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Shubnikov-de Haas oscillations in diluted magnetic semiconductors $(Cd_{1-x-y}Zn_xMn_y)_3As_2$

Vasilii S. Zakhvalinskii[1*], *Tatyana B.* Nikulicheva[1], *Erkki* Lähderanta[2], *Aleksey V.* Kochura[3,4], *Ekaterina A.* Nikitovskaia[1], *Evgeny A.* Pilyk[1,4], and *Mikhail A.* Pogrebneak[1]

[1]Belgorod National Research University, 85 Pobedy St, Belgorod, 308015, Russia
[2]Department of Mathematics and Physics, Lappeenranta University of Technology, PO Box 20, FIN-53852 Lappeenranta, Finland
[3]SouthWest State University, 94 50 Let Oktjabrja str., Kursk, 305040, Russia
[4]P.N. Lebedev Physical Institute of the RAS, 53 Leninskiyprosp., 119991, Moscow, Russia

Abstract. Single crystals of a diluted magnetic semiconductor $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ (CZMA) ($x + y = 0.4$;y=0.04 and 0.08) obtained by Bridgman method were used. The Shubnikov-de Haas (SdH) effect was observed within studying of the dependence of the resistivity on the magnetic field in CZMA solid solutions. The values of the cyclotron mass m_c, Hall and Shubnikov carrier concentrations were calculated.

1 Introduction

Diluted magnetic semiconductors (DMS) are the semiconductors in which a part of the cations is replaced by transition or rare-earth elements with partially filled d- or f-shells, respectively. These elements are randomly located in the semiconductor matrix, what leads to several types of interactions: the first, *sp-d* (*sp-f*) exchange interaction between the band carriers and the localized magnetic moments of the atoms of transition (or rare-earth) elements; the second, *d-d*(*f-f*) exchange interaction directly between the atoms of these elements.

The most known and studied DMS are Mn based solutions of semiconductors synthesized by different methods including crystallization from a melt and a molecular beam epitaxy [1, 2].At a sufficiently high concentration of magnetic ions, a ferromagnetic order appears in such DMS. Using materials with high Curie temperature (T_C) extends the capabilities of modern microelectronics and gives an impetus to develop spintronics [3]. By now, DMS structures with T_C ~200 K based on p-$(Ga_{1-x}Mn_x)As$ have been obtained [4]. In some materials such as p-(Ga, Mn)P, p- and n-(Ga, Mn)N, ferromagnetism was also detected at temperatures exceeding the room temperature [5].

On the other hand, a group of DMS based on the 3D Dirac semimetal Cd_3As_2 [6] is of particular interest. Recently evidences of an existence of a topological states in $(Cd_{1-x}Zn_x)As_2$ solid solutions have been observed [7, 8]. The research of magnetic solid solutions based on Cd_3As_2allowsusto trace the evolution of topological properties and will create prerequisites for a practical application of this unique material. The purpose of this article was to investigate the properties of solid solutions of a diluted magnetic semiconductor $(Cd_{1-x-y}Zn_xMn_y)_3As_2$.

2 Experimental details, results and discussion

A modified Bridgeman method was used to obtain single crystals of$(Cd_{1-x-y}Zn_xMn_y)_3As_2$ (CZMA) ($x + y = 0.4$; 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. All the investigated samples $(Cd_{1-x-y}Zn_xMn_y)_3As_2$ had a tetragonal crystal system (α''-Cd_3As_2), space group $P4_2/nmc$ [9].

The Shubnikov-de Haas (SdH) effect was observed within studying the dependence of the resistivity on the magnetic field in CZMA solid solutions. Measurements were made on the pulsed magnetic field facility in the temperature range from 1.6 K to 300 K and the magnetic fields from 0 to 25 T. The SdH oscillations observed in the CZMA samples are shown in Figure.

Increasing of an amplitude of the SdH oscillations in the investigated samples $(Cd_{0.6}Zn_{0.36}Mn_{0.04})_3As_2$ and $(Cd_{0.6}Zn_{0.32}Mn_{0.08})_3As_2$ with at increasing a magnetic field is similar to that observed earlier for other CZMA compositions [10, 11].

The amplitude of the SdH oscillations can be written as [2]:

$$A \sim B^{-1/2} z/\mathrm{sh}(z)\exp\left[-2\pi^2 m_c k_B T_D/(\eta e B)\right]\cos(\pi\nu) \quad (1)$$

* Corresponding author: zakhvalinskii@bsu.edu.ru

where $z = 2\pi^2 m_c k_B T/(\eta eB)$, T_D is the Dingle temperature, $\nu = gm_c/(2m_0)$, m_c is the cyclotron mass, m_0, $\hbar$, e and k_B are the physical constant.

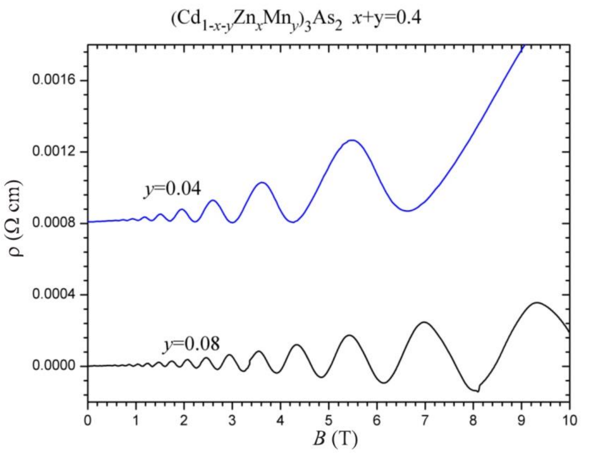

Figure. Shubnikov-de Haas oscillations in single crystals $(Cd_{1-x-y}Zn_xMn_y)_3As_2$($x + y = 0.4$;$y = 0.04$ and 0.08 at $T = 2.4$ K).

According to the results of [10], in our samples the g-factor should not depend on a temperature. So, an analysis of the amplitudes of the Shubnikov-de Haas oscillations using Eq. (1) and the values of the SdH amplitudes measured at two different temperatures at a fixed value of the magnetic field, as in conventional semiconductors, makes it possible to determine a number of parameters, for example, the cyclotron mass [9].The comparison of charge carrier concentrations obtained from Hall and Shubnikov measurements was carried out (Table). The Hall carrier concentration was calculated as follows [13]:

$$n_R = 1/(eR_H) \qquad (2)$$

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

Table. Parameters found from the SdH oscillations of CZMA samples ($x + y = 0.4$; $y = 0.04$ and 0.08) and for undoped Cd_3As_2 [15, 16].

y(Mn)	0.04	0.08	Cd_3As_2
n_R/n_{SdH}	0.97	1.04	1.2 [15]
$\mu_H \cdot 10^{-4}$, $cm^2V^{-1}s^{-1}$	2.28	1.53	2.9 [16]
P_{SdH},T^{-1}	0.061	0.025	0.02 [16]
$m_c(0)/m_0$	0.0409	0.0435	0.043 [16]

Shubnikov carrier concentration was calculated according to the equation [14]:

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

where P_{SdH} is the period of the SdH oscillations, the ratio n_R/n_{SdH} is close to unity, in accordance with results obtained previously for CZMA [10,11,13]. When considering the properties of solid solutions of $(Cd_{1-x-y}Zn_xMn_y)_3As_2$, we were based on the similarity of the band structure of Cd_3As_2 and InSb [16].

3 Conclusions

In this paper we performed an investigation of the Shubnikov de Haas effect in single crystals of solid solutions of diluted magnetic semiconductors $Cd_{1-x-y}Zn_xMn_y)_3As_2$($x + y = 0.4$; y=0.04 and 0.08), obtained by Bridgman method based on 3D Dirac semimetals Cd_3As_2. For both samples the value of the cyclotron effective mass of charge carriers m_c, Shubnikov n_{SdH} and Hall n_R concentration, mobility, μ_H, of charge carriers and period of oscillations P_{SdH}, were defined (Table). The obtained parameters do not conflict with similar results obtained previously for diluted magnetic semiconductors CZMA (x+y = 0.2; x+y = 0.3) [10, 11, 13].

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