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Magnetic properties of selected $A^{IV}B^{VI}$ semiconductors with manganese and with chromium

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The present dissertation is focused on the research of properties of two composite compounds belonging to the semimagnetic semiconductor class of materials. Undertaken issues are in the leading research areas of modern science, which are oriented on developing and inserting the materials with the combined features, electronic properties of semiconductors and magnetic properties typical for ferromagnetic compounds, into practical application. The aim of this dissertation was therefore to determine the influence of varying concentrations of the paramagnetic ions of manganese and chromium on the structural, magnetic, and transport properties of the two bulk compounds from the $A^{IV}B^{VI}$ group of the elements, i.e. $Ge_{1-x-y}Pb_xMn_yTe$ and $Ge_{1-x-y}Pb_xCr_yTe$.

The concentrations of substitutional ions are changing in a wide range, i.e. $0.155 < x < 0.311$, $0.019 < y < 0.136$ for $Ge_{1-x-y}Pb_xMn_yTe$ and $0.181 < x < 0.220$, $0.017 < y < 0.043$ for $Ge_{1-x-y}Pb_xCr_yTe$, which allows analysis of the effect of its changes on the structural, magnetic, and magnetotransport properties of the crystals. Structural characterization revealed that all the samples are composite compounds consisting of a GeTe-based matrix with PbTe-based clusters. In both phases appropriate concentrations of magnetic ion dopants are diluted. In the crystals with chromium ions Cr_5Te_8 precipitations were found. Magnetic properties of both semiconductors were significantly different. In $Ge_{1-x-y}Pb_xMn_yTe$ crystals the magnetic transition of the matrix to a spin-glass-like state was observed at temperatures between 44.0 and 92.7 K, and signatures of the transitions of the clusters were also visible below 20 K. In $Ge_{1-x-y}Pb_xCr_yTe$ samples at 130–150 K the Cr_5Te_8 precipitations indicate transition to a spin-glass-like state, while the matrix shows a paramagnet-ferromagnet transition for crystals with 4.3 and 3.8 at.% of Cr and transition to the spin-glass-like state for samples with lower average chromium content at 56.0 K, 66.4 K, and 37.2–39.8 K, respectively. In Cr-doped samples at the investigated temperatures there was no sign of magnetic transition in the PbTe-based clusters. For both alloys the spin-glass-like state of the matrix was caused by the long range indirect Ruderman-Kittel-Kasuya-Yoshina (RKKY) interaction and the presence of magnetic and structural disorder which leads to the spin frustration in the systems. The spin-glass-like state of Cr_5Te_8 precipitations was a consequence of their random position in the matrix and fluctuation of phase stoichiometry. For both compounds the magnetic properties of the matrix indicate a possible presence of clusters of interacting magnetic moments as result of local fluctuation of magnetic ions concentration.

The $Ge_{1-x-y}Pb_xMn_yTe$ and $Ge_{1-x-y}Pb_xCr_yTe$ crystals are p-type semiconductors with high carrier concentrations of the order 10^{20} to 10^{21} cm^{-3} and with metallic-like conductivity. In Mn-doped samples the metal-insulator transition at $T < 100$ K and phonon-assisted hopping through localized states were observed. Therefore in the Cr-doped crystals there were two local maxima in the $\rho_{xx}(T)$ function caused by critical scattering due to spin fluctuations. The anomalous Hall effect (AHE) was observed only in $Ge_{1-x-y}Pb_xMn_yTe$ crystals. AHE analysis revealed values of the anomalous Hall constant R_S typical for IV-VI semimagnetic semiconductors and skew scattering as a main mechanism responsible for the AHE in the studied system.

In both $Ge_{1-x-y}Pb_xMn_yTe$ and $Ge_{1-x-y}Pb_xCr_yTe$ crystals several contributions to magnetoresistance (MR) were observed, but in each alloy the character and physical mechanism responsible for them were different. Negative MR at low temperatures for crystals with Mn ions is due to spin-dependent carrier scattering by the localized magnetic moments. In Cr-doped samples negative MR was related to the magnetic transition of the Cr_5Te_8 phase and caused by critical scattering. At magnetic transition temperatures in Mn-doped semiconductors the maximum in the positive MR related to giant spin-splitting of the valance band was observed. In both alloys in the temperature range of magnetic ordering the superposition of small contributions from classical quadratic MR and linear MR related to the granular nature of the samples was observed.

In both solid solutions the Pb-ion concentrations have impact on the values of the magnetic exchange constant J_{pd}. Moreover, the magnetic phase with higher transition temperatures due to creation of an effective static magnetic field caused increase of the J_{pd} values for other phases. Therefore higher critical temperatures for relatively low magnetic ions concentration were possible to be obtained.

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