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A Study on the Temperature Dependence of Electrical Resistivity and Crystallization in Amorphous $Fe_{73.5}B_9Si_{13.5}Cu_1Nb_3$ Alloy

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***Abstract*— The temperature dependence of resistivity and crystallization behavior in amorphous $Fe_{73.5}B_9Si_{13.5}Cu_1Nb_3$ alloy has been studied using the four probe electrical resistivity in the temperature range 300 K – 1000 K, Differential Scanning Calorimetry (DSC) in the temperature range 300 K – 1000 K and X-ray diffraction (XRD). From the resistivity measurements, the resistivity of the sample at 303 K is found to be 83.75 μΩ-cm. The Curie Temperature (T_C), first step of crystallization and second step of crystallization of the sample are around the temperatures 593 K, 733 K and 883 K respectively. Thus, the resistivity measurements on the sample shows that the amorphous sample undergoes crystallization in two steps which is supported by DSC measurements on the amorphous sample . The Temperature Coefficient of Resistivity (TCR) and the Debye temperature (θ_D) of the sample are found to be 19 X 10^{-4} K^{-1} and 364.05 K, respectively. XRD patterns of the amorphous $Fe_{73.5}B_9Si_{13.5}Cu_1Nb_3$ ribbon annealed at 673 K showed α-Fe(Si) phase without any other phase. For the amorphous sample annealed at 823 K, Fe_2B phase appeared in addition to α-Fe(Si).**

***Index Terms*— electrical resistivity, differential scanning calorimetry, X-ray diffraction, curie temperature, crystallization temperature.**

I. INTRODUCTION

Alloys Fe-B-Si-Cu-Nb, also known as FINEMET, were developed in 1988 by Yoshizawa et al [1,2]. This family shows excellent soft magnetic properties for magnetic sensors applications and other industrial applications [1-5]. All these alloys show high permeability, high saturation induction, low coercivity and reasonably high resistivity.

Each element has a role in Fe-B-Si-Cu-B alloy. The pure iron is a ferromagnetic material; it has high saturation and permeability. The additional elements produce a decrease in magnetic saturation, but improve other magnetic properties. The silicon presence in the alloy decreases a little bit the saturation induction, but raises the electrical resistivity, reducing eddy currents, also lowering the magnetostriction, the magnetic anisotropy and the coercivity. The presence of copper in the alloy is the catalyst for the nucleation of the nanocrystals [6]. It was shown that alloys with 1% of Cu presents a homogeneous distribution of nanocrystals. The main effect of niobium in the alloy is to inhibit the nanocrystals growth during the

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annealing. Previous works showed that alloys of high content of Nb present smaller size of crystals than alloys of low or without any content of Nb . Nb is a stabilizer of amorphous phase and changes the Cu solubilization, thus promoting finer nanoclusters distribution. Boron in the alloy assists the niobium to inhibit the growth of nanocrystals [7,8].

Electrical resistivity is a structure sensitive characteristic of materials. In amorphous ferromagnets, the scattering of conduction electrons on the disordered structure is the main mechanism responsible for the electrical resistivity. Hence, amorphous metallic alloys have a much higher residual resistivity as compared to their crystalline analogs.

In this paper we present a study on the temperature dependence of resistivity and crystallization of amorphous $Fe_{73.5}B_9Si_{13.5}Cu_1Nb_3$ alloy using the four probe electrical resistivity, Differential Scanning Calorimetry (DSC) and X-ray diffraction (XRD).

II. EXPERIMENTAL

Amorphous $Fe_{73.5}B_9Si_{13.5}Cu_1Nb_3$ alloy was procured from our other researchers which was prepared by melt spinning technique. The thickness of the ribbon is about 30 µm and the width is about 5 mm. Resistivity measurements on the sample are done using Four Probe Method in the temperature range 30^0C - 800^0C. Similarly, Differential Scanning Calorimetry (DSC) studies are carried out in the temperature range 30^0C - 800^0C . X-ray diffraction (XRD) patterns are recorded for the samples annealed at 400^oC, $550\,^o$C and 700^oC for one hour.

III. RESULTS AND DISCUSSION

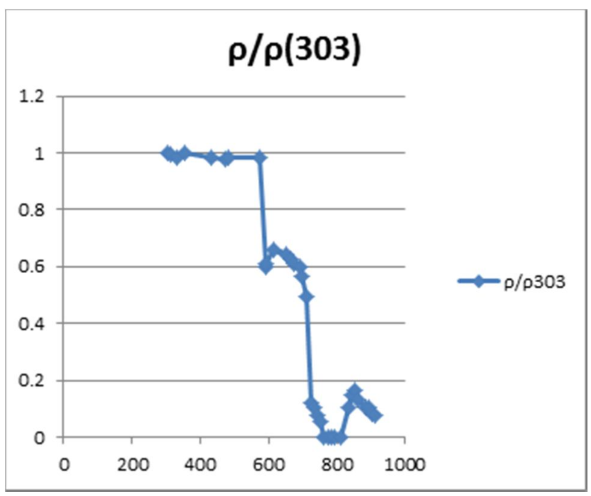

Figure 1 Temperarure dependence of resistivity ratio[ρ(T)/ρ(303)] in amorphous $Fe_{73.5}B_9Si_{13.5}Cu_1Nb_3$ alloy

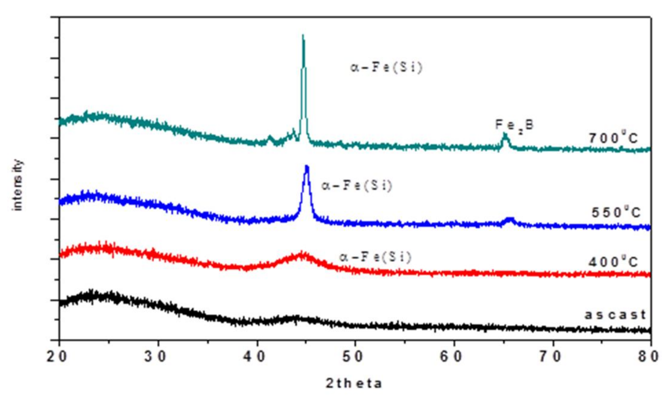

Figure 2 XRD plots of amorphous $Fe_{73.5}B_9Si_{13.5}Cu_1Nb_3$ alloy annealed at different temperatures

Figure 1 shows the temperature dependence of resistivity ratio [$\rho(T)/\rho(303)$] in amorphous $Fe_{73.5}B_9Si_{13.5}Cu_1Nb_3$ alloy in the temperature range 300 K – 1000 K. In Fig.1, a small drop in the resistivity ratio at 593 K gives the Curie temperature (T_C) of the sample. The first onset of crystallization starts from 613 K and is complete at 813 K. Thus, the growth of the crystalline phase α-Fe(Si) in the amorphous matrix can be observed in the first stage of crystallization. . The second onset of crystallization starts from 853 K and is complete at 913 K. Thus, the growth of the crystalline phases α-Fe(Si) and Fe_2B can be observed in the second stage of crystallization. . Hence, the resistivity measurements on the sample shows that the amorphous sample undergoes crystallization in two steps which is supported by the DSC measurements on the fresh amorphous sample. The first and second crystallization temperatures are thus found to be 733 K and 883 K, respectively. The resistivity of the sample at 303 K is 83.75 μΩ-cm. The Temperature Coefficient of Resistivity (TCR) and the Debye temperature (θ_D) of the sample are found to be $19 \times 10^{-4}\ K^{-1}$ and 364.05 K, respectively.

Figure 2 shows XRD patterns of amorphous $Fe_{73.5}B_9Si_{13.5}Cu_1Nb_3$ ribbons after annealing at different temperatures. It is found that α-Fe(Si) phase appears clearly without any other phase when the fresh sample is annealed at 400^oC(673 K) for one hour. As in Fig.2, an Fe_2B phase appeared in addition to α-Fe(Si) when a fresh sample is annealed at 550^oC(823 K) for one hour. When a fresh sample is annealed at 700^oC (973 K) for one hour , the peaks of α-Fe(Si) and Fe_2B become evident. Thus, from the XRD measurements the phases in the first and second crystallization steps are confirmed as α-Fe(Si) and α-Fe(Si) & Fe_2B, respectively. This observation is also supported by studies on the similar samples using other studies [9,10].

IV. Conclusions

The resistivity measurements on amorphous $Fe_{73.5}B_9Si_{13.5}Cu_1Nb_3$ alloy shows a two step crystallization which is supported by DSC. The Temperature Coefficient of Resistivity (TCR) and the Debye temperature (θ_D) of the sample are found to be $19 \times 10^{-4}\ K^{-1}$ and 364.05 K, respectively. XRD patterns of the amorphous $Fe_{73.5}B_9Si_{13.5}Cu_1Nb_3$ ribbon annealed at 673 K showed α-Fe(Si) phase without any other phase. For the amorphous sample annealed at 823 K, Fe_2B phase appeared in addition to α-Fe(Si).

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