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Pressure stress-impedance effect in FeCuNbSiB amorphours ribbons

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The stress-impedance effect in Fe73.5Cu1Nb3Si13.5B9 (at%) ribbons is measured to investigate the influences of vacuum annealing and pressure stress. The results can be explained by the influence of induced anisotropy in the magnetization processes at the chosen drive current frequency of 90 MHz. The maximum *SI*% value of the ribbon annealed at 300℃ is 2.52%.

pressure stress, stress-impedance, amorphours ribbon, anneal

1 Introduction

A strain or pressure applied to the soft magnetic materials causes a significant change in the impedance of soft magnetic materials, which is called the stress-impedance (SI) effect. Shen et al.[1] firstly reported the SI effect in negative magnetostrictive Co-based amorphous wire in 1997, where an SI ratio of 14% was obtained at 20 MHz with tensile stress of 14 MPa. Later, stress sensors based on the SI effect in amorphous soft magnetic wires were constructed[2,3]. However, only few results concerning the SI effect have been reported in soft magnetic films or multilayered films[4−7], and the test mode usually explored tension stress and torsion stress[8−10]. In this paper we presented for the first time the SI effect in FeCuNbSiB ribbons with the point pressure stress way.

2 Experimental

The initial material was produced as an amorphous ribbon by melt spinning technique. The amorphous state of as-cast wires was confirmed by X-ray diffraction (not shown here). The ribbon-shaped samples, 7 mm long, 5 mm wide, and 22－23 μm thick of the Fe73.5Cu1 Nb3Si13.5B9 (at%) alloy, were investigated in as-quenched state after annealing in vacuum for 0.5 to 3 h in the temperature ranging from 100 to 400℃.

All of the data presented in this work were measured using an Agilent 4294A impedance analyzer with the frequency range from 40 Hz to 100 MHz. The samples were connected to the analyzer with the designed unit with four coaxial cables. The pressure was applied by the CSS-3901D multi-caput creep testing machine. The contact area between pressure head and sample is 19 mm^2. The block diagram of the experimental set-up is shown in Figure 1.

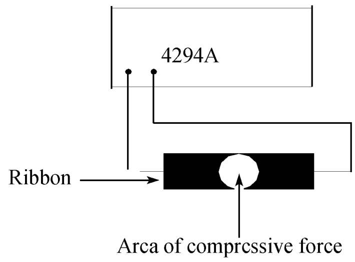

Figure 1 Experimental set-up for piezomagnetic properties measurement.

The stress impedance value (*SI*%) was given by

$$|SI\%| = \left|\frac{\Delta Z}{Z_{(0)}}\right| \times 100\% = 100\% \times \left|\frac{Z_{(x)} - Z_{(0)}}{Z_{(0)}}\right|,$$

where $Z_{(0)}$ is the impedance of the sample without stress,

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and $Z_{(x)}$ is the impedance when pressure stress value at the surface of amorphous strips is equal to x. Therefore, Z changes with stress at the surface of amorphous strips in the applied frequency range. The sensitivity of impedance ($\triangle Z$) was equal to the impedance difference between $Z_{(x)}$ and $Z_{(0)}$.

3 Results and discussions

Figure 2 shows the frequency dependence of *SI*% value for the as-cast ribbon. It can be seen that the *SI*% increases drastically with increasing of both frequency and stress. At the low frequency of 50 MHz the *SI*% value changes slightly. At high frequencies such as 70 and 100 MHz, the *SI*% value increases significantly. With the frequency of 100 MHz and the stress below 0.12 MPa, *SI*% value increases dramatically, and the slope of change curve of *SI*% reaches 8.25. However, when the stress is above 0.12 MPa, the *SI*% value increases smoothly. This microstress pair of ribbons impedance change is very sensitive to stress.

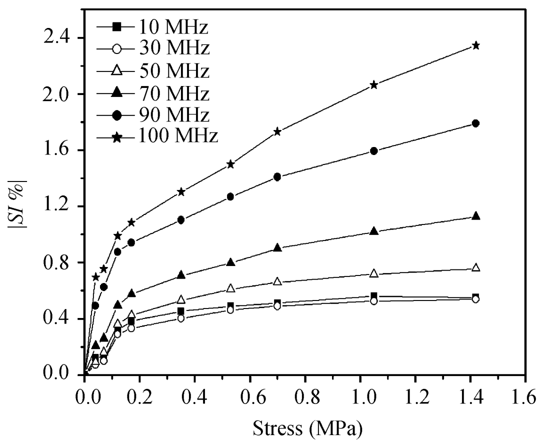

Figure 2 Dependence of *SI*% values of the amorphous ribbons as-cast on different stress.

It is seen that the *SI*% increases monotonically in magnitude with increasing stress, and the maximum *SI*% of 2.34% is obtained at the stress of 1.42 MPa at frequency of 100 MHz. It is well known that the applied pressure on the FeCuNbSiB ribbon causes the change in magnetic anisotropy, and thus leading to the change in magnetic permeability and the high frequency impedance. This is because the skin depth δ of magnetic ribbon is given by $\delta = \sqrt{2\rho / \omega\mu_0\mu}$, where ρ is the resistivity of magnetic ribbon, ω is the angular frequency, μ_0 is the vacuum permeability, and μ is the relative magnetic permeability. Thus, with $k=(1+i)/\delta$, the impedance of magnetic ribbon is $z = (k\rho l/2w)\coth(kt/2)$, where l, w and t are the length, width, and thickness of the magnetic ribbon, respectively. In the case of pressure stress, the magnetoelastic energy is liable to store in the thickness direction of the FeCuNbSiB ribbon, and the magnetic anisotropy increases with the increasing of pressure stress, thus the magnetic permeability decreases, leading to the decrease in the stress-impedance.

Figure 3 shows the stress dependence of the impedance ratios of *SI*% for the as-cast samples after annealing in vacuum for 2 h at temperatures of 100，200, 300 and 400℃, respectively (90 MHz). It can be seen that the *SI*% values of the annealed ribbons are larger than those of the as-cast ribbons. There exists an optimum stress where the value of *SI*% has a maximum for all samples investigated. It is worthy to note that the maximum *SI*% value ($SI\%(Z)_{max}$) is 2.5% for the ribbons annealed at 300℃.

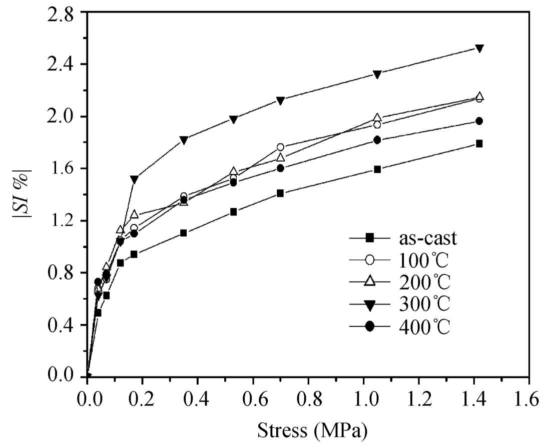

Figure 3 Stress dependence of the *SI*% values of the as-cast and annealed amorphous ribbons(90 MHz).

Figure 4 shows the effect of annealing temperature on $SI\%_{max}$ (90 MHz). It is evident that $SI\%(Z)_{max}$ increases with increasing annealing temperature up to the maximum 300℃ and then drops. This implies that the annealing temperature should not be too high. Otherwise, the samples tend to be crystallized and *SI*% value drops sharply. Such behavior is different from the case of FeCuNbSiB wires in ref. [8]. The largest *SI*% comes from the nanocrystalline state for FeCuNbSiB wires.

It is seen that the $SI\%(Z)_{max}$ increases with annealing temperature before 300℃. The internal stress and the increase of the soft magnetic properties of ribbons after annealing are released. Here, the elective anisotropy

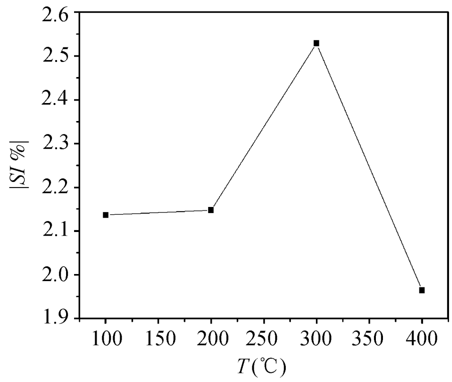

Figure 4 Dependence of the *SI*% value of the amorphous ribbons on annealing temperature (90 MHz).

field can be divided into two main parts: the field-induced anisotropy field and stress-induced anisotropy field (or magnetoelastic anisotropy field). The latter is determined by the coupling between magnetostriction and the stress of ribbons. For the magnetostrictive Fe73.5Cu1Nb3.5Si13.5B9 (at%) ribbons with transverse anisotropy, Figure 4 shows that proper annealing can reduce the stress of ribbons, and correspondingly, the elective anisotropy field drops substantially.

Figure 5 shows the stability of stress-impedance properties form six runs of measurement for as-cast amorphous ribbons (80 MHz). Except that the errors of the second run reached 0.2 Ω, all other errors were within ±0.08 Ω. This indicated that the stress-impedance stability of ribbons was satisfactory.

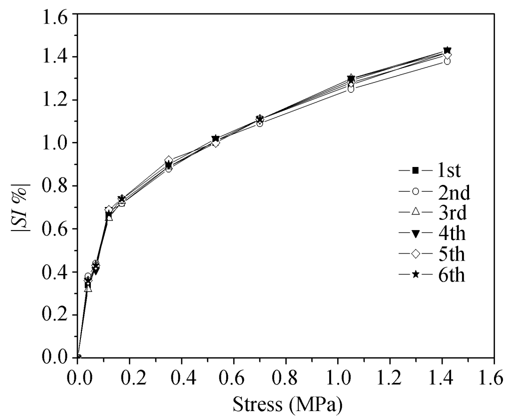

Figure 5 Stability of stress-impedance properties for as-quenched amorphous ribbons (80 MHz).

4 Conclusions

The following conclusions are drawn from the investigations.

1) The sensitivity to stress with transverse anisotropy can be enhanced after annealing, and the maximum *SI*% value of the ribbon annealed at 300℃ is 2.52%.

2) Microstress pair of ribbons impedance change is very sensitive, and the stress-impedance stability of ribbons is very good.

3) *SI*%(*Z*)max shows the maximum 2.52% at different annealing temperatures, the optimum annealing temperature is 300℃ in the study.

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