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TRANSVERSE MAGNETORESISTANCE OF UNIAXIALLY DEFORMED THIN POLYCRYSTALLINE n-Bi FILMS

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Large influence of uniaxial stretch (strain) S and compression P on transverse and perpendicular resistivity ρ and magnetoresistance (MR) of polycrystalline n-Bi films was investigated. The calculations were performed on the basis of polycrystalline Bi thin film model and electron intervalley repopulation in deformed film crystallites. The calculations show that in n-Bi films the influence of P on ρ can be many times larger because T-holes in Bi films significantly reduce the effect of deformation. It was found that S and P cause considerably different dependences of ρ and MR on magnetic field strength. The effect of P on the ρ and MR is of opposite sign as compared to S and can be larger than that of S. In strong non-quantizing magnetic field region the transverse ρ appears to be independent of deformation. The investigated high-quality 1.5 μm thick Bi films consisting of up to 200 μm length crystallites were deposited on non-crystalline substrate and annealed at critical temperature close to the film melting temperature. The experimental results confirm the theoretical predictions.

Keywords: bismuth, thin films, magnetoresistance, deformation

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1. Introduction

The low carrier concentration together with a small effective mass and a long mean-free path has made Bi an ideal material for quantum transport, galvanomagnetic, and deformation investigations. The highly anisotropic Fermi surface and high carrier mobility has also made Bi important in applications.

Strong anisotropy of the electrical conductivity of bulk bismuth and $Bi_{1-x}Sb_x$ single crystals under uniaxial stretch in binary C_2 axis direction was observed in Shubnikov–de Haas effect measurements at liquid helium temperature in Ref. [1] and in magnetoplasma waves at 77 K in Refs. [2, 3]. It was shown that the anisotropy and orientation of the Fermi surface hole "ellipsoid" and electron "ellipsoids" remain unchanged in a wide range of deformations. However, Lifshitz electron phase transitions and topological alterations of the Fermi surface ($3e + 1h \to 2e + 1h$, $3e \to 1e$, $3e \to 2e$) were observed. The stretch in the direction of C_2 axis causes the transitions of electrons from L_2- and L_3-valleys to L_1-valley with high resulting anisotropy of electron mobility. The electrical piezoeffect caused by the deformation-induced anisotropy of electron mobility in the semiconducting $Bi_{1-x}Sb_x$ was measured by the crossed induction coil technique [3].

The application of bulk single crystals is limited by their low mechanical strength and complicated technology required to prepare single-crystal devices. Many workers have studied the galvanomagnetic effects of the bismuth films extensively. They have found that a negative MR of the semiconducting $Bi_{1-x}Sb_x$ polycrystalline thin films at low temperatures is due to strong quantizing magnetic fields that transform the energy band structure of microcrystallites and the properties of semiconductor–semimetal transition at these fields [4]. A detectable anisotropy was experimentally observed in the uniaxially deformed and unannealed thin (30–650 nm) polycrystalline Bi films consisting of small crystallites [5, 6]. It was demonstrated that thin Bi and $Bi_{1-x}Sb_x$ films are promising in the development of deformation and magnetic field sensors [6, 7]. High-quality single-crystal (epitaxial) Bi films exhibit large magnetoresistance (MR) at low and room temperatures [7–9]. However, the fabrication of such films is expensive and complicated because special techniques such as molecular beam epitaxy (MBE) growth [9], or electrolytic deposition (electrodeposition) on orientated single-crystal substrates combined with special annealing [6, 8] are required.

Only recently high-quality Bi thin films have been

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produced using an inexpensive and useful method of the evaporation of Bi onto various non-crystalline dielectric substrates in high vacuum with a postannealing process at critical temperatures close to the film melting temperature [10, 11]. The large magnetoresistance of these films is associated with high anisotropy of L-electron mobility in large high-quality crystallites. The films of high quality can be used in a variety of industrial and practical applications. Recently we have reported our investigations on longitudinal magnetoresistance in high-quality stretched and compressed Bi films [12]. However, the influence of uniaxial deformation can be much larger for the transverse magnetoresistance, where the magnetic field $\boldsymbol{B}$ is in the film plane perpendicular to the current direction, and the perpendicular one, where $\boldsymbol{B}$ is perpendicular to the film plane.

In this paper the investigations of the large influence of uniaxial deformation on transverse and perpendicular magnetoresistance of high-quality thin polycrystalline n-Bi films are reported. The calculations are based on the previously proposed and improved polycrystalline Bi thin film model that includes electron transitions between L-valleys in deformed film crystallites. The calculations are compared with the experimental investigation results on high-quality thin polycrystalline Bi films.

2. Resistivity of uniaxially deformed polycrystalline Bi and $\mathrm{Bi}_{1-x}\mathrm{Sb}_x$ films

The total resistivity of a polycrystalline bismuth film results from the contributions of resistivities of individual microcrystallites. The majority of microcrystallites are at angle to the surface of the substrate so that the crystallite trigonal crystallographic axis C_3 is oriented to the surface normal at angles smaller than 5°. On the other hand, the microcrystallites are not pointing exactly in the same direction in a film plane and the state of the film can be treated as quasi-isotropic.

The resistivity of uniaxially deformed polycrystalline Bi films was calculated using the model proposed in Refs. [5, 6, 13] that was improved by taking into account the electron transitions between L-valleys in deformed film crystallites. The film was represented by a structure consisting of the microcrystallites having trigonal surfaces parallel to the film surface. The prepared Bi films thickness d is equal to the microcrystallite thickness. The resistivity ρ of these films can be represented as a series of resistances ρ_1/l_1 and ρ_{Gb}/l_2, where ρ_1 and ρ_{Gb} are the resistivity of the grain and the resistivity of the grain boundary, respectively. The grain size l_1 is much larger then the grain boundary thickness l_2, therefore

$$\rho(B) = \frac{\rho_1(B)}{2} + \frac{l_2 \rho_{\mathrm{Gb}}}{l_1}\,. \tag{1}$$

Since ρ_{Gb} is independent of magnetic field, MR is independent of the small term that contains ρ_{Gb}. In the absence of uniaxial deformation the state of thin film in the substrate plane can be treated as quasi-isotropic. However, the stretch or the compression in microcrystallites induces a transfer of electrons between L-valleys that can result in anisotropy of the film conductivity.

In uniaxially deformed Bi and $\mathrm{Bi}_{1-x}\mathrm{Sb}_x$, the energetic position of three electron L-valleys, as compared to the bottom of the valence zone at T and L points, depends on the direction and magnitude of the deformation. Either the stretch S in the direction of binary C_2 axis or the compression P in the bisectric C_1 axis causes a transfer of electrons from L_2- and L_3-valleys to L_1-valley. The compression in C_2 axis or the stretch in C_1 axis induces a transfer of electrons from L_1-valley to L_2- and L_3-valleys [1]. From Bi crystal symmetry and topology of the isoenergetic surfaces it follows that the microcrystallites in substrate plane roughly can be divided into two groups. One group of the microcrystallites has C_1 crystallographic axis while the other group has C_2 crystallographic axis randomly orientated in the Bi film plane at angles smaller than $\pm 15°$ with respect to the direction of uniaxial deformation. Due to mentioned electron repopulation between L-valleys, it follows that for microcrystallites of these two groups, in the presence of uniaxial deformation, the same type of anisotropy dominates [5]. Therefore, either the stretch or the compression can induce the anisotropy in conductivity measured in the film plane. A detectable anisotropy was experimentally observed in the uniaxially deformed and unannealed thin (30–650 nm) polycrystalline Bi films consisting of small crystallites [5, 6].

Theoretical calculations of intervalley repopulation and mobility of L-electrons in Bi microcrystallites [14] were based on the McClure equation [15]. The energy spectrum of electrons in this equation is assumed to be non-parabolic and the isoenergetic surfaces are nonellipsoidal. As it is easily predictable, the repopulation of electrons is much higher at lower temperatures, but even at 300 K there is a considerable part of extra electrons remaining in the higher-energy L_1-valley (about 50% in the lower-energy L_2-valley at deformation $\varepsilon_{xx} = 0.25\%$). This means that at 300 K the repopulation of electrons into one or two valleys is far from complete. It should noted that the Shubnikov–de Haas effect measurements at liquid helium temperature show that in Bi crystals the one-valley semiconductor is realized for deformation $\varepsilon_{xx} > 0.18\%$ [1]. The measurements of electrical piezoeffect in tellurium-doped semiconducting n-BiSb crystals at liquid nitrogen temperature show that under stretch in the direction of the binary C_2 axis the electron repopulation ratio is $n_1/n_L > 0.9$ at $-\varepsilon_{xx} \approx 0.15\%$. Here n_1 is electron concentration in L_1-valley and n_L is electron concentration in all L_1-, L_2-, and L_3-valleys [3]. This means that at liquid nitrogen temperature with $\pm\varepsilon_{xx} \approx 0.25\%$ the repopulation of electrons into one or two valleys should be complete.

The conductivity of undoped as-grown Bi films is fixed by concentration and mobility of L-electrons and T-holes. The total magnetoconductivity tensor of the film microcrystallites can be found by considering transport properties in undoped Bi films in non-quantizing magnetic fields and summing the partial contributions of L-electrons and T-holes. Calculations of resistivity and MR in non-quantizing magnetic field region were based on the polycrystalline film model making use of the crystallite resistivity tensor $\boldsymbol{\rho}$ elements obtained from mobility-field product calculations [10]. Typical mobility values of Bi at liquid nitrogen temperature for electrons in the vicinity of L points are $\mu_1 = 59$, $\mu_2 = 1.12$, $\mu_3 = 32.7$, $\mu_4 = -3.8$, and for T-holes they are $\nu_1 = \nu_2 = 9.38$, $\nu_3 \approx 5\nu_2$ in units of 10^4 cm^{2}V^{-1}s^{-1} [16]. Here the subscripts 1, 2, and 3 label binary, bisectric, and trigonal axis, respectively. The magnetoconductivity tensor of crystallites was determined using typical L-electron and T-hole mobility μ_i and ν_i values of bulk Bi and the measured concentration n of the film charge carriers. We assumed that the resistivity and MR dependence on uniaxial deformation of Bi films can be attributed to the deformation induced transition of electrons between L_1-valley and L_2- and L_3-valleys in the film crystallites. In addition, we assumed that at 77 K and the deformation $\pm\varepsilon_{xx} \approx 0.25\%$ the transition of electrons between L_1-valley and L_2- and L_3-valleys in Bi film crystallites was complete. The magnetoresistance was calculated by using the expressions $[R(B) - R(0)]/R(0)$, where $R(B)$ and $R(0)$ are film resistances at magnetic field B and in the absence of magnetic field, respectively. It should be noted that the concentration n of L-electrons and T-holes in Bi film crystallites was independent of deformation and magnetic field. Therefore, for comparison between typical experimental and calculated transverse ρ_{T} and perpendicular ρ_{Π} resistivities of Bi film, the inverse mobility $n\,e\,\rho_i$ was used

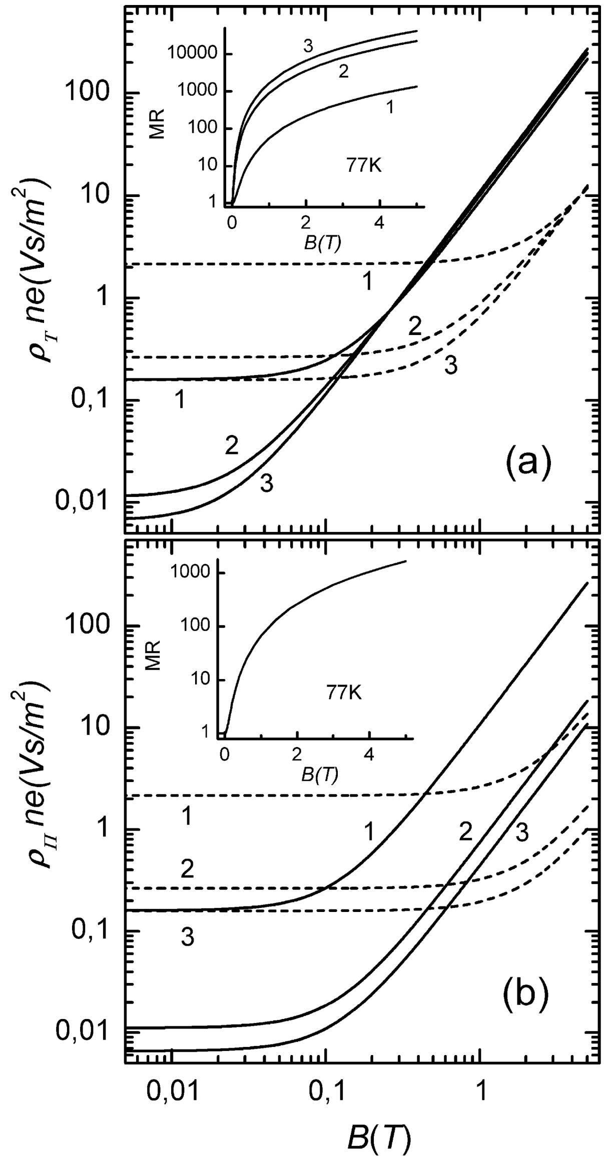

Fig. 1. Calculations of the $n\,e\,\rho_i$ and MR field dependences for polycrystalline n-Bi films: (a) for transverse resistivity ρ_{T} and (b) for perpendicular resistivity ρ_{Π} in the compressed (curves *1*), undeformed (curves *2*), and stretched (curves *3*) films at 77 K (solid curves) and 300 K (short dash curves). The insets in (a) and (b) show calculated MR magnetic field dependences.

3. Transverse and perpendicular MR in deformed Bi films

3.1. MR in n-type Bi films

The calculated data suggest that the uniaxial deformation effect on MR is larger in n-type, e. g. Te-doped, Bi films where MR is due to electrical conductivity of L-electrons. A comparison of calculated values of $n\,e\,\rho_i$ for transverse ρ_{T} and for perpendicular ρ_{Π} resistivities of the n-Bi film at 77 K and 300 K is shown in Fig. 1. Here electron concentration in all L_1-, L_2-, and

L_3-valleys n is independent of deformation and magnetic field. We assume that the deformation is enough for the repopulation of electrons into one or two valleys to be complete in the temperature range considered. As can be seen, the deformations of film due to uniaxial compression P increase resistivity whereas due to stretch S they decrease it. The magnitude of both ρ_Π and ρ_T strongly depends on the unixial deformation at weak magnetic fields, when $\omega_\mathrm{c}\tau \ll 1$ (here ω_c and τ are cyclotron frequency and relaxation time of charge carriers). However, here ρ_Π and ρ_T only slightly depend on B. In this B range $\rho_\Pi(P)/\rho_\Pi(P_0) \approx \rho_\mathrm{T}(P)/\rho_\mathrm{T}(P_0)$ and $\rho_\Pi(S_0)/\rho_\Pi(S) \approx \rho_\mathrm{T}(S_0)/\rho_\mathrm{T}(S)$.

The influence of uniaxial compression deformation P is by an order of magnitude larger than that due to the stretch S. At 77 K temperature $\rho_\Pi(P)/\rho_\Pi(P_0) \approx 14$ and $\rho_\Pi(S_0)/\rho_\Pi(S) \approx 1.6$, with $\rho_\Pi(P)/\rho_\Pi(S) \approx 24$. The calculations show that the higher resistivity of compressed film is due to microcrystallites with high anisotropy of the electron mobility. The perpendicular resisistivity ratio, $\rho_\Pi(P)/\rho_\Pi(P_0)$ and $\rho_\Pi(S_0)/\rho_\Pi(S)$, is independent of B, while the perpendicular MR is independent of the deformation in a whole classical magnetic field range (see inset of Fig. 1(b)). The ρ_Π and ρ_T show different effects of deformation at higher magnetic fields, when $\omega_\mathrm{c}\tau > 1$. In such magnetic fields the effect of uniaxial deformation on ρ_T decreased as B was increased and ρ_T appeared almost independent of deformation at $\omega_\mathrm{c}\tau \gg 1$. On the other hand, the MR was found to be dependent on the uniaxial deformation.

The compression significantly reduced the transverse MR, while the stretch increased MR (see inset of Fig. 1(a)). In stretched n-Bi film at 77 K and at 2.6 T magnetic fields the transverse MR was ≈10000.

As can be seen from Fig. 1(a, b) the peculiarities of calculated $n\,e\,\rho_i$ magnetic field dependences at 300 K as compared to those at 77 K are pushed to higher magnetic field range in proportion to $(\omega_\mathrm{c}\tau)^{-1}$. At 300 K and at weak magnetic fields $\rho_\Pi(P)/\rho_\Pi(P_0) \approx \rho_\mathrm{T}(P)/\rho_\mathrm{T}(P_0) \approx 8$. It should be noted that the transition of electrons between L_1-valley and L_2- and L_3-valleys at 300 K and at deformation $\pm\varepsilon_{xx} = 0.25\%$ in fact has not finished. Therefore, the influence of the uniaxial deformation on ρ_Π and ρ_T can be noticeably less.

3.2. MR in deformed pure Bi films

Figure 2 shows the calculated magnetic field dependences of the $ne\rho_\mathrm{T}$ and $ne\rho_\Pi$ in uniaxial deformed and undeformed pure Bi and n-Bi films. As can be seen

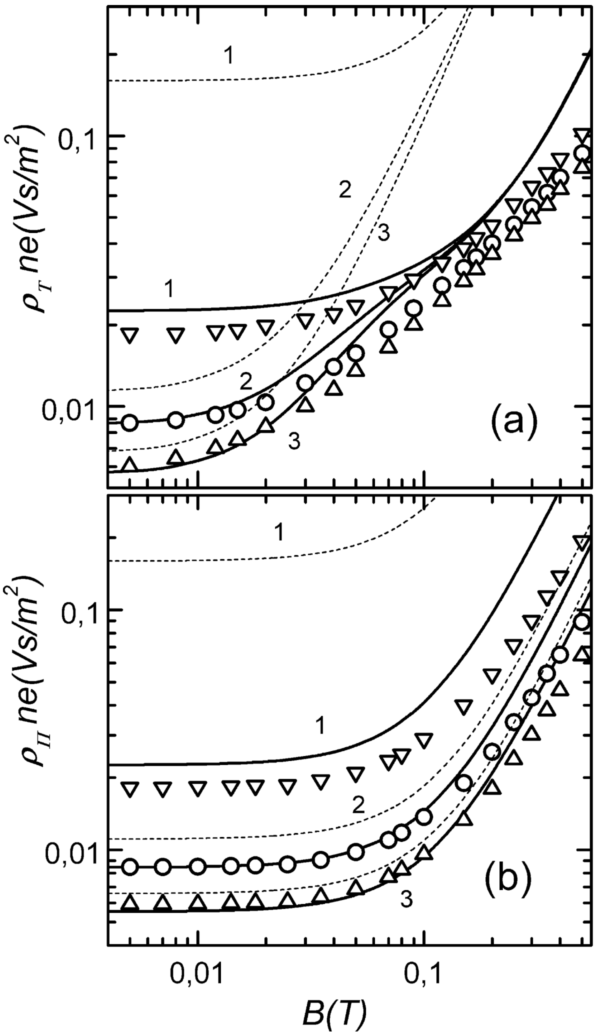

Fig. 2. Magnetic field dependences of quantity $n\,e\,\rho_i$ for polycrystalline Bi and n-Bi films at 77 K: (a) transverse resistivity ρ_T and (b) perpendicular resistivity ρ_Π. Calculations: for Bi film (solid curves) and for n-Bi film (short dashed curves); for compressed (curves *1*), undeformed (curves *2*), and stretched (curves *3*) films. Experimental results: for 1.5 μm thick Bi film at $\pm\varepsilon_{xx} \approx 0.25\%$ (down-triangles for compressed, circles for undeformed, and up-triangles for stretched).

from Fig. 2(a, b), in deformed Bi film the dependence of calculated ρ_Π and ρ_T on magnetic field is qualitatively similar to that in n-Bi. However, T-holes reduce the deformation effect in ρ_Π and ρ_T. The holes cause a strong decrease of uniaxial deformation effect in uniaxially compressed Bi films. The ratio $\rho_\Pi(P)/\rho_\Pi(0) \approx 3$ at 77 K and zero magnetic field. For comparison, in n-Bi one finds $\rho_\Pi(P)/\rho_\Pi(0) \approx 14$. However, in strained Bi and n-Bi films $\rho_\Pi(0)/\rho_\Pi(S) \approx 1.6$.

The strong decrease of ρ_Π, ρ_T of compressed film could be explained by difference in anisotropy of conductivity caused by electrons and holes. The Fermi surface of T-holes is an ellipsoid of revolution with its major axis along the trigonal axis. The holes in the film plane have isotropic mass. In the film plane the isotropic conductivity due to T-holes strongly reduces the anisotropy of the total conductivity determined by L-electrons. Particularly the T-holes strongly reduce the deformation effect in compressed films when the conductivity is caused by crystallites with high anisotropic conductivity.

The large changes in transverse ρ_{T} and perpendicular ρ_{Π} resistivity were obtained in magnetic fields when both electrons and holes satisfy the condition $\omega_{\mathrm{c}}\tau \geq 1$. This is also caused by a difference in mobility and anisotropy of electron and hole mobility. On the other hand, the conductivity caused by T-holes in plane perpendicular to film plane is anisotropic. The holes are responsible for the transverse MR and $\rho_{\Pi}(B)/\rho_{\Pi}(B_0)$ dependence on the uniaxial deformation in magnetic field region, where $\omega_{\mathrm{c}}\tau > 1$.

4. Experiment

Bismuth thin polycrystalline films were prepared by thermal vacuum evaporation onto Corning 7059 glass substrates. The deposition of 99.999% pure Bi was performed using a Mo boat at a pressure of 10^{-6} torr and an evaporation rate of $\sim$1.5 nm/s. The distance between the Bi source and the substrate was about 10 cm. The films were plated at substrate temperature 390 K. The film thickness d varied from 0.3 to 1.5 μm. The annealing process was performed in vacuum at critical temperature T_{A} near the film melting temperature [10, 11]. At this temperature small molten crystallites create favourable conditions for the growth of larger crystallites having a higher quality and more ordered crystalline structure. The size of the crystallites ranged from 50 to 200 μm. In this way obtained films had high-quality crystalline structure and large MR. At 77 K and 2.6 T magnetic field they exhibited MR up to 14000%. These values are comparable to the MR of thicker single-crystal films fabricated by electrodeposition onto a Si (100) wafer with thin Au underlayer [7] and also of epitaxial Bi films grown by MBE [9].

Sample films were shaped in a form of 2 mm wide strips. Thin Ag films at the ends of the strips, which were deposited onto the Bi film using suitable masks, served as electrical contacts. Finally, Cu leads were attached to Ag contact areas by means of Ag based conducting epoxy. The experimental arrangement in deformation investigations was similar to that used in Ref. [6]. The deformation $\pm\varepsilon_{xx}$ in thin Bi films was created with the help of external force $\pm F$ applied to the system consisting of thin film and glass substrate plate. The mechanical parameters of the system allowed us to evaluate the deformation $\pm\varepsilon_{xx} = \pm\Delta l/l_0$, where Δl is the change in the film length l_0. The $\pm\varepsilon_{xx}$ was calculated assuming that the tension in the system is elastic:

$$\pm\varepsilon_{xx} = \pm\frac{6F\,l}{Y\,b\,d^2}\,, \tag{2}$$

where l is the distance between the centre of the thin film element and a point where the force $\pm F$ is applied, b and d are the glass plate width and thickness, Y is the modulus of elasticity (Young's modulus). The error in deformation measurement was up to 10%. The homogeneous deformation over the film surface and thickness was achieved by choosing suitable film and glass plate dimensions. Measurements of perpendicular and transverse resistivity were performed at 77 K in dc magnetic fields up to 2.6 T. The experimental values of ρ_{Π} and ρ_{T} were calculated from the measured values of the Bi film sheet resistance $R_{\mathrm{s}}(B)$, film overall dimensions, and concentration of charge carriers. The deformation $\varepsilon_{xx} \approx 0.25\%$ corresponds to the complete electron repopulation in Bi film crystallites and, therefore, the knowledge of precise values of the deformation is unimportant. The typical experimental $\rho = f(\pm\varepsilon_{xx})$ curves exhibited saturation at $\pm\varepsilon_{xx} \approx 0.2\%$.

5. Results and discussion

The experimental dependences of the transverse and perpendicular magnetoresistances on magnetic field strength for the undeformed, stretched, and compressed 1.5 μm thick undoped polycrystalline Bi films is shown in Fig. 2. As seen from experimental results in Fig. 2, a large effect of uniaxial deformation on the resisistivity is observed. It should noted that the measured effect of uniaxial deformation on resisistivity and deformation induced anisotropy of the electrical conductivity in annealed at critical temperatures Bi films is over ten times larger than that in unannealed polycrystalline Bi films at crystallite size from 200 to 400 nm.

As seen from Fig. 2, a qualitative agreement between the calculated and experimental magnetic field dependences of deformed and undeformed Bi film resistivities is obtained. However, the calculations show stronger deformation effect. The difference between calculated and experimental $\rho_{\Pi}\,n\,e$ and $\rho_{\mathrm{T}}\,n\,e$ values depends on the deformation type. At zero magnetic field the experimental ratios are $\rho_i(P)/\rho_i(0) \approx 2.1$ and $\rho_i(0)/\rho_i(S) \approx 1.5$ (the calculated ones are 3 and 1.6, respectively). A good fit between the experimental and calculated values of resistivity is obtained for stretched films. However, the discrepancy obtained for compressed films could not be explained by the measurement error.

The compressed Bi film partly consisted of the microcrystallites with high anisotropy of the electron mobility, therefore, the influence of the isotropic extra scattering on deformation effect can be large. The isotropic grain boundary scattering in suitably annealed Bi films is weak. However, isotropic extra carrier scattering from film surface or imperfections which reduce the anisotropy of electrical conductivity and MR can come into play [9]. In Ref. [10] it was found that an increase of the film thickness d from 0.3 to 1.5 μm increases the value of MR by up to 80%. At $d < 1$ μm, the MR versus d dependences are sublinear and tend to saturation at $d > 1$ μm. This property was explained assuming that at 77 K the finite-size effects are important in carrier scattering from the film surface, since they influence carrier mobility and MR. The decrease of MR in 0.3 μm film was noticeably dependent on magnetic field B. In a perpendicular geometry the cyclotron orbits of the free charge carriers are in the film plane. In contrast, in the transverse geometry the cyclotron orbits become perpendicular to the film plane. Therefore, the surface scattering can noticeably reduce the transverse MR. As can be seen from Fig. 2, the difference in the experimental and calculated values of transverse resistivity for undeformed 1.5 μm film at $\omega_c\tau > 1$ is not small.

Another factor that reduces Bi film anisotropy and deformation effect can be the abovementioned disorientation of C_1 and C_2 axis of crystallites in the film plane with respect to the direction of uniaxial deformation. On the other hand, the anisotropy of the electron scattering and deformation effect can be slightly reduced by presence of small angles between crystallite C_3 axis and the film surface normal. However, the better then expected agreement between the experimental and calculation lets us to suppose that these factors will reduce the deformation effect only slightly. Alternatively, the maximal experimental magnitude of $\rho(P)/\rho(P_0)$ for n-Bi also could be reduced by an extra carrier scattering. Therefore, the ratio $\rho_{\Pi}(P)/\rho_{\Pi}(P = 0)$ could be as high as 11.

6. Conclusions

Our investigations show that large uniaxial deformation effect in high-quality polycrystalline Bi and n-Bi films is the result of topological alterations of the Fermi surface which reflects the energy band structure of microcrystallites and the intervalley repopulation of electrons between high anisotropic L-valleys. The calculations suggest that the uniaxial deformation effect can be very large in doped n-type Bi films, where anisotropy of film conductivity is determined by concentration and mobility of L-electrons. The results presented in this paper confirm our earlier explanations of the origin of deformation effects in Bi polycrystalline films [5] and indicate new directions for further investigations. High-quality Bi films can be prepared using various non-crystalline substrates and, therefore, may be suitable in a variety of industrial and practical applications, e. g. in the development of high-sensitivity magnetic field and deformation sensors.

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KRYPTINGAI DEFORMUOTŲ PLONŲ POLIKRISTALINIŲ n-Bi SLUOKSNIŲ SKERSINĖ MAGNETOVARŽA

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Santrauka

Didelis polikristalinių Bi sluoksnių mechaninis atsparumas, unikalios elektrinės savybės ir pigi jų gamybos technologija lemia plačias jų panaudojimo perspektyvas. Deformuotų Bi polikristalinių sluoksnių skersinė (magnetinis laukas sluoksnio plokštumoje statmenas srovei) ir statmena (laukas statmenas sluoksnio plokštumai ir srovei) savitoji varža ρ ir magnetovarža MR buvo tirtos naudojant išplėtotą teorinį polikristalinio sluoksnio modelį. Jame buvo atsižvelgta į kryptingos deformacijos sukeltą elektronų persiskirstymą tarp L slėnių. Polikristalinis Bi sluoksnis turi izotropinį laidumą. Buvo parodyta, kad kryptingai deformuoto polikristalinio Bi sluoksnio kristalituose turėtų būti stebima skirtingo dydžio, tačiau tos pačios krypties laidumo anizotropija. Tai lemia ir sluoksnio anizotropiją. Sluoksnį tempiant jo plokštumoje, pagrindinė laidumo anizotropijos ašis sutampa su deformacijos kryptimi, o jį suspaudus – statmena deformacijai. Skaičiavimai parodė, kad suspaudus polikristalinį n-Bi sluoksnį yra stebimas didelis skersinės ir statmenos varžos pokytis. Sluoksnį tempiant magnetovaržos pokytis yra daug mažesnis ir turi priešingą ženklą nei spaudžiant. Ypatingai didelis iki 1400% magnetovaržos pokytis stebimas suspaudus n-Bi sluoksnį 77 K temperatūroje. Deformuotame polikristaliniame Bi sluoksnyje stebima skirtinga skersinės ir statmenos ρ priklausomybė nuo magnetinio lauko. Stipriuose magnetiniuose laukuose skersinė ρ nepriklauso nuo deformacijos, o deformacijos poveikis statmenai ρ nepriklauso nuo magnetinio lauko. Panašios, tik silpnesnės ρ priklausomybės išlieka ir esant 300 K, tik pasislenka į didesnių magnetinių laukų sritį. Poveikį ρ mažina mažesnis elektronų persiskirstymas tarp L slėnių. Švariame Bi puslaidininkiniame sluoksnyje T skylės, turėdamos trigonalinėje plokštumoje izotropinį judrį, žymiai sumažina L elektronų lemtą sluoksnio laidumo anizotropiją, o tuo pačiu ir deformacijos poveikį.

Eksperimente tirta kryptingai deformuotų 0,3–1,5 μm storio polikristalinių Bi sluoksnių skersinė ir statmena varža. Sluoksniai buvo gauti vakuuminio garinimo būdu, vėliau juos iškaitinant krizinėje temperatūroje, artimoje sluoksnio tirpimo temperatūrai. Tokių sluoksnių kristalitų skersmuo gali siekti kelis šimtus mikronų. Didelė magnetovarža (esant 77 K ir 2,6 T siekianti 14000%) rodo gerą tokių sluoksnių kokybę. Sluoksniai buvo kryptingai deformuojami iki 0,25%, kada 77 K temperatūroje elektronai turi visiškai persiskirstyti tarp L slėnių. Matavimų rezultatai patvirtina prielaidą, kad kryptingai deformuojant polikristalinį Bi sluoksnį jo skersinė ir statmena varža kinta dėl elektronų persiskirstymo tarp anizotropinių L slėnių.