Journal of Alloys and Compounds 454 (2008) L10–L13

Journal of ALLOYS AND COMPOUNDS

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Letter

Structure and soft magnetic properties of V-doped Finemet-type alloys

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Received 19 November 2006; received in revised form 22 December 2006; accepted 25 December 2006
Available online 10 January 2007

Abstract

Structure and soft magnetic properties of V-doped $Fe_{73.5}Cu_1Nb_{3-x}V_xSi_{13.5}B_9$ nanocrystalline alloys have been investigated. It is revealed that the microstructure and soft magnetic properties are strongly effected by the addition of V element. The best combined soft magnetic properties have been obtained at V = 1.5 at.%. The $Fe_{73.5}Cu_1Nb_{1.5}V_{1.5}Si_{13.5}B_9$ nanocrystalline alloy shows the highest initial permeability (135,000), lower coercivity (0.79 A/m) and moderate saturation field (1.26 T). The alloy also exhibits very low core loss ($P_{0.02/200}$ = 31 kW/m^3). The V-doped Finemet-type soft magnetic alloys are therefore suitable for core materials in power transformers.

Keywords: Finemet alloy; Nanocrystalline alloy; Soft magnetic property; Core loss

1. Introduction

The soft magnetic properties of Finemet alloys have been extensively studied during the last decade [1–6]. Their excellent soft magnetic behavior is the result of the averaging out of the magnetocrystalline anisotropy (BCC-Fe rich nanocrystals) via magnetic interactions (exchange coupling) with the residual amorphous phase.

A number of workers have investigated the effects on the soft magnetic properties of the substitution of additional alloying elements for Fe in the $Fe_{73.5}Si_{13.5}B_9Cu_1Nb_3$ alloy composition to further improve the properties as well as the substitution of Cr, U, Ta, etc., for Nb [3–6]. No significant improvements in soft magnetic properties were reported over those of the base composition. In the quest to achieve properties superior to those of the well-known Fe–Nb–Cu–Si–B system, the element Nb has been substituted by V element in present experiment. The aim of this work was to study the effect of partial substituting Nb by V on the structure and some magnetic properties of the $Fe_{73.5}Cu_1Nb_{3-x}V_xSi_{13.5}B_9$ (x = 1, 1.5, 2) alloys. On the other hand, there is an important economical benefit in this type of alloys because the cost of V is lower than Nb.

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doi:10.1016/j.jallcom.2006.12.133

2. Experimental

$Fe_{73.5}Cu_1Nb_{3-x}V_xSi_{13.5}B_9$ (x = 0, 1, 1.5, 2) amorphous ribbons were prepared by the melt spinning technique. Heat treatments were performed at temperatures 460 and 630 °C for 30 min without magnetic field and then quickly cooled in furnace in a nitrogen atmosphere in order to determine the optimum annealing temperature range, which corresponds to the maximum value of initial permeability and the minimum value of coercivity. The structure of samples was checked with X-ray diffractometry and high-resolution TEM. The bulk value of the coercive field was determined from hysteresis loop traced with a fluxmeter and core losses were determined from the hysteresis loops traced at different frequency and magnetic field with a digital storage oscilloscope.

3. Results and discussion

The results presented in this section are for samples heat treated at an optimum annealing temperature to develop the minimum dc coercivity for each of the compositions investigated. This was found to be 540 °C for $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ and 560 °C for all of the V-containing compositions.

First, we examined the microstructure of the nanocrystalline $Fe_{73.5}Cu_1Nb_{3-x}V_xSi_{13.5}B_9$ (x = 0, 1, 1.5, 2) alloys by high-resolution TEM. Fig. 1 shows the TEM image of the nanocrystallized $Fe_{73.5}Cu_1Nb_{3-x}V_xSi_{13.5}B_9$ (x = 0, 1, 1.5, 2) alloys. The alloys consist of nanoscale α-Fe grains, about 8–15 nm in size, embedded in a residual amorphous matrix randomly. Fig. 2 shows the grains size of these crystallized alloys determined from TEM images using 10 randomly selected areas for each case. We can see that with the increasing content of V

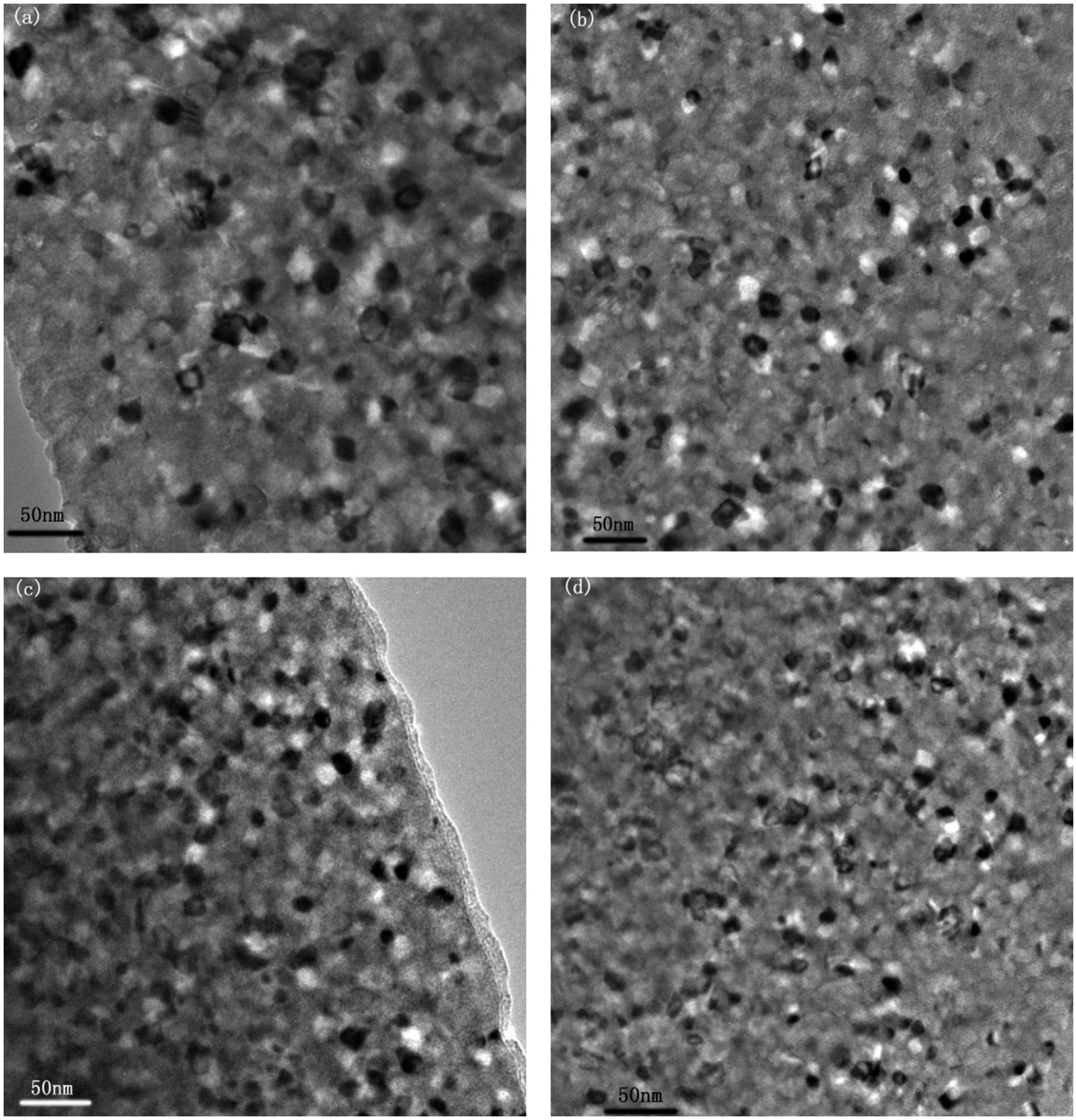

Fig. 1. TEM image of the nanocrystallized $Fe_{73.5}Cu_1Nb_{3-x}V_xSi_{13.5}B_9$ alloys: (a) $X=0$; (b) $X=1$; (c) $X=1.5$; (d) $X=2$.

element, the size of α-Fe grains is decreased. When the content of V element is up to 2%, the grain size of α-Fe is decreased to 9 nm, which is far smaller than that of the V-free Finemet alloy (12.5 nm). From these, we can conclude that V element can restrain the growth of α-Fe grains in the crystallization of Finemet-type alloys.

Fig. 3 shows the coercivity (H_c), the saturation polariztion (J_s) and the initial permeability (μ_i) of nanocrystalline $Fe_{73.5}Cu_1Nb_{3-x}V_xSi_{13.5}B_9$ ($x=0$, 1, 1.5, 2) alloys. From Fig. 3, we can see that the addition of V element decreases the coercivity, from 1.2 A/m for Finemet alloy ($x=0$) to 0.55 A/m for $Fe_{73.5}Cu_1Nb_1V_2Si_{13.5}B_9$ ($x=2$), while the initial permeability was initially increased by the addition of V element, from 87,000 for Finemet alloy ($x=0$) to 135,000 for $Fe_{73.5}Cu_1Nb_{1.5}V_{1.5}Si_{13.5}B_9$ ($x=1.5$) and then decrease to 125,200 when the content of V element is up to 2 at.%. The effect of substituting Nb for V on the saturation polariztion J_s can also be seen in Fig. 3. It is clearly that there is almost no change in saturation polariztion J_s in the range of X from 0 to 2 at.%. From above data, it can be thought that the partial substitution of Nb by V in Finemet alloy can increase the initial permeability and decrease the coercivity. And nanocrystalline $Fe_{73.5}Cu_1Nb_{1.5}V_{1.5}Si_{13.5}B_9$ alloy has the best combined soft magnetic properties over the range of X studied, such as the highest initial permeability (135,000), the lower coercivity (0.79 A/m) and moderate saturation field (1.26 T). So, it can be thought that the partial substitution of Nb for V is helpful in get higher initial permeability and lower coercivity without deteriorating saturation polariztion J_s in Finemet soft magnetic alloys.