Effect of length and annealing conditions on magnetoimpedance of Co 68 Fe 5 Si 12 B 15 amorphous ribbons

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Effect of length and annealing conditions on magnetoimpedance of $Co_{68}Fe_5Si_{12}B_{15}$ amorphous ribbons

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The effect of conventional annealing and Joule annealing on magnetoimpedance (MI) of $Co_{68}Fe_5Si_{12}B_{15}$ ribbons was studied. The ribbons used for the MI measurements were 1 and 5 cm long. The as cast 5-cm-long ribbons exhibit a larger MI compared with the 1-cm-long ribbons, at all frequencies. The maximum MI of the as cast ribbons of 5 cm length is 17% at 600 kHz whereas for the 1-cm-long ribbons it is 3% at 500 kHz. Conventional annealing carried out at 200 and 300 °C for 1 h results in the decrease of the MI in both the 5 and 1-cm-long ribbons, respectively. The Joule annealing of the 5-cm-long ribbons employing a current of 500 mA for 5 min. causes the increase of the MI to 26% at 800 kHz. For the 1 cm Joule-annealed ribbon, employing a current of 500 mA for 5 min., the maximum MI observed is 6% at 500 kHz. © *2006 American Institute of Physics*.
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INTRODUCTION

One of the most significant properties of amorphous soft ferromagnetic materials is the magnetoimpedance (MI), a property useful for materials to be used as magnetic-field detecting sensors.[1,2] These devices are very sensitive and have quick response to magnetic field. MI is the change in the impedance of the material in an external steady magnetic field which is applied along the length of the ribbon and is related to the changes in the magnetization (permeability) of the ribbon due to the steady magnetic field.[3]

The MI has been extensively studied in Co and Fe rich amorphous ribbons and wires.[4–6] The MI effect is very sensitive to the composition, sample shape, annealing conditions, and stress. In amorphous materials, MI can be optimized by inducing transverse anisotropy by subjecting the materials to thermal or stress treatments. However, few reports are available on the influence of geometrical dimensions on MI.[7,8]

In this paper the MI effect in $Co_{68}Fe_5Si_{12}B_{15}$ ribbons is presented. The effect of ribbon length on the MI is explained by comparing the MIs of 1- and 5-cm-long ribbons. The maximum MI ratios obtained for the as cast and conventional and Joule-annealed ribbons, respectively, are compared.

EXPERIMENTAL DETAILS

The $Co_{68}Fe_5Si_{12}B_{15}$ alloy was prepared by arc melting the high pure constituent elements (transition metals—99.95%, Silicon—99.99%, and Boron—99.5%) in argon atmosphere. The ingot was melted several times to obtain a homogenized mixture. The weight loss after the melting was less than 0.5%. The ribbons were prepared by the melt-spinning technique in argon atmosphere. The ribbons obtained were 1–2 mm wide and 30–40 μm thick. The MI measurements were carried out on 1- and 5-cm-length ribbons using an impedance analyzer (HP 4192A) in the frequency range 500 kHz–2 MHz, by keeping the amplitude of the alternating current as 10 mA in the above frequency range. A magnetic field up to 100 Oe was applied using a Helmholtz coil. The MI ratio is defined as

$$\frac{\Delta Z}{Z}\,\% = \frac{Z(H) - Z(H_{\max})}{Z(H_{\max})}100, \quad (1)$$

where $Z(H)$ is the impedance at a field H and $Z(H_{\max})$ is the impedance at the field at which it saturates.

Conventional annealing was done in vacuum at 200 and 300°C for 1 h. Joule annealing was carried out with the application of steady currents of 500 and 800 mA for 5–15 min durations.

RESULTS AND DISCUSSIONS

Figures 1(a) and 1(b) show the field dependence of MI of the as cast ribbons of 5 and 1 cm lengths, respectively, at 500 kHz, 600 kHz, 800 kHz, and 1 MHz. At all frequencies, the MI values of the 5-cm-long ribbon are higher than those of the 1-cm-long ribbon. The MI attains a maximum value of 17% for 5-cm-long ribbon and 3% for 1-cm-long ribbon, at 600 kHz.

The variation of MI with length can be explained using demagnetizing field theory. For long ribbons the demagnetizing field is less effective compared with the short ribbon. For short ribbons, the effect of demagnetizing field is larger and complex domain structures are formed at the ends. Thus, the domain walls are pinned inside the closure structures and as a result the permeability is lower compared to the long ribbons.[8,9] The MI therefore, is smaller in short ribbons than in long ribbons.

Thermal treatments modify the structure and properties of the amorphous magnetic materials through stress release and structural relaxation of the amorphous phase or through the growth of the crystallized layer at the sample surface.[10]

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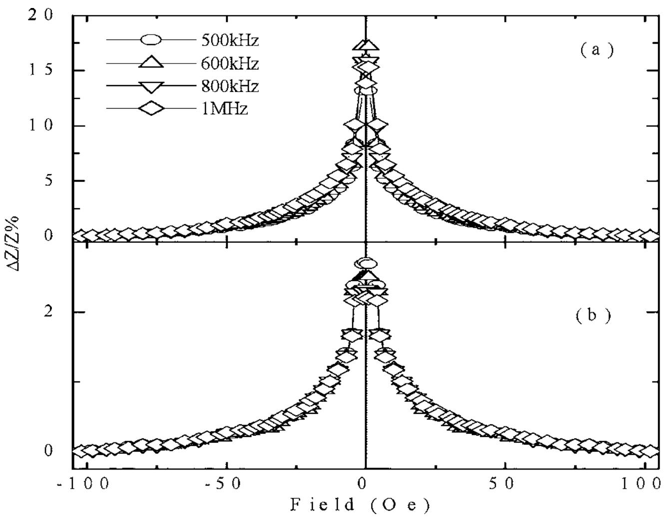

FIG. 1. MI of as cast $Co_{68}Fe_5Si_{12}B_{15}$ ribbons of (a) 5 cm and (b) 1 cm length, respectively, measured at different frequencies.

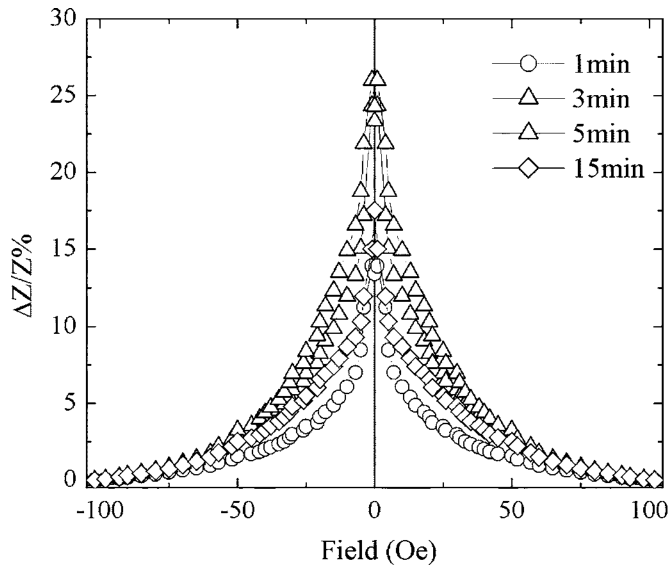

FIG. 3. MI at 800 kHz for Joule-annealed $Co_{68}Fe_5Si_{12}B_{15}$ ribbons employing a 500 mA current.

The kinetics of the different thermal treatments, i.e., conventional annealing, Joule annealing, etc., is different, because the internal structure of the ribbon is modified differently.

Figures 2(a) and 2(b) show the MI patterns of conventionally annealed ribbons of 5- and 1-cm-length, respectively, at 800 kHz (the frequency at which the MI is maximum). After annealing at 200 °C for 1 h, the maximum MI for the 5-cm-long ribbon decreases to 15%. The MI decrease might be due to the crystallization of the ribbon, which leads to an increase of the magnetocrystalline anisotropy. Increasing the annealing temperature to 300 °C causes the MI to decrease further to 8%. However, for the 1-cm-long ribbon, probably because of the effect of the complex domain structure dominating over that of the grain growth, the MI is not affected until the ribbon is annealed at 300 °C after which, the MI decreases to 2%.

Figure 3 shows the MI of Joule-annealed (employing a current of 5 mA between 1 and 15 min) 5-cm-long ribbons at a frequency of 800 kHz. The MI increases with increasing the Joule-annealing time and it reaches a maximum value of 26% for 5 min Joule-annealed ribbon. Further increase in the Joule-annealing time to 15 min causes the MI to decrease to 18%. The kinetics of the Joule annealing is somewhat slower than that of the conventional annealing; thus, Joule annealing for a short interval (up to 5 min) relaxes the internal stresses in the ribbon resulting in the increase of the MI. With further increase in annealing time, the crystallization takes place increasing the anisotropy and resulting in the decrease of the MI. Joule annealing of 1-cm-long ribbon for 5 min employing a current of 500 mA causes the MI to increase to 6% at 500 kHz.

Figure 4 shows the MI of Joule-annealed ribbons for 5 min employing annealing currents of 500 and 800 mA. For 800 mA Joule-annealed ribbon MI is less compared with the 500 mA Joule-annealed ribbon and this probably is due to

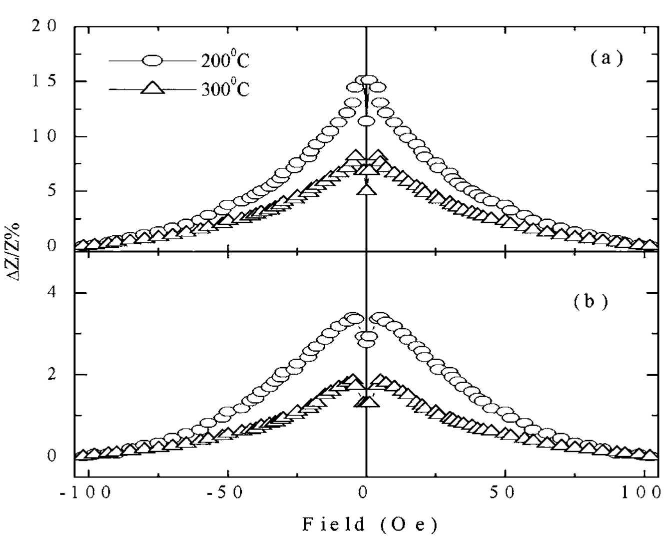

FIG. 2. MI of conventionally annealed $Co_{68}Fe_5Si_{12}B_{15}$ ribbons of (a) 5 cm and (b) 1 cm long, at 800 kHz.

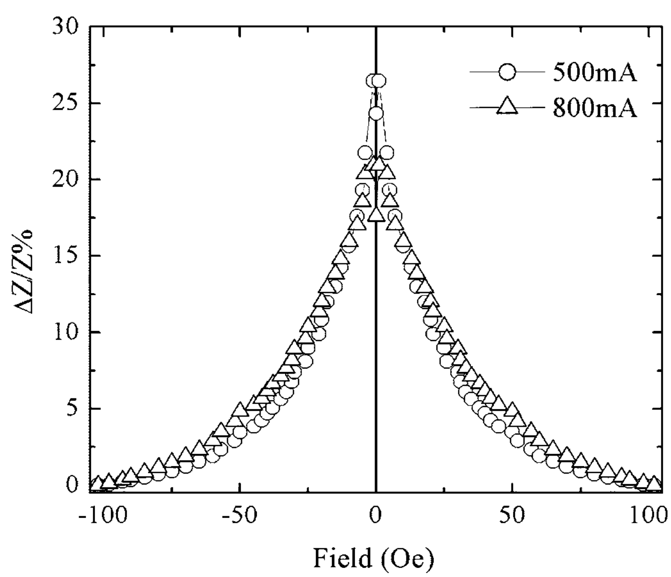

FIG. 4. MI at 800 kHz for Joule-annealed $Co_{68}Fe_5Si_{12}B_{15}$ ribbons employing currents of 500 and 800 mA.

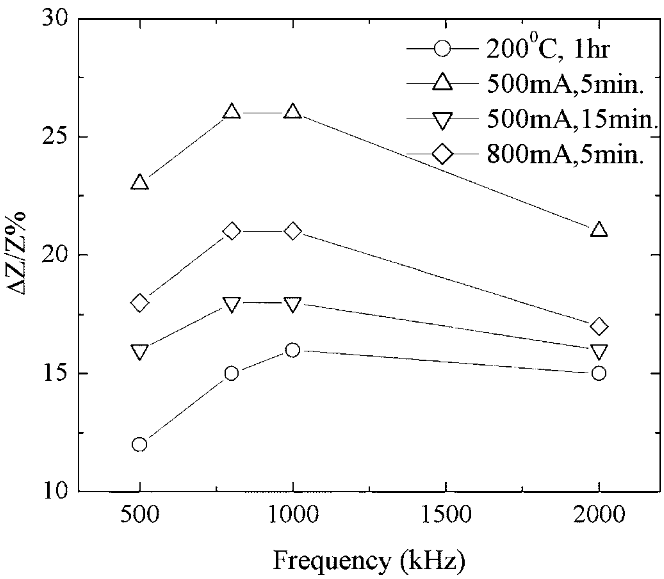

FIG. 5. Maximum MI of $Co_{68}Fe_5Si_{12}B_{15}$ ribbons vs frequency for different annealing conditions.

the crystallization of the ribbon by the passage of high current leading to more heating compared to the 500 mA current. Figure 5 shows the MI of annealed ribbons at different frequencies. The MI increases with increase of the frequency and attains a maximum value in the frequency range 800 kHz–1 MHz. At higher frequencies, the stronger skin effect leads to an inhomogeneity in the current distribution along the ribbon and the decrease of the permeability originating from the strong suppression of domain walls movement and hence, a decrease in the MI.

CONCLUSIONS

Magnetoimpedance variation with the length of the ribbon and different annealing conditions has been studied for $Co_{68}Fe_5Si_{12}B_{15}$ ribbons. Ribbons of 5 cm length exhibit larger MI compared with 1-cm-long ribbon probably due to the effect of demagnetizing fields. The MI has also been studied with different annealing conditions. Joule-annealed ribbons, employing a current of 500 mA for 5 min, show the maximum MI amongst all the ribbons.

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