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Magnetic field-induced strain of ferromagnetic Ni_2MnGa shape memory alloy

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Magnetic field-induced strain (MFIS) of a stoichiometric Ni_2MnGa exhibiting a martensite transformation at 202 K and an intermediate phase transformation at 250 K was investigated. Magnetostrictions of the parent phase (286K) and the intermediate phase (240K) are -7.5×10^{-5} and $-3.2\ \times 10^{-5}$, respectively. When magnetic field is applied along the $[001]_P$ direction at 77 K after cooling down to 77 K without magnetic field, MFIS of -3.8×10^{-2} is observed. In association with this MFIS, all variants completely convert to the variant whose *c*-axis is parallel to the field direction. This single variant state is also obtained just below the martensitic transformation temperature when the specimen is cooled under a magnetic field of 3.2 MA/m applied along $[001]_P$.

Key words: magnetic field-induced strain, ferromagnetic shape memory alloy

1. INTRODUCTION

Since the first discovery of a giant magnetic field-induced strain (MFIS) due to the rearrangement of martensite variants in Ni-Mn-Ga alloys by Ullakko et al.[1], this system has been intensively studied. Most works concerning to the MFIS of this system have been made by using alloys with non-stoichiometric compositions, and MFIS of 6% and more have been reported so far.[2,3] Although these alloys exhibit giant MFIS at room temperature, they are not suitable for a theoretical approach for explaining MFIS from microscopic point of view. One difficulty, for example, is the unclearness of site occupancy of atoms for non-stoichiometric alloys. It is desirable to investigate the alloy with stoichiometric composition for constructing a theoretical model. However, as far as the authors are aware, there is no experimental result of MFIS of the stoichiometric Ni_2MnGa.

The purpose of this work is, therefore, to investigate basic properties such as martensitc transformation behavior, magnetism as well as MFIS of a stoichiometric Ni_2MnGa single crystal.

2. EXPERIMENTAL PRICEDURE

A stoichiometric Ni_2MnGa single crystal was prepared by a floating zone method in argon atmosphere with a growing rate of 4 mm/h. After determining its orientation by a Laue back-reflection technique, the crystal was cut into parallelepiped specimen by using an electro-discharge machine. The size of the specimen for thermal expansion and MFIS measurements is 2.0 mm along $[001]_P$ direction and 2.2 mm$\times$ 2.1 mm perpendicular to it. The size of the specimen for magnetic susceptibility measurements is 2.5 mm along $[001]_P$ direction and 1.0 mm$\times$ 1.0 mm perpendicular to it. Specimens were solution treated at 1073 K for 100 h followed by ordering treatment at 923 K for 3 h.

Magnetic susceptibility was measured by a superconducting quantum interference device (SQUID) magnetometer. The thermal expansion and MFIS was measured by using a sensitive three terminal capacitance method.

3. RESULTS AND DISCUSSION

Fig.1 shows temperature dependence of magnetic susceptibility of the Ni_2MnGa single crystal. Measurement was made by applying a magnetic field of 80 kA/m along $[001]_P$ direction. In the cooling process, the susceptibility gradually increases with decreasing temperature, and shows an inflection point at 376 K. This corresponds to Curie temperature. The susceptibility continues to increase as temperature decreases and shows a small dip at 250 K. This dip corresponds to the transformation to an intermediate phase.[4] On farther cooling, the susceptibility shows an abrupt decrease at 202 K. This is the martensitic transformation temperature, and the decrease is due to the increase in the magnetocrystalline anisotropy. The temperature hysteresis between cooling and heating processes associated with the martenstic transformation is about 6 K. These transformation behaviors are in good agreement with those reported previously[4,5].

In this study, we evaluate the fraction (f_c) of martensite variants whose *c*-axis orientates along the field direction. In order to calculate f_c, the lattice parameter of the present specimen is required. Then, we made x-ray experiments in the cooling process by using powder specimen. The obtained lattice parameters are shown in Fig.2. The lattice parameters are consistent with previously reported ones.[5]

Prior to examining MFIS of the martensite phase, the magnetostriction of the parent and the intermediate phases was measured. The magnetostriction of the parent phase at 286 K is $\lambda_{001} = -7.5\times 10^{-5}$ (contraction), and that of the intermediate phase at 240 K is $\lambda_{001} = -3.2 \times 10^{-5}$. These magnetostriction recovers in the field removing process. Then, the specimen was cooled down to 77 K without magnetic field. During this

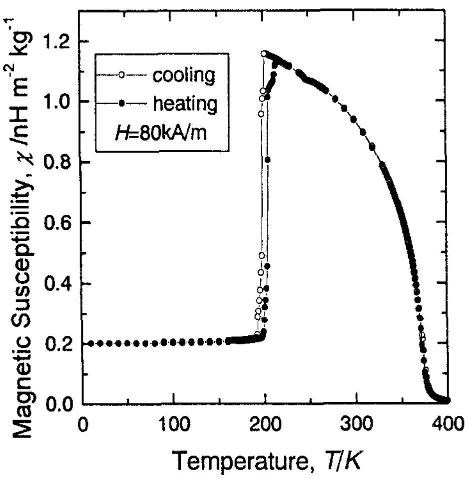

Fig.1 Temperature dependence of magnetic susceptibility for Ni2MnGa.

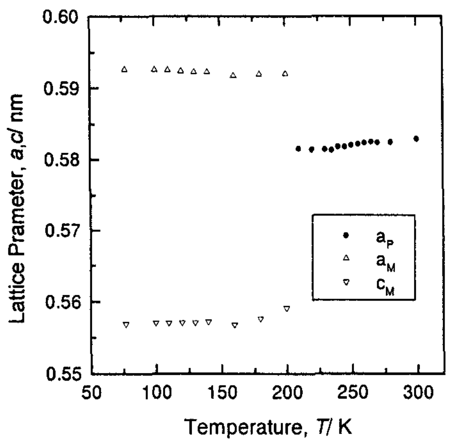

Fig.2 Temperature dependence of lattice parameter of a Ni2MnGa powder specimen.

cooling process, the specimen contracted by 0.01%, where f_c is about 30%.

After this zero-field cooling, the MFIS was measured along the $[001]_P$ direction at 77 K, and the result is shown in Fig.3. In the field applying process, the specimen starts to contract at the field of about 0.3 MA/m. The strain reaches the saturated value of 3.7% at the field of 0.7 MA/m, although it does not increase smoothly. The fraction f_c at this state is calculated to be 100 %, meaning that the specimen is composed of the single variant whose c-axis lies along the field direction. From the result, it is apparent that c-axis is the easy axis of magnetization like non-stoichiometric alloys[2]. The field-induced strain does not recover in the field removing process. Then, we applied magnetic field again; the MFIS of this process is smaller than 0.001 %. This value is quite reasonable because the specimen is already composed of the single variant and there remains no region which can be converted by the application of magnetic field. It is

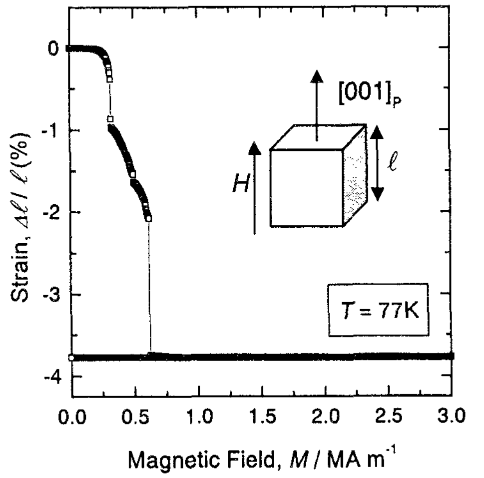

Fig.3 MFIS of Ni_2MnGa. Measurement was made along the $[001]_p$ direction by applying the magnetic field along the $[001]_P$ at 77 K.

speculated from the result that the magnetostriction of the martensite phase is in the order of 10^{-5}.

We also measured the strain during the cooling process under an applied magnetic field of 3.2 MA/m along $[001]_P$ direction. In this filed-cooling process, f_c also reaches 100 % just below its martensitic transformation temperature.

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