Journal of Magnetism and Magnetic Materials 322 (2010) 3000–3003

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

Magnetic properties of $YFe_{12-x}Mo_x$ compounds and magnetocaloric effect of $YFe_{9.5}Mo_{2.5}$

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ARTICLE INFO

Article history:
Received 29 October 2009
Received in revised form
4 May 2010
Available online 19 May 2010

Keywords:
Magnetic property
Magnetocaloric effect
$YFe_{12-x}Mo_x$

ABSTRACT

The characterization and magnetic properties of $YFe_{12-x}Mo_x$ (x=2.0, 2.5 and 3.0) with the $ThMn_{12}$-type structure, and the magnetocaloric effect of $YFe_{9.5}Mo_{2.5}$ were investigated. A directional growth was observed in $YFe_{10}Mo_2$ alloy. A broad peak in the zero-field-cooling (ZFC) magnetization curve of the $YFe_{12-x}Mo_x$ compounds is ascribed to the existence of ferromagnetic clusters with different site moments and scattered orientations of the moments. The broad range of the peak is reduced with increasing Mo content. A weak peak is observed near 190 K in the ZFC curve of YFe_9Mo_3, which is associated with the 8i sites being mostly occupied by Mo atoms. $YFe_{9.5}Mo_{2.5}$ has a magnetic entropy change of −1.09 J/kg K for a field change of 5 T at 277 K.

1. Introduction

Because of its energy efficiency and environment-friendly behavior, the magnetic refrigeration based on magnetocaloric effect (MCE) has become a promising alternative of competitiveness to gas-compression refrigeration technology widely in service [1–7]. Currently, there is a great deal of interest in utilizing the MCE for application of magnetic refrigerators, specially, at room temperature. Typically, a giant MCE observed in various systems is closely related to field-induced first-order phase transitions, which leads to considerable thermal/magnetic hysteresis consuming the relative cooling power of magnetic refrigerant materials [1–7]. It should be realistic to search new magnetic refrigerant materials with a large and reversible magnetic entropy change ΔS_M accompanied with a second-order phase transition. Therefore, it is of importance to explore compounds with Curie temperature near room temperature, which may exhibit large magnetic entropy changes.

It is known that $RFe_{12-x}T_x$ compounds with tetragonal $ThMn_{12}$-type structure can be stabilized by introduction of transition metals T=Ti, Mo, V, Cr, W and Si [8–14]. However, $RFe_{12-x}Mo_x$ compounds [8–10] have different magnetic behaviors from other $RFe_{12-x}T_x$ compounds with T=Ti, V, Cr, W and Si [8,11]. $YFe_{12-x}Mo_x$ compounds were investigated [12–14] in order to obtain information on the magnetic properties of the Fe sublattice in the compounds of this type. On the other hand, magneto-history effects were observed in $YFe_{10}Mo_2$ and $YFe_{9.5}Mo_{2.5}$, which are very similar to the behaviors existing in spin glasses and amorphous alloys [15,16]. The Curie temperature of $YFe_{9.5}Mo_{2.5}$ was determined to be 300 K, very close to room temperature [17]. In consideration of its Curie temperature (close to room temperature) and magnetic behaviors in the low field, it is expected that if the $YFe_{9.5}Mo_{2.5}$ compound showed the MCE accompanied by a second-order phase transition, it would be an appropriate candidate for magnetic refrigerators. In this work, the characterization and magnetic properties of $YFe_{12-x}Mo_x$ (x=2.0, 2.5 and 3.0) compounds are investigated and the MCE of the $YFe_{9.5}Mo_{2.5}$ compound is studied.

2. Materials and method

$YFe_{12-x}Mo_x$ (x=2.0, 2.5 and 3.0) alloys were prepared by arc melting from 99.9% starting materials and then annealed in vacuum at 1100 °C for 24 h. The structure of the $YFe_{12-x}Mo_x$ alloys was characterized by means of X-ray diffraction (XRD). The morphology and elements distribution of bulk alloys were measured by means of scanning electron microscopy (SEM) and backscattered electron (BSE). The magnetic properties were studied by using a superconducting quantum interference device magnetometer (SQUID, Quantum Design Inc.) in a magnetic field of 50 mT in the temperature range from 100 to 380 K and also in fields up to 5 T around room temperature.

3. Results and discussions

The XRD patterns (as shown in Fig. 1) of non-aligned powders of the $YFe_{12-x}Mo_x$ alloys indicate that they were almost single

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doi:10.1016/j.jmmm.2010.05.019

phase with $ThMn_{12}$-type structure. A small amount of Y_2Fe_{17} impurity was present in the $YFe_{10}Mo_2$ alloy. The XRD pattern of the bulk $YFe_{10}Mo_2$ alloy is different from that of its non-aligned powders, but similar to that of aligned $YFe_{10.25}Mo_{1.75}N_y$ [17]. As shown in the inset of Fig. 1, the intensity of (4 0 0) line becomes the strongest and the (0 0 2), (2 0 2) and (2 2 2) peaks almost disappear. This pattern suggests that the $YFe_{10}Mo_2$ alloy may have a directional growth. As shown in Table 1, the lattice parameters a and c, together with the unit-cell volume V of the $YFe_{12-x}Mo_x$ compounds are increased with an increase in the Mo content x [18]. This is reasonable, since the atomic size of Mo is larger than that of Fe. The SEM and BSE images of the bulk $YFe_{12-x}Mo_x$ alloys are shown in Fig. 2. The surface of $YFe_{9.5}Mo_{2.5}$ and YFe_9Mo_3 is satin. Some strips observed only in $YFe_{10}Mo_2$ may be associated with directional growth, which is consistent with XRD analysis above. The BSE images of the $YFe_{12-x}Mo_x$ alloys show that one phase exists.

Fig. 3 shows the temperature dependence of the magnetization of $YFe_{12-x}Mo_x$ (x=2.0, 2.5 and 3.0) compounds, recorded in an applied field of 50 mT. The zero-field-cooling (ZFC) and field-cooling (FC) processes exhibit an irreversible behavior. The ZFC and FC magnetization curves coincide with each other at high temperatures, but separate at low temperatures [16]. This indicates that clusters of spins are involved in the freezing process. The irreversible behavior of the magnetic response in a field of 50 mT may be attributed to magnetic anisotropy [16]. The ZFC peak in low temperature is broad, which may be due to the existence of ferromagnetic clusters with different site moments and scattered orientations of the moments [13]. As shown in Fig. 3, the broadened range of the peak is decreased with increase in the Mo content, in agreement with the decrease of ferromagnetic clusters with different site moments. Christides et al. [15] observed a similar behavior in $YFe_{10}Mo_2$, which was attributed to the disorder of the 8i sites occupied partially by Mo. In particular, there is a weak peak near 190 K in the ZFC curve for YFe_9Mo_3 (shown in Fig. 3(b)), which may be associated with that all the 8i sites are mostly occupied by Mo in Mo-richer compounds, similar with the previous report for YFe_8Mo_4 [13]. The Curie temperatures T_C of $YFe_{10}Mo_2$, $YFe_{9.5}Mo_{2.5}$ and YFe_9Mo_3 are 345, 297 and 180 K, respectively, which decrease with increase in the Mo concentration. However, for $YFe_{10}Mo_2$, the magnetization does not tend to zero when temperature is higher than T_C (as shown in Fig. 3(a)), due to the existence of the minor phase Y_2Fe_{17}. However, as mentioned above, the presence of Y_2Fe_{17} could not be observed obviously from the images of SEM and BSE, which may be due to its little amount in the sample. It is noticed that the FC magnetization of $YFe_{10}Mo_2$ decreases with

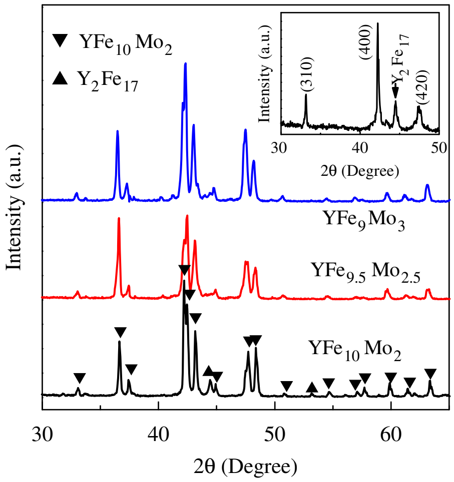

Fig. 1. XRD patterns of non-aligned powders for $YFe_{1-x}Mo_x$ (x=2.0, 2.5 and 3.0) alloys. The XRD pattern of the bulk $YFe_{10}Mo_2$ alloy was shown in the inset.

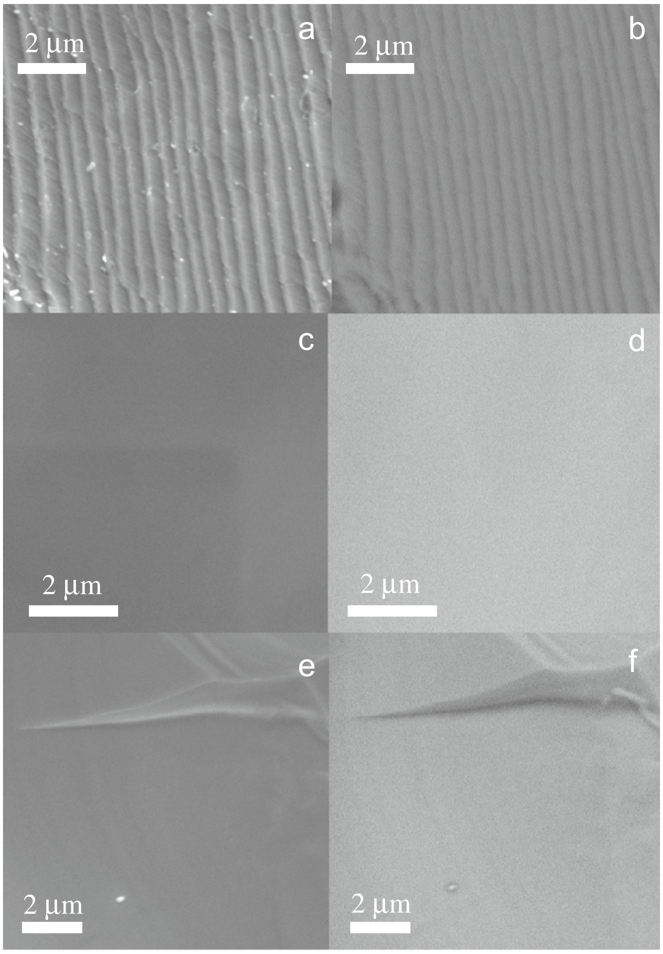

Fig. 2. (a), (c) and (e) SEM images; (b), (d) and (f) BSE images of $YFe_{10}Mo_2$, $YFe_{9.5}Mo_{2.5}$ and YFe_9Mo_3 compounds, respectively.

Table 1
Lattice parameters a, c, and the unit-cell volume V and the Curie temperature T_C of the $YFe_{12-x}Mo_x$ compounds.

$YFe_{12-x}Mo_x$				
x	a (Å)	c (Å)	V (Å^3)	T_C (K)
2.0	8.552	4.798	351.0	345
2.5	8.561	4.804	352.1	297
3.0	8.574	4.818	354.3	180