Electrical and Magnetic Properties of Homogeneous $Cd_{1-x}Mn_xGeAs_2$ Compound

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Complex diluted magnetic semiconductors, such as II-IV-V_2 chalcopyrite materials, are perceived as prospective candidates for being used in spintronics. Room temperature ferromagnetism in $Cd_{1-x}Mn_xGeAs_2$ alloys with θ as high as 330 K for the crystal with 5.1 at.% of Mn was found (via direct observation of NMR spectra characteristic of MnAs hyperfine structure) to be related to the presence of MnAs clusters. However, in order to understand the complex magnetic properties of ferromagnetic semiconductor systems, it is necessary to study low paramagnetic ion alloying regime, where the aggregation of magnetic impurities does not occur.

We present the structural, electrical, and magnetic properties of bulk $Cd_{1-x}Mn_xGeAs_2$ crystals with low Mn content, x, varying from 0 to 0.037. Our samples have good structural quality, with lattice parameters changing as a function of the Mn content, x, according to the Vegard rule.

The transport properties of our samples show p-type conductivity due to impurity states present near valence band, with activation energy of about 200 meV. The carrier transport in our samples at temperatures higher than 150 K is thermally activated, while at $T < 150$ K a degenerated transport dominates. The carrier mobility shows the presence of ionic carrier scattering centers with concentration from 6 to 15×10^{17} cm^{-3}. The scattering centers are not related to the Mn impurities.

The paramagnetic Curie-Weiss behavior indicates that the majority of Mn ions in our samples are isolated (randomly distributed in the host $CdGeAs_2$ lattice). The estimates of the active Mn content in most of our samples, give values similar to those obtained with the use of the EDXRF method. That indicates that the majority of Mn ions substitute the Cd positions in the $CdGeAs_2$ lattice, and possess Mn^{2+} charge state with high magnetic momentum. We prove that the total solubility of Mn in $Cd_{1-x}Mn_xGeAs_2$ is around $x = 0.04$, a value lower than for II-VI and rather high with respect to III-V DMS bulk crystals grown under thermal equilibrium conditions. Both II-VI and III-V DMS we may consider as ternary analogs of $Cd_{1-x}Mn_xGeAs_2$. The negative Curie-Weiss temperatures, with values increasing as a function of x are observed indicating an antiferromagnetic exchange interaction. The average value of the exchange parameter, $J/k_B \approx$ -1.8±1 K, is of the same order as those observed in II-VI DMS and in very dilute III-V DMS with carrier concentration below 10^{19} cm^{-3}. This result may be explained by assuming the superexchange via an anion.

[1] S.C. Erwin and I. Žutić, *Nat. Mater.* **3**, 410 (2004).
[2] L. Kilanski et al., *Solid State Commun.* **151**, 870 (2011).