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Temperature dependence of magnetic properties in Ni-Mn-Ga shape memory alloys

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Due to exhibiting giant field-induce strain, the Ni_2MnGa shape memory alloys are great interest for both scientific researches and industry applications. The non-stoichiometric $Ni_{50}Mn_{25+x}Ga_{25-x}$ alloys with x varied from 1.5, 2.5 to 4 have been fabricated by arc-melting. Martensitic transformation temperature for structure transformation from tetragonal to cubic (T_M) was observed from the magnetization, electrical resistivity and X-ray diffraction studies as functions of temperature below 400 K. We found that T_M increases roughly from 280 K to 310K with increasing x from 1.5 to 4. However, the Curie transition (T_C) is roughly at 380 K for all the samples, it is insensitive to the variation of Mn/Ga ratio. The electrical resistivity data exhibit a deep near T_M and a slope change near T_C. We have experimentally demonstrated that the shape memory effect can be occurred at room temperature with a proper concentration variation of Mn and Ga.

1 Introduction

Ferromagnetic shape memory alloy (FSMA) Ni_2MnGa provides the possibility in microelectromechanical systems (MEMS) [1, 2] with large magnetic-field-induced strain [3]. Up to 6% magnetic-field-induced strain has been reported at room-temperature in magnetic fields below 1 T [4]. With decreasing temperature, the structure of Ni_2MnGa transformed from cubic austenite to tetragonal martensitic, and it shows giant strain related to the motion of the martensitic twin boundary by magnetic field [5–7]. Many efforts have been focused on the magnetic behaviors of Ni_2MnGa system, and relatively very few reports [8] on its electrical resistivity behavior. In this study, we reported the properties of electrical resistivity and magnetization measurement as a function of temperature of the varied Ni_2MnGa compound alloys.

2 Experiments

The ingot of NiMnGa samples was prepared by arc-melting with the high purity elements (99.99 at %) under an Ar atmosphere, and remelted at least three times to ensure homogeneity. They were vacuum-

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sealed in quartz tube and annealed at 1100 °C for ten days, followed by ice water quenching for three samples of NiMnGa where Mn is substituted for Ga from x = 1.5 to 4 in $Ni_{50}Mn_{25+x}Ga_{25-x}$.

A powder specimen for X-ray analysis was prepared from the same ingot which was studied using the Philips X'Pert X-ray diffractometer with CuKα radiation. The electrical resistivity was measured using a commercial (Quantum design) Physical Property Measurement System (PPMS). The magnetization of these compounds were measured in superconducting quantum interference device (SQUID) magnetometer.

3 Results and discussion

Crystal structure of different temperature from 100 K to 370 K was analyzed by X-ray diffraction for all the samples. Take the $Ni_{50}Mn_{26.5}Ga_{23.5}$ in Fig. 1 for example. It is clear that when the temperature is above 280 K, two peaks appear near 2θ = 44° and 81°, which shows that the single phase is of cubic austenite structure. For the type of cubic $L2_1$, Ni atoms occupy (0,0,0) and (1/2,1/2,1/2) site, Mn occupy (1/4,1/4,1/4) site, and Ga occupy (3/4,3/4,3/4) site [9]. When temperature decreases below 260 K, four peaks that occur near 2θ = 43°,45°,80° and 83° were monitored, indicating that pure tetragonal martensite phase crystallizes. For this structure, Ga atoms are placed on the corners and center of cell. A Mn atom is placed between one pair of Ga along the c axis, and another Mn atom occupy the center of face which vertical with c-axis. Ni atoms occupy the faces of the tetragonal cell, such that two of them lay at 1/4 and 3/4 height at the center of the face [10]. The cubic and the tetragonal co-exist in the temperature that ranges from 260 K to 280 K. It is clear in X-ray diffraction pattern that with the decrease of temperature, the structure transform from cubic to tetragonal in Ni_2MnGa alloy.

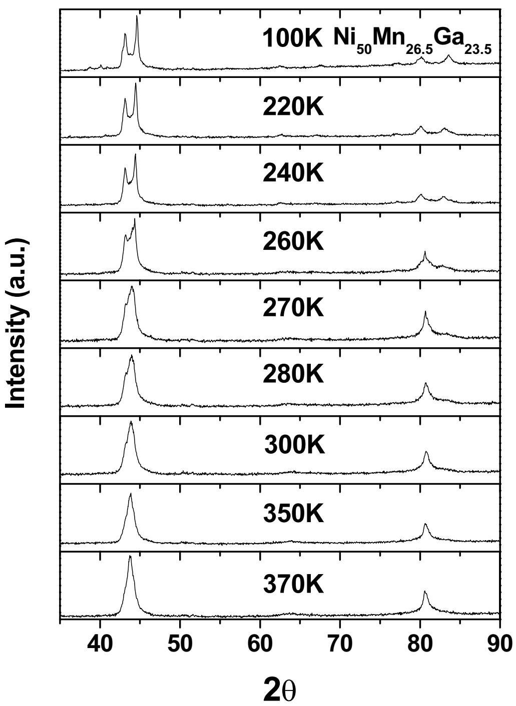

Fig. 1 X-ray diffraction at different temperatures from 100 K to 370 K for $Ni_{50}Mn_{26.5}Ga_{23.5}$ alloy.

Figure 2 shows the typical temperature dependence of magnetization curves M(T) for alloys of $Ni_{50}Mn_{25+x}Ga_{25-x}$ (x = 1.5, 2.5, 4) in low magnetic field H = 100 Oe. These results indicate the existence of two sharp phase transitions: For example $Ni_{50}Mn_{26.5}Ga_{23.5}$, the transition occurred at 280K is related to the martensitic transition (T_M) from tetragonal structure at low temperature to cubic structure at high temperature. The result is consistent with Fig. 1. The T_M increases from 280 K for sample with x = 1.5 to 290 and 310 K for samples with x = 2.5 and 4 as shown in Fig. 2. However, the Curie transition (T_C) is roughly at 380 K for all the samples, therefore, it is insensitive to the addition of Mn/Ga ratio [11].

Figure 3 shows the electrical resistivity as a function of temperature between 10 and 400 K for samples $Ni_{50}Mn_{25+x}Ga_{25-x}$ (x = 1.5, 2.5, 4) under an external magnetic field of 100 Oe. For temperatures below 50 K, the resistivity is roughly independent to the temperature [8]. For temperatures between 50 K and T_M, it decreases with increasing temperature. The structure transforms from tetragonal below T_M to cubic above it. For temperatures above T_M, the resistivity increases with increasing temperature; however, it shows a knee near T_c = 380 K. This is a typical behavior for magnetic phase transition at T_c.

Figure 4 shows the electrical resistivity curves under zero field cooling (ZFC) and field cooling (FC) for $Ni_{50}Mn_{27.5}Ga_{22.5}$. The applied magnetic field is kept at 100 Oe. It is obvious that ZFC and FC curves overlap in cubic structure region (i.e. above T_M). For temperatures below T_M, the ZFC and FC curves becomes apart from each other, and those curves insensitive to magnetic field. At 10 K, the change of resistivity is only 0.14% for field increased to 3 T. Near the structure transition temperature, which is between 280 K to 300 K, the resistivity data exhibit a hysteresis, and the variation of the resistivity is roughly 7%.

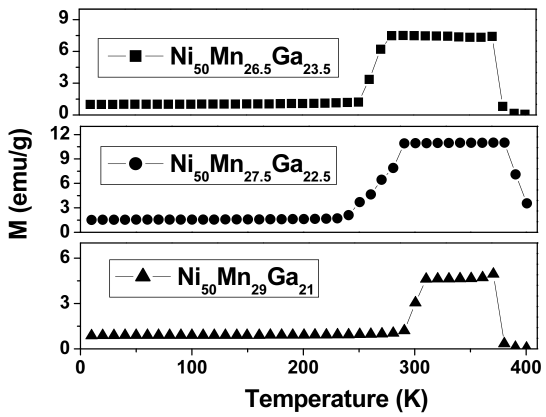

Fig. 2 Magnetization curves for $Ni_{50}Mn_{25+x}Ga_{25-x}$ (x = 1.5, 2.5, 4) in low magnetic field H = 100 Oe.

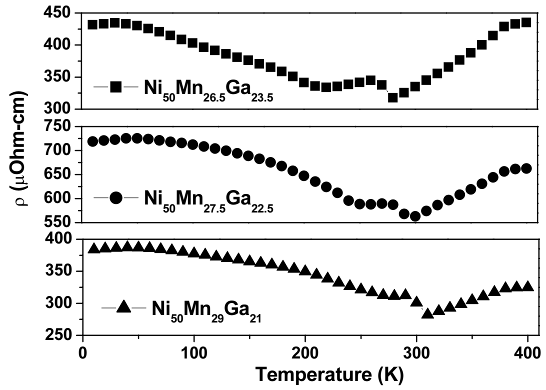

Fig. 3 Resistivity as a function of temperature for the alloys $Ni_{50}Mn_{25+x}Ga_{25-x}$ (x = 1.5, 2.5, 4) with 100 Oe.

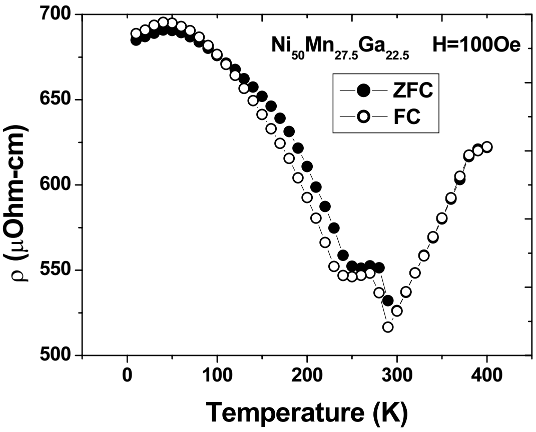

Fig. 4 The ZFC and FC curves with the balance of temperatue in $Ni_{50}Mn_{27.5}Ga_{22.5}$ with 100 Oe.

4 Summary

Martensitic transformation temperature for structure transformation from tetragonal to cubic was observed from the magnetization, electrical resistivity and X-ray diffraction studies as functions of temperature below 400 K for three $Ni_{50}Mn_{25+x}Ga_{25-x}$ alloys with x varied from 1.5, 2.5 to 4. T_M increases roughly from 280 K to 310 K with increasing x from 1.5 to 4. However, the Curie transition (T_C) is roughly at 380 K for all the samples, it is insensitive to the variation of Mn/Ga ratio.

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