Magnetoresistance of \((\text{Zn}_{1-x}\text{Mn}_{x})_3\text{As}_2\) 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 \((\text{Zn}_{1-x}\text{Mn}_{x})_3\text{As}_2\) \((0 < x < 0.13)\) 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 \((\text{Zn}_{1-x}\text{Mn}_{x})_3\text{As}_2\), shortly ZMA, belong to a new class of semimagnetic semiconductors based on the II–V compound \(\text{Zn}_3\text{As}_2\). At room temperature the crystal structure of these materials is tetragonal with space group \(I4_1\text{cd}\) [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 \(0.01 < x < 0.13\) were grown from stoichiometric amounts of \(\text{Zn}_3\text{As}_2\) and \(\text{Mn}_3\text{As}_2\) 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

---

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