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Giant magnetoresistance in $Y_{0.9}La_{0.1}Mn_6Sn_6$ compound*

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Magnetic transitions and magnetoresistance effect of the $HfFe_6Ge_6$-type $Y_{0.9}La_{0.1}Mn_6Sn_6$ compound have been investigated in the temperature range of 5–380K. The sample displays antiferromagnetic behaviour in the whole temperature range below Néel temperature T_N=309K. The metamagnetic transition from antiferromagnetism to ferromagnetism can be induced by an applied field. The metamagnetic transition field decreases monotonically from 2T at 5K to 0.4T at 300K. The giant magnetoresistance effect is observed with the metamagnetic behaviour, such as −10.4% at 245K under a field of 5T.

Keywords: rare-earth manganese compounds, giant magnetoresistance, metamagnetic transition
PACC: 7530K, 7530V, 7550E

1. Introduction

After the first report on the giant magnetoresistance (GMR) in Fe/Cr multilayers,[1] GMRs have been discovered in a number of systems, such as granular alloys,[2,3] manganese perovskites,[4−7] and bulk intermetallic compounds.[8−13] Though many models have been proposed to explain the GMR effect, it is widely accepted that the GMR effect is caused by a spin-dependent electron scattering simultaneously when the magnetic structure changes from an antiferromagnetic (AFM) to ferromagnetic (FM) configuration by the application of a magnetic field. In this case, the GMR effect can be observed in bulk intermetallic compounds with a magnetic-field-induced transition, for instance $SmMn_2Ge_2$ or $Fe_{0.5}Rh_{0.5}$, where the GMR effect occurs at a first-order metamagnetic transition from the AFM to FM state.[10,11] However, the GMR effect is usually achieved below room temperature and limited to comparatively high metamagnetic transition fields in these compounds.

Recently, the GMR effect has been observed also in the $HfFe_6Ge_6$-type (space group $P6/mmm$) RMn_6Sn_6 (R=Sc, Y, and Gd–Lu) compounds and their derivatives, i.e. $YMn_6Sn_{5.8}Ga_{0.2}$, $Y_{0.8}Dy_{0.2}Mn_6Sn_6$, and $Y_{0.7}Ce_{0.3}Mn_6Sn_6$.[12−15] All these compounds are composed of R and Mn layers alternately stacked along the c-axis in the sequence Mn–(R, Sn)–Mn–Sn–Sn–Sn–Mn. The interlayer Mn–Mn coupling through the Mn–Sn–Sn–Sn–Mn slab is always FM, while that within the Mn–(R, Sn)–Mn slab depends on the nature of R elements.[15,16] Among them, YMn_6Sn_6 shows an inhomogeneous helical antiferromagnetism below T_N=333K,[16] and undergoes the metamagnetic transition to the FM arrangement under a field of 2T at 5K, accompanied by a magnetoresistance (MR) effect of −5% at 5T.[12] The metamagnetic transition and the helical magnetic structure in YMn_6Sn_6 suggest that the exchange interactions between Mn interlayers are weak and very sensitive to the Mn–Mn interatomic distance and the modification of the chemical bond.[17] So, as naturally layered materials, RMn_6Sn_6 compounds provide an interesting complement to the studies of artificial multilayer materials.

In this paper, we report the effect of La substitution for Y on the magnetic and transport properties in the $Y_{0.9}La_{0.1}Mn_6Sn_6$ compound. As Y and La are nonmagnetic, this compound offers the possibility for a study of the Mn–Mn interactions in relation to the Mn–Mn interatomic distance, temperature, and magnetic field.

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2. Experimental

The $Y_{0.9}La_{0.1}Mn_6Sn_6$ polycrystalline sample was synthesized by melting the constituent elements in a highly purified Ar atmosphere by the standard arc-melting technique. The ingot was annealed at 1003K for ten days and rapidly cooled down to room temperature. X-ray diffraction (XRD) study was carried out using a Rigaku Rint 1400 diffractometer with Cu $K\alpha$ radiation at room temperature. The magnetization and MR measurements were carried out in the temperature range of 5–380K using a superconducting quantum interference device magnetometer with a maximum field of 5T. The MR was measured using the standard four-probe dc technique with an electric current (100mA) parallel to the magnetic field. The sample used in MR measurements was a square-cross-section rod in dimensions of about 10mm×2mm×2mm.

3. Results and discussion

The crystal structure of $Y_{0.9}La_{0.1}Mn_6Sn_6$ was investigated by XRD and displays peaks characteristic of the $HfFe_6Ge_6$-type structure with minor unknown impurity. Due to the larger ionic radius of La compared with Y, the substitution leads to an increase in the lattice constants a and c, which are 0.5530nm and 0.9010nm for $Y_{0.9}La_{0.1}Mn_6Sn_6$, respectively. The Mn–Mn interatomic distance in Mn (001) planes is equal to $a/2$, and that between layers is proportional to c. So the increase of the lattice constants induced by the substitution means the enlargement of the Mn–Mn interatomic distances within and between the layers.

The temperature dependence of electrical resistance (R) for $Y_{0.9}La_{0.1}Mn_6Sn_6$ was measured in zero field and at 5T (see Fig.1(a)). The result shows that $Y_{0.9}La_{0.1}Mn_6Sn_6$ follows a typical metallic behaviour. For comparison, the temperature dependences of MR and magnetization are both presented in Fig.1(b). Since the introduction of small quantities of La in the YMn_6Sn_6 matrix does not greatly change the magnetic structure, $Y_{0.9}La_{0.1}Mn_6Sn_6$ also displays inhomogeneous helical AFM behaviour in the whole temperature range below T_N=309K. The ratio of $[R(H) - R(0)] \times 100\%/R(0)$ has been used to denote MR. The MR increases gradually from −5.2% at 5K to −1% at 55K, then decreases quickly with increasing temperature, and reaches the minimum (MR=−10.3%) at 245K. The solid triangles in Fig.1(b) represent the MR values taken from the MR-$\mu_0 H$ measurements at various temperatures. They coincide closely with the result of MR-T measurement, suggesting that these results are very reliable.

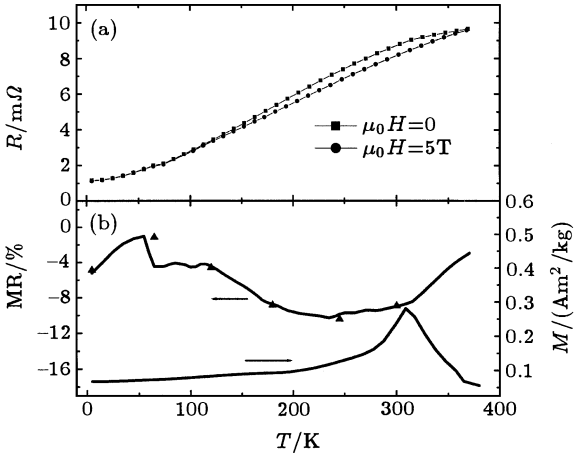


Fig.1. Temperature (T) dependence of electronic resistance (R) under zero field and 5T field (a), and MR magnetization for $Y_{0.9}La_{0.1}Mn_6Sn_6$ (b). The thermal magnetization curve was measured at 0.01T. The solid triangles represent the MR values taken from the MR-$\mu_0 H$ measurements at various temperatures.

To understand the effect of the external magnetic field on magnetic properties, we have measured the temperature dependence of the magnetization for $Y_{0.9}La_{0.1}Mn_6Sn_6$ in various fields (see Fig.2). The strong influence of the magnetic field on magnetic properties is observed in the AFM state between 5K and 309K, and the temperature range of the AFM state narrows with increasing magnetic field. The external magnetic field equal to 3T can transform the sample into the FM state, implying a metamagnetic transition.

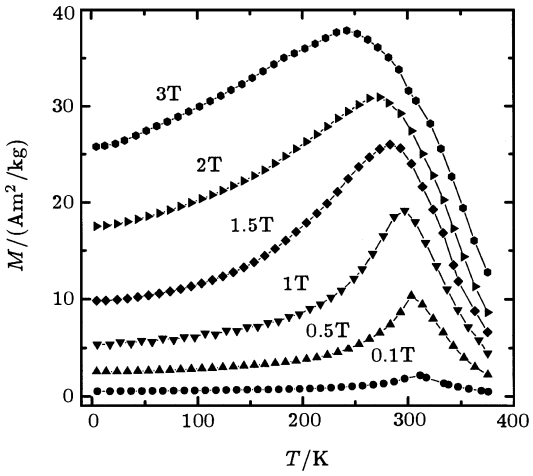


Fig.2. Temperature dependence of magnetization for $Y_{0.9}La_{0.1}Mn_6Sn_6$ under various magnetic fields.

Figure 3 shows the magnetic field dependence of the magnetization at various temperatures for the powder sample. The magnetization increases linearly initially and then rises rapidly at a fixed temperature, indicating a metamagnetic transition from an AFM to FM state. The threshold field ($\mu_0 H_{\rm th}$), taken at the maximum slope of the magnetization isotherms, decreases monotonically with increasing temperature, i.e. from 2T at 5K to 0.4T at 300K. This is in good agreement with the results shown in Fig.2. At 300K, the metamagnetic transition field in $Y_{0.9}La_{0.1}Mn_6Sn_6$ reaches 0.4T while the $\mu_0 H_{\rm th}$ in YMn_6Sn_6 is 1T,[12] demonstrating a weakening of the interlayer AFM interaction by the introduction of La. The increase of the Mn–Mn interatomic distance, especially the Mn–Mn distance along the c-axis, is one of the causes for this change of the magnetic interaction. Another cause is the change of the nature of R site. In $HfFe_6Ge_6$-type RMn_6Sn_6 compounds, the interlayer interaction through the Mn–Sn–Sn–Sn–Mn slab is always FM, whereas the Mn–Mn coupling through the Mn–(R, Sn)–Mn slab depends strongly on the nature of R elements.[17] The La substitution may change the electronic structure, leading to the AFM coupling weakening. The relation of the Mn–Mn interaction and the electronic configuration should be studied further. No saturation on isothermal magnetization curves is observed up to fields of 5T, which implies that the sample does not acquire a collinear FM state but rather goes into a canted FM state in the range of fields studied.

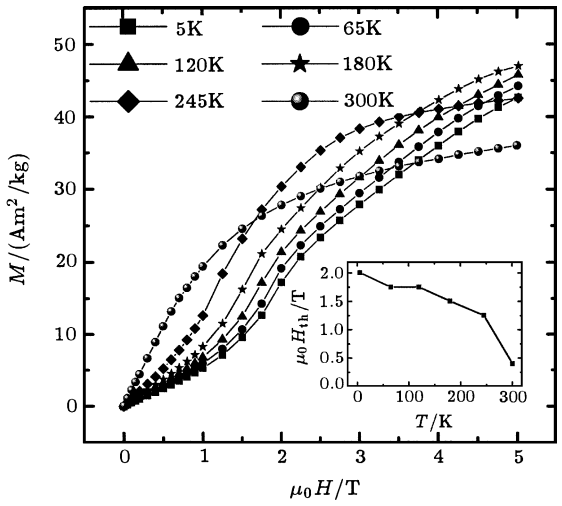


Fig.3. Magnetic field dependence of magnetization for $Y_{0.9}La_{0.1}Mn_6Sn_6$ at various temperatures. The inset shows the temperature dependence of the threshold field $\mu_0 H_{\rm th}$.

Figure 4 shows the magnetic field dependence of the MR and magnetization for $Y_{0.9}La_{0.1}Mn_6Sn_6$ at 5K and 245K, by first increasing the field to 5T and then decreasing it to zero field. At 5K, the sudden development of negative MR around $\mu_0 H_{\rm th}$ indicates that the sample undergoes a metamagnetic transition from an AFM to FM state. This transition is accompanied by the onset of a marked hysteresis in the MR-$\mu_0 H$ curves, indicating the transition of first order. Similar transitions in MR have been observed earlier in $SmMn_2Ge_2$-based and YMn_6Sn_6-based compounds.[9,12–15] Similar phenomena have been also observed at 245K. It is worth noting that $Y_{0.9}La_{0.1}Mn_6Sn_6$ displays the GMR effect at 245K under a magnetic field of 5T (MR=−10.4%).

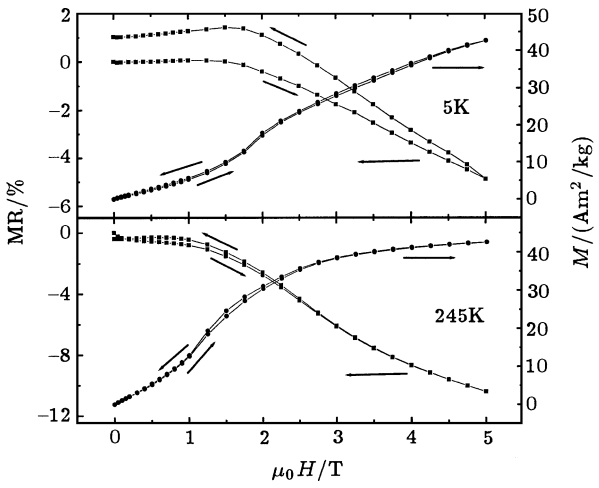


Fig.4. Magnetic field dependence of MR and magnetization for $Y_{0.9}La_{0.1}Mn_6Sn_6$ at 5K and 245K.

4. Conclusion

In summary, $Y_{0.9}La_{0.1}Mn_6Sn_6$ displays the AFM behaviour in the whole magnetic ordering temperature range. The metamagnetic transition from an AFM to FM arrangement can be induced by applying sufficiently strong magnetic field, and the $\mu_0 H_{\rm th}$ decreases monotonically with increasing temperature. Accompanied by metamagnetic transitions, the GMR effect is observed, such as −10.4% at 245K under a magnetic field of 5T. For their relatively simple fabrication technique, relatively low threshold fields and the GMR effect around room temperature, the bulk compounds including $Y_{0.9}La_{0.1}Mn_6Sn_6$ with metamagnetic transition seem to be potential materials for GMR devices.

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