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MAGNETIC PROPERTIES AND MAGNETOIMPEDANCE EFFECT IN $TM_{70}Cr_5Si_{10}B_{15}$ (TM = Fe, Co, Ni) ALLOYS

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Amorphous $TM_{70}Cr_5Si_{10}B_{15}$ (TM = Fe, Co, Ni) alloys were prepared by rapid quenching technique. Saturation magnetization of the amorphous ribbons was investigated by using SQUID and vibrating sample magnetometer from 5 to 800 K. For these two ferromagnetic alloys, the saturation magnetization up to 0.4 T_c can be described by the Bloch relation, $M_s(T) = M_s(0)[1 - BT^{3/2} - CT^{5/2}]$. The spin wave stiffness constants and the range of exchange interaction were analyzed from the magnetization behaviour. And the temperature dependence of the magnetoimpedance effect was investigated in conjecture with their magnetic properties from 10 to 300 K.

1. Introduction

A number of studies have been reported on the low temperature magnetic properties and the magnetic excitations of locally isotropic amorphous metallic ferromagnets over the last 10 years[1)-4)]. There are many experimental evidences in the literature[1)-5)] showing that the magnetization at low temperature can be adequately described by Bloch's relation:

$$\begin{aligned} \triangle M_s(T)/M_s(0) &= BT^{3/2} + CT^{5/2} \\ &= B_{3/2}(T/T_c)^{3/2} + C_{5/2}(T/T_c)^{5/2} \end{aligned} \quad (1)$$

It is from the Bethe-Slater curve that the sign of the exchange integral between transition metals depends sensitively on their interatomic distance. Especially, Cr atoms indicates a negative exchange integral so it is interesting to study the TM-Cr-Si-B alloy system. Recently, it was shown by the present authors, there exists antiferromagnetic (AFM) coupling in transition metal based amorphous alloy with Cr element[6)].

The magnetoimpedance(MI) effect has a classical electromagnetic behavior where the impedance is changing under the application of a longitudinal magnetic field. The electromagnetic origin of the MI effect has been conjectured to the combination of a skin effect and field dependence of the circumferential magnetic permeability associated with the circular motion of magnetic moments.

In this work, we report the effects of a transition metals(TM) such as Fe, Co and Ni in TM-Cr-Si-B alloy on their magnetic properties and the magnetoimpedance effect at low temperature.

2. Experiment

Amorphous $TM_{70}Cr_5Si_{10}B_{15}$ (TM=Fe,Co,Ni) alloys were prepared by the single roller melt-spinning method in Ar atmosphere. The ribbons were 1 mm wide and 20 μm thick. The amorphous state of the samples was verified by X-ray diffraction using Cu-Kα radiation. The temperature dependence of the saturation magnetization was measured from 5 K to 800 K in the external magnetic field of 10 kOe using a SQUID and a VSM. In order to estimate the values of spectroscopic splitting g factor, FMR experiments were carried out at room temperature.

The MI measurements were carried out along the ribbon axis with longitudinal magnetic field. The sample was attached in the cold finger of a closed cycle cryostat (10 K～300 K). For the four-terminal MI measurement, a silver paint has been used to attach the terminals where the separation between the current leads and the voltage leads are about 15 mm and 10 mm, respectively. The external field applied by a solenoid on the top of a cryogenic chamber can be swept through the entire cycle equally divided by 800 steps from -150 Oe to 150 Oe. For the comparison of MIR curves at different temperatures the driving currents were fixed at 10mA. Because of capacitive interferences between wires in the cryogenic chamber, the measured MI values diminished by a factor.

3. Results and Discussion

Fig. 1 shows a typical temperature-dependence of saturation magnetization in amorphous $Fe_{70}Cr_5Si_{10}B_{15}$ and $Co_{70}Cr_5Si_{10}B_{15}$ alloys with an external field of 10 kOe. We obtained values of the saturation magnetizations at 0 K, $M_s(0)$ = 152.8 emu/g ($Fe_{70}Cr_5Si_{10}B_{15}$) and 79.5 emu/g ($Co_{70}Cr_5Si_{10}B_{15}$), respectively, by extrapolating M_s to 0 K. The saturation magnetization of Fe-based amorphous alloy was much higher than that of Co-based alloys as was already observed in the other similar systems[7)]. The Curie temperatures can be determined using the Arrot plots from the isofield magnetization curve. Curie temperatures of Fe and Co based amorphous alloy samples were estimated about 600 K and 730 K respectively. The saturation magnetization behaviour of $Ni_{70}Cr_5Si_{10}B_{15}$ alloy appears to be paramagnetic as shown in Fig. 2. This result indicates that Ni acts as non-magnetic atom in an amorphous state. The reduced magnetization is plotted versus $T^{3/2}$ below about 0.4 T_c in Fig.3. There is a good relationship between the reduced magnetization and $T^{3/2}$ at lower temperature, as expected from eq. (1). The Bloch coefficients B and C were obtained from Fig. 2 by least square fitting.

The values of B and C are 24.2 x $10^{-6}K^{-3/2}$ and 1.2 x $10^{-8}K^{-5/2}$ for $Fe_{70}Cr_5Si_{10}B_{15}$ alloy, and 17.9 x $10^{-6}K^{-3/2}$ and 0.95 x $10^{-8}K^{-5/2}$ for $Co_{70}Cr_5Si_{10}B_{15}$ alloy, respectively. By conventional linear spin wave theory, the Bloch coefficient B is related to the spin wave stiffness constant D through

$$D = (2.612)^{2/3}[g\ \mu_B\ /\ B\ M_s(0)]^{2/3}\ [\kappa_B\ /\ 4\pi] \tag{2}$$

where g is spectroscopic splitting factor, μ_B is Bohr magneton and k_B is the Boltzmann constant. The spectroscopic splitting factor g represents the relativecontribution of orbital magnetic moment to total magnetic moment. The estimated values of g from the experiment found to be 2.20 and 2.11 for $Fe_{70}Cr_5Si_{10}B_{15}$ and $Co_{70}Cr_5Si_{10}B_{15}$ alloys, respectively.

This result indicates that the contribution of orbital magnetic moments in $Fe_{70}Cr_5Si_{10}B_{15}$ alloy is larger than for the $Co_{70}Cr_5Si_{10}B_{15}$ alloy. The values of spin wave stiffness constant for $Fe_{70}Cr_5Si_{10}B_{15}$ and $Co_{70}Cr_5Si_{10}B_{15}$ alloys obtained from eq. (3) are 117.2 and 198.8 meVÅ^2 respectively. The D value of $Co_{70}Cr_5Si_{10}B_{15}$ alloy is much higher than $Fe_{70}Cr_5Si_{10}B_{15}$ alloy. This result provides a measure of the range of the exchange interaction[10].

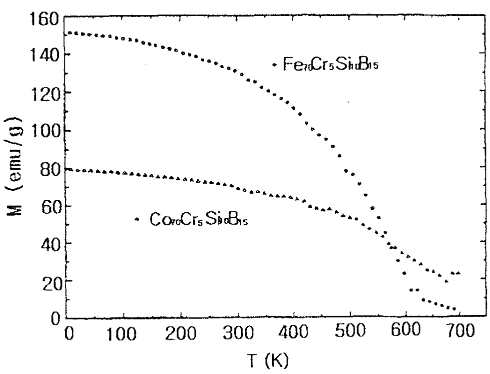

Fig. 1. The temperature dependence of saturation magnetization for amorphous $Fe_{70}Cr_5Si_{10}B_{15}$ and $Co_{70}Cr_5Si_{10}B_{15}$ alloys.

The magneto-impedance ratio (MIR) can be defined as $MIR(H) = \Delta Z/Z(H_{\max}) = 1 - |Z(H)/Z(H_{\max})|$ where $H_{\max}$ is an external magnetic field sufficient for saturating the magnetoimpedance. $H_{\max} = 150$ Oe was taken in our experiment.

The MI effect as a function of frequency can be explained in terms of the skin effect. Because the transverse circumferential permeability μ_ϕ affects the penetration depth[12] in ferromagnetic materials, we can expect that the frequency dependence of the

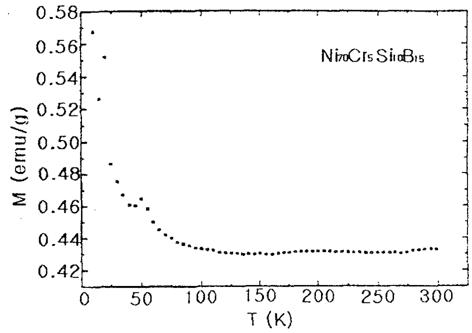

Fig. 2. The temperature dependence of saturation magnetization for amorphous $Ni_{70}Cr_5Si_{10}B_{15}$ alloy.

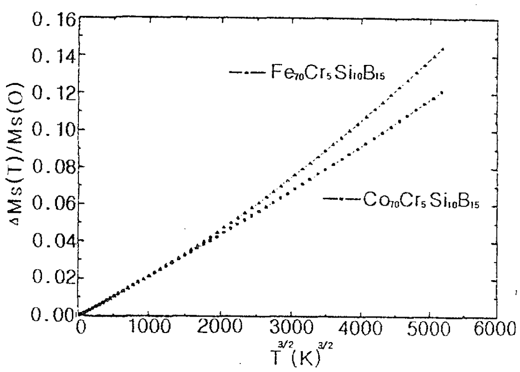

Fig. 3. The reduced magnetization versus $T^{3/2}$ for amorphous $Fe_{70}Cr_5Si_{10}B_{15}$ and $Co_{70}Cr_5Si_{10}B_{15}$ alloys.

impedance is proportional to $(\omega\mu_\phi)^{1/2}$. Therefore MIR values are increasing with the increment of frequency as clearly shown in Fig. 4 and 5.

The experimental results are plotted selectively due to lack of space in Fig. 4 for $Fe_{70}Cr_5Si_{10}B_{15}$ alloy, and Fig. 5 for $Co_{70}Cr_5Si_{10}B_{15}$ alloy, respectively. As shown in the Figures, MIR is increasing as frequency increases and MIR is decreasing rapidly as the external field increases [11].

The shapes of the MIR curves of $Fe_{70}Cr_5Si_{10}B_{15}$ alloy were not changed at temperature variation except MIR values. However, there are drastic changes of MIR shapes as well as their magnitudes in $Co_{70}Cr_5Si_{10}B_{15}$ alloy. Because the magnetic permeability is sensitive to the temperature, the MIR is changing rapidly as a function of temperature. The coupling energy between magnetic moments at low temperature is larger than that at high temperature by reducing thermal activation energy. Therefore, the circular motion of magnetic moments will be suppressed at low temperature resulting in lower permeabilities thereby reducing MIR values. The big broadening MIR curves at low temperature in $Co_{70}Cr_5Si_{10}B_{15}$ alloy may be caused by the increment of internal anisotropy field due to large magnetic coupling between domains compared to $Fe_{70}Cr_5Si_{10}B_{15}$ alloy. Further research should be done to verify this explanation.

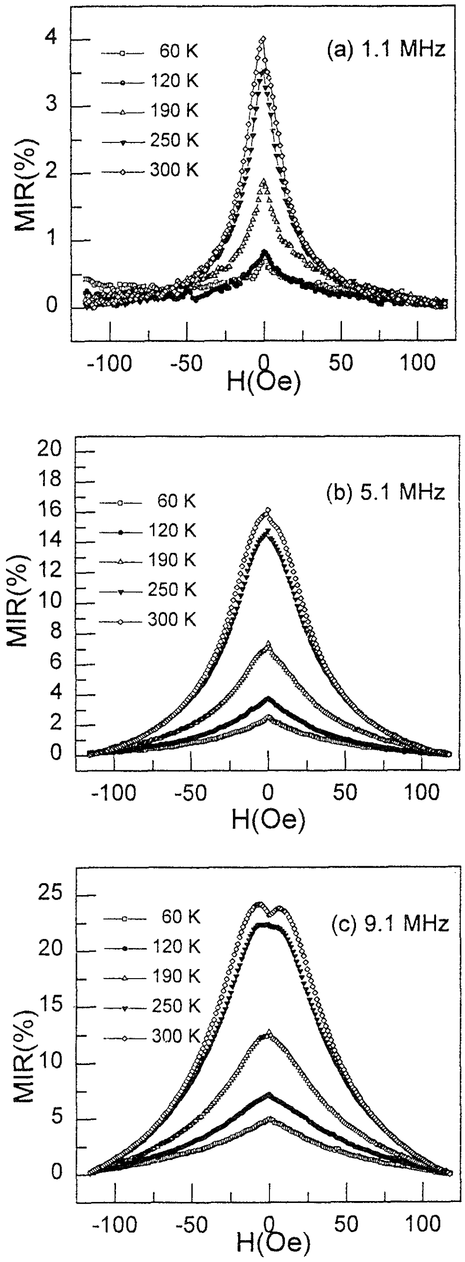

Fig. 4 The MIR vs the exernal field H for various temperaures at the frequency of (a) 1.1 MHz, (b) 5.1 MHz, and (c) 9.1 MHz in $Fe_{70}Cr_5Si_{10}B_{15}$ alloy.

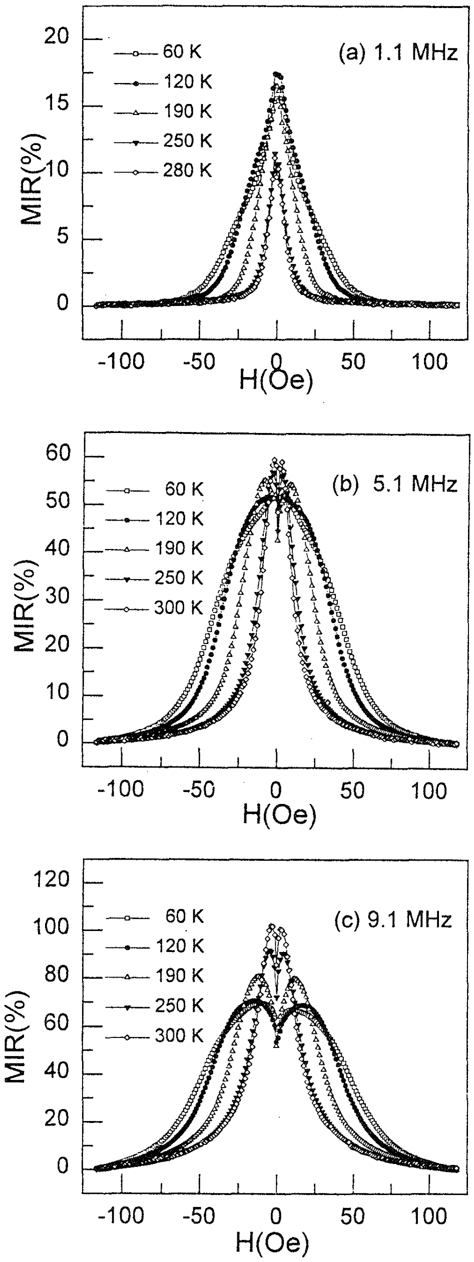

Fig. 5 The MIR vs the exernal field H for various temperaures at the frequency of (a) 1.1 MHz, (b) 5.1 MHz, and (c) 9.1 MHz in $Co_{70}Cr_5Si_{10}B_{15}$ alloy.

Acknowledgement

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