Li (Zn,Mn) As as a new generation ferromagnet based on a I-II-V semiconductor [REIMEI project]

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Ferromagnetic systems obtained by doping transition metals into semiconductors [1] have generated extensive studies since early 1990's [2] because of their potential use for spin-sensitive electronics (spintronics) devices. In prototypical systems based on III-V semiconductors, such as (Ga,Mn) As and (In,Mn) As, substitution of divalent Mn atoms into trivalent Ga or In sites leads to severely limited chemical solubility, resulting in chemically metastable specimens available only as thin films [1]. Their materials quality exhibits high sensitivity on preparation methods [3], and self-doping of hole carriers via substitution prohibits electron doping. To overcome these difficulties, Masek *et al*. [4] theoretically proposed systems based on a I-II-V semiconductor LiZnAs, where magnetism due to isovalent (Zn,Mn) substitution may be decoupled from carrier doping with excess/deficient Li concentrations.

Recently we succeeded in synthesizing bulk poly-crystal specimens of $Li_{1+y}(Zn_{1-x}Mn_x)$ As and $Li_{1+y}(Cd_{1-x}Mn_x)$P at the Institute of Physics (IOP) of Beijing [5]. As shown in Fig. 1 for Li (Zn, Mn) As, these systems exhibit ferromagnetism with T_c up to 50 K in nominally Li-excess (y = 0.05–0.2) compounds with Mn concentrations x = 0.03−0.15, and a very low coercive field (30−100 Oe) promising for spin manipulations. Resistivity show metallic conductivity for Li deficient and Li excess systems. The Hall resistivity exhibits anomalous Hall term due to spontaneous magnetization, and, to our surprise, p-type carriers in Li excess systems. This is likely due to excess Li substituting the Zn or Cd site and forming an acceptor.

We performed MuSR measurements in $Li_{1.1}(Zn_{0.95}Mn_{0.05})As$, and confirmed static magnetic order below T_c ~ 27 K, with the full volume fraction at T = 0 [5]. In a plot of the muon spin relaxation rate (which represent the ordered moment size times concentration) and T_c, the results from Li (Zn,Mn) As and (Ga,Mn) As [6] exhibit a common slope, which suggests a common ferromagnetic interactions. These results are consistent with Local Density Approximation and quantum Monte-Carlo calculations by Gu and Maekawa.

The availability of bulk specimens allowed NMR studies in these two systems with signals from ^{7}Li and ^{31}P nuclei. The Li NMR in Li (Zn,Mn) As exhibits sharp peaking of the relaxation rate $1/T_1$ at the ferromagnetic transition temperature T_C. The observed scaling of $1/T_1T$ with $1/(T+T_W)$, appearing with a positive T_W in a wide temperature region above T_C, suggests an influence of antiferromagnetic coupling between Mn moments located in nearest-neighbor geometry.

As shown in Fig. 2, ferromagnetic Li (Zn,Mn) As (T_C ~ 50 K) and semiconducting LiZnAs have a crystal structure similar to those of antiferromagnetic LiMnAs (T_N ~ 450 K) and superconducting LiFeAs (T_c ~ 25 K), having common square-lattice As layers with 10% lattice constants matching. This feature may enable fabrication of junction devices of various combinations of these systems for spin-sensitive electronics.

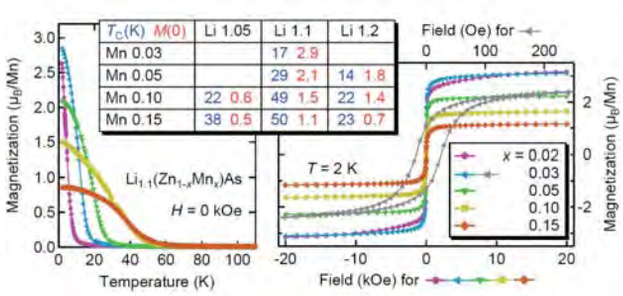

Fig. 1 Magnetization M (H) of $Li_{1.1}$ ($Zn_{1-x}Mn_x$) As. The gray symbol shows in a very small coercive field of 30-100 Oe. The inset table shows the values of T_c and the average ferromagnetic ordered moment size M (T=2K;H=2kOe) per Mn derived from magnetization measurements for nominally Li excess systems. (cited from [5])

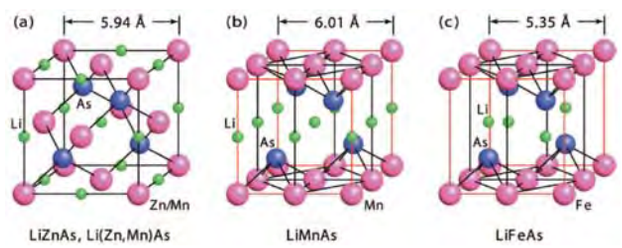

Fig. 2 Crystal structures of Li(Zn,Mn)As, LiMnAs and LiFeAs.

References

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