Journal of Magnetics 3(2), 41-43 (1998)

Annealing Effect of Permeability Spectra in Amorphous $Fe_{83}Zr_7B_8Cu_2$

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(Received 13 July 1998)

The frequency spectra of complex permeability have been measured as a function of ac field amplitude in the annealed amorphous $Fe_{83}Zr_7B_8Cu_2$ ribbons. The longitudinal permeability results from the rotational magnetization at small fields, h_o<5 mOe in as-quenched samples. However, at the further increase of h_o, the wall motion begins to be involved in the low frequency region. The permeability from the wall motion drastically decreases in the annealed sample, while that from the rotational magnetization increases up to annealing temperature of 500°C and then drops there after.

1. Introduction

A lot of works on the magneto-impedance (MI) have been studied in the soft magnetic amorphous materials for the sensitive sensor applications [1]. MI is understood as the effect of magnetic field on the permeability in ac current direction, which gives rise to new motivation for permeability analysis.

The local internal stress inherent to as-quenched amorphous state can be relieved when annealing proceeds at increasing temperature, but, the crystalline anisotropy degenerating magnetic properties is induced by the annealing with the formation of grains larger than the correlation length of ferromagnetic exchange [2]. The initial permeability in amorphous ribbons has been analyzed in terms of the domain wall motion and magnetization rotation by taking into account the local anisotropy constants associated with the external and internal stresses at the defects [3]. However, there is no available report for the separation of domain wall motion and magnetization rotation components in the permeability. In this work, we measured the frequency spectra of complex permeability in the annealed amorphous $Fe_{83}Zr_7B_8Cu_2$ ribbons and discussed the results in terms of domain dynamics.

2. Experimental

The amorphous $Fe_{83}Zr_7B_8Cu_2$ ribbons were prepared by rapid quenching technique in Ar atomsphere and annealed at temperatures between 500-600 °C for 1 hour. The dimension of sample is 30 μm thickness, 3 mm width and 30 mm length. The spectra of real and imaginary parts of complex permeability, $\mu(f)=\mu'(f)-j\mu''(f)$, were measured by an impedance analyzer in the frequency range of f=0.1-10 MHz. The amplitude of ac current applied to a small solenoid coil around the sample was set to a constant value during the frequency sweep.

3. Results and Discussion

3.1 ac field amplitude

Figs. 1(a) and (b) show the frequency spectra of real (μ') and imaginary (μ'') parts of permeability, respectively, with various amplitudes of applied ac field ho in a as-quenched sample. For small amplitude of h_o<5 mOe, spectra show a typical Debye-type relaxation at $f\approx1.5$ MHz [4], where the center of relaxation is marked by an arrow in μ''. As the amplitude increases over 5 mOe, the frequency for the μ'' peak shifts to a low frequency. This reflects that another relaxation process begins to be involved in low frequency region. Hence, we can suggest two successive relaxations in the permeability spectra for $h_o\geq5$ mOe as

$$\begin{aligned}\mu(f) &= \mu'(f) - j\mu''(f)\\ &= 1 + \frac{\mu_{lo}}{1+(f/f_{lo}^o)^2} + \frac{\mu_{hi}}{1+(f/f_{hi}^o)^2}\\ &\quad - j\left(\frac{\mu_{lo}(f/f_{lo}^o)}{1+(f/f_{lo}^o)^2} + \frac{\mu_{hi}(f/f_{hi}^o)}{1+(f/f_{hi}^o)^2}\right) \qquad (1)\end{aligned}$$

where μ_{lo} and f_{lo}^o are the magnitude and relaxation frequency in low frequency region, respectively. They are sensitive to the amplitude h_o as shown in Figs. 1(a) and (b). The quantities μ_{hi} and f_{hi}^o denote the values in the high frequency region, and they are nearly independent of h_o.

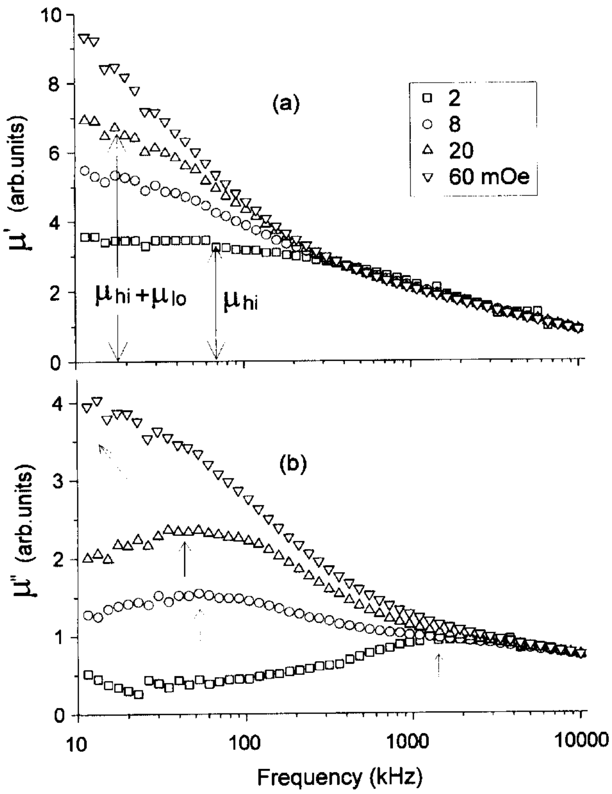

Fig. 1. Permeability spectra of real (a) and imaginary (b) parts at various ac fields (h_o) in as-quenched samples.

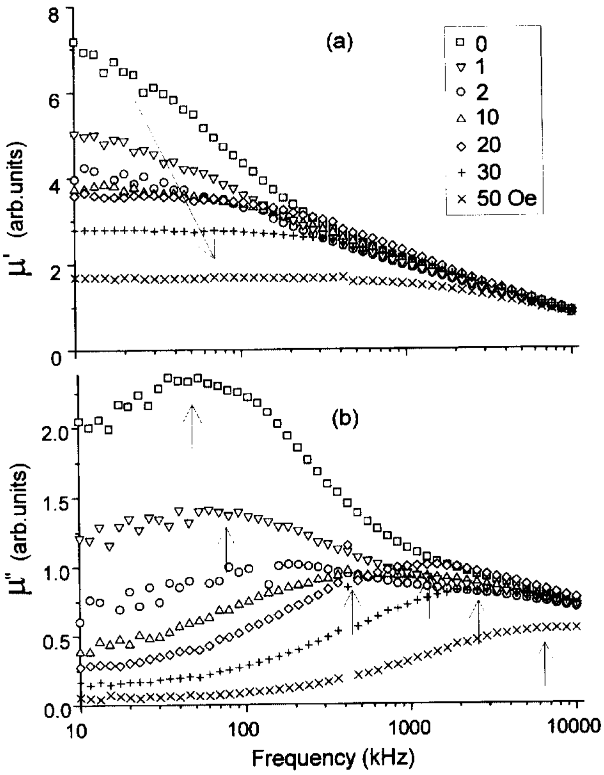

Fig. 3. Permeability spectra of real (a) and imaginary (b) parts at various bias fields h_o=20 mOe along transverse direction (H_T) in as-quenched samples.

3.2 Transverse bias field

There are domains oriented to parallel and transverse to ribbon axis due to the quenched-in stress, where the permeability in longitudinal direction results from the wall motion and rotational magnetization. The schematic domains in the parallel (type I) and the transverse (type II) directions are shown in Fig. 2. As the transverse bias field (H_T) increases, the amount of magnetization due to wall motion in domain I decreases, but the rotational magnetization in domain II increases, because the H_T could increase the volume fraction of domain II at the expense of domain I.

Fig. 3 shows the variation of the permeability spectra for h_o=20 mOe, with transverse field H_T in an as-quenched sample. As H_T increases, permeability decreases and the relaxation frequency shifts to high frequency. The relaxation frequency for H_T=30 Oe is close to that for small ac fields h_o<5 mOe. Such a change of permeability with the transverse field suggests that the low and high frequency relaxations are ascribed to the wall motion and rotational magnetization processes, respectively. Accordingly μ_{hi} of Fig. 1, from eq. (1), results from the rotational magnetization for h_o<5 mOe. Whereas superposition of μ_{lo} and μ_{hi} results from the both domain dynamics for $h_o \geq 5$ mOe.

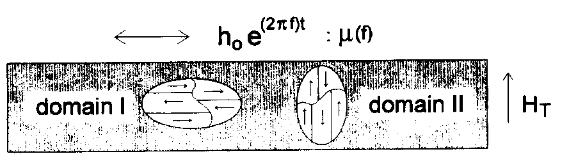

Fig. 2. Schematic domains resulting in the wall motion (type I) and rotational magnetization (type II), respectively.

3.3 Annealing effect

The μ_{lo} sensitively depends on the amplitude h_o, while μ_{hi} is nearly independent of h_o in as-quenched samples. However, the high frequency relaxation is observable irrespective of h_o in the annealed sample, showing a

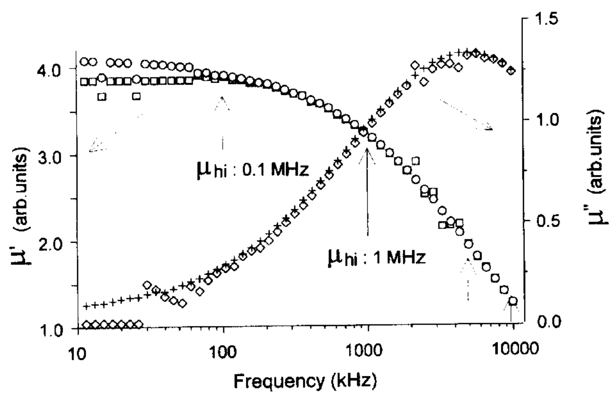

Fig. 4. Permeability spectra of real (□ -2, ○ -60 mOe) and imaginary (◇ -2, +-60 mOe) parts at various ac fields in 500°C annealed sample.

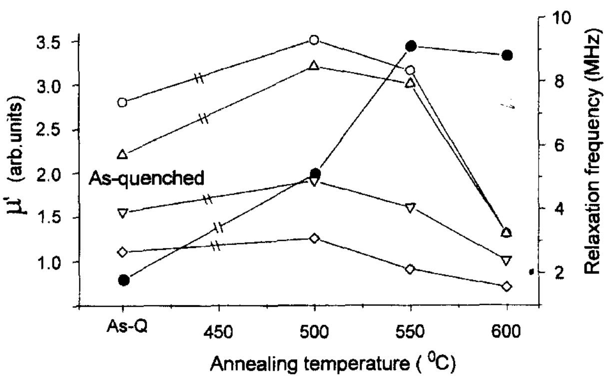

Fig. 5. Annealing temperature dependence of permeability from rotational magnetization, μ_{hi} at various frequencies (○ -0.1, △ -1, ▽ -5, ◇ -10 MHz).

drastic decrease of permeability from wall motion in Figs. 4(a) and (b). It indicates that the rotational magnetization is the only active mechanism in the annealed samples. The impeication is the changes of the domain from type I to type II in Fig. 2 after the annealing. Such a variation is opposite that of to usual amorphous materials upon annealing, and may be due to the stress relief in longitudinal direction.

The dependence of μ_{hi} on annealing temperature T_a is shown in Fig. 5, from which it is seen that value of μ_{hi} at 0.1 MHz varies greatly compared to that at high frequencies. The μ_{hi} increases up to $T_a \approx 500$°C, and shows a drastic decrease at $T_a \geq 600$°C, due to the growth of crystalline grain larger than the correlation length of ferromagnetic exchange [2]. However, the relaxation frequency represented by solid circles in Fig. 5, is measured to increase with T_a, suggesting that the upper frequency for the rotational magnetization increases with T_a.

4. Conclusion

The frequency spectra of complex permeability have been measured as a function of ac field amplitude h_o in the annealed amorphous $Fe_{83}Zr_7B_8Cu_2$ ribbons. The longitudinal permeability spectra of typical Debye-type relaxation results from the rotational magnetization at small ac amplitudes of h_o<5 mOe in as-quenched samples. However, at the further increase of h_o, the wall motion begins to be involved in low frequency region, showing two successive Debye-type relations in permeability spectra. The decreasing permeability in the low frequency region with the transverse field suggests that the low and high frequency relaxations are ascribed to the wall motion and rotational magnetization processes, respectively.

The permeability in the low frequency region drastically decreases in the annealed sample, indicating that the rotational magnetization is only active, due to the transformation of domain in longitudinal direction to transverse after the annealing. The permeability from the rotational magnetization increases up to annealing temperature of 500°C and then shows a decrement thereafter, due to the growth of crystalline grain larger than the correlation length of ferromagnetic exchange.

Acknowledgement

Research at Sun Moon University was supported by Korea Research Foundation made in Program year 1998, and research at Chungbuk National University was supported by Korea Ministry of Education Research Fund for Advanced Materials in 1997.

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