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Anomalous cyclotron mass dependence on the magnetic field and Berry's phase in $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ solid solutions

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Abstract

Shubnikov–de Haas (SdH) effect and magnetoresistance measurements of single crystals of diluted II–V magnetic semiconductors $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ ($x + y = 0.4$, $y = 0.04$ and 0.08) are investigated in the temperature range $T = 4.2 \div 300$ K and in transverse magnetic field $B = 0 \div 25$ T. The values of the cyclotron mass m_c, the effective g-factor $g*$, and the Dingle temperature T_D are defined. In one of the samples ($y = 0.04$) a strong dependence of the cyclotron mass on the magnetic field $m_c(B) = m_c(0) + \alpha B$ is observed. The value of a phase shift close to $\beta = 0.5$ indicates the presence of Berry phase and 3D Dirac fermions in a single crystals of $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ in one of the samples ($y = 0.08$).

Keywords: Shubnikov–de Haas effect, cyclotron mass, cadmium arsenide, 3D topological Dirac semimetals, diluted magnetic semiconductor, Berry's phase, topological insulator

(Some figures may appear in colour only in the online journal)

1. Introduction

An increasing interest in Cd_3As_2 and its solid solutions is connected with the theoretical data [1] and experimental investigations applying angle-resolved photoemission spectroscopy (ARPES) [2]. Cadmium arsenide is a three-dimensional (3D) topological Dirac semimetal (TDS). In comparison to other 3D TDSs such as BiO_2 and Na_3Bi [3, 4], Cd_3As_2 is stable and it demonstrates a high carrier mobility. In single crystals Cd_3As_2 the quasiparticle dispersion law is linear in all three directions of momentum space. This results in quantum spin, Hall effect, giant diamagnetism and Dirac immunity of the fermions to the spin–orbit interaction [3]. Detailed studies by ARPES of single crystals Cd_3As_2, taking into consideration the real crystal structure, enabled mapping of the Brillouin zone, locate the Dirac point and to investigate the dispersion from the Dirac cone along all three directions of momentum (k_x, k_y and k_z). Also it has been found that the Fermi energy level E_F pins to the Dirac point. The upper Dirac cone is not occupied by the charge carriers and it has not been visible in the experiment by ARPES. To visualize the upper Dirac cone, doping with electrons by injection of alkaline earth atoms was performed. This led to rising of E_F up to 250 meV above the Dirac point, making it possible to visualize the upper Dirac cone. Thus gapless nature and Dirac semimetal phase in Cd_3As_2 has been proved experimentally.

Also there is a great interest connected with study of Dirac semimetal properties during the transition to the other phases under external influences. In single crystals of $(Cd_{1-x}Zn_x)_3As_2$ solid solutions has been experimentally observed phase transition from Dirac semimetal (DS) to semiconductor (SC) with increasing of Zn concentration above $x = 0.38$ [5]. When changing Zn_x concentration the temperature dependence of the resistivity changes from metallic behavior with $x = 0 \div 0.31$ to semiconductor with $0.38 \div 0.58$. For $x = 0.38$ $\rho(T)$ decreases with the temperature decreasing down to 200 K,

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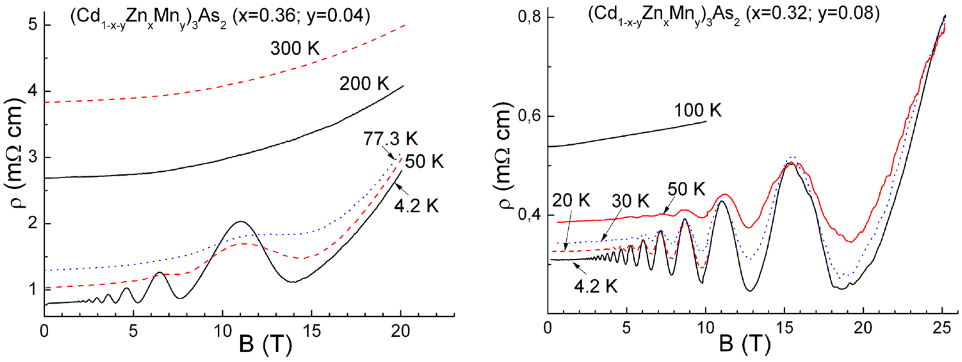

Figure 1. SdH oscillations observed at 4.2–50 K in CZMA ($x + y = 0.4$) for $y = 0.04$ (on the left) and $y = 0.08$ (on the right).

and below this temperature $\rho(T)$ begins to raise. This complex behavior can be linked with the fact that the material of this composition is a narrow band semiconductor with opening of the forbidden zone at the composition $x \geqslant 0.38$. Fermi energy of Cd_3As_2 can be adjusted by doping or as result of preparation the solid solution.

The purpose of this study was to investigate the properties of a solid solution $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ compound ($x + y = 0.4$) containing Mn ($y = 0.04$ and 0.08).

2. Experimental details

The modified Bridgeman method was used to obtain single crystals of $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ (CZMA), grown from stoichiometric amounts of Cd_3As_2, Zn_3As_2 and Mn_3As_2 by slow cooling 5°C h^{-1} of a melt in the range near the melting point 840 °C and near the α-β phase transition temperature 465 °C at the presence of a temperature gradient 2°C cm^{-1}. We obtained ingots with the single-crystal blocks volume more than 1 cm^3. The Mn concentrations of the crystals were $y = 0.04$ and 0.08. The composition and homogeneity of the samples were analyzed by x-ray powder diffraction and energy-dispersive x-ray spectroscopy (EDX) methods. The x-ray experiment was carried out on a diffractometer DRON-UM (FeKα—radiation, $\lambda = 1.93604$ Å, $\Theta - 2\Theta$—method). Determination of Miller indices and specification of the unit cell parameters was carried out using the crystal structure data α''-Cd_3As_2 (space group $P4_2/nmc$) [6]. All the investigated samples $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ had a tetragonal crystal structure, space group $P4_2/nmc$.

In single crystals of prototype material $(Cd_{1-x}Zn_y)_3As_2$, the SdH oscillations showed no strong dependence on the crystallographic direction [7]. In our studies of the magnetoresistance for Mn-doped samples [11, 18, 20] the variation between the samples of the same composition the cutted in different directions was not more than 1–2%. These differences are comparable to the errors occurring from nonequipotential and differences of the probes resistance. Therefore, the CZMA specimens were cut from the bulk crystals in random orientation. The electrodes were attached to rectangular prism of size $1 \times 1 \times 5\,mm^3$ by soldering. Magnetoresistance measurements were made in transverse magnetic field configuration in pulsed magnetic fields up to 25 T applying six-probe method. To perform this measurement, the sample probe was inserted in a He exchange gas Dewar flask, where the temperature could be adjusted with 0.5% accuracy.

3. Results and discussion

Well-resolved single-period SdH oscillations are observed in all investigated CZMA ($x + y = 0.4$) specimens at temperatures between $T = 4.2$ and 50 K (figure 1).

Clear linear dependence of the reverse magnetic field, $1/B_{min}$, of the maximum of the SdH oscillations on their quantum number was observed and the SdH period, P_{SdH}, did not depend on the magnetic field (figure 2).

That gave an opportunity to interpret the observed oscillations as SdH, due to formation of Landau levels in magnetic field. Furrier analysis of oscillations, that are presented in figure 1. for samples CZMA $y = 0.04$ and $y = 0.08$, revealed frequency, $H_F = 20$ T and $H_F = 40$ T, respectively. The results of Fast Fourier Transform (FFT) analysis are presented in figure 3. for the samples $y = 0.04$ (on the left) and $y = 0.08$ (on the right). Our results are in good agreement with the experiments on quantum transport in the 3D Dirac semimetal Cd_3As_2. Based on the results of Shubnikov–de Haas oscillations study, a linear dependence of the Landau indices n on the reciprocal magnetic field $1/B_{min}$ was plotted. The dependence crosses the x axis at the point $\beta = 0.58$ [8]. The value of a phase shift close to $\beta = 0.5$ indicates the presence of Berry phase and 3D Dirac fermions in a single crystals of Cd_3As_2. For the 6th Landau level, using the Lifshitz–Kosevich formula, the authors calculated the cyclotron effective mass $m_c \approx 0.044m_0$ and Fermi velocity $\upsilon \approx 1.1 \times 10^6$ m s^{-1} [8]. As can be seen from the inserts in figure 3, for our CZMA sample ($y = 0.08$) the magnitude of the phase shift was $\beta = 0.44$ close to $\beta = 0.5$, which also suggests that single crystals of the CSMA solid solution $y = 0.08$ demonstrate properties of a Dirac semimetal. As will be shown below in table 1, the values of effective cyclotron mass m_c determined in the present work are also close to those obtained in [8].

On the inserts in the figure 3 it is presented the H_F/H_N dependence from N. It is seen that the results perfectly fit the strict line, that for the sample $y = 0.08$ crosses horizontal axis N in point $\beta \approx 0.44$, which attests the presents of Berry's phase in this sample. Phase shift β for Dirac fermions is equal 0.5, but there are possible some deviations, such as $\beta \approx 0.45$ and 0.7 in topologic insulators $Bi_{2-x}Cu_xSe_3$ [9]. As known from the work [9] Berry's phase was observed in any orientation of

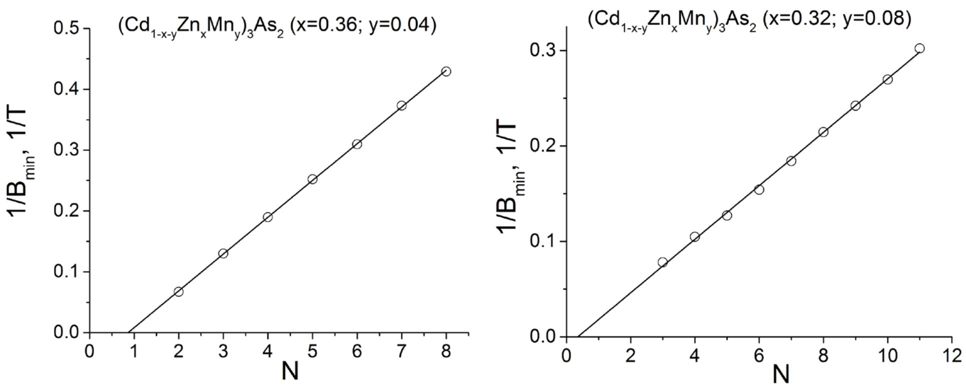

Figure 2. Linear dependence of the reverse magnetic field maximum $1/B_{\min}$ of their number N of samples for CZMA ($x + y = 0.4$; $y = 0.04, 0.08$).

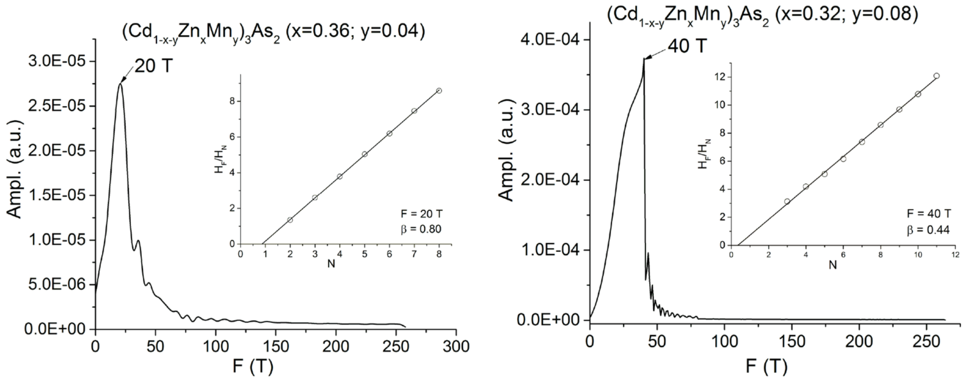

Figure 3. Results of FFT analysis of SdH oscillations in solid solutions $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ for samples ($x = 0.36$; $y = 0.04$) (on the left) and ($x = 0.32$; $y = 0.08$) (on the right).

magnetic field, and, as a conclusion, can be observed during investigation of oscillations of cross-sectional magnetoresistance. On the basis of fan diagrams for 2D Landau bands for various samples inclination angles with respect to the direction of magnetic field, the authors [9] make a conclusion that in conducting 2D-channels that Berry's phase does not depend on the direction of magnetic field. From the literature it is known that in case of linear dispersion close to degenerate Dirac point in topological insulators the wave function for electron on cyclotron orbit acquires Berry's phase, and in SdH effect the resistance oscillates as $\Delta\rho \sim \cos[2\pi\,(H_F/H + 1/2 + \beta\,)]$, $2\pi\beta$ is Berry's phase [10]. Thus, the analysis allowed to find Berry's phase in samples CZMA ($x = 0.36$; $y = 0.04$).

The density of states becomes a periodical function, as in case of Dirac fermions, and as in case of regular electrons.

The comparison of charge carrier concentrations obtained from Hall and Shubnikov measurement was carried out. The Hall carrier concentration was calculated as follows [11]:

$$n_R = R_H/e$$

where n_R is the concentration of charge carriers, e is electron charge and R_H is Hall coefficient.

Shubnikov carrier concentration was calculated according to the formula [12]:

$$n_{SdH} = \frac{1}{3}\pi^2\left(\frac{2e}{\hbar P_{SdH}}\right)^{3/2}.$$

Table 1. Parameters found from the SdH oscillations of CZMA samples ($x + y = 0.4$; $y = 0.04$, $y = 0.08$) and for pure Cd_3As_2 [8, 13–15].

	$(Cd_{0.6}Zn_{0.36}Mn_{0.04})_3As_2$	$(Cd_{0.6}Zn_{0.32}Mn_{0.08})_3As_2$	Cd_3As_2
n_R/n_{SdH}	0.97	1.04	1.2 [13]
$\mu_H \cdot 10^{-4}$ ($cm^2\,V^{-1}\,s^{-1}$)	2.28	1.53	2.9 [14]
P_{SdH} (T^{-1})	0.061	0.025	0.02 [14]
$m_c(0)/m_0$	0.0409	0.0435	0.044 [8]
$\alpha/m_0 \times 10^3$ ($1/T$)	3.3	0	
T_D (K)	12.7	13.2	9.8 [15]
$T_{D\mu}$ (K)	4.4	6.4	

Here $\hbar$ is a reduced Planck constant and $P_{SdH} = \Delta B^{-1}/\Delta N$ is period of the Shubnikov–de Haas oscillations. For $y = 0.04$ and $y = 0.08$ P_{SdH} is equal to 0.06 $1/T$ and 0.025 $1/T$, respectively, and does not depend on the temperature.

The ratio n_R/n_{SdH} is close to unity, in accordance with results obtained previously for CZMA [16–18]. This is probably connected with some non-sphericity of the Fermi surface [7].

The transformation of the SdH oscillations in our samples with increasing temperature is similar to that observed in ordinary semiconductors [19]: the SdH amplitudes showed monotonic decrease when T was increased, but the positions of the

SdH maximum did not change significantly in the temperature interval studied.

Here, it was sufficient to take into account only the amplitude of the first harmonics of SdH oscillations, A, since other harmonics were estimated to be not more than 1%. To calculate the cyclotron effective mass m_c a two temperature method was applied. Here it is used a ratio of two measured amplitudes A_{T_1} and A_{T_2} at temperatures T_1 and T_2 in a magnetic field [17]:

$$\frac{A_{T_1}}{A_{T_2}} = \frac{X_1/\sinh X_1}{X_2/\sinh X_2} \quad (1)$$

where A_{T_i} is the amplitude of the oscillations at T_i, $X = 2\pi^2 m_c k_B T_D/(\hbar e B)$, m_c is cyclotron effective mass, T_D is Dingle temperature, $\nu = g m_c/m_0$, m_0 is electron mass and k_B Boltzmann constant. By solving a nonlinear equation (1), we find the cyclotron effective mass m_c of charge carriers (figure 4). The accuracy of this method is $\varepsilon = 10^{-3}$.

The cyclotron mass does not depend on B when the concentration of manganese is $y = 0.08$ but in sample $y = 0.04$ is seen an anomalous dependence on the cyclotron mass on the magnetic field. The values $m_c(0)$ and α of linear law $m_c(B) = m_c(0) + \alpha B$ are shown in table 1.

The amplitude of the Shubnikov–de Haas oscillations can be expressed by the following relationship [12]:

$$A \sim B^{-1/2} X/\sinh(X) \exp\left[-2\pi^2 m_c k_B T_D/(\hbar e B)\right] \cos(\pi\nu),$$

which can be written using a linear function $m_C(B)$:

$$\ln\left[AB^{1/2}\sinh(X)/X\right] \sim \ln\left[\cos(\pi\nu)\right] - 2\pi^2 \alpha k_B T_D/(\hbar e) - 2\pi^2 m_c(0) k_B T_D/(\hbar e B). \quad (2)$$

Firstly, the right side has linear dependence on function $1/B$ and, secondly, it does not depend on temperature. Both of these conditions are fulfilled with sufficient accuracy (figure 5). This confirms the linear relationship between the m_c and B. It also indicates that T_D does not depend on T. Dingle temperature values were obtained from the slope of the left side of the equation (2) versus $1/B$ (figure 5). It's clear that $T_D \gg T_{D\mu}$, where $T_{D\mu} = \hbar e/(\pi k_B m_c(0)\mu)$ defines the broadening of the Landau levels due to scattering of electrons by lattice defects. A similar situation has been observed in the CZMA for $x + y = 0.3$ [18], where the T_D and $T_{D\mu}$ values were analyzed in the temperatures of 24–44 K and 3.6–22 K, respectively.

As seen in figure 4 the linear dependence $m_c(B) = m_c(B) =$ can be observed in sample with low content of manganese ($y = 0.04$) and it becomes negligible with increasing concentration of manganese ($y = 0.08$).

As mentioned above, the rising of Mn concentration leads to changes in transport properties of diluted magnetic semiconductor $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ $(x + y = 0.4)$. The results of SdH oscillation investigations in the $y = 0.08$ samples (figure 1 on the right) showed the absence of phase shift β figure 3 on the right) and evidence of Berry's phase. Thus, the $(Cd_{0.6}Zn_{0.32}Mn_{0.08})_3As_2$ sample is not a topological insulator, but demonstrate anomalous dependence of cyclotron mass of charge carriers from magnetic field.

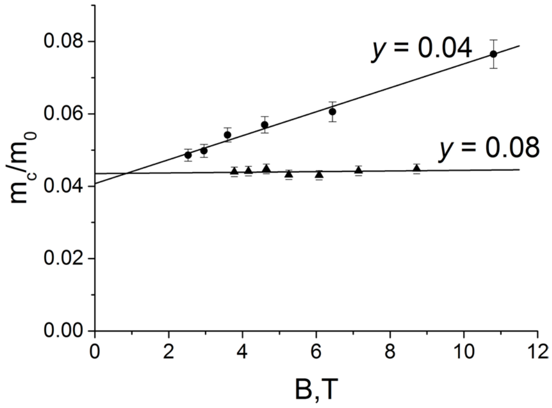

Figure 4. Field dependence of the cyclotron mass of the samples $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ $(x + y = 0.4)$ for $y = 0.04$ and y = 0.08.

We can assume that the magnetic field dependence of the cyclotron mass is determined by the position of the impurity level of manganese in CZMA single crystals and the spectrum of non-parabolic zone. A possible reason for this dependence can be abnormal sensitivity of the band gap to the applied magnetic field. If E_g depends on B, basically, due to the shift of the conduction band edge, then changing of the bandgap $E_g(B)$ can be calculated by analogy with the InSb model type in magnetic fiend [16].

As it was mentioned above, the rising of Mn concentration leads to changes in transport properties of solid solution of diluted magnetic semiconductor $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ $(x + y = 0.4)$. According to results of SdH oscillations in the sample $y = 0.04$ (figure 1 on the right) it is missing phase shift β (figure 3 on the right) and evidence of Berry's phase. Thus, the $(Cd_{0.6}Zn_{0.36}Mn_{0.04})_3As_2$ sample is not a topological insulator, but demonstrates anomalous dependence of charge carriers cyclotron mass on the magnetic field.

We can assume that the magnetic field dependence of the cyclotron mass is determined by the position of the impurity level of manganese in CZMA single crystals and the spectrum of non-parabolic zone. A possible reason for this dependence can be abnormal sensitivity of the band gap to the applied magnetic field. If E_g depends on B, basically, due to the shift of the conduction band edge, then changing of the bandgap $E_g(B)$ can be calculated by analogy with the InSb model type in magnetic fiend [16]. The results of such calculations (figure 6) shows, that increasing Eg leads to a decrease in the Fermi energy level, that may be related to a shift of the conduction band edge, and with the spectrum non-parabolic zone and may influence the observed dependence $m_c(B)$. This explanation of the anomalous dependence $m_c(B)$ was proposed in articles [13, 16], devoted to the study of gapless semiconductors and solid solutions of narrow-gap semiconductors. Dependence of the band gap $E_g(B)$ on B for CZMA $(x + y = 0.4;\ y = 0.04)$ was calculated in analogy with [13, 16].

Previously, we have carried out studies of Shubnikov–de Haas oscillations in the temperature range 1.6–300 K under hydrostatic pressure up to 14 kbar in the samples CZMA of $(x + y = 0.3)$ and $(x + y = 0.2)$ compounds [11]. The investigation of SdH oscillations under pressure have shown that for CZMA compounds $(x + y = 0.3)$ the anomalous dependence

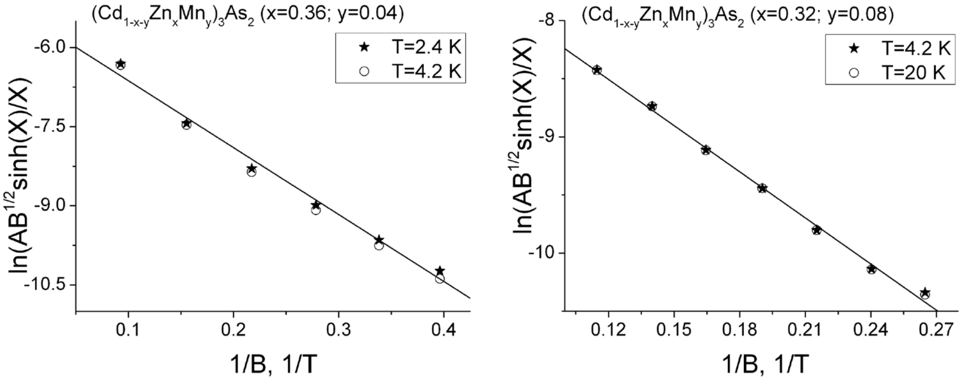

Figure 5. The left side of the equation (2) versus $1/B$ for samples $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ for $y = 0.04$ (left) and 0.08 (right) at $T = 2.4$, 4.2 and 20 K.

$m_c(B)$ does not disappear at the hydrostatic pressure up to $p = 14$ kbar. The dependence on pressure effective factor $g*$ and m_c was investigated [11]. The behavior of both parameters is not contrary to the three band Kane model [19]. On the other hand, in this case we have not received substantial additional information on the band structure. In contrast to [20], wherein in the rather narrow band solid solution the acceptor narrow band resonant with the conduction band were observed. As it is known in semiconductors [18], including gapless semiconductors [13], the cyclotron mass should not depend on the magnetic field.

Similar anomalous dependence $m_c(B)$ has not been observed in other dilute magnetic (semi magnetic) semiconductors. Moreover, we did not observe such relationship during the study of SdH oscillations in the CZMA samples with $x + y = 0.2$. Studies of the SdH oscillations in the CZMA samples ($x + y = 0.2$) under pressure allowed to determine the existence of two resonant zones. CZMA ($x + y = 0.2$) is narrow-gap semiconductor of n-type with the Fermi energy E_F lying deep inside the conduction band. Therefore, the properties of CZMA should be influenced by the band charge carriers occupying states that are significantly higher than the bottom of the conduction band. According to the band structure of type InSb, the band gap at low temperatures was calculated using the linear relationship E_0 [eV] $= -0.095 + 1.2x$ (where x is the total concentration of Zn and Mn) [20].

According to our calculations for ($x + y = 0.2$), ($x + y = 0.3$) and ($x + y = 0.4$) the width of the forbidden zone is $Eg = 0.145$ eV, $E_g = 0.265$ eV and $E_g = 0.365$ eV respectively. For ($x + y = 0.2$) it was found that there are two areas of acceptor resonance in the conduction band at $E_{A1} \approx 0.$ 22 eV and $E_{A2} \approx 0.29$ eV, their width is $D_1 \approx 15$ meV and $D_2 \approx 10$ meV, the value of the density of states $g_{A1}(E_{A1}) \approx 4.1 \times 10^{19}$ eV^{-1} cm^{-3} and $g_{A2}(E_{A2}) \approx 6.3 \times 10^{19}$ eV^{-1} cm^{-3}. Behavior of these zones and the Fermi energy dependence on the pressure is described in [20]. These resonance zones depends in different ways on the pressure and each pair of samples had an equal concentration of charge carriers $n_R(0)$. The pressure dependence of the SdH oscillation amplitudes, $\Delta_{SdH}(p)$, are different. This confirms the presence of two narrow zones of acceptor resonance states in the CZMA conduction band.

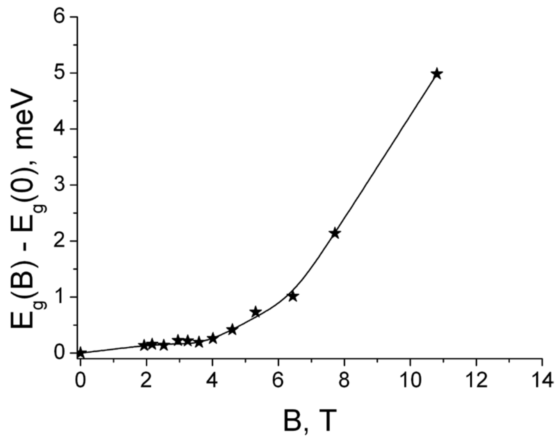

Figure 6. The relative change of the band gap in the samples $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ ($y = 0.04$) with increasing magnetic field.

The amplitudes Δ_{SdH} depend on the concentration of electrons, n, and participating in the oscillations in the case of coinciding Cd_3As_2 with the Hall concentration (hence the Fermi surface is represented by a single ellipsoid). However, in [21] it was made a conclusion that the Fermi surface is represented by two ellipsoids. They studied SdH oscillations in Cd_3As_2 single crystals measured in three independent directions of the magnetic field along the crystallographic axes $[1\,1\,2]$, $[4\,4\,\bar{1}]$, and $[1\,\bar{1}\,0]$. But if the Fermi level lies in the conduction band and a second conduction band is 300 meV above the Fermi level, this should not affect the period of SdH oscillations. Thus, our consideration of single ellipsoid Fermi surface is possible.

In the case of small acceptors when the acceptor ionization energy is of the order of spin–orbit splitting of the valence band on the spin split-off area, there are specific quasi-stationary state of the acceptor. These conditions fall into areas of continuous spectrum of light and heavy holes. In such cases, the wave function of holes consists of a localized portion, formed by spin-split-off band, and part of delocalized states of zones of light and heavy holes.

In the case of a resonance acceptor band, a part of conduction band electrons are captured by acceptors, depending on the position of the Fermi level with respect to the maximum of acceptor band.

When the pressure increases, $E_F(p)$ shifts to high energy levels. If $E_F(0)$ is located near the bottom of E_g, near the maximum of acceptor band, n will decrease with increasing p leading to an increase in $\Delta_{SdH}(p)$. Otherwise, when $E_F(0)$ is localized near the upper edge of the acceptor band, there is a decrease of n due to the pressure of occupation of empty acceptor states. This decrease will be small, and is comparable to the growth of n due to the compression of the material. This leads to a decrease in $\Delta_{SdH}(p)$ when p increases [20]. However, as mentioned above, in the CZMA samples $(x + y = 0.2)$ the dependence $m_c(B)$ was not observed. Therefore, it is impossible to identify clearly the reason for anomalous dependence $m_c(B)$ and to observed resonance levels.

In [5] it was observed in $(Cd_{1-x} - Zn_x)_3As_2$ solid solutions that a basic frequency of the SdH oscillations decreases with increasing x in the interval $x < 0.29$. For $0.29 \leqslant x \leqslant 0.38$ there was a presence of a mixture of frequencies, whose ratio varied depending on the magnitude of the magnetic field and temperature. Such a complex, multi-frequency behavior of the SdH oscillations were observed just in the range of compositions in which we observed an abnormal relationship $m_c(B)$ in samples CZMA $(x + y = 0.4; x + y = 0.3)$. Both $(Cd_{1-x}Zn_x)_3As_2$ in the compositions range $0.29 \leqslant x \leqslant 0.38$ [5] and CZMA $(x + y = 0.4; x + y = 0.3)$ are either semi-metal or narrow-gap semiconductor.

4. Conclusions

In this paper we performed investigation of the Shubnikov–de Haas effect in single crystals of solid solutions of dilute magnetic semiconductors $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ $(x + y = 0.4;$ $y = 0.04$ and $y = 0.08)$, obtained by Bridgman method based on 3D Dirac semimetals Cd_3As_2. For both samples $y = 0.04$ and $y = 0.08$ the value of the cyclotron effective mass of charge carriers m_c, Dingle temperature T_D, parameter $T_{D\mu}$, Shubnikov n_{SdH} and Hall n_R concentration, mobility, μ_H, of charge carriers and period of oscillation P_{SdH}, were defined (table 1). The obtained parameters do not conflict with similar results obtained previously for diluted magnetic semiconductors CZMA $(x + y = 0.2; x + y = 0.3)$ [11, 18, 20]. A strong field dependence of the cyclotron effective mass was observed in crystals with low Mn $(y = 0.04)$. All results are in good agreement with earlier results for quaternary $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ [11, 18, 20] and ternary $(Cd_{1-x}Zn_x)_3As_2$ [5] solid solution. We made also analysis of works devoted to the band structure of Cd_3As_2 [14, 15, 21–23] and similar structures and properties of ternary solid solution $(Cd_{1-x}Zn_x)_3As_2$ [5]. However, it was impossible to determine the reason of the anomalous dependence of the effective mass of charge carriers $m_c(B)$ in the low concentration of Mn $(y = 0.04)$ definitely. In the high concentration of Mn in CZMA $(y = 0.08)$ the absence of this relationship were observed. The CZMA $(y = 0.08)$ samples demonstrated properties of Dirac semimetals. The dependence H_F/H_N on N insertion in figure 3 (on the left) showed the phase shift $\beta \approx 0.44$, that is an evidence of presence of Berry's phase in this sample.

Thus it was found that solid solution of diluted magnetic semiconductor $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ $(x + y = 0.4)$ demonstrates the properties of topological insulator in case of the concentration of Mn $y = 0.08$ and anomalous dependence of cyclotron mass from the magnetic field in case of the concentration of Mn decreases to $y = 0.04$.

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