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Direct and Inverse Magnetocaloric Effect in $Ni_{1.81}Mn_{1.64}In_{0.55}$ Multifunctional Heusler Alloy

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Abstract. The magnetocaloric effect (MCE) in $Ni_{1.81}Mn_{1.64}In_{0.55}$ Heusler alloy has been measured by the direct method. The field dependences of the magnetization were obtained. The phase transition temperatures were determined. The maximal adiabatic temperature change ΔT_{ad} near the Curie temperature is 1.8 K under the magnetic field change ΔH = 18 kOe. The inverse MCE (ΔT_{ad} = -3.72 K) in the same field change takes place near the temperature of martensitic transformation.

Introduction

The MCE is a phenomenon of adiabatic temperature change of the magnetic material induced by change of external magnetic field. Recent experimental studies have shown that Ni-Mn-X (X = Ga, In, Sn, Sb) Heusler alloys are also attractive for magnetic refrigeration systems [1, 2]. Moreover, Heusler alloys are characterized by the sequence of magnetic, structural and modulation phase transitions, which can be controlled by external influence. Heusler alloys have a complex of interesting physical properties associated with these transitions. In addition, they are the excellent model objects for study of the physical properties of strongly correlated electron systems.

The interest to Ni-Mn-In compounds is related to a presence in these alloys the metamagnetic and structural transitions, which take place in non-stoichiometric compositions [3, 4, 5, 6]. Near the metamagnetic and structural transitions, the Heusler alloys show large inverse MCE, the magnetoresistance, the ferromagnetic shape memory effect and other interesting properties.

In this work we experimentally study the magnetic and magnetocaloric properties of $Ni_{1.81}Mn_{1.64}In_{0.55}$ Heusler alloy.

Experimental details

The polycrystalline ingot with nominal composition $Ni_{1.81}Mn_{1.64}In_{0.55}$ was prepared by an arc-melting method in argon atmosphere. The ingot was annealed for 9 days and quenched in cold water. Samples (8×4×2 mm) were cut from middle part of the ingot.

The temperatures of phase transitions were determined from the thermomagnetic dependences (zero field cooling – field cooling – field heating (ZFC-FC-FH) protocol) by Vibrating Sample Magnetometry (VSM, Versalab, QD) at different magnetic fields up to 30 kOe in the temperature range of 50–400 K. The heating and cooling rate was 5 K/min.

The MCE measurements were performed by the setup produced by AMT&C [7]. In this setup, the adiabatic temperature change ΔT_{ad} of the sample was registered by the direct method by means of the thermocouple. The magnetic field up to 18 kOe was produced by Halbach permanent magnet and was measured by the Hall probe. Signals from the thermocouple and the Hall probe were recorded simultaneously that allowed to measure ΔT_{ad} as a function of magnetic field H.

Measurements near the temperature of martensitic transformation were made by two protocols. In the first one, "the effect of the second measurement" was taken into account [8]. First, the sample was cooled to the temperature T- (process 1→2, Fig. 1), where T- is less than the martensite finish temperature M_f. After that, the sample was heated to temperature T_1 (process 2→3, Fig. 1). At this temperature, the magnetic field was changed from 0 to 18 kOe and ΔT_{ad} was measured simultaneously. To return in initial state (point 2, Fig. 1) the magnetic field is turned off and the sample is cooled to the temperature T- (process 3→2, Fig. 1). Such measurements (the heating protocol) of adiabatic temperature change ΔT_{ad} were repeated for other temperatures (processes 2→4→2, 2→i→2 and so on, Fig. 1).

The analogous measurements were fulfilled at cooling. In this case the temperature of the sample in initial state was above the austenite finish temperature A_f (the cooling protocol).

In the second protocol the adiabatic temperature change ΔT_{ad} was measured at heating from the temperature less the martensite finish temperature M_f and at cooling from the temperature above the austenite finish temperature A_f without returning to initial temperature. The MCE measurements near the Curie point were made only with the help of the second protocol.

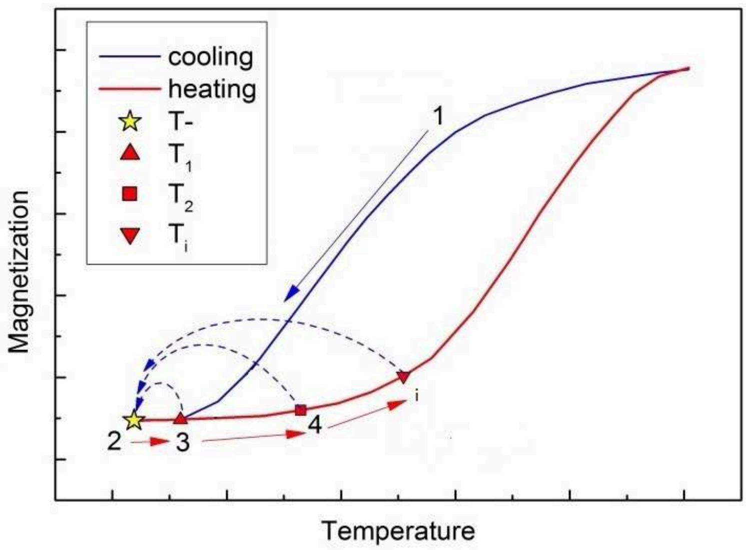

Fig.1. The scheme of the first protocol of MCE measurements at heating near the martensitic transition temperature.

Results and discussion

The magnetization curves of $Ni_{1.81}Mn_{1.64}In_{0.55}$ Heusler alloy are shown on Fig. 2. It is seen that in the alloy two phase transitions occur. The high-temperature transition is the magnetic phase transition from a paramagnetic cubic phase to a ferromagnetic cubic one (the Curie point, T_C = 320 K). The second transition is the structural phase transition from the ferromagnetic austenite phase to antiferromagnetic-like martensitic phase. The temperatures of start and finish of martensite/austenite states are M_S = 214 K, M_F = 205 K, A_S = 219 K, A_F = 231 K. The shift of martensitic transformation temperature induced by an external magnetic field is -7.5 K/T.

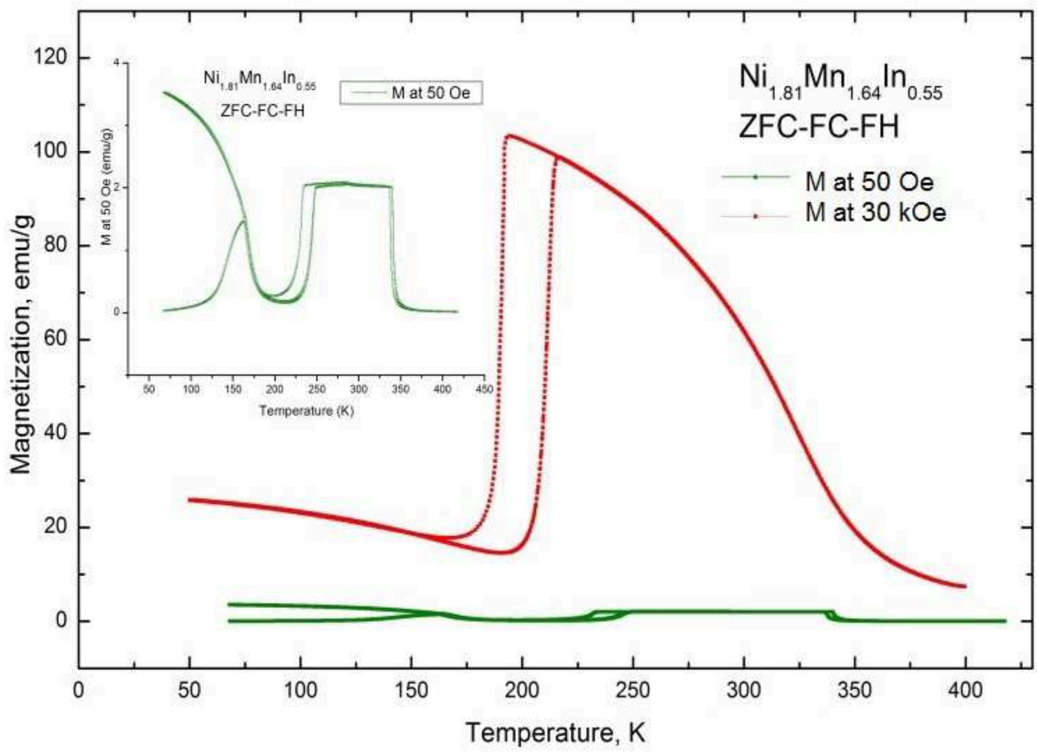

Fig.2. The thermomagnetization curves of the $Ni_{1.81}Mn_{1.64}In_{0.55}$ Heusler alloy.

Fig. 3 shows the temperature dependences of the adiabatic temperature change ΔT_{ad} for $Ni_{1.81}Mn_{1.64}In_{0.55}$ Heusler alloy. It is seen that at changing of the external magnetic field from 0 to 18 kOe the maximum value of direct MCE ΔT_{ad} = 1.8 K observed near the Curie temperature (T_C=320 K). The heating and cooling protocols in this case give the same results for value of MCE.

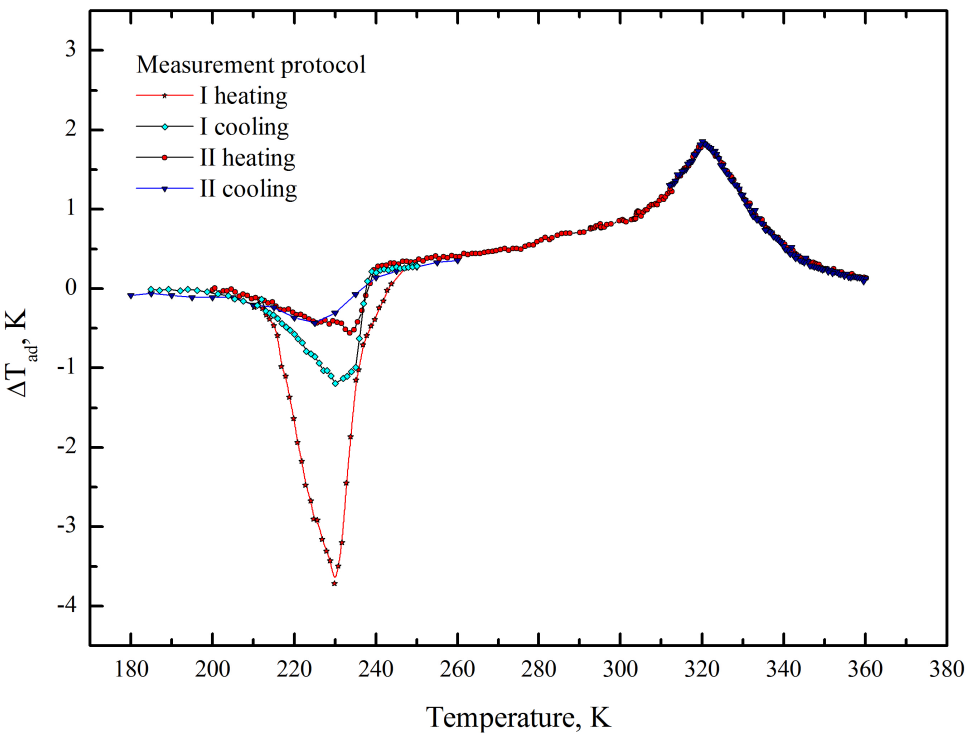

Fig.3. The temperature dependences of the adiabatic temperature change ΔT_{ad} for the $Ni_{1.81}Mn_{1.64}In_{0.55}$ Heusler alloy upon the magnetic field variation of ΔH = 18 kOe.

From Fig. 3 also follow that at the temperature of martensitic phase transition significant inverse MCE is observed. Its values measured with the help of first protocol at heating and cooling are ΔT_{ad} = -3.72 K and ΔT_{ad} = -1.26 K, respectively. We can see also that the significant difference in the values of ΔT_{ad} measured by the help of first and second protocols near the martensitic transition exist. Obviously, it is caused by irreversibility of the first order phase transition.

Conclusion

Martensitic and magnetic transformation behaviors of $Ni_{1.81}Mn_{1.64}In_{0.55}$ Heusler alloys were investigated. The magnetostructural transformation from the antiferromagnetic-like martensite to the ferromagnetic austenite phase was studied. The martensitic start and finish (M_S = 214 K, M_F = 205 K), and austenitic start and finish (A_S = 219 K, A_F = 231 K), and Curie (T_C = 320 K) temperatures were determined. In the $Ni_{1.81}Mn_{1.64}In_{0.55}$ alloy the shift of martensitic transformation temperature induced by an external magnetic field was found as -7.5 K/T. The adiabatic temperature change ΔT_{ad} under the external magnetic field change from 0 to 18 kOe was measured by direct method. The maximum positive value (ΔT_{ad} = 1.8 K) of MCE is observed at the Curie temperature. The giant inverse MCE (ΔT_{ad} = -3.72 K) is observed at the magnetostructural phase transition. This value agree with the giant inverse MCE for Co-doped Ni-Mn-In system [9].

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References

[1] K. Gschneidner, Jr., V.K. Pecharsky, Int. J. Refrig. 31 (2008) 945-961.

[2] A. Planes, L. Manosa, M. Acet, J. Phys.: Condens. Matter. 21 (2009) 233201.

[3] Z. D. Han, D. H. Wang, et. al., Appl. Phys. Lett. 89 (2006) 182507.

[4] K. Oikawa, W. Ito, et. al., Appl. Phys. Lett. 88 (2006) 122507.

[5] V. V. Kokorin, V. V. Koledov, et. al., Appl. Phys. Lett. 116 (2014) 103515.

[6] V.D. Buchelnikov and V.V. Sokolovskiy, Phys. Met. Metallogr. 112 (2011) 633-665.

[7] Y.I. Spichkin, et al., Proc. 3rd IIF-IIR Intern. Conf. Magnetic Refrigeration at Room Temperature, (Des Moines, Iowa, USA,2009) P. 173.

[8] V. Khovaylo, V. Koledov, V. Shavrov et al., Proc. Second IIF – IIR Intern. Conf. Magnetic Refrigeration at Room Temperature (Portoroz, Slovenia, 2007). P. 217-6.

[9] J. Liu, T. Gottschall, K.P. Skokov, J.D. Moore and O. Gutfleisch, Nature Matter. 11 (2012) 620.