Giant Stress-Impedance Effect in Amorphous and High-Current-Density Electropulsing Annealed $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ Ribbons *

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The stress-impedance (SI) effect has been observed in as-cast and high-current-density electropulsing annealed $Fe_{73.5}Cu_1$- $Nb_3Si_{13.5}B_9$ ribbons. Large SI ratios of -35% and 25% have been obtained in high-current-density electropulsing annealed samples but not in as-cast samples. The SI effect changes drastically with the density of the annealing current and the longitudinally applied stress during the annealing process. The effective permeability has been shown to be responsible for the SI effect.

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Recently, sensitive SI effects have been observed in amorphous wires.[1] This phenomenon has prompted potential applications in detecting very small mechanical motion and vibration of the human body, plants and artificial structures.[2−4] The effect has been reported to be the strongest for cold drawn and then tension annealed $Co_{72.5}Si_{12.5}B_{15}$ amorphous wires having negative magnetostriction of -3×10^{-6}. The ac wire voltage decreases by 30% and increases by 15% under applied tensile stress of 80 MPa at frequencies of 20 MHz and 400 kHz, respectively. Even though potential applications of the SI effect have been suggested and explored, the basic mechanisms responsible for the SI effect remain not well understood. Until now all reports on SI have been related to Co-based amorphous wires. As for the magnetostrictive ribbons, a giant SI effect can also be expected in Fe-based amorphous ribbons. In this Letter, we report on the variation of SI in the $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ ribbon having positive magnetostriction tailored with high-current-density electropulsing annealing. The effects of current annealing and longitudinal tensile stress applied during the annealing process on the impedance have also been analysed in terms of effective permeability.

The amorphous ribbons, having positive magnetostriction with nominal composition $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$, were prepared by the melt-quenching method. Samples with a width 1 ± 0.1 mm, thickness 35 ±1 μm and length 65 mm were annealed for 25 s by high-current-density electropulsing with and without the applied tensile stress of 100 MPa. The amorphicity of the as-cast sample was examined by x-ray diffraction using Co K_α radiation.

The impedance was measured by means of the four-probe method using a YY2816 precision inductance analyser at a frequency of 300 kHz with a driving current $I_{\rm rms} = 15$ mA. The effective permeability was deduced from the measurement of equivalent impedance of the coil with a sample. The sample, or the coil, was connected to the analyser with four coaxial cables. Both the impedance and the effective permeability have been measured as a function of applied tensile stress. The SI ratio is defined as $(\Delta Z/Z) = 100\% \times [Z(\sigma) - Z(0)]/Z(0)$, where $Z(0)$ is the impedance for external tensile stress $\sigma = 0$ and $Z(\sigma)$ is for any given applied tensile stress σ. The tensile stress up to 120 MPa was applied by hanging a weight. The measurements of impedance are performed at room temperature.

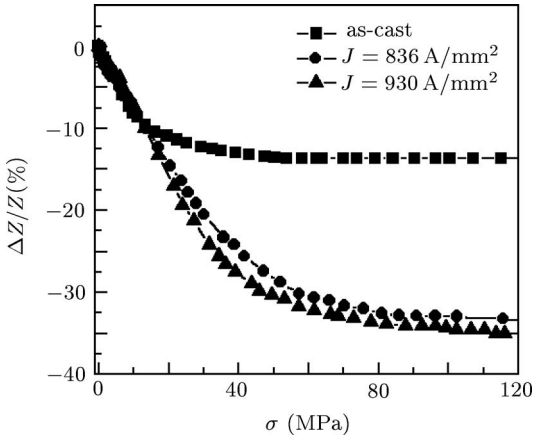


Fig. 1. Stress-impedance ratios versus longitudinal tensile stress for as-cast and high-current-density electropulsing annealed $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ ribbons.

Figure 1 shows the longitudinal tensile stress dependences of the SI ratios for the as-cast and high-current-density electropulsing annealed samples. Though the SI ratios of as-cast and high-current-density electropulsing annealed samples change monotonically from zero to saturation values when the applied tensile stress increases from zero to 120 MPa, the SI effects of high-current-density electropulsing annealed samples are larger than those for the as-cast sample. After high-current-density electropulsing annealing, the as-cast $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ ribbon crystallized, which results in the increase of permeability.

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It can be seen from Fig. 2 that both the effective permeability and the change are drastically improved after the high-current-density electropulsing annealing.

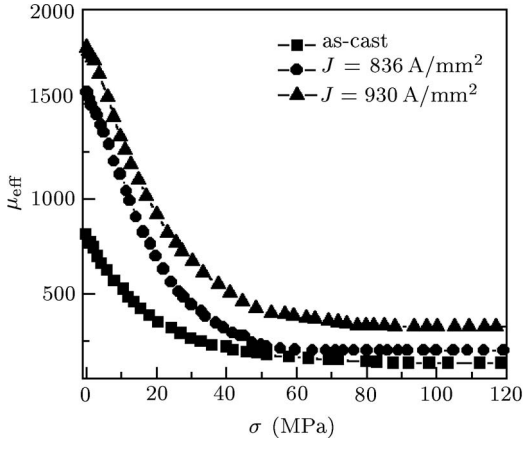


Fig. 2. Effective permeability versus longitudinal tensile stress for as-cast and high-current-density electropulsing annealed $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ ribbons.

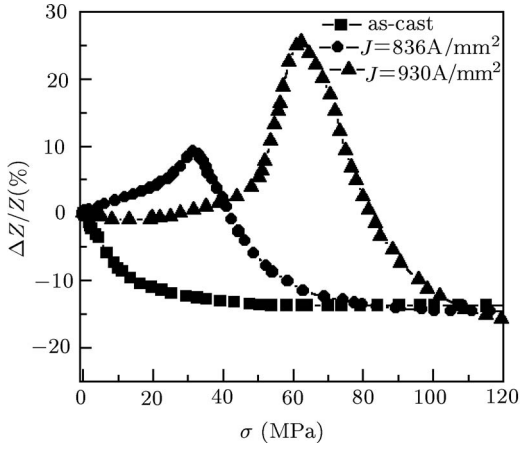


Fig. 3. Stress-impedance ratios versus longitudinal tensile stress for as-cast ribbon and samples annealed by high-current-density electropulsing under applied tensile stress of 100 MPa.

Figure 3 shows the $\Delta Z/Z$ ratio as a function of applied tensile stress for samples annealed by high-current-density electropulsing under the applied tensile stress of 100 MPa. The SI ratio of the as-cast sample is also presented for comparison. It can be clearly seen from Fig. 3 that the SI behaviour of the samples annealed by high-current-density electropulsing under applied tensile stress is different from that of the as-cast sample. For the samples annealed by the high-current-density electropulsing annealing under the applied tensile stress, the SI ratios first increase with applied tensile stress and reach the maximum positive values, then decrease with the applied tensile stress and become negative. The effective permeability $\mu_{\rm eff}$ versus σ has also been studied in order to investigate the influence of the permeability upon the SI as shown in Fig. 4. Comparing Fig. 1 with Fig. 2 and Fig. 3 with Fig. 4, one can find that there is a direct correlation between SI and the effective permeability $\mu_{\rm eff}$. The different SI behaviour between the as-cast and high-current-density electropulsing annealed samples comes from the different permeability properties between them, and indicates different magnetic structures.

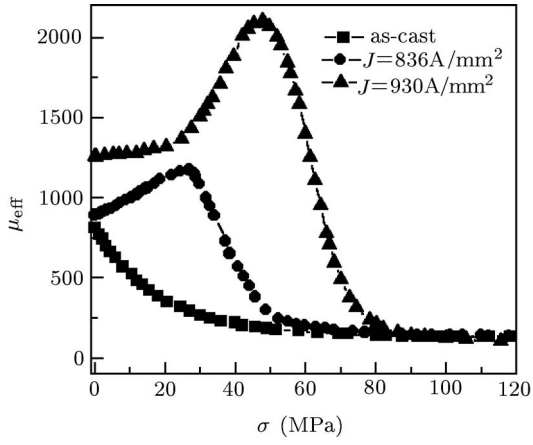


Fig. 4. Effective permeability versus longitudinal tensile stress for as-cast ribbons and samples annealed by high-current-density electropulsing under applied tensile stress of 100 MPa.

In summary, the SI of the as-cast and high-current-density electropulsing annealed $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ ribbons has been measured. After high-current-density electropulsing annealing, the SI decreases monotonically with the increase of applied tensile stress σ and the maximum negative SI ratio of -35% is obtained. The samples annealed by high-current-density electropulsing under applied tensile stress of 100 Mpa exhibit a positive SI effect and the maximum positive SI ratio of 25% is obtained. The effective permeability is responsible for its SI effect. The mechanism of SI in high-current-density annealed materials and the detailed relationship between the structure and SI need further investigation.

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