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Temperature Dependence of The Magnetoimpedence Effect in Nanocrystalline $Fe_{84}Zr_7B_6Cu_1Al_2$ Alloy

Hye-Suk Kwon, Heebok Lee, Yong-Kook Kim*, Sung-Ho Yoon*,
Taik-Kee Kim*, Seong-Cho Yu**,

Dept. of Phys. Education, Kongju Nat'l. Univ., Kongju 314-701, Korea
*Division of Material Sci., Chungnam Nat'l. Univ., Taejon 305-764, Korea
**Dept. of Phys, Chungbuk Nat'l. Univ., Cheongju 361-763, Korea

Abstract

The nanocrystalline $Fe_{84}Zr_7B_6Cu_1Al_2$ alloy was annealed at 450 ℃ and 550 ℃ for 1 hour to achieve the ultra-soft magnetic properties such as large magnetoimpedence ratio(MIR), the incremental permeability ratio(PR), nearly zero coercivity, zero magnetostriction, etc. The PR and MIR of the sample were measured from 100 kHz to 10 MHz at a cryogenic chamber where the temperature can be varie from 10 K to 300 K. The increment of MIR value is proportional to increasing temperature. The maximum PR values measured at high frequency above 1 MHz remain almost same despite of the temperature variation from 10 K to 300 K except the sharpness in PR curves. However, the maximum PR values measured below 1 MHz show drastic increment at above 150K due to thermal activation of magnetic domains.

1. Introduction

It is well known that a suitable annealing of the Fe-Zr based alloys leads to a nanoscale grain-size multiphase structure, which has excellent soft magnetic properties[1]. Giant magnetoimpedence(GMI) has been extensively studied in the last few years due to its technological impact. Recently, large and sensitive changes of incremental permeability ratio(PR) on magnetoimpedence effect as a function of applied field in ultra-soft magnetic materials have been studied intensively because of the increasing prospectives of novel applications in magnetic sensors [2]-[4]. The investigation of the temperature dependence of the PR effect is very important for scientific interests and the thermal stability of magnetic sensors [4].

The aim of this paper is to study the teperature depedence of magnetoimpedence effect in $Fe_{84}Zr_7B_6Cu_1Al_2$ annealed at 450 ℃ and 550 ℃ respectively. Furthermore, the correlation between PR effect and manetoimpedence with the variation of temperature has been studied in nanocrystalline $Fe_{84}Zr_7B_6Cu_1Al_2$ alloy.

2. Experimental method

Amorphous ribbons of the composition $Fe_{84}Zr_7B_6Cu_1Al_2$ were fabricated by rapid quenching technique in Ar gas atmosphere. The dimensions of the samples chosen for the measurement of MI effect and PR were 14 mm in length and 5 mm in width with 19 μ m in thickness. Annealing was performed in vacuum for 1 hour at various temperatures (450 ℃, 550 ℃, respectively).

This system measures the magnetoimpedance(MI) on low temperature range , from 10 K to 300 K. The Magnetoimpedance (MI) was measured using an ac four - probe technique. So personal computer controls the procedure of experiment that all sections of measurement system are connected by GPIB BUS. The drive current amplitude used was 10mA. During the MI measurements, the magnetic field has been swept through the entire cycle (-150 to 150 Oe). HP34401A multimeter was used measuring the magnetic field by measuring current through coil. High frequency current (10mA) was applied the sample with signal generator (SYTRON 1720), was varied with GPIB. To measure current through the sample, transformer (FLUKE RF Probe) was used. The effect of the earth's magnetic field has been minimized by suitable positioning of the sample. The frequency of MI measurement was ranging from 100 kHz to 10 MHz, and the ac current was fixed at 10 mA for all maesurement. The change of longitudinal permeability as a function of external field can be measured by the same system with a set of primary and secondary coils instead four terminals in the MI system. Averaging PR with sweeping fields, changing frequencies, and keeping a constant ac current are performed by a computer program.

3. Results and discussion

Fig 1. shows that increasing MIR proportional to increasing temperature at 2.1 MHz annealed (a) 450 ℃ and (b) 550 ℃ samples. In Fig.1. (a), values of MIR didn't reach value of the GMI except that of the GMI measured 250 K. However, those of Fig.1.(b) had value of the GMI. The MIR curves varies very sensitively when applied external magnetic field H_{ex} is ± 20 Oe, but shapes of those have not been changed as variation of the temperatures. This consideration represents that domain wall motion and atomic moment motion at skin of sample in prominent at more lower temperature than the room temperature. Especially, the positions of maxima of the MIR curves have not been changed because anisotropy magnetic field that influenced position of maximum value isn't influenced the variation of temperature. As shown in the Fig. 2, MIR increases as frequency increases and MIR decreases rapidly as the external field increases producing the bell shaped curves. Since H_{ex} is a hard axis field with respect to the circumferential anisotropy, the magnetic field applied along the ribbon axis suppresses the circular magnetization by domain wall movements at the low frequency region, or the motion of localized magnetic moments at the high frequency region. Our experiment was performed in the high frequency region (100 kHz - 10 MHz) where domain wall movements are highly damped. As the circumferential permeability decreases rapidly along with the increment of the external field, it is responsible for MI effects in the soft ferromagnetic ribbons[5]-[6]. This process accompanied by rapid reduction in the circumferential soft magnetic properties of the samples as the external field increases affects the voltage across the ribbon ends. Therefore MIR can be measured directly from the changes of this voltage. The ac current flowing through the sample generates an easy-axis driving field that causes a circular magnetization field

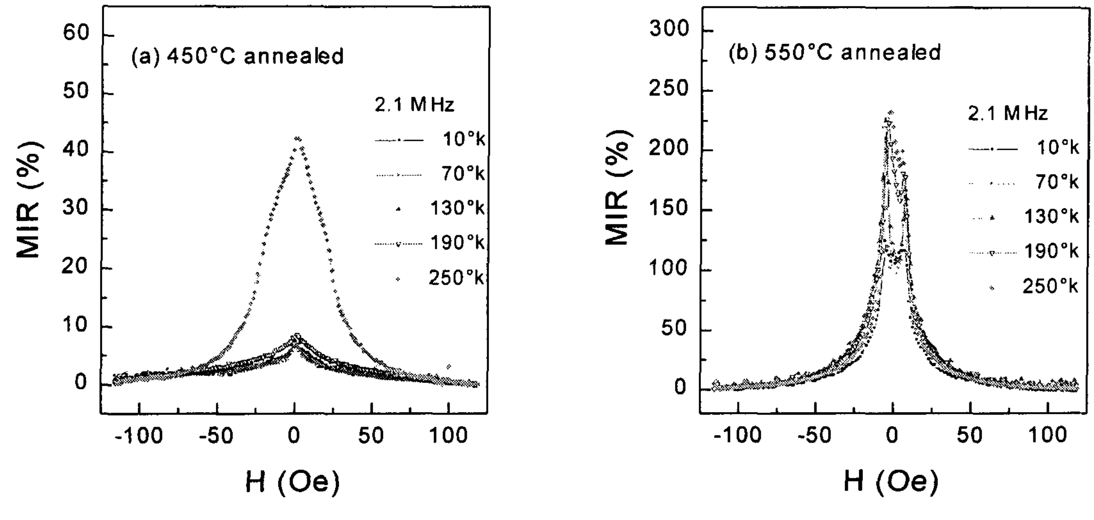

Fig. 1 The *MIR* vs H_{ex} curves at various temperatures measured at 2.1 MHz in (a) 450 ℃ annealed and (b) 550 ℃ annealed.

Fig.2 shows that frequency dependence of the MIR in various temperatures. The value of MIR saturated at 4.1 MHz both sample annealed at 450 ℃ and annealed at

550 ℃. In this case, the increment of MIR is influenced by atomic wall motion less then skin effect in high frequency region. As observed in Fig.2, The MIR at room temperature is 7~8 times as low as others' (a), but that of Fig. 2 (b) similar to others' except measured at 10 K. samples Annealed at 550 ℃ are found that the value of the MIR increase abruptly as increase the frequency above 100 kHz.

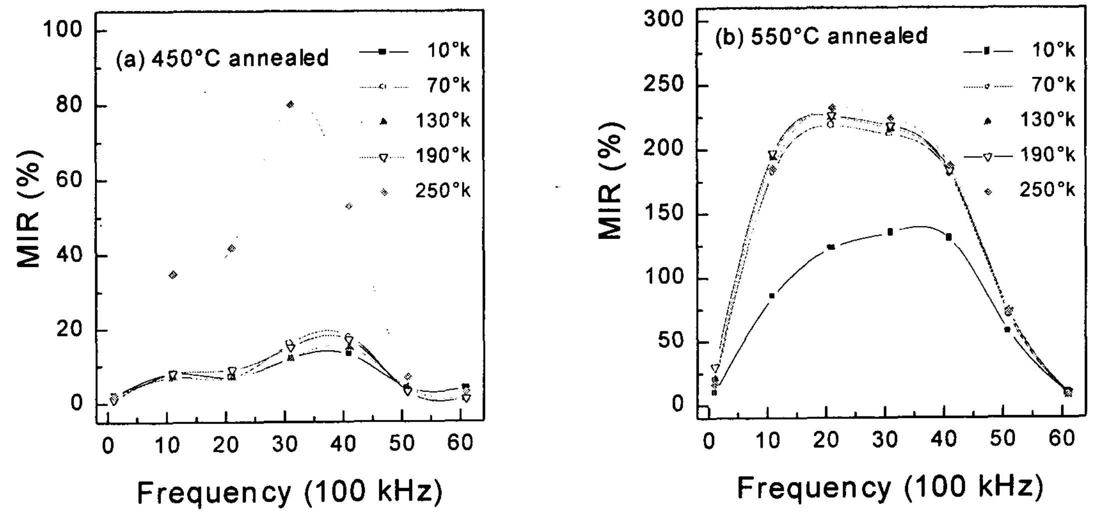

Fig. 2. The MIR vs frequency curves at various temperatures in (a) 450 ℃ annealed and (b) 550 ℃ annealed.

The PR curves are also plotted in Fig. 3 as a function of the external field. Only few curves are selectively shown in the Figure due to lack of space. One notes that the changes of the magnetoimpedance are much related to the changes of longitudinal permeability in the present of an external field as clearly shown in Fig. 3. The full width at half maximum(FWHM) in the longitudinal PR curves weren't changed very much for the samples annealed at 450 ℃ regardless of the presenting magnetic field during the heat treatment. However big changes of the FWHM in the PR curves of the sample annealed at 550 ℃ indicate that structural changes such as crystallization have been occurred.

The broadening MIR curves along with increment of frequency may arise from the circumferential permeability that is somewhat different from longitudinal permeability as shown in Fig. 3. One may adapt a model for the transverse biased permeability in thick ferromagnetic films where eddy current damping and the ripple field H_R incorporating with the anisotropy field H_K give rise to the peak of permeability at an external field as well as the broadening of the permeability changes as a function of the external field to explain broadening MIR curves at high frequency7). It is worthily noting that the magnetoimpedance increases as frequency increases because the impedance is proportional to $(\omega\mu_\phi)^{1/2}$ even in case of the decrement of the transverse permeability at high frequency.

The PR can be defined as $PR(H) = \triangle\mu/\mu\ (H_{max}) = 1-|\mu\ (H)/(H_{max})|$ where $H_{\max}$ is an external magnetic field sufficient for saturating PR. $H_{\max}$ =150 Oe was taken in our experiment. The frequency dependence of PR in the sample has shown typical behavior where the shapes of PR curves are getting broader with the increment of the frequency [4].

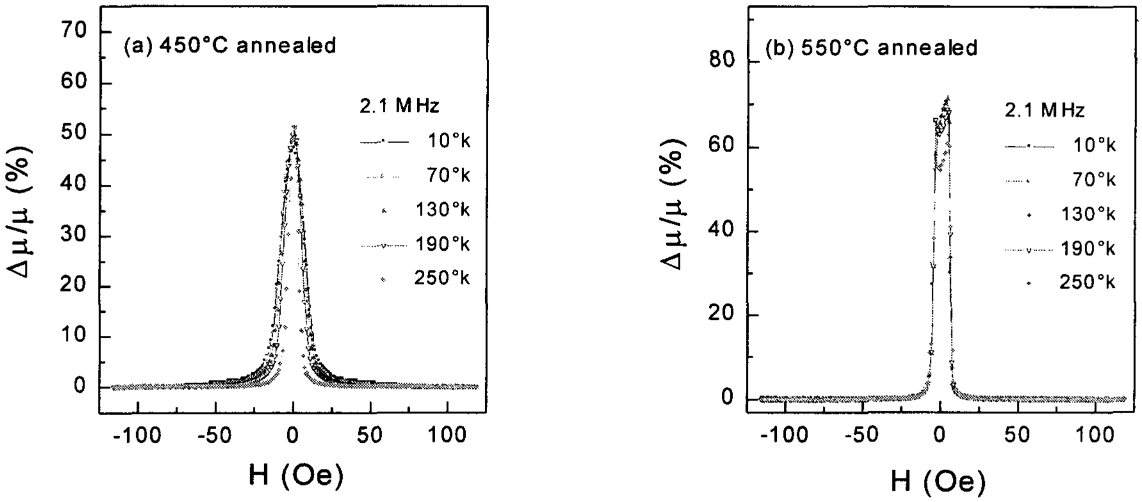

Fig. 3. The PR vs the external field H measured at 2.1 MHz in various temperatures (a) 450 ℃ annealed and (b) 550 ℃ annealed.

As shown Fig. 4, the overall shapes of PR are almost same except the magnitude and broadness. The PR decreases rapidly producing the sharp peak due to the decrement of permeability as the external field increases.

One may adapt a model for the PR in soft magnetic materials where the external field incorporating with the anisotropy distribution gives rise to the peak in the PR curve at near zero external field and the dynamic nature of magnetic domains **at** the measured frequency further affects to the shape of the PR curves [8]. Since the lighter magnetic domains interact with high frequency driving field and more sensitive to the local variation of an internal magnetic field than the heavier magnetic domains The frequency dependance of the PR curves becomes broader as the measured frequency increases due to local anisotropy distribution..

The temperature dependance of the maximum PR values was remained same or slightly increased as the temperature increases at high frequency range except the sharpness of the PR curves. However, the exchange energy between large magnetic domains play a role at low frequency range below 1MHz as shown in Fig. 2. This result implies that the exchange energy between magnetic domains can be reducd drastically as temperature increases above 150 K due to themal activation of magnetic domains. The sharpness of the PR curves incresed as the temperature increases due to the reduction of the exchange energy between magnetic domains masured at high frequency.

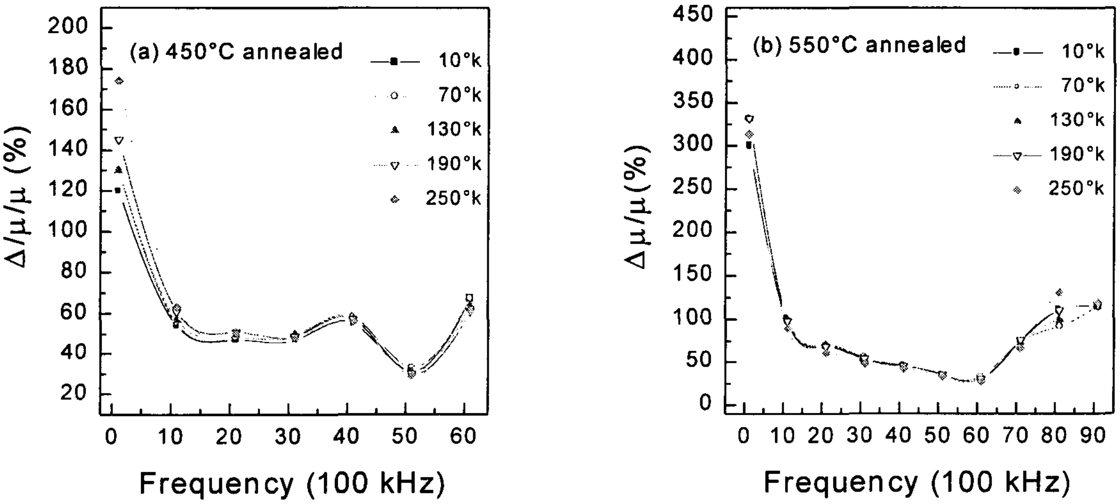

Fig. 4 The PR vs frequency curves at various temperatures in (a) 450 ℃ annealed and (b) 550 ℃ annealed.

4. Conclusion

We have obtained following results that soft magnetic properties vary with low temperature in $Fe_{84}Zr_7B_6Cu_1Al_2$ annealed at 450 ℃ and 550 ℃ respectively.

The MIR increase in proportional to increasement of temperature at 2.1 MHz in samples annealed at 450 ℃ and 550 ℃. Values of MIR didn't reach value of the GMI except measured 250 K. However, those annealed at 450 ℃ had value of the GMI. The MIR curves varies very sensitively when applied external magnetic field H_{ex}

is ± 20 Oe, but shapes of those have not changed with variation of the temperatures. The overall shapes of PR are almost same except the magnitude and broadness. The PR decreases rapidly, producing the sharp peak due to the decrement of permeability as the external field increases.

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