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Thermomagnetic Properties of $LaFe_{11.0}Co_{0.8}(Si_{1-x}Al_x)_{1.2}$ ($x = 0$, 0.6) Alloys

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In the present work, Curie temperature, refrigeration capacity and cooling power of the $LaFe_{11.0}Co_{0.8}(Si_{1-x}Al_x)_{1.2}$ (where $x = 0$, 0.6) alloys, are investigated. The value of Curie temperature was found to be 280 and 290 K for $x = 0$ and 0.6, respectively. The determined values of cooling power (RCP) and refrigeration capacity (RC) differ only slightly for both investigated alloys. The maximum values of RCP and RC obtained under the change of external magnetic field from 0 to 5 T are 433 J/kg (for $x = 0$) and 290 J/kg (for $x = 0.6$), respectively.

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1. Introduction

The discovery of giant magnetic entropy change in $Gd_5Si_2Ge_2$ [1] started extensive studies of magnetocaloric effect in wide range of alloys. Due to high content of Gd in the alloy and thus its high price, the Fe-based systems seem to be more attractive in the final applications [2, 3]. Of particular interest among them are $La(Fe,Si)_{13}$-type alloys, which show giant magnetocaloric effect due to first order phase transition near Curie temperature. Previous studies of these alloys focused mostly on magnetic entropy change, alloying, phase structure, microstructure and preparations technique [4-8]. The aim of this paper is to investigate in more details their thermomagnetic behaviour and to estimate their cooling power (RCP) and refrigeration capacity (RC).

2. Samples preparation and experimental method

$LaFe_{11.0}Co_{0.8}(Si_{1-x}Al_x)_{1.2}$ $x = 0$, 0.6 alloys were prepared by arc-melting of high purity elements under low pressure of Ar. Subsequently samples were annealed in quartz tubes under Ar atmosphere at 1323 K for 28 and 49 days for $x = 0$ and $x = 0.6$, respectively. XRD data were collected using Bruker D8 Advance diffractometer with CuK_α radiation. X-ray diffractometry was supported by Rietveld analysis using PowderCell 2.4 package [9]. Magnetic studies were carried out using Quantum Design MPMS-XL-5, equipped with 5 T magnet over the temperature range 100-400 K.

3. Results and discussion

XRD patterns revealed coexistence of two crystalline phases. Rietveld analysis showed that expected cubic $NaZn_{13}$-type phase reaches 97 vol.% for both samples. The calculated lattice constant a for $NaZn_{13}$-type phase was equal to 11.49 and 11.55 Å, respectively for $x = 0$ and $x = 0.6$. The second crystalline phase corresponds to the α-Fe, with lattice constant $a = 2.86$ Å, which didn't change with the alloy composition.

Magnetization vs. temperature $M(T)$ dependence with corresponding first derivative dM/dT are shown in Fig. 1. Values of magnetization and its first derivative were normalized to the maximum value. For $LaFe_{11.0-}Co_{0.8}Si_{1.2}$ alloy the T_C reaches 280 K and for $LaFe_{11.0}Co_{0.8-}(Si_{0.4}Al_{0.6})_{1.2}$ the T_C is higher and amounts to 290 K. The second method used for the T_C estimation is the Arrott plot technique. Arrott plots $M^2 = f(\mu_0 H/M)$ were determined from magnetization curves collected in temperature range 180–400 K. Arrott plots for $x = 0$ and $x = 0.6$ alloys are shown in Fig. 2a and 2b, respectively. When the measurement temperature corresponds to the Curie temperature, the $M^2 = f(\mu_0 H/M)$ dependence is almost straight line. Values of Curie temperatures, determined from Arrott, are similar to those obtained from the $M(T)$ dependences. The $M = f(H)$ curves, measured at different temperatures, let us to calculate magnetic entropy changes, ΔS_M, using thermodynamic Maxwell equation [1]. Maximum value of ΔS_M reaches 12 and 7.7 J/(kg K) for $x = 0$ and 0.6, respectively. Temperature dependences of magnetic entropy change allowed us to calculate two important parameters.

The first one, RCP, is determined [10] using:

$$\mathrm{RCP} = -\Delta S_{M max} \times \delta T_{FWHM}, \tag{1}$$

where: RCP is the cooling power, $\Delta S_{M max}$ is the maximum of magnetic entropy change and δT_{FWHM} is the full width at half maximum of ΔS_M temperature dependence.

The second one, RC, is estimated [11] using:

$$\mathrm{RC}(\delta T, H_{\max}) = \int_{T_{cold}}^{T_{hot}} \Delta S_M(T, H_{\max}) dT, \tag{2}$$

where: RC is the cooling capacity, $\delta T = T_{hot} - T_{cold}$ is the temperature interval of thermodynamic cycle and H_{max} is the maximum value of external magnetic field.

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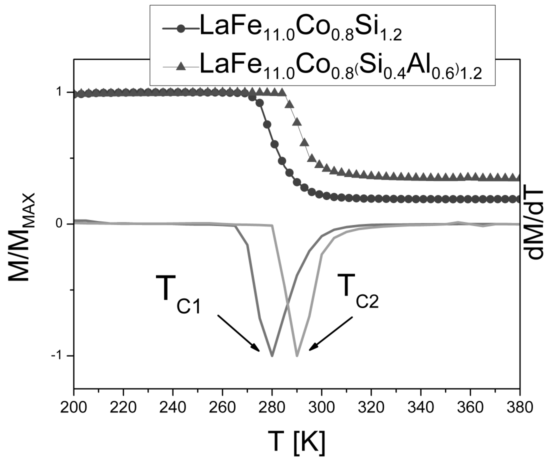

Fig. 1. Temperature dependence of magnetization and its first derivative for both investigated samples.

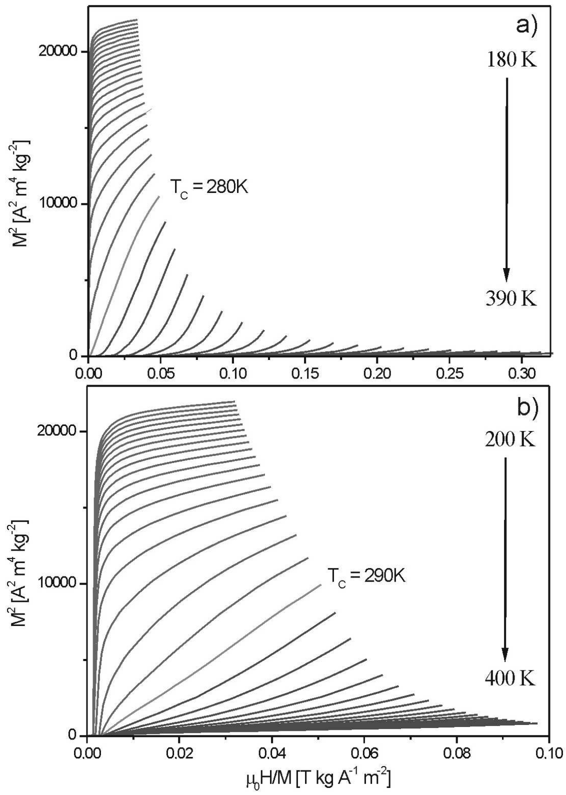

Fig. 2. Arrott plots obtained for both investigated samples (a) $LaFe_{11.0}Co_{0.8}Si_{1.2}$ alloy; (b) $LaFe_{11.0}Co_{0.8}(Si_{0.4}Al_{0.6})_{1.2}$.

The calculated values of relative cooling power (RCP) and cooling capacity (RC) are collected in Table. For both compositions, the values of RCP and RC are similar. As the magnetic entropy change for $LaFe_{11.0}Co_{0.8}Si_{1.2}$ alloy is almost two times higher than for $LaFe_{11.0}Co_{0.8}(Si_{0.4}Al_{0.6})_{1.2}$ alloy, one can conclude that the addition of Al causes broadening of full width at half maximum of magnetic entropy change from 35 K to almost 60 K. This effect leads to the maintainance of values of the RCP and the RC even though the decrease of maximum of magnetic entropy change is observed.

TABLE

Values of cooling power and cooling capacity of $LaFe_{11.0}Co_{0.8}Si_{1.2}$ / $LaFe_{11.0}Co_{0.8}(Si_{0.4}Al_{0.6})_{1.2}$.

Content x	$\mu_0\Delta H$ (T)	RCP (J/kg)	RC (J/kg)
0 / 0.6	1	77 / 72	61 / 55
	2	166 / 160	126 / 121
	3	246 / 250	193 / 188
	4	339 / 332	263 / 256
	5	423 / 433	290 / 280

4. Conclusions

It was shown in the present work that the addition of Al to $LaFe_{11.0}Co_{0.8}Si_{1.2}$-based alloy causes expansion of lattice parameter and an increase of Curie tempearature. Additionally Al causes broadening of temperature range of magnetic entropy change, thus increasing the possibility of application of this alloy.

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