicon and germanium semiconductors operating with an electron charge. But the electron has a spin and orbital angular momentum, which is used in spintronics, which takes advantage of both non-volatile magnetic memory and high-speed electrical information processing systems. In spintronics [1; 2], to convert an electric signal, not only the charge degree of freedom of an electron is used, but also a spin, which allows creating fundamentally new spintronic devices. The electron has orbital degrees of freedom, acting on which it is also possible to regulate the transport and dielectric characteristics in a magnetic field

In chalcogenides, there is a relationship between the parameters of the magnetic and electrical subsystems [3–7] and the effect of magnetoresistance [8–12]. To date, manganese oxide compounds (manganites of the $LaMnO_3$ type) [13–17], europium chalcogenides, $CdCr_2Se_4$, and $HgCr_2Se_4$ selenides [18–20] are being intensively studied. In the MeXMn1-XS sulfide systems (Me = 3d metal) synthesized on the basis of α-MnS monosulfide and undergoing the metal – insulator transition [21–24], the CMR effect was found to be comparable with its value in manganites [25–28].

Manganese chalcogenides MnSe and MnTe are antiferromagnets (AFM) and undergo structural and magnetic transitions with an increase in the degree of hybridization of manganese cations with Se and Te anions [29; 30]. The change of the transport properties from the semiconductor to metal at the temperature near the room one. MnTe crystallizes in a hexagonal structure of the NiAs type [29]. Mn manganese monoselenide MnSe exhibits a structural phase transition from the cubic phase to the NiAs structure in the temperature range 248 K < T < 266 K [30], and below this temperature phase coexistence is observed in the sample.

The antiferromagnet MnTe consists of ferromagnetically ordered spins in the plane that are oriented antiferromagnetically along the hexagonal axis. The spins are located in the base plane and have anisotropy of the light plane type with a Néel temperature T = 340 K [31]. For MnSe, the Néel temperature in the cubic modification is TN = 135 K, and in the hexagonal NiAs phase it coincides with the structural transition temperature TS = 272 K. Manganese chalcogenides are semiconductors with p – type conductivity, which have an energy gap in the spectrum of single particle electronic excitations for MnSe (2.0–2.5) eV and MnTe (0.9–1.3) eV with polaron type charge carriers [32]. The effect of magnetoresistance in a magnetically ordered cubic phase was detected on MnSe samples when approaching the Néel temperature with the electrical resistivity ρ = 104 – 103 Ohm · cm [33]. A decrease in the metal – anion Mn–Te bond length, according to theoretical calculations of the band structure [34], induces a change in the crystal structure from hexagonal to cubic with antiferromagnetic ordering with a binding energy of one Mn–Te pair EZB, H = −0.31 eV/bond with bond length RAF = 2.70 Å, and with ferromagnetic ordering EZB, H = −0.51 eV/bond with RF = 2.71 Å. In the NiAs structure, the bond length is R(Mn–Te) = 0.273 Å. The lattice constant a = 5.44 Å in MnSe with a NaCl structure is somewhere in the middle between 2RF and 2RH; therefore, when selenium is replaced by tellurium at low concentrations, the formation of Mn-Te-Mn ferromagnetic bonds with anisotropy of the light plane type is possible. As a result, the formation of the angular phase and enhancement of the magnetoresistive effect in anion-substituted $MnSe_{1-X}Te_X$ solid solutions are possible. Substitution of selenium with tellurium leads to suppression of the hexagonal phase and to the single-phase state of the $MnSe_{1-X}Te_X$ system with a face-centred cubic structure with space group (225) [35] in the temperature range 120 K < T < 300 K and in the concentration range $0.1 \le X \le 0, 4$ [36]. Local non-correlated lattice deformations are possible, which will cause a change in the electronic structure and a change in resistance during the hopping type of conductivity along with changes in the magnetic properties [37–38].

The aim of this work is to detect the magnetoresistive effect and to elucidate the microscopic mechanism of the influence of the magnetic field on the transport properties of MnSe1-XTeX solid solutions ($0.1 \le X \le 0.4$) based on a comprehensive study, electrical resistivity, current-voltage characteristics and optical absorption spectra depending on temperature and magnitude of the magnetic field.

Materials and research methods. The electrical resistivity is measured by a standard four-probe compensation method using direct current in the temperature range 77–300 K in a magnetic field of up to 13 kOe. Fig. 1 shows a temperature dependence of the resistance of $MnSe_{1-X}Te_X$ solutions for all compositions ($0.1 \le X \le 0.4$). At $T < T_N$, a deviation from the linear dependence $\ln\rho = \ln\rho_0 + \Delta E/T$ is observed. The activation energy $\Delta E \approx$ (0.07–0.09) eV is practically independent of the composition in these samples.

The effect of a magnetic field on transport properties was investigated in two ways. First, the change in resistance was measured by the temperature of $MnSe_{1-X}Te_X$ solid solutions located both in a magnetic field and in its absence. Secondly, at a fixed temperature, the current-voltage characteristics were studied in a zero magnetic field and in a field H = 13 kOe. Fig. 2 shows the current-voltage characteristics of manganese chalcogenides $MnSe_{1-X}Te_X$ for composition X = 0.1 at temperatures (100, 140 and 190 K). The $U(I)$ dependences are linear and independent of the magnitude of the magnetic field at T < 100 K. It was established that the resistance of the samples decreases in the magnetic field and the greatest change (about 100 %) was found in the neighbourhood of the Néel temperature for a composition with X = 0.1 (fig. 3, *a*). For a concentration with X = 0.2, a decrease in resistance was found in the paramagnetic region at a temperature above the Néel temperature and in the temperature range 160 K < T < 270 K is 5 % (fig. 3, *b*). For high concentrations, magnetoresistance (MR) was not detected.

The magnetic moment of the samples was measured in a magnetic field of 0.8 T in the temperature range 80 K < T < 700 K in two modes: cooling in a zero magnetic field and in a magnetic field of 0.8 T.

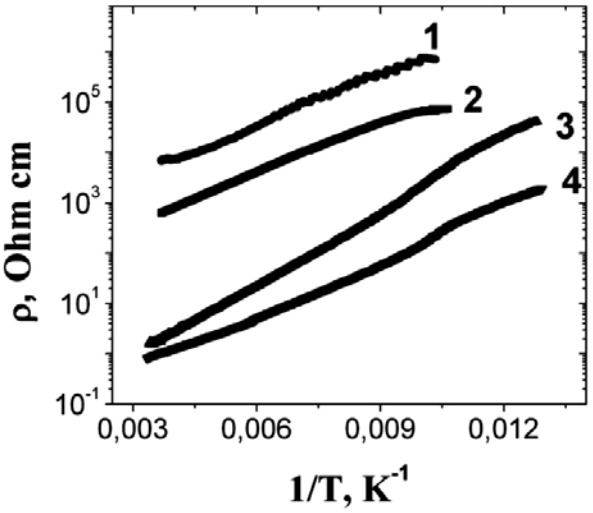

Fig. 1. Temperature dependence of the electrical resistivity $MnSe_{1-X}Te_X$ solutions with concentration of $X = 0.1$ (1), 0.2 (2), 0.3 (3), 0.4 (*b*)

Рис. 1. Температурные зависимости удельного электросопротивления для твердых растворов $MnSe_{1-X}Te_X$ с концентрацией замещения $X = 0{,}1$ (1), 0,2 (2), 0,3 (3), 0,4 (*b*)

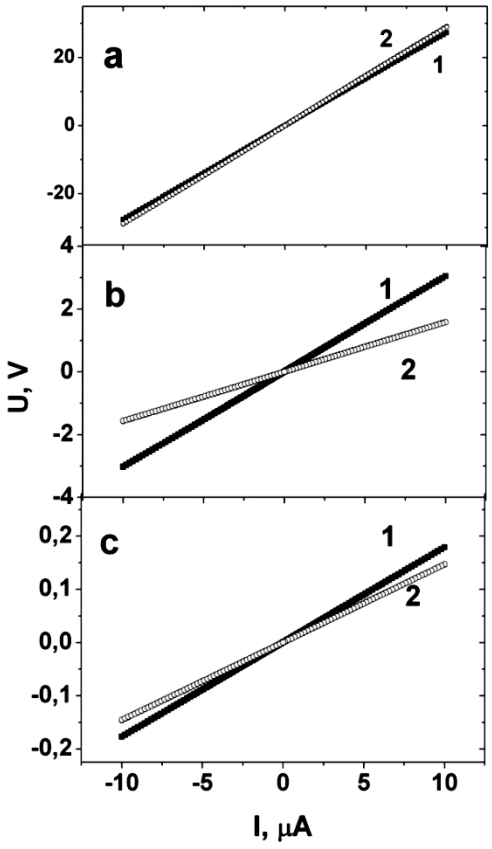

Fig. 2. The current-voltage characteristic of the $MnSe_{1-X}Te_X$ solid solution ($X = 0.1$) in a magnetic field $H = 1$ T (2) and in a zero magnetic field (1) at different temperatures T: 100K (*a*), 140K (*b*), 190K (*c*)

Рис. 2. Вольт-амперная характеристика твердого раствора $MnSe_{1-X}Te_X$ ($X = 0{,}1$) в магнитном поле $H = 1$ Т (2) и в нулевом магнитном поле (1) при разных температурах T: 100 К (*a*), 140 К (*b*), 190 К (*c*)

The dependence of the susceptibility on the history of the sample was found. Thus, the susceptibility of a sample cooled in a magnetic field is lower compared to a sample in a zero field. The relative change in the magnetic moment $(\sigma(H)-\sigma(0))/\sigma(0)$ is shown in fig. 3 (curves 3 and 4) and is in qualitative agreement with the temperature behavior of the magnetoresistance.

For $X = 0.1$, the relative change in the magnetic moment sharply increases in the neighbourhood of the Néel temperature and decreases in absolute value at $T = 220$ K, where the magnetoresistance disappears. For a composition with $X = 0.2$, a quantitative agreement is observed between the change in the magnetic moment and magnetoresistance as a function of temperature. The paramagnetic Curie temperature (θ), determined from the high-temperature inverse susceptibility, gradually decreases with increasing concentration of tellurium. In the molecular field approximation, $\theta = 2/3S(S + 1)zJSe$ for MnSe and for low concentrations, the paramagnetic Curie temperature of the $MnSe_{1-X}Te_X$ solid solution can be represented as $\theta = 2/3S(S + 1)(zJSe(1 - x) + JTex)$ or the normalized dependence $\theta(x)/\theta(MnSe) = 1 + x(\lambda - 1)$ is used to determine the sign of the exchange J(Mn-Te-Mn). The fitting functions with the ratio of the exchange parameters λ = J(Mn-Te-Mn)/J(Mn-Se-Mn) = –1.25 and –0.25 describe the experimental results well. For concentrations X <0.3, the sign of the exchange interaction changes to ferromagnetic with a decrease in the exchange value with increasing bond length, according to the theoretical prediction [34].

The formation of polarons or regions with a high concentration of electron density can be traced from the optical absorption spectra shown in fig. 4 for compositions $X = 0.2$ and 0.4 in the energy range 2000–12 000 cm^{-1}. Electromagnetic radiation can be absorbed by charge carriers during interband transitions, free charge carriers within the same energy zone and crystal lattice vibrations. The low-energy absorption spectrum provides information on phonon spectra and plasmon vibrations in semiconductors, in the high-energy region, on the band gap, on the structure of the valence band and the conduction band near their extrema. For frequencies $\omega < 5000$ cm^{-1}, an increase in the absorption of electromagnetic radiation is observed, caused by an increase in the electron concentration and metallization of the samples. However, these compositions of $MnSe_{1-X}Te_X$ solid solutions retain the activation type of conductivity. A sharp decrease in the absorption intensity below the maximum with energy $\omega = 9700$ cm^{-1} for $X = 0.4$ corresponds to the band gap of MnTe $\omega = 9100$ cm^{-1}. Those. at this concentration, Mn-Te-Mn bonds flow along the lattice. Near the bottom of the conduction band, additional absorption maxima are observed with $\omega_1 = 6300$ cm^{-1} and with $\omega_2 = 8700$ cm^{-1}, located in energy below the bottom of the conduction band by $\Delta E_1 = 3400$ cm^{-1} and $\Delta E_2 = 1000$ cm^{-1}. Possibly, these lines correspond to bound states of an electron and a hole, which form a hydrogen-like spectrum of excitons. The spectral line energies are described by the formula $E_n = 1.2–0.42/n^2$ eV with exciton binding energy $E_b = 0.42$ eV. We estimate the exciton radius from the formula $Rn = n^2\varepsilon m a_B/\mu$, where m is the mass of a free electron, a_B is the Bohr radius of the hydrogen atom, ε is the high-frequency permittivity for a small-radius exciton ε = 8 for MnSe [39], μ is the reduced electron and hole mass. For $\mu = 0.5m$, the exciton radius is $R_1 = 0.8$ nm = = 1.4 Å. Small-radius excitons move through the Mn-Te system and, at different effective masses of the electron and hole, contribute to the conductivity.

Magnetoresistance model. When anionic substitution occurs, chemical pressure and a change in the crystal field of the octahedron arise as a result of the difference in the ionic radii of selenium and tellurium. At low concentrations, when the octahedron consists of five selenium atoms and one tellurium atom, the bond lengths in the octahedron become not equivalent, which leads to a local increase in the crystal field and a change in the electron density between t_{2g} and e_g orbitals, i. e. to the formation of an electron on the t_{2g} orbital and a hole on the e_g orbital and to a change in the spin state of manganese ions in the neighbourhood of tellurium ions. The sign of the exchange interaction will also change as a result of the double exchange of electrons in e_g orbitals and the kinetic exchange in the t_{2g} subsystem. Distortion of the octahedron induces the splitting of t_{2g} and e_g orbitals with different projections of the $+–L^z$ orbital momentum onto the selected axis. The energy of the deformed octahedron decreases as a result of the rotation of the octahedra in the temperature range 200–250 K depending on the tellurium concentration and with a further decrease in temperature, it is possible that the manganese ions shift with a local change in the lattice symmetry, for example, of the orthorhombic type.

The microscopic model can be represented as ferromagnetic clusters in the neighbourhood of tellurium ions with a random orientation of the anisotropy axes and with orbital moments. In the $MnSe_{1-X}Te_X$ solid solution, we distinguish two temperature ranges, for $X = 0.1$ in the vicinity of the Néel temperature and for $X = 0.2$ in the paramagnetic region above the Néel temperature. For a composition with $X = 0.1$, the magnitude of the ferromagnetic exchange in the clusters exceeds the antiferromagnetic exchange in the MnSe matrix and an angular phase forms with a random orientation of the weak magnetic moment in the cluster in the antiferromagnetic region. When heated, the interaction between the clusters decreases, and the magnetic moments are oriented in the direction of the magnetic field, as a result, the ferromagnetic spin-spin correlation function along the transverse components of the spin increases, and the correlation radius increases. Above the Néel temperature, spin-spin correlations and the correlation radius decrease as a result of thermal fluctuations of the spin moment. In the off-diagonal Anderson model, this corresponds to a change in the width of the potential well and is associated with the temperature dependence of the electron localization radius in the form $\xi = A\left|1 - T/T_N\right|$. The magnetoresistance in semiconductors, the conductivity of which is described in a model with a variable jump length, has an exponential dependence

$$\left(\rho(H) - \rho(0)\right)/\rho(0) = \exp\left(-BH\xi\right) - 1 = \\ = \exp\left(-BH/\left|(1 - T/T_N)\right|\right) - 1, \quad (1)$$

where B is the parameter, H is the external magnetic field, ξ is the electron localization radius [40, 41]. The experimental data on magnetoresistance are satisfactorily described in the framework of this model with a field H = 0.8 T and a parameter B = 0.13 T^{-1} for $T > T_N$, and B = 0.05 T^{-1} in the magnetically ordered region. The fitting functions are shown in fig. 3, *a*, curve 5.

For the composition X = 0.2, the magnitude of the ferromagnetic exchange is much smaller than the antiferromagnetic interaction and the electrons are localized within the lattice constant, in potential wells, the width of which is fixed and the potential barrier varies with temperature. Here, one can use the model of tunneling of spin polarized electrons between potential wells in the form

$$\left(\rho(H)-\rho(0)\right)/\rho(0)=1/\left(1+xP_1P_2\cos\theta\right)-1, \quad (2)$$

where x is the concentration of the wells, $P_{1,2}$ is the degree of polarization of the electrons, the angle θ between the axes of polarization of the electrons. The spin polarization of electrons is due to orbital ordering. Suppose that the polarization value $P_{1,2}$ is the same for all clusters and disappears at a temperature of orbital ordering T_0 according to a power law $P_{1,2} = P_0(1-T/T_0)^{1/4}$. To qualitatively understand the processes of electron tunneling between clusters with polarization axes are in the range of angles from $0 < \theta < \pi$, we consider a simple model when the anisotropy field H_A is parallel to and orthogonal to the external magnetic field. As a result of competition between the Zeeman interaction and the anisotropy field, the electron spin (polarization direction) will rotate in the direction of the external magnetic field with increasing temperature.

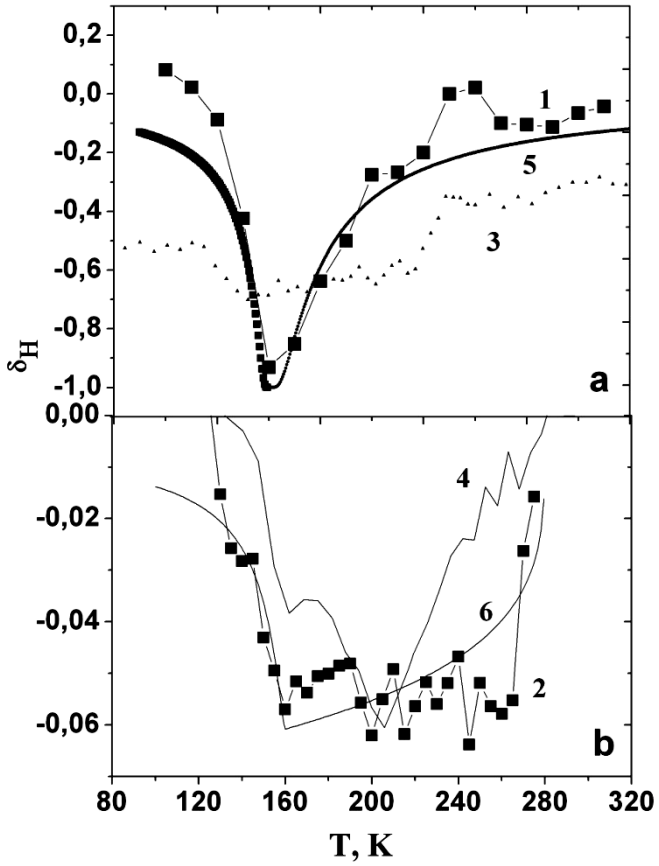

Fig. 3. Temperature dependences of the magnetoresistance of $MnSe_{1-X}Te_X$ chalcogenide with X = 0.1 (1) (*a*) and 0.2 (2) (*b*) at H = 13 kOe. The relative change in the magnetic moment σ (H) – σ (0) / σ (0) for X = 0.1 (3) and X = 0.2 (4). Fitting functions: for a concentration of X = 0.1 (5) from equation (1) at H = 0.8 T, B = 0.13 T^{-1} in the region of $T > T_N$, and B = 0.05 T–1 in $T < T_N$; for X = 0.2 (6) from equation (5) with parameters T_0 = 280 K, T^* = 160 K, n = 2/3, λ = 0.1, cluster concentration x = 0.08

Рис. 3. Температурные зависимости магнитосопротивления халькогенида $MnSe_{1-X}Te_X$ с X = 0,1 (1) (*a*) и 0,2 (2) (*b*) при H = 13 кЭ. Относительное изменение магнитного момента σ (H) – σ(0)/σ(0) для X = 0,1 (3) и X = 0,2 (4). Подгоночные функции: для концентрации X = 0,1 (5) из уравнения (1) при H = 0,8 Т, B = 0,13 Т – 1 в области $T > T_N$, и B = 0,05 Т–1 в $T < T_N$; для X = 0,2 (6) из уравнения (5) с параметрами T_0 = 280 K, T^* = 160 K, n = 2/3, λ = 0,1, концентрация кластеров x = 0,08

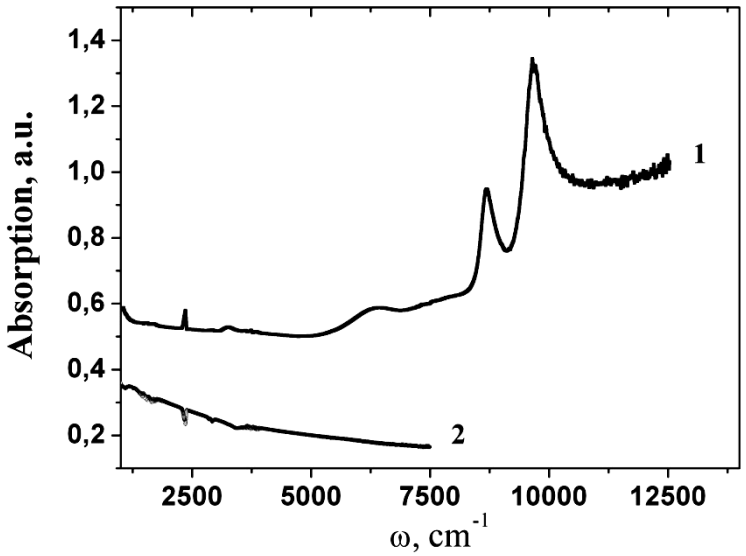

Fig. 4. Optical absorption spectra for $MnSe_{1-X}Te_X$ solid solutions with $X = 0.2$ (1), 0.4 (2) at $T = 300$ K

Рис. 4. Спектры оптического поглощения для твердых растворов $MnSe_{1-X}Te_X$ с $X = 0{,}2$ (1), 0,4 (2) при $T = 300$ К

The correlation between the spins is determined by orbital ordering. The energy of the magnetic system has the form

$$E = -SH\cos\theta - SH_A\cos(\gamma - \theta), \qquad (3)$$

where H_A is the anisotropy field, γ is the angle between the external magnetic field and the anisotropy field. The minimum energy value is achieved at an angle of:

$$\cos\theta = 1/\sqrt{\left(1 + H_A^2\sin^2\gamma/\left(H + H_A\cos\gamma\right)^2\right)}. \qquad (4)$$

The anisotropy field decreases with increasing temperature according to a power law in the form $H_A = K(1 - T/T^*)^n$, where T^* is the temperature at which the anisotropy field caused by rhombic distortion disappears. The ratio of the magnetic field to the anisotropy constant is denoted by $\lambda = H/K$. Then the temperature dependence of the magnetoresistance is presented in the form

$$\left(\rho(H) - \rho(0)\right)/\rho(0) =$$
$$= 1/\left(1 + xP_0^2\left(1 - T/T_0\right)^{1/2}/\sqrt{\left(1 + \left(1 - T/T^*\right)^{2n}/\lambda^2\right)}\right). \qquad (5)$$

In fig. 3, *b*, function (5) describes the experimental results with parameters $T_0 = 280$ K, $T^* = 160$ K, $n = 2/3$, $\lambda = 0.1$, cluster concentration $x = 0.08$. The tunneling model of spin-polarized electrons with orbital ordering explains the experimental results on magnetic properties and magnetoresistance.

The structure and electrical properties of thin films. With a change in the dimension of the system, the physical properties of materials change. In bulk samples of manganese telluride, the resistance is independent of the magnetic field; however, magnetoresistance with a maximum in the region of 200 K was found in thin-film MnTe compounds [42].

Positive magnetoresistance was found in topological insulators [43]. In a bulk Bi_2Te_3 sample, magnetoresistance (MR) is about 15 % at room temperature, and in Bi_2Te_3 thin films the giant MR effect reaches 600 % at room temperature [44; 45]. The observed large MR values at room temperature are directly related to a decrease in the dimension of the topological insulator. The magnetoresistance on 200 nm Bi_2Se_3 films has a linear temperature dependence and is retained in strong magnetic fields, including the high temperature region [46]. The MR effect is explained by the presence of two channels with high carrier mobility, which coexists with the usual bulk channel with a mobility of 60 $cm^2V^{-1}S^{-1}$ at high temperatures in thin Bi_2Se_3 films [47]. With decreasing temperature, the carrier density in the channel with high mobility decreases significantly and free carriers freeze below 85 K, leaving only a conducting bulk channel in the film.

A positive MR may be caused by the competition between the degenerate orbital states of the electron and strong electron correlations [48]. In the vicinity of the transition temperature of the orbitally ordered phase to the paraphase, the "spectral weight" shifts to the Fermi level. In this temperature range, the magnetic field again leads to an increase in the gap width and to stabilization of the orbital order. For narrow-gap semiconductors with a width of $W = 1$ eV, the corresponding temperature for the magnetoresistive effect is $T \approx 600$ K [48].

An increase in the magnetic field resistance in thin films of Sr_2CrWO_6 antiferromagnets is associated with the suppression of the long-range antiferromagnetic order and the formation of a short-range fluctuation region that enhance electron scattering [49].

When passing from bulk to thin-film samples in the MnSe and MnTe chalcogenides, the Néel temperature and activation energy decrease several times [50]. In the MnSe and MnTe films, the cubic structure of NaCl [51]

and the hexagonal NiAs structure [52] stabilize respectively. It is possible to detect an increase in the magnetoelectric effect in polycrystalline thin-film compounds in comparison with bulk samples of the $MnSe_{1-X}Te_X$ system.

Thin film polycrystalline compounds of manganese chalcogenides $MnSe_{1-X}Te_X$ were obtained by flash method deposition of previously synthesized solid solutions on glass slides. The precursors were powders with a grain size of 0.1 to 0.3 mm. Deposition was carried out in a vacuum installation for films deposition of type UVN-71R-2.

The pressure in the reaction chamber during deposition was 10^{-2}–10^{-3} Pa. The temperature of the tantalum evaporator was maintained at ~ 2000 °C. The substrates were located at a distance of 10 cm from the evaporator. The temperature of the substrates was 250–300 °C.

The evaporator temperature was significantly higher than the melting point of the solid solutions. Therefore, when a small mass of material enters the evaporator, it evaporates instantly, which ensures, after crystallization on a substrate located at a considerable distance from the evaporator, the composition and structure corresponding to bulk substances. A device based on shock vibration supplied the precursor to the evaporator. The film thickness ranged from 157 nm to 960 nm. The substrates consisted of quartz.

The X-ray diffraction analysis of the thin-film chalcogenide compounds $MnSe_{1-X}Te_X$ was carried out on a DRON-3 apparatus in CuKα radiation at a temperature of 300 K after they were obtained and after measurements of the magnetic and electrical properties. The structure of thin-film compounds differs from the face-centered cubic structure of bulk polycrystalline $MnSe_{1-X}Te_X$ of the same concentration [51]. According to X-ray diffraction analysis, the substitution of selenium by tellurium in thin-film chalcogenide compounds of the $MnSe_{1-X}Te_X$ system leads to a decrease in the peak intensities characteristic of the cubic structure and leads to the appearance of a nickel – arsenide (NiAs) hexagonal structure. The lattice parameter increases with increasing concentration of the substituting element, and the ratio c/a ~ 1.4 is less than 1.63 characteristic of bulk MnTe with a hexagonal NiAs type structure, which indicates a compression of the hexagonal densely packed structure.

In the temperature dependence of the resistance for $X = 0.1$, a maximum is observed due to the polymorphic transition (fig. 5). With an increase in the concentration of substitution, the maximum is smoothed out. Carrier transfer can occur as a result of electron hopping between domain walls, or due to diffusion of walls. These are activation processes where the electron mobility is determined by the expression $\mu = \mu_0 \exp(-E_a / k_0 T)$, where $\mu_0 = \frac{ba^2\nu}{k_0 T}$, ν is the hopping frequency equal to the phonon frequency (~10^{13} Hz), and a is the distance between domain walls [53]. A process of wall diffusion as a result of interaction with acoustic spin waves is possible. The wall flux is proportional to the diffusion coefficient $j \sim D \sim v\lambda$, where v is the spin wave velocity, λ is the mean free path, which is proportional to the spin correlation radius $\lambda \sim \xi = B/(1 - T/T_N)$.

The more spins deviate from the antiferromagnetic arrangement, the less is the energy loss when moving the wall. The diffusion of domain walls in an antiferromagnetic matrix increases with increasing temperature as $D \sim 1/(1 - T/T_N)$.

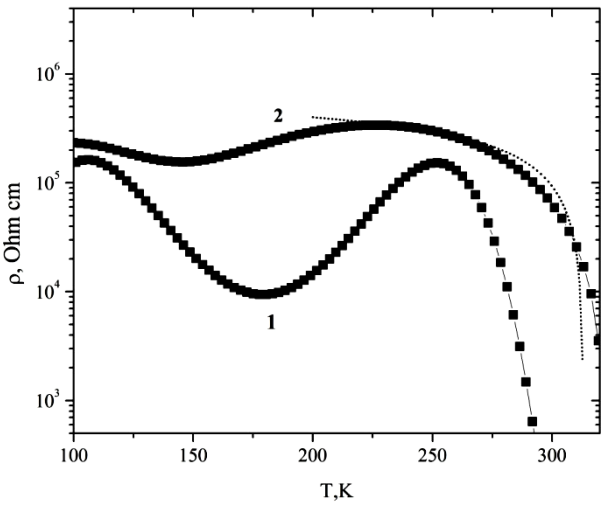

Fig. 5. The temperature dependence of the electrical resistivity for films MnSe0.9Te0.1 (1) and MnSe0.8Te0.2 (2). The dotted line indicates that the temperature dependence of the resistance is described by a power function (6)

Рис. 5. Зависимость электросопротивления от температуры для пленок MnSe0,9Te0,1 (1) и MnSe0,8Te0,2 (2). Пунктирная линия указывает, что зависимость сопротивления от температуры описывается степенной функцией (6)

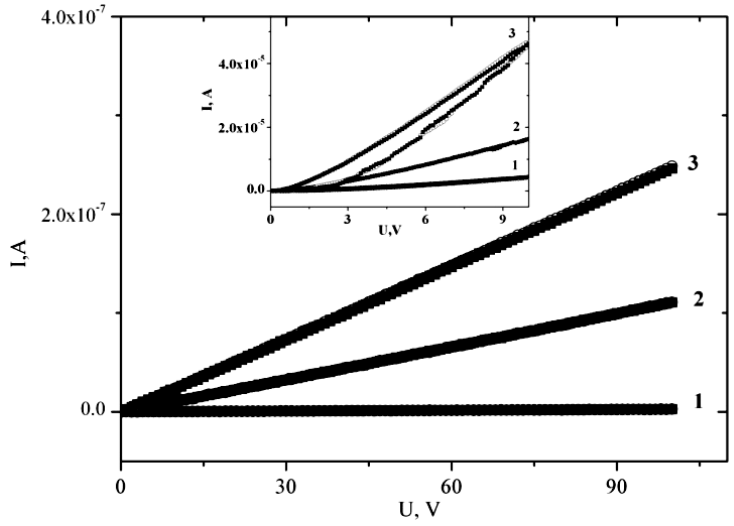

Fig. 6. The current-voltage characteristics measured in a zero magnetic field (empty circles) and field 12 kOe (black circles). MnSe0.9Te0.1 at T = 80 K(1), 180 K(2) and 220 K(3).
Insert: MnSe0.8Te0.2 at T = 80 K(1), 180 K(2) and 280 K(3)

Рис. 6. Вольт-амперные характеристики, измеренные в нулевом магнитном поле (светлые кружки) и поле 12 кЭ (черные кружки). MnSe0,9Te0,1 при T = 80 K (1), 180 K (2) и 220 K (3).
Вставка: MnSe0,8Te0,2 при T = 80K (1), 180K (2) и 280K (3)

The functional dependence of conductivity on temperature is presented in the form

$$\sigma = \frac{A}{T\exp\left(-E_a / kT\right)} + \frac{B}{\left(1-\frac{T}{T_N}\right)}, \qquad (6)$$

where A and B are adjustable parameters. For the composition with X = 0.2, function (1) describes the experimental results with A = 1 10^{-3}, B = 0.4 10^{-6}, E_a = 0.021eV. Above 200 K, the diffusion contribution prevails, and below the hopping carrier tunneling mechanism does.

The existence of domain walls above the polymorphic transition is confirmed from the current–voltage (I–V) characteristics measured at fixed temperatures in a zero magnetic field and in a field of 12 kOe. Fig. 6 shows the I–V characteristics for polycrystalline films of the $MnSe_{1-X}Te_X$ system (X = 0.1 and 0.2). For samples with a low substitution concentration, X = 0.1, the I–V characteristics are linear and independent of the applied field over the entire temperature range. With an increase in the concentration above the polymorphic transition temperature, the I–V characteristic hysteresis is detected, the width of which decreases in a magnetic field and, at voltages above 6 V, the hysteresis width changes by 10–20 %. With an increase in the magnetic field, the density of domain walls decreases and their mobility decreases.

Conclusion. In antiferromagnetic samples of $MnSe_{1-X}Te_X$ with a cubic structure, the effect of magnetoresistance in the neighbourhood of the Néel temperature of about 100 % was found for a composition with a substitution concentration of X = 0.1. The decrease in resistance in a magnetic field is due to an increase in the electron localization radius in potential wells as a result of competition between ferromagnetic and antiferromagnetic interactions and a reduction in the width of the potential barrier. For a composition with X = 0.2, a negative magnetoresistance in the paramagnetic state was discovered, which is caused by the tunneling of spin polarized electrons with orbital ordering and a change in the angle between the directions of polarization of electrons in potential wells as a result of competition between the spin interaction with an external magnetic field and anisotropy field. A correlation was found between the spin-glass behavior of the magnetization of samples cooled in and without a magnetic field and the temperature dependence of the magnetoresistance.

Peaks were found in the optical absorption spectra of $MnSe_{1-X}Te_X$ for a composition with X = 0.4. Near the bottom of the conduction band, there are additional absorption maxima located in energy below the bottom of the conduction band. It is possible that these lines correspond to bound states of an electron and a hole, which form a hydrogen-like spectrum of excitons.

In $MnSe_{1-X}Te_X$ thin polycrystalline films for x < 0.2, magnetoresistance is absent. The existence of domains and domain walls from the hysteresis of the I–V characteristic, which decreases in a magnetic field and is caused by a decrease in the density of domain walls in a magnetic field, is found.

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