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Materials

Giant magnetoimpedance effect in as quenched $Fe_{89-x}Zr_7B_4Cu_x$ (x=1.0-2.5) ribbons

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Abstract: The giant magnetoimpedance (GMI) effect in as-quenched $Fe_{89-x}Zr_7B_4Cu_x$ (x=1.0-2.5) ribbons is reported. The as-quenched $Fe_{89-x}Zr_7B_4Cu_x$ (x=1.0-2.5) ribbons were prepared by the vacuum melt-spun processes with the quenching speed of 37 m/s. The magnetoimpedance measurement were performed at room temperature, where the current flows through the length of the ribbons in the direction parallel to the dc fields. Results show that values Z (impedance), R (resistance) and X (reactance) for both H=0 A/m and H=5 127 A/m increases with increasing ac frequency. This can be explained by the skin effect mechanism. The GMI effect almost can not be found in the Cu content (mass fraction) range $x \leq 1.5\%$. With increasing Cu content $x > 1.5\%$, the GMI effect become evident for as-quenched $Fe_{89-x}Zr_7B_4Cu_x$ (x=1.0-2.5) ribbons. GMI ratio ($Z(0)-Z(H)/Z(0)$) in as quenched $Fe_{86.5}Zr_7B_4Cu_{2.5}$ with melt-spun quenching speed of 37 m/s can reaches 33.69% at H=5 127 A/m. This indicated that good GMI properties can be also obtained in as-quenched FeZrBCu ribbons without annealing.

Keywords: giant magnetoimpedance effect; as quenched ribbons; FeZrBCu

Recent research on the strong effect of high frequency-impedance upon dc magnetic fields has attracted much attention due to its potential application in magnetic sensors and heads [1-4]. This effect called as giant magnetoimpedance (GMI) was interpreted as arising from a classical electrodynamics origin [2,4]. When the frequency of the current become high enough, the skin effect plays an important role, diminishing the effective section of the conductor. Since the penetration depth of the skin effect depends on the circular or transverse magnetic permeability, the impedance as well as the resistance and reactance vary with dc magnetic field *via* the permeability. The GMI effect firstly observed in rich Co based amorphous CoFeSiB wires with non zero-magnetostriction constant. Recently, it has been found that CoFeSiB, FeCuNbSiB and FeZrBCu ribbons [4-8] also show GMI effect. To obtain good GMI properties rich Fe based GMI materials are usually treated by the heating at 500-800℃ [5-6]. In the present work, the GMI effect in as quenched $Fe_{89-x}Zr_7B_4Cu_x$ (x=1.0-2.5) ribbons is reported. Results show that the GMI ratio ($Z(0)-Z(H)/Z(0)$) in as-quenched $Fe_{86.5}Zr_7B_4Cu_{2.5}$ with melt-spun quenching speed of 37 m/s can reach 33.69%. This indicated that good GMI properties can be also obtained in as-quenched FeZrBCu ribbons without annealing.

1 Experimental

The as-quenched $Fe_{89-x}Zr_7B_4Cu_x$ (x=1.0-2.5) ribbons were prepared by the vacuum melt-spun processes with the quenching speed of 37 m/s. The magnetoimpedance measurement were performed with a HP4192A impedance analyzer at room temperature. DC fields were provided by a pair of Helmholtz coils. The current flows through the length of the ribbons in the direction parallel to the dc fields.

2 Results and discussion

Figure 1 shows the frequency dependence of the impedance, resistance and reactance of an as-quenched ribbon $Fe_{89-x}Zr_7B_4Cu_x$ (x=2) at room temperature for fields H=5 127 A/m and H=0 A/m, respectively. It can be clearly seen that values Z, R and X for both H=0 A/m and H=5 127 A/m increases with increasing ac frequency. This can be explained by the skin effect mechanism. With the increase of the ac frequency, the current tends to flow near the surface and the impedance rises accompanying the decrease of the penetration depth. It can be found from figure 1 that values Z are lower for H=5 127 A/m than for H=0 A/m. This showed that the magnetoimpedance effect can be obtained for as-quenched ribbon $Fe_{87}Zr_7B_4Cu_2$. Meanwhile, the values resistance and reactance for H=5 127 A/m are smaller than those for H=0 A/m, showing the magnetoresistance and magnetoreactance.

The frequency dependence of the magnetoimpe-

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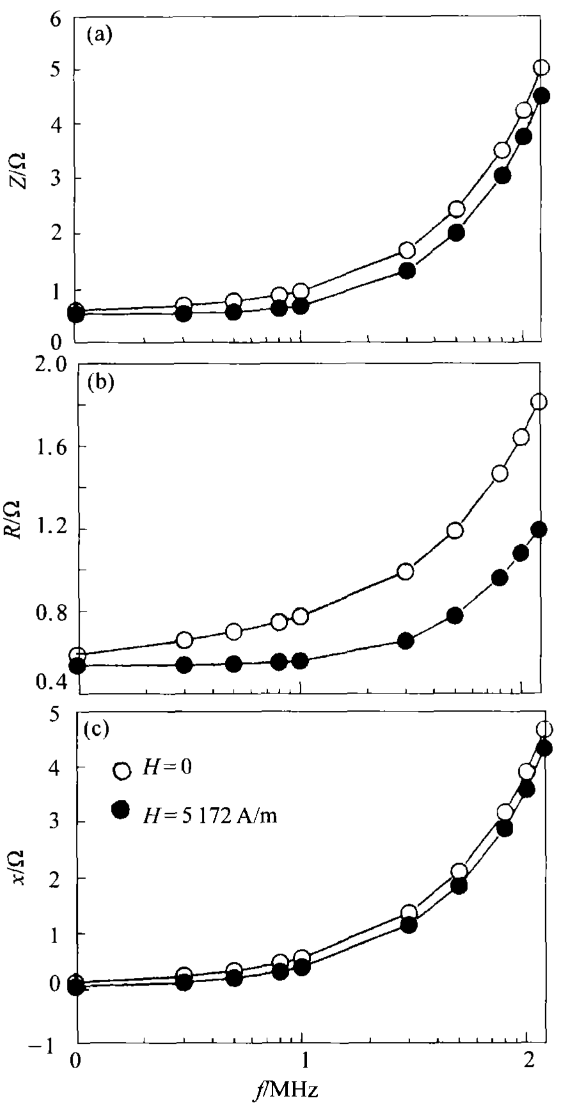

Figure 1 The frequency dependence of the impedance (a), resistance (b) and reactance (c) of an as-quenched ribbon $Fe_{89-x}Zr_7B_4Cu_x$ (x=2) at room temperature for fields H=5 127 A/m and H=0 A/m, respectively.

dance ratio $(Z(0)-Z(5\ 127\ A/m))/Z(0)$ for as quenched ribbon $Fe_{87}Zr_7B_4Cu_2$ is shown in **figure 2**. The $(Z(0)-Z(5\ 127\ A/m))/Z(0)$ is 9.92% at f=100 kHz. With increasing frequency, the ratio $(Z(0)-Z(5\ 127\ A/m))/Z(0)$ increases, undergoes a maximum value of 27.25% at about f= 1 MHz, and then decreases. The $(Z(0)-Z(5\ 127\ A/m))/Z(0)$ is 10.25% at f= 12 MHz.

Figure 3 shows the Cu content dependence of the maximum magnetoimpedance ratio $[|Z(0)-Z(5\ 127\ A/m)|]_{max}$ for as-quenched $Fe_{89-x}Zr_7B_4Cu_x$ (x=1.0-2.5) ribbons. The GMI effect almost can not be found in the Cu content range $x \le 1.5$. With increasing Cu content $x > 1.5\%$, the GMI effect become evident for as quenched $Fe_{89-x}Zr_7B_4Cu_x$ (x=1.0-2.5) ribbons. The addition of Cu may be helpful in reduction the crystalline size. The GMI ratio $[|Z(0)-Z(5\ 127\ A/m)|]_{max}$ can reach 33.69 % for the as-quenched $Fe_{86.5}Zr_7B_4Cu_{2.5}$ ribbon.

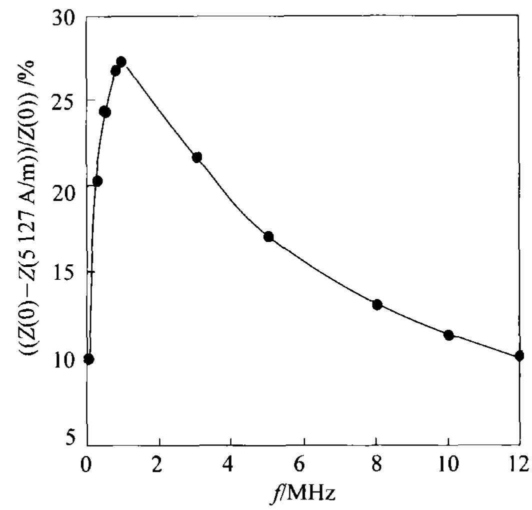

Figure 2 The frequency dependence of the magnetoimpedance ratio for the as quenched ribbon $Fe_{87}Zr_7B_4Cu_2$.

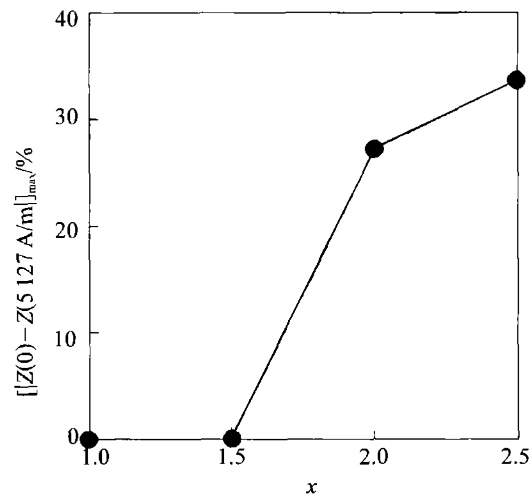

Figure 3 The Cu content dependence of the maximum magnetoimpedance ratio for as quenched $Fe_{89-x}Zr_7B_4Cu_x$ (x=1.0-2.5) ribbons.

The dc field dependence of ratios of the magnetoimpedance $(Z(H)-Z(0))/Z(0)$, magnetoresistance $(R(H)-R(0))/R(0)$ and magnetoreactance $(X(H)-X(0))/X(0)$ for as-quenched $Fe_{86.5}Zr_7B_4Cu_{2.5}$ ribbon are shown in **figure 4**. At lower frequency f=100 kHz, the $(Z(H)-Z(0))/Z(0)$ decreases monotonically with increasing dc fields. The value $(Z(H)-Z(0))/Z(0)$ is −14.95 % at H=5 172 A/m. However, at higher frequency f= 12 MHz with increasing dc fields the $(Z(H)-Z(0))/Z(0)$ increases at first, undergoes a small positive peak at about H = (5 000/4π) A/m ≈398 A/m, and finally drops to the negative values. The value $(Z(H)-Z(0))/Z(0)$ is −11.26 % at H=5 172 A/m. A large value of −33.69% for $(Z(H)-Z(0))/Z(0)$ at H= 5 127 A/m can be obtained at a frequency f =1 MHz. The peak phenomenon can be attributed to the transverse magnetic anisotropy in ribbons, being connected with the mag-

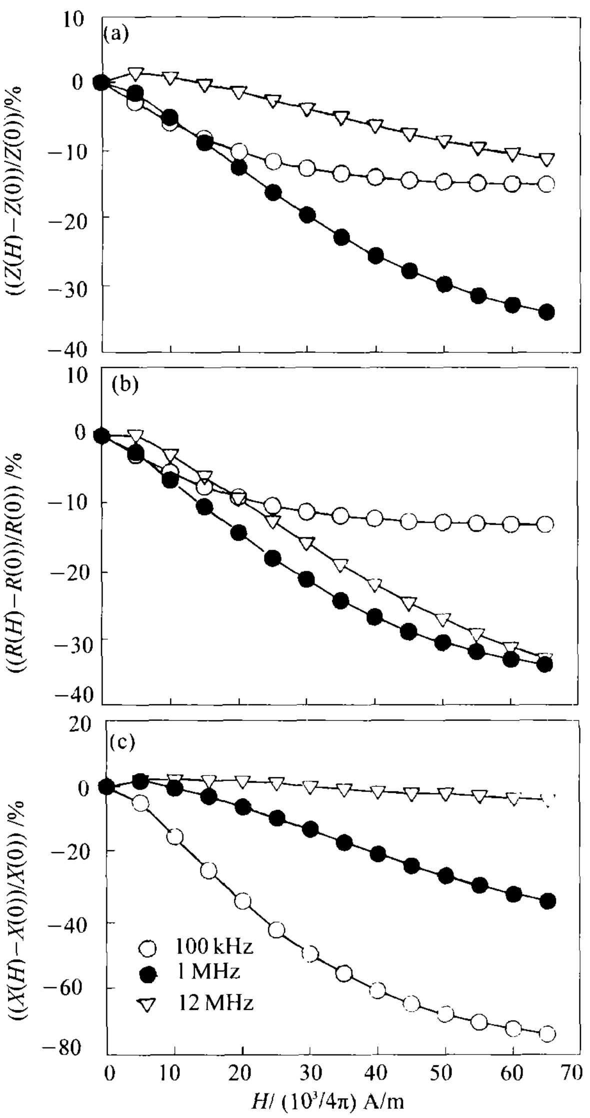

Figure 4 The dc field dependence of ratios of the magneto-impedance (a), magnetoresistance (b) and magnetoreactance (c) for as-quenched $Fe_{86.5}Zr_7B_4Cu_{2.5}$ ribbon.

neto-elastic energy [2]. The transverse anisotropy field for as quenched $Fe_{87}Zr_7B_4Cu_2$ ribbon can then be estimated as about 398 A/m. Also from figure 2, it can be seen that the magnetoreactance $(X(H)-X(0))/X(0)$ shows peak phenomenon at frequency f=1 MHz already, but no peak has been observed for magnetoresistance at the same frequency yet. This implies that the reactance depends more sensitively than the resistance. Values $(X(H)-X(0))/X(0)$ with H=5 172 A/m are −73.04% at f= 100 kHz, larger than −3.66% at f=12 MHz. In contrast, values $(R(H)-R(0))/R(0)$ with H=5 172 A/m are −13.13% at f=100 kHz, smaller than 32.89% at f=12 MHz. At 100 kHz, the $(Z(H)-Z(0))/Z(0)$ is very similar to the $(R(H)-R(0))/R(0)$, since Z is dominated by the R term. At higher frequencies such as 12 MHz, the $(Z(H)-Z(0))/Z(0)$ behaves as the $(X(H)-X(0))/X(0)$, where the Z is controlled by the X term. At low frequency, the giant magnetoinduction effect occurs and magnetoresistance is very small [1]. At higher frequencies, skin effect become strong, both R and X varies with the dc field and the magnetoimpedance effect as the combined effects of the magnetoresistance and magnetoreactance results from the variation of the permeability [2].

3 Conclusion

In this work the giant magnetoimpedance effect in as quenched $Fe_{89-x}Zr_7B_4Cu_x$ ribbons is reported. Results show that good GMI properties can be obtained in as cast $Fe_{89-x}Zr_7B_4Cu_x$ ribbons with x=2-2.5 without annealing. The GMI ratio $|\Delta Z|/Z(0)$ in as-quenched $Fe_{86.5}Zr_7B_4Cu_{2.5}$ with melt-spun quenching speed of 37 m/s can reach 33.69%.

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