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Effect of transition metal (TM) on the crystallization and the magnetic properties of $Fe_{62}Co_{10}Si_{10}B_{13}Nb_4TM_1$ melt-spun ribbons

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Abstract Crystallization and magnetic behavior of melt-spun $Fe_{62}Co_{10}Si_{10}B_{13}Nb_4TM_1$ amorphous ribbon where TM = Ni, Cr, V, Pd, Pt, Ti, Ta and Zr were examined. The alloy with Pt as transition metal showed the lowest crystallization temperature of 823 K among the studied alloys. Significant increase in crystallization temperature was observed when the atomic radius of the substituted transition metal was varied from that of Pt. High Curie temperature and high saturation magnetization were recognized for the alloys containing Pd, Pt or Ti. The amorphous alloys except the alloys containing Ti or V showed good soft magnetic properties.

Introduction

Recently, much attention has been paid to the development of Fe–Co based alloys for high temperature magnetic applications [1–3]. Fe–Co–Zr–B–Cu-based soft magnetic alloys known as HITPERM is the most studied material which has very high Curie temperature and saturation induction in the nanocrytalline state. It also exhibited good ac magnetic properties [4]. Attempts have also been made to develop soft magnetic materials by partially replacing Fe by Co in FINEMENT type of alloy systems [5, 6]. However, the coercivity in all these alloys is very high in their nanocrystalline state compared to the amorphous one. It was found that addition of Co in Fe–Si–B–Nb–Cu system changes the crystallization behavior and controlling grain size below 20 nm is difficult when Co concentration increased above 5 at%. The decrease of driving force for Cu-clustering with increasing Co content is the reason for such larger grain size in the naocryatlline state [7]. Hence, in the nanocrystalline state, which is necessary for high Curie temperature and high saturation induction, the coercivity of Fe–Co-based alloys keeps very rather high values. Cu, which plays a major role for nanocrystallization and hence controlling the soft magnetic properties in Fe-based system, is ineffective when a large amount of Co is added to the system. Thus there has been need to search for a new Fe–Co-based alloy having high Curie temperature, high saturation induction and moderate soft magnetic properties. In this paper attempts have been made to examine the crystallization behavior and magnetic properties of $Fe_{62}Co_{10}Si_{10}B_{13}Nb_4TM_1$-based alloys where TM stands for the Transition Metals.

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Experimental

Ingots with nominal composition of $Fe_{62}Co_{10}Si_{10}B_{13}Nb_4 TM_1$ (TM = Ni, Cr, V, Pd, Pt, Ti, Ta, Zr) were prepared by arc melting. Rapidly solidified ribbons with 1 mm wide and 0.025 mm thick were produced by ejecting the molten ingot on a Cu-wheel rotating at a circumferential velocity of 40 m/s. The amorphous nature of the ribbons was confirmed by XRD analysis.

Crystallization behavior was investigated using a Differential Scanning Calorimeter (Seiko Instruments Inc., DSC-6300) in Ar-atmosphere at a scanning rate of 0.67 K/s. The Curie temperature was measured from the endothermic peak on the DSC curve. The saturation magnetization was measured using a VSM at a magnetic field of 400 kA/m. Soft magnetic properties of coercivity and permeability were measured using a B-H Analyzer.

Results and discussion

Figure 1 shows the DSC curves of the melt-spun alloys. It is clear that the transition metal has influence on the crystallization temperature (T_x) and Curie temperature (T_c). Both T_x and T_c are plotted against the atomic radius of the studied transition metal in Fig. 2. The crystallization temperature decreases with an increase in the atomic radius of the transition metal and is lowest for TM = Pt. The large increase in the crystallization temperature is seen for TM = Ti. The T_x slowly increases with a further increase in the radius of TM such as Ta and Zr. The Curie temperature also changes in a complex manner with the radius of the transition metal. When Ni is replaced by Cr the Curie temperature decreased but the same was found to increase for TM = V. The sharp increase in T_c to 709 K is seen for TM = Pd. But substituting with TM having atomic radius greater than Pd the Curie temperature was found to decrease. Similar change with TM is also recognized for magnetization (Fig. 3). One can see an initial decrease when Ni is replaced by TM with larger atomic radii such as Cr and V, followed by a sharp increase in saturation magnetization when Pd is added as TM. Further enhancement in saturation magnetization was observed by the addition of TM with larger atomic radii such as Pt and Ti. However, rapid decrease in saturation magnetization is observed by the addition of Ta or Zr. These results indicate that the intrinsic magnetic properties such as Curie temperature and saturation magnetization can be enhanced for the amorphous $Fe_{62}Co_{10}Si_{10}B_{13}Nb_4TM_1$ alloys

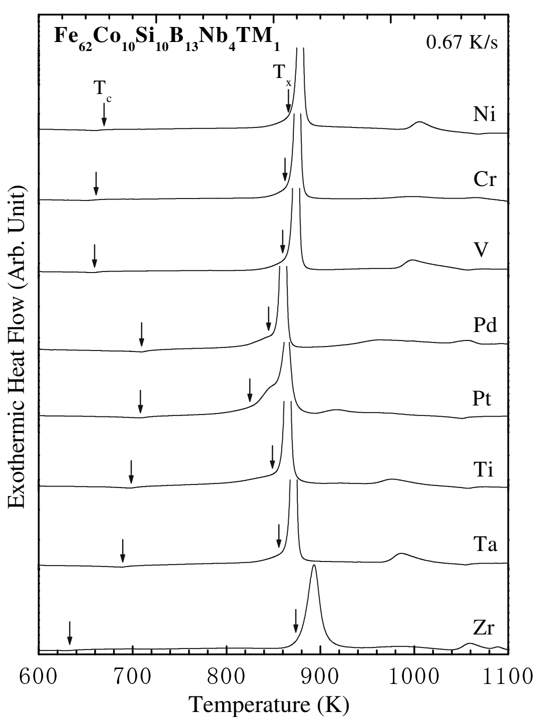

Fig. 1 DSC curves of melt-spun $Fe_{62}Co_{10}Si_{10}B_{13}Nb_4TM_1$ (TM = Ni, Cr, V, Pd, Pt, Ti, Ta, Zr) amorphous alloys

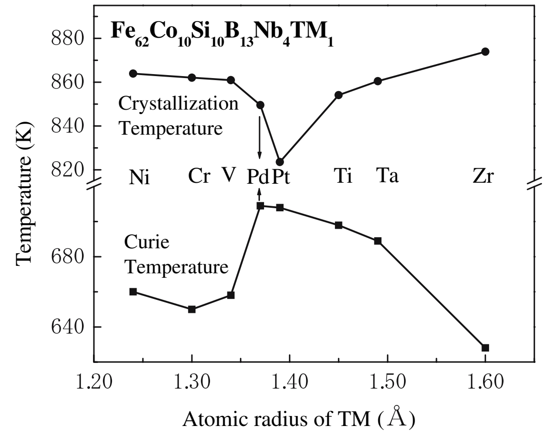

Fig. 2 Crystallization temperature (T_x) and Curie temperature (T_c) against the atomic radius of transition metal (TM = Ni, Cr, V, Pd, Pt, Ti, Ta, Zr) in melt-spun $Fe_{62}Co_{10}Si_{10}B_{13}Nb_4TM_1$ amorphous alloys

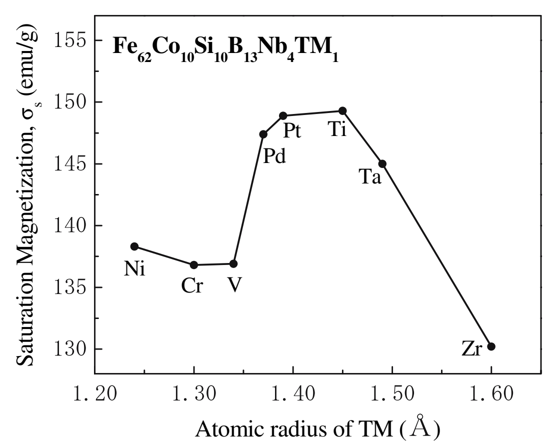

Fig. 3 Saturation magnetization (σ_s) against the atomic radius of transition metal (TM = Ni, Cr, V, Pd, Pt, Ti, Ta, Zr) in melt-spun $Fe_{62}Co_{10}Si_{10}B_{13}Nb_4TM_1$ amorphous alloys

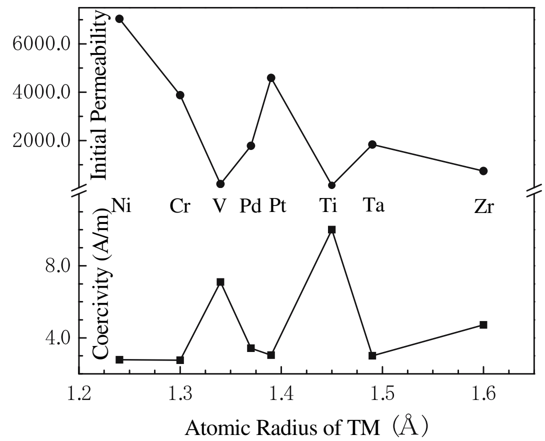

Fig. 4 Coercivity (H_c) and initial permeability (μ_i) against the atomic radius of transition metal (TM = Ni, Cr, V, Pd, Pt, Ti, Ta, Zr) in melt-spun $Fe_{62}Co_{10}Si_{10}B_{13}Nb_4TM_1$ amorphous alloys

containing TM = Pd, Pt or Ti. This is presumably because the special TM elements with radii of 1.37–1.45 Å cause the separation between magnetic atoms in such a way that the exchange interaction becomes maximum so as to result in higher values of T_c and saturation magnetization.

The extrinsic magnetic properties like coercivity and initial permeability of the $Fe_{62}Co_{10}Si_{10}B_{13}Nb_4TM_1$ amorphous alloys are shown in Fig. 4. Ni containing alloy showed best soft magnetic properties measuring a coercivity as low as 2.78 A/m for H_c and 7×10^3 for μ_i. The drastic reduction soft magnetic properties were observed for the V- and Ti-containing alloys. The reduction may be due to the generation of internal misfit strain caused by the addition of the elements with unsuitable atomic radius. The other transition metals such as Cr, Pd, Pt, Ta and Zr exhibited good soft magnetic properties.

Conclusions

The additional effect of transition metals with different atomic radii for melt-spun $Fe_{62}Co_{10}Si_{10}B_{13}Nb_4TM_1$ amorphous alloys was examined. The crystallization temperature decreases significantly to 823 K for TM = Pt. In the case of TM = Pd, Pt or Ti, the alloys exhibited high saturation magnetization as well as high Curie temperature. However, the alloy with TM = Ti showed poor soft magnetic properties i.e. higher coercivity and lower permeability. All the present results indicate that the addition of 1% Pd for the $Fe_{62}Co_{10}Si_{10}B_{13}Nb_4TM_1$ system can produce good soft magnetic properties with high Curie temperature and high saturation magnetization as well as moderate thermal stability.

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