Application of Nanocrystalline Cores in Integrated Service Digital Networks

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Application of Nanocrystalline $\text{Fe}_{74}\text{Cu}_1(\text{NbMo})_3\text{Si}_{13}\text{B}_9$ alloy as mini-transformer cores in Integrated Service Digital Networks (ISDN) has been investigated. After annealing properly, the cores possess excellent soft magnetic properties. The permeability and inductance is comparable of that of permalloys and cobalt-based amorphous cores. Meanwhile the alloy has a saturation induction up to 1.2T, which results in the enhancement of its anti-bias field ability while keeping high permeability and inductance. After proper annealing, the cores have the following magnetic properties: saturation induction $B_s=1.2\text{T}$, coercive force $H_c=2.1\text{A/m}$, inductance at 10kHz $L=11\mu\text{H}$, inductance at 10kHz under bias current of 145mA (number of turns=1) $L_{145}=9.5\mu\text{H}$. In the meantime, the cores show excellent frequency performance.

Key words: nanocrystalline alloy, ISDN, inductance

1. Introduction

In recent years, the Integrated Service Digital Network (ISDN) has been rapidly developed. It requires a large number of mini-transformers and common mode chokes in order to make information to be transmitted between sub-networks and terminal equipment correctly¹⁾. Traditionally, ferrite or Co-based amorphous alloys are used as core materials of these mini-transformers and chokes. However, ferrite cores have the disadvantage of low Curie temperature and low saturation induction²⁾, while Co-based amorphous alloys are limited for their high costs. Fe-based nanocrystalline alloys have become one of the key candidates in soft magnetic materials for ten years³⁾. They have been widely studied for applications as core materials because of their high permeability, high saturation induction and low core loss. In the present work we report our results on the investigation of nanocrystalline FeCuMoSiB alloy as core material of mini-transformers in ISDN.

2. Experimental

Master alloy with a nominal composition of $\text{Fe}_{74}\text{Cu}_1(\text{NbMo})_3\text{Si}_{13}\text{B}_9$ (at%) was made in a vacuum inducting furnace. The amorphous ribbons with a dimension of $4.5 \times 0.025\text{mm}$ were prepared by a single roller technique. The ribbons were wound into cores of 6.5mm in inner diameter, 9.5mm in outer diameter, and 4.5mm in height. The cores were annealed at 773K-833K for one hour in argon atmosphere with a transverse magnetic field of 500A/m. The inductance characteristics and effective permeability of the cores under different frequency and bias current were measured with an impedance analyzer.

3. Results and Discussion

Table 1 shows the main magnetic properties of the properly annealed $\text{Fe}_{74}\text{Cu}_1(\text{NbMo})_3\text{Si}_{13}\text{B}_9$ cores. It is clear that the alloy possesses not only high saturation induction, but also high inductance under large bias field. This is very important for transformer cores in ISDN¹⁾. In order to get high permeability under large bias field (i.e. good anti-bias current ability), the cores must be annealed in a proper transverse magnetic field.

Table 1 comparison of magnetic properties of $\text{Fe}_{74}\text{Cu}_1(\text{NbMo})_3\text{Si}_{13}\text{B}_9$ alloys with other materials

	$(\text{CoFe})_{71}\text{Ni}_{10}\text{Mo}_2\text{Si}_{10}\text{B}_{16}$ ²⁾	Ferrites Mn-Zn ²⁾	$\text{Fe}_{74}\text{Cu}_1(\text{NbMo})_3\text{Si}_{13}\text{B}_9$
Saturate induction	0.5-0.8T	<0.5T	1.2T
Curie point	<623K	<473K	833K
Coercive force	<2A/m	20A/m	2.1A/m
Inductance (no bias)	11 μH	10 μH	11 μH
Inductance(under bias current)*	8.5 μH	8 μH	9.5 μH

*Measured at 10kHz with a number of turns of 1, an irritating current of 5 mA, and a bias current of 145mA.

Traditionally, mini-transformer cores for ISDN were made of ferrite or Co-based amorphous alloys¹⁾. For comparison, some properties of ferrite and Co-based amorphous alloys are listed in table 1. It can be seen that the nanocrystalline alloy has not only higher saturate induction, but also higher permeability (this will be shown in fig.1) and lower core loss under high frequency than the others. In fact, the properties of the nanocrystalline alloy are comparable with that of permalloys and ferrites. Meanwhile the nanocrystalline alloy has a Curie temperature of about 833K, which is much higher than that of ferrites. That means that it has good performance under much higher temperature.

Figure 1 gives the inductance and the corresponding effective permeability of the properly annealed nanocrystalline $\text{Fe}_{74}\text{Cu}_1(\text{NbMo})_3\text{Si}_{13}\text{B}_9$ alloy and Co-based amorphous alloy $(\text{CoFe})_{71}\text{Ni}_1\text{Mo}_2\text{Si}_{10}\text{B}_{16}$ ²⁾ under different bias current. Since the nanocrystalline $\text{Fe}_{74}\text{Cu}_1(\text{NbMo})_3\text{Si}_{13}\text{B}_9$ alloy has high saturate induction of 1.2T, it exhibits high permeability and inductance under a bias current of more than 150mA, i.e., it has an excellent anti-bias field ability. In fact, its anti-bias field ability is perhaps the best among the commonly used soft magnetic materials used under high frequency. In addition, its permeability and inductance under no bias field is almost as high as that of Co-based amorphous alloy.

Fig.1 Comparison of inductance of nanocrystalline $\text{Fe}_{74}\text{Cu}_1(\text{NbMo})_3\text{Si}_{13}\text{B}_9$ and amorphous alloy $(\text{CoFe})_{71}\text{Ni}_1\text{Mo}_2\text{Si}_{10}\text{B}_{16}$ ²⁾ under different bias-current

Figure 2 shows the frequency dependence of effective permeability and inductance of the nanocrystalline $\text{Fe}_{74}\text{Cu}_1(\text{NbMo})_3\text{Si}_{13}\text{B}_9$ alloy. It is clear that the frequency performance of the nanocrystalline alloy is almost the same as that of the $(\text{CoFe})_{71}\text{Ni}_1\text{Mo}_2\text{Si}_{10}\text{B}_{16}$ amorphous alloy over a wide frequency range.

Fe-based nanocrystalline alloys were originally developed by Y.Yoshizawa et al³⁾. After annealing above their crystallization temperature (500°C in general), bcc Fe grains with a diameter of about 10-15nm precipitate from the amorphous matrix, resulting in a structure of combination of bcc Fe phase and remaining amorphous matrix³⁾⁻⁴⁾. Magnetic properties of the alloy can be optimized because of the decrease of the effective magnetic anisotropy, according to the well-known random anisotropy model⁴⁾. However, few work has been done on the anti-bias field ability of the nanocrystalline alloys up to now. It seems clear from our results that the newly developed nanocrystalline $\text{Fe}_{74}\text{Cu}_1(\text{NbMo})_3\text{Si}_{13}\text{B}_9$ alloy possesses excellent anti-bias field ability because of the ideal combination of high permeability and high saturate induction.

4.Conclusions

The newly developed nanocrystalline $\text{Fe}_{74}\text{Cu}_1(\text{NbMo})_3\text{Si}_{13}\text{B}_9$ alloy has excellent magnetic

Figure 2 Frequency dependence of inductance of nanocrystalline $\text{Fe}_{74}\text{Cu}_1(\text{NbMo})_3\text{Si}_{13}\text{B}_9$ and amorphous $(\text{CoFe})_{71}\text{Ni}_1\text{Mo}_2\text{Si}_{10}\text{B}_{16}$ alloy

properties and outstanding anti-bias field ability which are comparable with that of permalloys and Co-based amorphous alloys. After the optimum annealing, the alloy has the typical magnetic properties as follows: saturate induction $B_s=1.2\text{T}$, coercive force $H_c=2.1\text{A/m}$, Inductance at 10kHz $L=11\mu\text{H}$, inductance at 10kHz and a bias current of 145mA $L_{145}=9.5\mu\text{H}$. Meanwhile, its frequency performance is almost the same as that of Co-based amorphous alloys. Therefore, it can be widely used for mini-transformer cores in ISDN.

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