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,MnGa shape memory alloys are great interest for both scientific researches and industry applications. The non-stoichiometric Ni₅₀Mn₂₅₊ₓGa₂₅₋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 (Tᵥ) was observed from the magnetization, electrical resistivity and X-ray diffraction studies as functions of temperature below 400 K. We found that Tᵥ increases roughly from 280 K to 310K with increasing x from 1.5 to 4. However, the Curie transition (Tₓ) 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 Tᵥ and a slope change near Tₓ. 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,MnGa 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,MnGa 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,MnGa 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,MnGa 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_{x}Mn_{20-x}Ga_{20+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 L2₁, 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_{x}Mn_{20-x}Ga_{20+x} alloy.

![Fig. 1 X-ray diffraction at different temperatures from 100 K to 370 K for Ni_{x}Mn_{20-x}Ga_{20+x} alloy.](image-url)
Figure 2 shows the typical temperature dependence of magnetization curves $M(T)$ for alloys of $\text{Ni}_{50}\text{Mn}_{25+x}\text{Ga}_{25-x}$ ($x = 1.5, 2.5, 4$) in low magnetic field $H = 100$ Oe. These results indicate the existence of two sharp phase transitions: For example $\text{Ni}_{50}\text{Mn}_{26.5}\text{Ga}_{23.5}$, 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 $\text{Ni}_{50}\text{Mn}_{25+x}\text{Ga}_{25-x}$ ($x = 1.5, 2.5, 4$) 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 $\text{Ni}_{50}\text{Mn}_{25+x}\text{Ga}_{25-x}$. 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%.

Figure 2: Magnetization curves for $\text{Ni}_{50}\text{Mn}_{25+x}\text{Ga}_{25-x}$ ($x = 1.5, 2.5, 4$) in low magnetic field $H = 100$ Oe.

Figure 3: Resistivity as a function of temperature for the alloys $\text{Ni}_{50}\text{Mn}_{25+x}\text{Ga}_{25-x}$ ($x = 1.5, 2.5, 4$) 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_{27.5}Ga_{22.5} 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.

References


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