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Effect of P Addition on Microstructure and Soft Magnetic Properties of $Fe_{(73.5-x)}Nb_3Cu_1P_xSi_{13.5}B_9$ alloys

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Introduction

Nanocrystalline Fe-Si-B-Nb-Cu alloys have attracted great interest for their excellent soft magnetic properties which can be compared with the more expensive Co-based amorphous alloys [1]. High cooling rate, however, is necessary to get these alloys in amorphous state because of lower glass-forming ability. Phosphorus is a deep eutectic element [2], which shows good glass-forming ability. In this work the effects of P addition on microstructure and soft magnetic properties of nanocrystalline $Fe_{73.5-x}Nb_3Cu_1P_xSi_{13.5}B_9$ alloys are studied.

Experiments:

The ingots of nominal atomic compositions $Fe_{(73.5-x)}Nb_3Cu_1P_xSi_{13.5}B_9$ (x=0, 1, 3) were prepared by melting the mixture of the pure metals and the Fe-B and Fe-P alloys in an induction furnace with argon atmosphere. The ingots were crashed into small pieces of less than 8 mm. The ribbons were prepared by single-roll melt-spun method under the argon atmosphere. The ribbons are 25 ~ 30 μm thick and 0.7~0.8 mm wide. The crystallization temperature was determined by using the differential scanning calorimetry (DSC) with scanning rate of 10 K/min. Crystal structure was examined by X-ray diffraction (XRD) using Cu-K_α radiation. The coercivity was measured by using a vibrating sample magnetometer (VSM) with maximum field of 7 kA/m.

Results and discussions

Fig. 1 shows the DSC curves of the $Fe_{(73.5-x)}Nb_3Cu_1P_xSi_{13.5}B_9$ (x=0, 1, 3) amorphous alloys. By doping the alloy with P the primary crystallization temperature and crystalline peak temperature shift to higher values. The temperatures are 796 K and 823 K, 801 K and 851 K, 803 K and 853 K for x=0 (curve a), 1(curve b) and 3(curve c), respectively. The curves a and b show two crystallization peaks while curve c exhibits three crystallization peaks.

The alloys were annealed at each primary crystallization peak for 60 min. (comment: show the annealing temperatures in tab. 1) The XRD patterns (Fig. 2) show that the α-Fe(Fe_3Si) phase precipitates during annealing. The grain size increases with the increase of annealing temperature (table 1). Hereafter the annealed alloy of x=0, 1 and 3 is denoted as sample a, b and c, respectively.

The coercivity H_c of the ribbons increases with increasing grain size of the α-Fe(Fe_3Si) phase as is shown in Table 1.

Table 1 Coercivity of sample a, b and c

sample (x)	grain size (nm)	H_c (A/m)
a (0)	8.8	1.5
b (1)	9.2	2.1
c (3)	15.3	3.5

μ' and μ'' as functions of frequency are shown in Fig. 3 for the samples a, b and c. The permeability was measured in very small magnetic field (0.117 A/m). Therefore μ' is essentially determined by the initial permeability μ_i. The permeability at 1 kHz decreases monotonously with increasing P content, from 3.04×10^4 for sample a (x=0) to 0.71×10^4 for sample c (x=3). The corresponding relaxation frequency increases from 27.5 kHz to 204.1 kHz.

Fig.4 shows the core loss of the toroidal ribbons as a function of frequency. The core loss was obtained from the phase shift between the exciting current and the induced voltage. At 1 kHz, the core loss of sample c, with the largest coercivity, is much larger than for the other samples. With increasing frequency the differences between the core losses of samples a, b and c become smaller.

References

[1] Y. Yoshizawa, S. Oguma, K. Yamauchi, J. Appl. Phys. 64 (1988) 6044.

[2] M. Shapaan, A. Bardos, L.K. Varga, J. Lendvai, Mater. Sci. and Eng. A366 (2004) 6-9

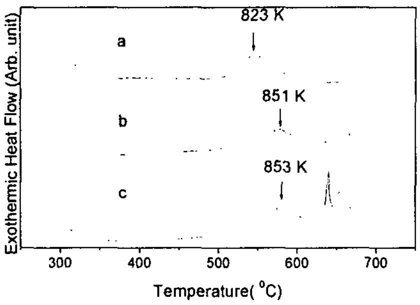

Fig. 1.

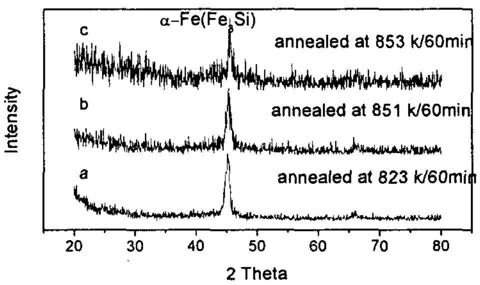

Fig. 2

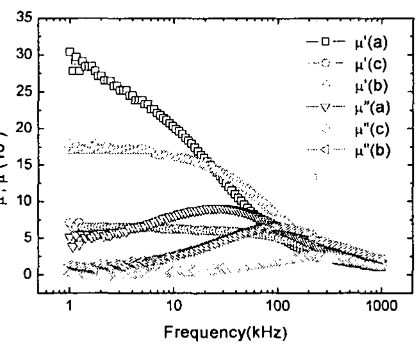

Fig. 3.

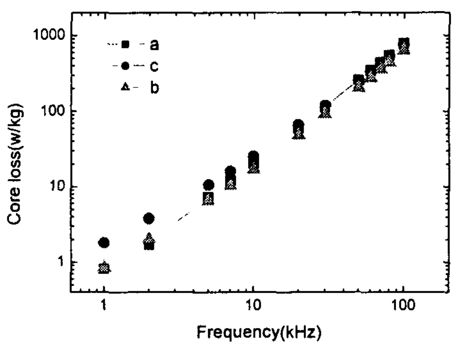

Fig. 4.