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## STRUCTURE AND TRANSPORT PROPERTIES OF DOUBLE DOPED Mg<sub>1-x</sub>(Al<sub>0.5</sub>Li<sub>0.5</sub>)<sub>x</sub>B<sub>2</sub>

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A series of polycrystalline samples of  $Mg_{1-x}(Al_{0.5}Li_{0.5})_xB_2$  ( $0 \le x \le 0.6$ ) and  $Mg_{1-x}Al_xB_2$  ( $0 \le x \le 0.4$ ) were synthesized by the conventional solid state reaction method and their structure and superconductivity were investigated by means of x-ray diffraction (XRD), ac susceptibility and resistivity. The XRD patterns of  $Mg_{1-x}(Al_{0.5}Li_{0.5})_xB_2$  ( $0 \le x \le 0.6$ ) samples show that the predominant phase was of  $MgB_2$  type and there was a minor amount of impurity phases for the  $x \le 0.4$  samples. A marked increase in intensity of impurity phases can be clearly observed for the x = 0.6 sample. Similar to Al doping, the double doping leads to a decrease in both the lattice parameters *a* and *c* as shown in the inset of Fig. 1.

To obtain the superconducting transition temperature, both resistivity and ac susceptibility measurement were made. The  $T_c$  obtained from magnetic measurement is approximately consistent with that from  $\rho$ -T curves. Fig. 1 illustrates the variation of zero resistivity,  $T_c^0$ , as a function of substitution level x for Mg<sub>1-x</sub>(Al<sub>0.5</sub>Li<sub>0.5</sub>)<sub>x</sub>B<sub>2</sub> and

Mg<sub>1-x</sub>Al<sub>x</sub>B<sub>2</sub>. The  $T_c$ s for the double-doped samples are systematically higher than that of the single Al doped samples. The difference of  $T_c^0$ s between the two systems increases and it reaches about 10 K for the two x = 0.4 samples.

High-pressure experimental results indicated that MgB<sub>2</sub> remains strictly hexagonal until the high pressure [1]. The large value of critical temperature variation with small modification in the unit-cell volume demonstrates that Mg-B and B-B bonding distances crucial in the are superconductivity, which



**Fig. 1.**  $T_c^0$  dependence of doping level *x* for  $Mg_{1-x}(Al_{0.5}Li_{0.5})_xB_2$  and  $Mg_{1-x}Al_xB_2$ . The inset illustrates the lattice parameter *a* and *c* as a function of *x*.

can be used to understand our results, i.e., Al doping in  $Mg_{1-x}Al_xB_2$  leads to a faster decrease in lattice parameters than the double doping with the same doping level, thus the decrease in  $T_c$  with Al doping is faster than that with double doping.

To clarify the factors that influence the superconducting transition temperature, we calculated the dependence of  $T_c$  on the unit-cell volume and plotted  $T_c(V)$  in Figure 2.

The result from high-pressure experiment was also given in the figure for comparison. At low doping level, the volume dependence of  $T_c$  values are close for the three cases and the  $T_{\rm c}s$  show a approximately linear volume dependence. With further decreasing  $V_{\rm v}$  a deviation remarkable from linear  $T_{\rm c}(V)$  behavior for the chemical substituted cases can clearly observed. be The structural transition for the Al doped MgB<sub>2</sub> system taking place as x0.1 may be a possible factor causing the deviation. However, the structural transition, as well as the 'pressure effect', cannot be used to account for the fact that



ig.2  $T_c$  as a function of unit-cell volume for  $Mg_{1-x}(Al_{0.5}Li_{0.5})_xB_2$  and  $Mg_{1-x}Al_xB_2$  and  $MgB_2$ .

with same unit-cell volume the double-doped system has lower  $T_c$  than Al doped system. Obviously the change of carrier concentration is not the main cause resulting in different  $T_c(V)$  between the two systems. In fact, the effect of carrier concentration on  $T_c$  is a little different between MgB<sub>2</sub> and high  $T_c$  cuprates. Hall effect experimental results [2] showed that the charge carriers in MgB<sub>2</sub> are holes with a density of  $1.7 - 2.8 \times 10^{23}$  holes cm<sup>-3</sup> at 300 K, which is about two orders of magnitude higher than the charge carrier density for high Tc cuprates. This value corresponds to 2.5 - 4 holes per unit-cell in MgB<sub>2</sub>. Therefore a little change in carrier concentration may not show significant influence on  $T_c$  in MgB<sub>2</sub> system, which is in contrast to that in high- $T_c$ cuprates. From the variation of lattice parameters with doping one may find that in order to get same unit-cell volume, the doping level for the double doped system is always higher than the Al doped system, which means that the disorder for the former is higher than that for the latter with same unit-cell volume. The strong disorder or localized structural distortion may be the origin causing the different  $T_c(V)$ .

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