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Glass formation and magnetic properties of Fe-based metallic glasses fabricated by low-purity industrial materials

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Abstract: Fe-based metallic glasses of $(Fe_{74}Nb_6B_{20})_{100-x}Cr_x$ (x=1, 3, 5) with high glass forming ability (GFA) and good magnetic properties were prepared using low-purity raw materials. Increasing Cr content does not significantly change glass transition temperature and onset crystallization temperature, while it enhances liquidus temperature. The addition of Cr improves the GFA of the $(Fe_{74}Nb_6B_{20})_{100-x}Cr_x$ glassy alloys compared to that in Cr-free Fe−Nb−B alloys, in which the supercooled liquid region (ΔT_x), T_{rg} and γ are found to be 50−54 K, 0.526−0.538, and 0.367−0.371, respectively. The $(Fe_{74}Nb_6B_{20})_{100-x}Cr_x$ glassy alloys exhibit excellent soft magnetic properties with high saturation magnetization of 139−161 A·m^2/kg and low coercivity of 30.24−58.9 A/m. Present Fe−Nb−B−Cr glassy alloys exhibiting high GFA as well as excellent magnetic properties and low manufacturing cost make them suitable for magnetic components for engineering application.

Key words: Fe-based metallic glasses; Cr; glass forming ability; magnetic property

1 Introduction

Fe-based metallic glasses are commercially the most important metallic materials due to their plentiful natural resources and other unique physical and mechanical properties [1−5]. Nowadays, they were served in the field of functional materials, such as magnetic core, electrical devices, switch transformer, and electronic micro- components. In order to extend their industrial applications, great endeavor has been devoted to the development of new Fe-based metallic glasses with high glass forming ability, good magnetic properties and low manufacturing cost.

In 1988, YOSHIZAWA et al [6] developed the soft magnetic material in the Fe−M−B (M=Zr, Hf, or Nb) alloy system with high saturation magnetization. Later, the glass formation, the structure upon crystallization, and the magnetic properties of the metallic glasses or nanocrystalline in ternary Fe−Nb−B alloy system [7−10] were intensively investigated. STOICA et al [11] reported ternary $Fe_{66}Nb_4B_{30}$ bulk metallic glasses (BMG) with a supercooled liquid region of 31 K, mechanical strength of 4 GPa, and Curie temperature of 646 K. YAO et al [12,13] pointed out that the best glass former was pinpointed at $Fe_{71}Nb_6B_{23}$ with a critical diameter of 1.5 mm, which exhibits ultrahigh fracture strength reaching 4.85 GPa and compressive plastic strain up to 1.6%. However, most Fe-based metallic glasses are still expensive by using high-purity raw materials and are inefficient to produce, which limits their commercial applications. Due to relatively low glass forming ability, practical applications of conventional Fe-based metallic glasses have been limited in the form of rapidly solidified ribbons or thin film. In order to reduce production costs, some researchers attempted to fabricate Fe-based metallic glasses using industrial raw materials [14,15]. These Fe-based metallic glasses not only possess large GFA, high thermal stability and other desirable properties, but also have the advantage of low cost. Recent studies indicated that minor addition of the alloying element has shown beneficial effect on GFA and mechanical properties [13,16−19]. The addition of chromium (Cr) has been reported to significantly improve the soft magnetic properties and corrosion resistance [20−22], and large amount of Cr decreases the GFA. In the present study, with the aim of searching new Fe-based metallic glasses, we developed quaternary

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$(Fe_{74}Nb_6B_{20})_{100-x}Cr_x$ (x=1, 3, 5) glassy alloys by using low-purity raw materials. The effects of Cr content on the GFA and magnetic properties were investigated to provide guidance for practical application of the Fe-based metallic glasses.

2 Experimental

Master alloy ingots with nominal composition of $(Fe_{74}Nb_6B_{20})_{100-x}Cr_x$ (x=1, 3, 5) were arc-melted six times under the Ti-gettered argon atmosphere by using pure Fe (99.8%), Nb (99.8%), Cr (99.8%), and Fe−17.5%B master alloy (mass fraction). The master alloy ingots were firstly purified with B_2O_3 by fluxing method in order to remove the impurities as much as possible, and then the melt-spun ribbons were prepared by injecting the molten alloys contained in a quartz tube on the surface of a single copper roller with a linear velocity of 40 m/s and ejection pressure of 20 kPa under the Ar protective atmosphere. The resulting ribbons with a thickness of 20−30 μm were obtained.

Phase constitution was identified by X-ray diffractometer (XRD, Bruker D8 advance) with Cu K_α as a radiation. Thermal behaviors of the glassy ribbons were studied using a differential scanning calorimetry (DSC, Mettler-Toledo TGA/DSC1) at a continuous heating rate of 40 K/min. Room temperature magnetic hysteresis loops were measured using a vibrating sample magnetometer (VSM, Lake Shore 7410) at a magnetic field of 7.96×10^5 A/m.

3 Results and discussion

3.1 Structure analysis

Figure 1 shows the XRD patterns taken from the melt-spun $(Fe_{74}Nb_6B_{20})_{100-x}Cr_x$ (x=1, 3, 5) alloys. It can be found that only a broad diffraction halo in the 2θ range of 35°−55° for the alloys with different Cr contents was detected and no other sharp diffraction peaks corresponding to a crystalline phase were found. The XRD results indicated that fully amorphous structure can be obtained for all the compositions with different Cr contents.

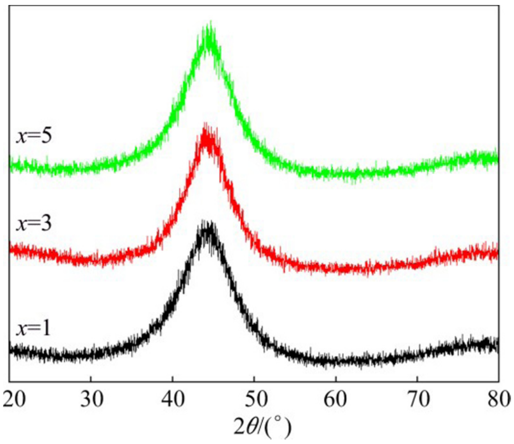

Fig. 1 XRD patterns of melt-spun $(Fe_{74}Nb_6B_{20})_{100-x}Cr_x$ (x=1, 3, 5) alloys

3.2 Effect of Cr addition on glass forming ability

Figure 2 illustrates the DSC traces taken from the $(Fe_{74}Nb_6B_{20})_{100-x}Cr_x$ (x=1, 3, 5) glassy alloys at a constant heating rate of 40 K/min. A distinct glass transition followed by the appearance of a supercooled liquid region and then crystallization events are clearly observed, as shown in Fig. 2(a). The glass transition temperature T_g, onset crystallization temperatures T_{x1} and T_{x2}, melting temperature T_m, and liquidus temperature T_l were listed in Table 1. All DSC traces reveal two exothermic peaks, indicating that they undergo a two-stage crystallization event. When the Cr content is equal to 1% (mole fraction), the values of T_g and T_{x1} are 824 K and 875 K, respectively. As is evident from this figure, increasing Cr content does not change remarkably the values of T_g and T_x, which is in accordance with that reported by LONG et al [22]. The supercooled liquid

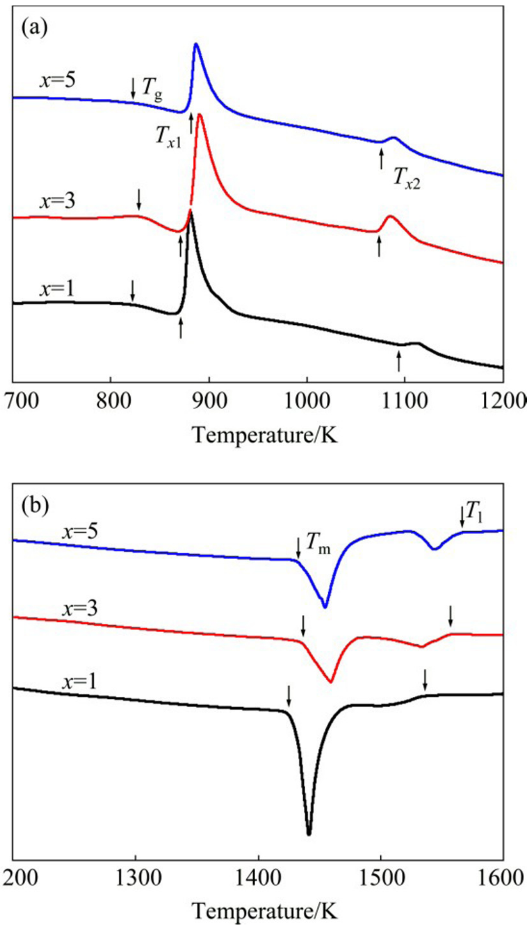

Fig. 2 DSC traces of $(Fe_{74}Nb_6B_{20})_{100-x}Cr_x$ (x=1, 3, 5) glassy alloys at constant heating rate of 40 K/min: (a) Low temperature region; (b) High temperature region