Journal of Magnetism and Magnetic Materials 140–144 (1995) 2021–2022

Magnetoresistance of $(Zn_{1-x}Mn_x)_3As_2$ in region of hopping conductivity

R. Laiho [a,*], K. Lisunov [b], V. Stamov [b], V. Zahvalinsky [b]

[a] *Wihuri Physical Laboratory, University of Turku, 20500 Turku, Finland*
[b] *Institute of Applied Physics, Kishinev, Moldavia*

Abstract

Magnetoresistance (MR) of $(Zn_{1-x}Mn_x)_3As_2$ $(0 \leq x \leq 0.13)$ is measured at $4 < T < 20$ K. In applied fields < 1 T positive MR is observed for all compositions investigated. Above 1 T it is negative. The positive contribution is attributed to shift of the mobility threshold, and the negative one to suppression of the underbarrier spin-flip scattering of holes in the magnetic field.

The alloys $(Zn_{1-x}Mn_x)_3As_2$, shortly ZMA, belong to a new class of semimagnetic semiconductors based on the II–V compound Zn_3As_2. At room temperature the crystal structure of these materials is tetragonal with space group $I4_1cd$ [1]. ZMA has interesting magnetic properties, including freezing of moments near 200 K, as observed for single crystals with $x \geq 0.02$ [2]. Another noticeable feature is the existence of a pronounced paramagnetic tail in the susceptibility curves $\chi(T)$ below $T \sim 50$ K [2]. In addition to these phenomena also a low-temperature spin-glass phase at $T < 4$ K has been observed [3].

Here we report results of magnetoresistance (MR) investigations of ZMA, made to complete recent low-temperature conductivity measurements of these alloys [4].

Single crystals of ZMA with $0.01 \leq x \leq 0.13$ were grown from stoichiometric amounts of Zn_3As_2 and Mn_3As_2 by using a modified Bridgeman method. The compositions and homogeneity of the samples were analyzed by X-ray and microprobe methods. MR measurements were made in fields of 0–4 T by using the six-probe dc technique. The specimens were cooled in a He exchange gas dewar and their temperature was controlled with an accuracy of 0.5%.

As shown in Fig. 1, the relative magnetoresistance $[R(H)-R(0)]/R(0)$ of ZMA $(x = 0.02)$ has a complex dependence on the applied field H and the temperature T, including both a negative (nMR) and a positive (pMR) contribution. In the nMR region the data has a tendency to collapse to a single curve at high values of the parameter H/T (Fig. 2). The pMR has a similar tendency at small values of H/T (Fig. 3). Therefore, these contributions can be considered to be functions of H/T, pMR having an additional exponential decay with T. Both pMR and nMR decrease when x is increased. At the same time the field H where MR changes its sign shifts to higher values.

When the temperature is lowered, a transition to the hopping conductivity with a constant activation energy takes place in ZMA at $T \sim 10$ K [4]. In addition, samples with $x \sim 0.01$ are close to the metal–insulator transition [4]. In such situation pMR is known to originate mostly from an increase of the activation energy by the magnetic field [5]. This mechanism can also be used to explain the exponential decay of pMR with T observed experimentally.

The scaling of nMR and pMR with H/T points out to a possibility of spin-flip scattering of charge carriers. This phenomenon appears usually in systems with paramagnetic

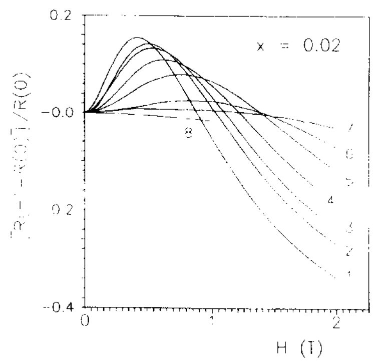

Fig. 1. Field dependence of the magnetoresistance in ZMA at temperatures 4.2 K (1), 4.8 K (2), 5.3 K (3), 6.1 K (4), 7.8 K (5), 10.6 K (6), 15.4 K (7), 19.5 K (8).

* Corresponding author. Fax: +358-21-2319836; email: erlah@utu.fi.

SSDI 0304-8853(94)00711-X

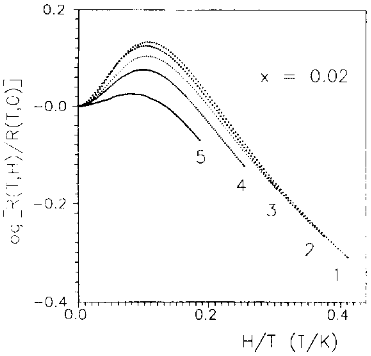

Fig. 2. Collapse of nMR to a single line at high values of H/T, $T = 4.8$ K (1), 5.3 K (2), 6.1 K (3), 7.8 K (4), 10.6 K (5).

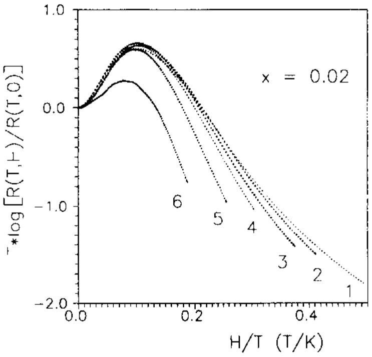

Fig. 3. Collapse of pMR to a single line at low values of H/T, $T = 4.2$ K (1), 4.8 K (2), 5.3 K (3), 6.1 K (4), 7.8 K (5), 10.6 K (6).

impurities in the region of the metallic conductivity. In ZMA this type of conductivity is not observed [4]. However, as suggested in Ref. [4] the spin-flip scattering of holes by the magnetic moments of manganese may take place during their transitions between acceptor centers (a variant of 'underbarrier scattering'). Such a process would lead to an anomalous decrease of the conductivity when x is increased. This agrees with the observation in ZMA [4].

We conclude that the presence of nMR in ZMA is due to suppression of the spin-flip scattering in a magnetic field. The reason for the H/T-scaling of pMR is not clear. Presumably it results from a finite negative contribution to the total MR beginning from the lowest values of H where pMR is a predominant factor. The deviation of the curve measured at $T = 10.6$ K from the other curves in Fig. 3 correlates well with the suggested transition temperature to the hopping conductivity [4].

References

[1] A. Pietratszko and K. Lukaszevicz, Phys. Stat. Sol. (a) 18 (1973) 723; G.C. De Vries, E. Frikkee, R.B. Helmholdt, K. Kopinga and W.J.M. De Jonge, Physica B 156 & 157 (1989) 321.

[2] A.V. Lashkul, E. Lähderanta, R. Laiho and V. Zachvalinskiy, Phys. Rev. B 46 (1992) 6251.

[3] C.J.M. Denissen, Sun Dakun, K. Kopinga, W.J.M. de Jonge, H. Nishihara, T. Sakakibara and T. Goto, Phys. Rev. B 36 (1987) 5316.

[4] K. Lisunov, A. Lashkul, R. Laiho, V. Zachvalinski, A. Mäkien and E. Lähderanta, J. Phys. C 5 (1993) 5113.

[5] B.I. Shklovskii and A.L. Efros, Electronic Properties of Doped Semiconductors (Moscow, Nauka, 1979).