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Low temperature specific heat (zero field and with field) of Fe and Mn-doped MgB_2

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ABSTRACT

Polycrystalline samples of MgB_2 superconductor (Mn-doped as well as pristine) were investigated by measurements of the electrical resistivity, magneto-resistance in the temperature range of 4–300 K. All the samples show metallic behaviour. It is observed that the upper critical field slightly decreases with Mn concentration. Specific heat measurements were performed with field as well as without field. For comparison, we also prepared one Fe-doped and specific heat measurements were also carried out on this sample. It is observed that the jump in specific heat decreases with increase in Mn content.

1. Introduction

The discovery of superconductivity in MgB_2 [1] has evoked an unprecedented research in experimental as well as theoretical work. It has drawn tremendous attention due to the fact that it is a simple inter-metallic compound and exhibits a remarkably high transition temperature of about 39 K [1,2]. MgB_2 shows a lower anisotropy, large coherence lengths and better current flow across the grain boundaries than the cuprates based superconductors [3]. This makes MgB_2 a fairly good candidate for practical applications. The superconducting properties of cuprates based superconductors could be improved by doping with various compounds and the same way several studies have been done on doping with MgB_2 samples. Chemical substitution, like in other superconductors, serves as a useful tool to modify the structure and other physical properties of MgB_2 to study the underlying mechanism of superconductivity and improve some of its important parameters for the practical applications. Lot of work has been reported on Al-doped [4–7] and 3-d transition metal substitutions [8–10] in Mg sub-lattice and the general feature of these reports is the fact that these substitutions lower the transition temperature. None of the studies have been able to enhance the transition temperature of the compound. Nevertheless, these studies have been useful in the sense that they clarify the role of the different scattering centres.

Among the various substitutions, there are only three successful reports on Mn doping, viz. two on single crystals [11,12] and the other on bulk samples [13]. The most remarkable feature of Mn substitution is that it exhibits the most rapid decrease in transition temperature. This has been attributed to a different mechanism viz. due to spin-flip scattering and (or) pair-breaking effect [14]. These reports are primarily limited to properties like transition temperatures and upper critical fields. In fact there are no reports on electrical and thermal properties like thermal conductivity, thermo-power and specific heat on Mn-doped samples. Specific heat, in particular is a powerful tool to understand the thermodynamics of the transition. Keeping this in mind, we have prepared high-quality Mn-doped bulk samples of MgB_2. Due to rapid decrease in transition temperature we have used low concentrations of Mn. On the other hand, the magnetic element Fe shows much slower variation in T_c in comparison with Mn [10] and hence we are presenting comparison with Fe-doped sample. In this paper we are communicating first report on effect of Mn doping on specific heat (zero field and with fields) of MgB_2 compounds.

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Table 1
Values of transition temperature (T_c), upper critical field [$H_{c2}(0)$] and lattice parameters "a" and "c" for the samples $Mg_{1-x}Mn_xB_2$ with various x values.

Mn content x (%)	T_c (K)	$H_{c2}(0)$ (Tesla)	a parameter [±0.001 Å]	c parameter [±0.001 Å]
0	39.0	26.3	3.084	3.513
0.5	37.7	24.9	3.080	3.535
1	37.6	23.7	3.081	3.525
1.5	37.4	23.6	3.079	3.526
2	36.9	23.1	3.081	3.527

2. Experimental details

Polycrystalline samples of $Mg_{1-x}Mn_xB_2$ have been prepared using solid state reaction technique. The starting precursor powders for sample preparation are crystalline magnesium (99.8%), amorphous boron (95–97%) and manganese powder. The powders were then well mixed and ground for 60 min. The resultant powder was pressed into pellets. Each of the pellets was then wrapped in Ta foil with the presence of some Mg turnings and annealed at 900 °C for 15 min with heating and cooling rate of 15 °C/min. The tubular furnace was then turned off and samples were allowed to cool down to room temperature. Similar procedure was used for Fe-doped sample. X-ray diffraction method was used to see if the samples were single phased and to determine the lattice parameters. The XRD patterns indicate that all the samples used for present studies were single phased. We have observed an almost linear decrease in c parameter with Mn substitution. On the other hand there is an increase in a parameter with increase in Mn content. The lattice parameters are given in Table 1.

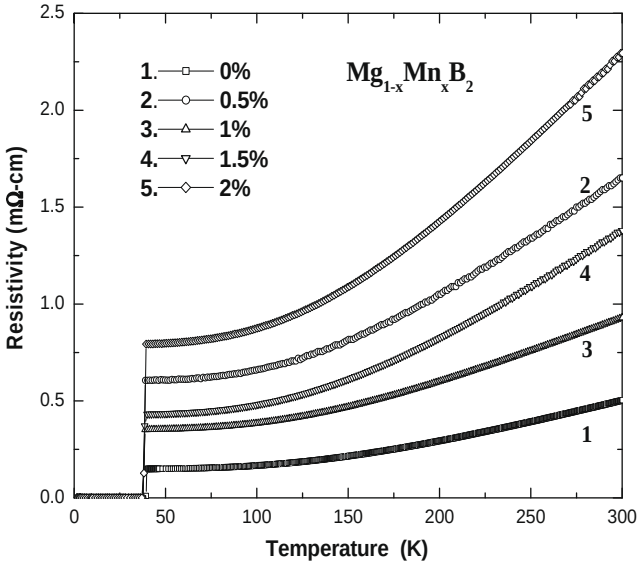

Fig. 1. Resistivity versus temperature plots of the samples $Mg_{1-x}Mn_xB_2$ for various values of x.

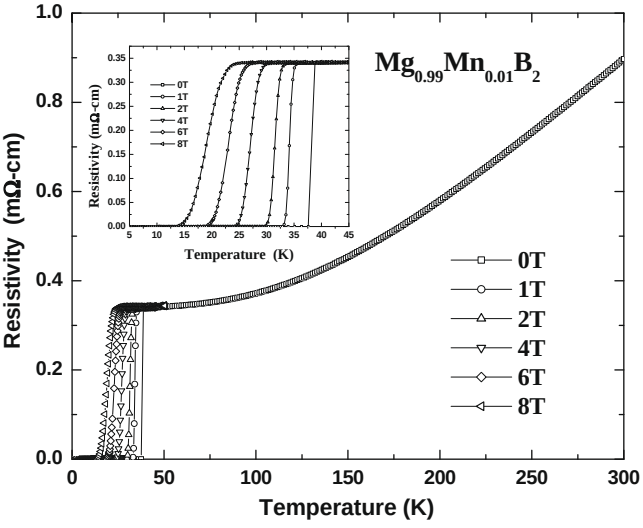

Fig. 2. Resistivity versus temperature plots of the sample $Mg_{0.99}Mn_{0.01}B_2$ for various fields.

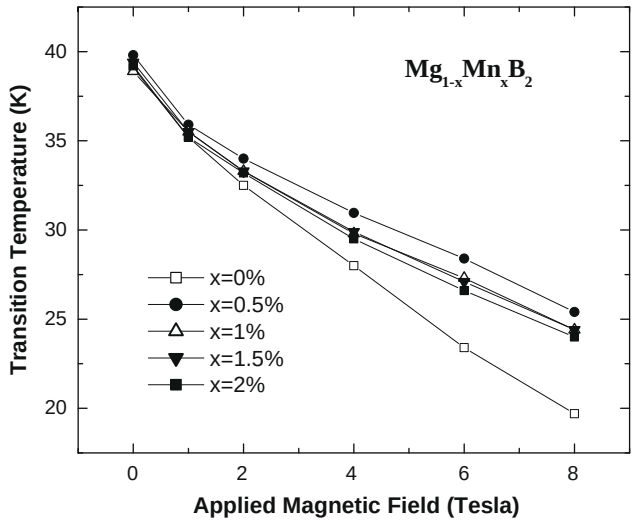

Fig. 3. Transition temperature of the samples at various applied fields.

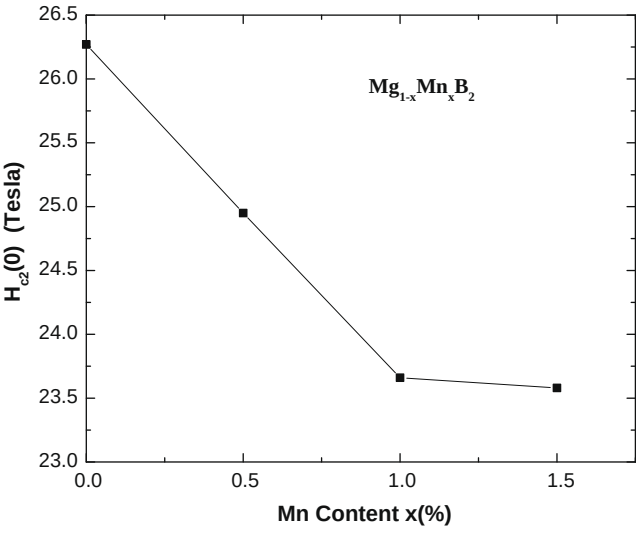

Fig. 4. Variation of $H_{c2}(0)$ of $Mg_{1-x}Mn_xB_2$ compounds with Mn concentration (x%).