Spin Glass Behaviour of Fe-7.6 at% Zr Amorphous Alloy Studied by AC-Susceptibility and Magnetic Viscosity

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Spin Glass Behaviour of Fe - 7.6 at% Zr Amorphous Alloy Studied by AC-Susceptibility and Magnetic Viscosity.*

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Synopsis

The spin glass behaviour of the Fe - 7.6 at% Zr amorphous alloy was studied by ac-susceptibility and dc-magnetization measurements. A cusp of linear susceptibility and a sharp negative peak of non-linear susceptibility characterize the spin glass transition. This transition is also accompanied by the remarkable relaxation of the dc-magnetization.

I. Introduction

The concentration dependence of the Curie temperature of Fe-Zr amorphous alloys indicates a maximum around 15 ~ 20 at% Zr. The alloys containing more than 40 at% Zr show a spin glass behaviour, which is interpreted as the dilution of magnetic atoms. On the other hand, it has been observed by low-field thermomagnetization measurements that the alloys containing less than 12 at% Zr show the magnetic freezing state connected with spin glass at low temperatures.[1)]

Recently, we reported a reentrant spin glass behaviour of the Fe-rich Fe-Zr amorphous alloy system studied by the ac-susceptibility χ_0.[2)] Upon application of a superposed dc-field, χ_0 shows two sharp peaks at the freezing temperature T_f and the Curie temperature T_c for 8.6 ~ 10.5 at% Zr alloys. With decreasing Zr concentration, T_c decreases and T_f increases, and they show a tendency

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to coincide. It was pointed out that the 7.6 at% Zr alloy is situated near the percolation limit of the long-range ferromagnetic order. In the present paper, we report some new results on the ac-susceptibility and the magnetic viscosity measurements for the 7.6 at% Zr amorphous alloy.

II. Experimental

The sample with nominal composition of 7 at% Zr was prepared in an argon atmosphere by the melt-spinning method. The composition of the sample was confirmed to be 7.6 at% Zr by chemical analysis.

The ac-susceptibility was measured in the ac-field with frequency ω = 85 Hz and amplitude H_{ac} = 0.1 $\sim$ 6 Oe by a mutual inductance Hartshorn method. In some cases the dc-field H_{dc} was superposed. The specimen was a ribbon of about 5 mm length, 1 mm width and 20 μm thickness. The external fields, H_{ac} and H_{dc}, are applied parallel to the direction of the length. The measurements were performed during heating after zero field cooling. The earth's field was shielded by a Permalloy cylinder, so that the resultant dc-field was less than 0.05 Oe in the zero dc-field measurement. The induced voltage in a search coil is composed of some components. In this work, $\chi_0{}^t$ and $\chi_2{}^t$ were measured as the components of frequencies ω and 3ω, respectively. On the condition that the external field H is sufficiently small, $\chi_0{}^t$ and $\chi_2{}^t$ are regarded as the response of magnetizations which are proportional to H and H^3, respectively; these are called the linear susceptibility χ_0 and the non-linear susceptibility χ_2. The units of $\chi_0{}^t$ and $\chi_2{}^t$ are arbitrary but the relative values are given consistently.

The magnetic viscosity was measured by using a vibrating sample magnetometer. The relaxation of the magnetization was measured by an application of step fields in a time range between 1 and 10^3 sec.

III. Results and discussion

Figure 1 shows the temperature dependence of $\chi_0{}^t$ and $\chi_2{}^t$ in zero dc-field for the 7.6 at% Zr amorphous alloy. As the ac-field H_{ac} increases, the maximum becomes larger and sharper. The cusp of $\chi_0{}^t$ for small ac-fields shows a single transition around T_f = 114 K. The broadening of cusp by increasing ac-field implies a sensitive-

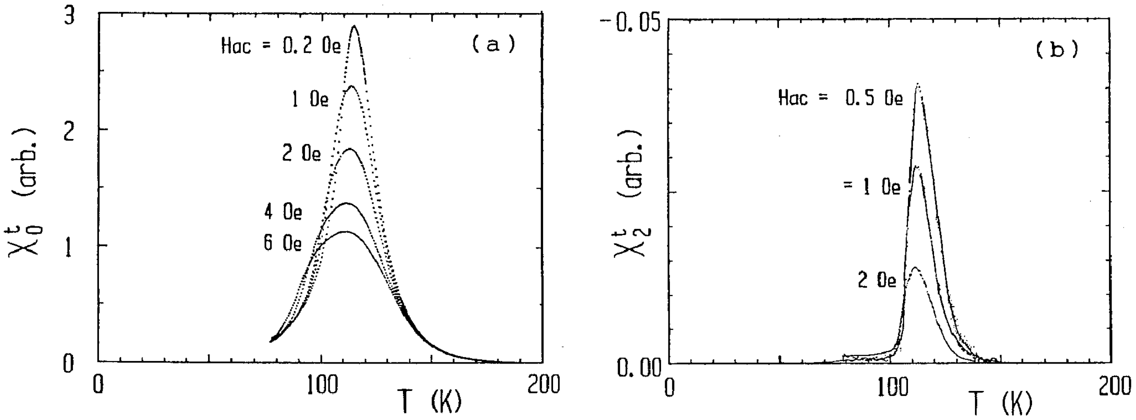

Fig. 1 The temperature dependence of ac-susceptibility in zero dc-field for the 7.6 at% Zr alloy.
(a) χ_0^t, the response of fundamental frequency ω.
(b) χ_2^t, the response of 3rd harmonics 3ω.

ness of the transition of this alloy. The $\chi_2{}^t$ is observed only in the vicinity of T_f and shows a sharp negative peak at T_f. With decreasing ac-field, $\chi_2{}^t$ becomes sharper. When H_{ac} is sufficiently small, $\chi_0{}^t$ and $\chi_2{}^t$ are regarded as linear susceptibility χ_0 and non-linear susceptibility χ_2, respectively. It is well known that the spin glass transition is characterized by the cusp of χ_0 and the negative divergence of χ_2. Therefore, it is concluded that the 7.6 at% Zr alloy shows the spin glass transition at T_f = 114 K in small applied fields.

The measurements of χ_0 in superposed dc-fields were reported in our previous paper.[2] The cusp of χ_0 is divided into two broad peaks by the superposed dc-field. These peaks correspond to T_f and T_c, indicating an appearance of the field induced ferromagnetic phase. It is thus considered that the 7.6 at% Zr alloy shows a reentrant spin glass behaviour in large applied fields. It was also reported in our previous paper[3] that the temperature dependence of the imaginary component of ac-susceptibility χ_0'' shows a sharp peak corresponding to T_f and drops rapidly to zero at higher temperatures. With superposing dc-field, this peak shifts to lower temperatures and there is no anomaly corresponding to T_c.

These behaviours imply that remarkable magnetic relaxation occurs near T_f. The ac-susceptibility measurement is suitable to study the relaxation in a time range shorter than few seconds. On the other hand, the relaxation process in a longer time range can be studied by dc-magnetization measurements. As was reported in our previous paper,[4] the magnetization change after removing the field was studied for Fe-Hf amorphous alloys which show the similar magnetic behaviour to the Fe-Zr amorphous alloys.

Figure 2 shows the relaxation of the magnetization for the 7.6 at% Zr alloy. The magnetic field H is applied at t=0, held until t=100 or 200 sec and removed abruptly. In response to the applied field, the magnetization increases rapidly at t=0, further increases slowly until t=100 or 200 sec, then decreases rapidly and further decreases slowly.

Detailed studies were made for the increase in magnetization after applying the field of 10 Oe at various temperatures. The results are shown in Fig.3, in which the time intervals are plotted in a log scale. Similar results were obtained for applied field of 5 Oe. The magnetization approximately obeys a logarithmic law:

$$M(t) = M_1 + S \operatorname{Log} t$$

where M(t) is the magnetization at time t in units of second, M_1 is the magnetization at t=1 and S is a magnetic viscosity constant. Figure 4 shows the temperature dependence of M_1 and S/H, where H is the applied field. The S/H has a sharp peak corresponding to T_f and drops rapidly to zero above this peak. With decreasing applied field, S/H becomes sharper and shifts to higher temperatures. The behaviour of S/H is similar to that of the imaginary component of ac-susceptibility χ_0''.[4)]

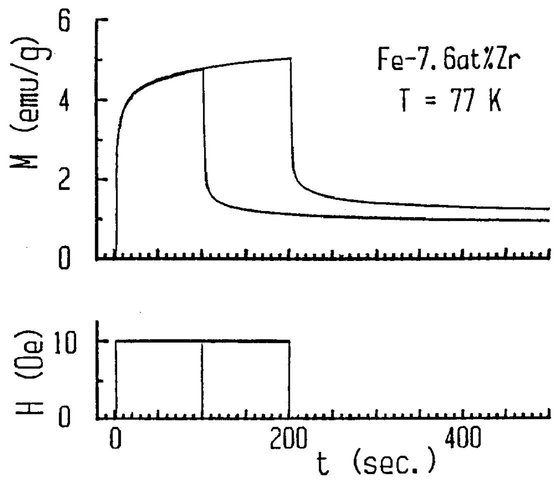

Fig. 2 Magnetic viscocity for the Fe - 7.6 at% Zr alloy.

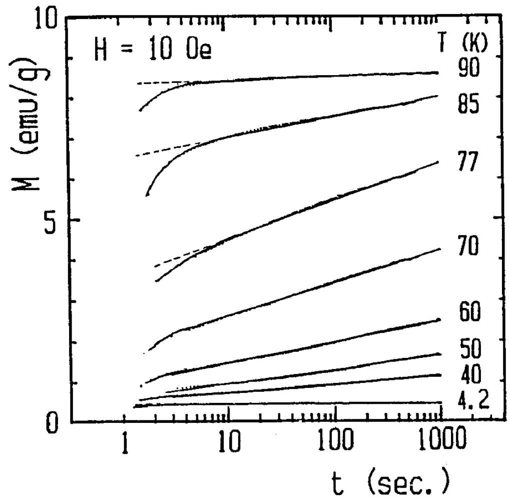

Fig. 3 The time dependence of magnetization M after applying dc-field at various temperatures.

For several spin glass systems, it has been recognized that the irreversibility appears at freezing because there are several metastable magnetic states below T_f. Therefore, T_f depends on the applied field H. Figure 5 shows the H-T_f lines determined by the maximum of χ_0'' and S/H for the 7.6 at% Zr alloy. With increasing field, T_f shifts to lower temperatures, but the two lines disagree with each other. It is considered that this difference is caused by the difference in the time scale and that these lines are connected with the Almeida-Thouless line.[5]

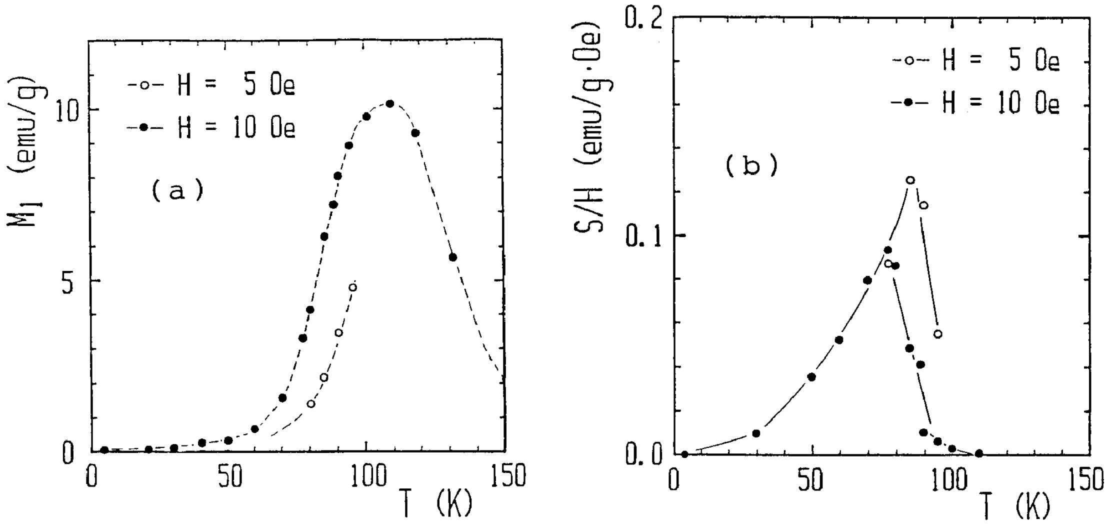

Fig. 4 The temperature dependence of parameters M_1 and S/H of the magnetic viscosity for the 7.6 at% Zr alloy. (a) M_1, (b) S/H.

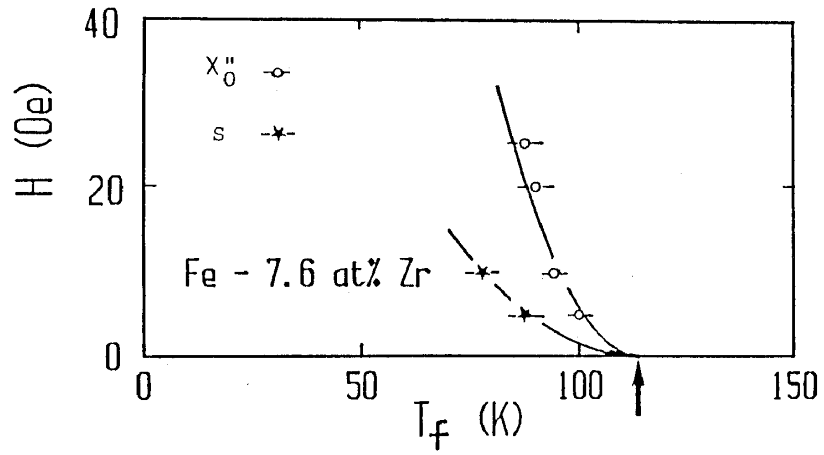

Fig. 5 The field dependence of the freezing temperature T_f for the 7.6 at% Zr alloy, determined from the maximun of χ_0'' (o) (ref.4) and the maximum of S (✶) (Fig.4). An arrow indicates the T_f at H=0 determined from the peaks of χ_0^t and χ_2^t (Fig.1).

IV. Conclusions

The spin glass like behaviour for the Fe - 7.6 at% Zr amorphous alloy was studied by ac-susceptibility and dc-magnetization measurements. The cusp of $\chi_0{}^t$ and sharp negative peak of $\chi_2{}^t$ characterize the spin glass transition for the 7.6 at% Zr alloy. These behaviours are different from those of the reentrant spin glass transition for the 8.6 ~ 10.5 at% Zr alloys. The spin glass transition for the 7.6 at% Zr alloy is very sensitive to applied fields; the direct spin glass transition is observed only in sufficiently small fields, and the reentrant spin glass transition is observed in larger fields.

The freezing state is accompanied by the relaxation of the magnetization. The temperature dependence of the imaginary part of ac-susceptibility χ_0'' and that of the magnetic viscosity constant S show a sharp peak at the freezing temperature T_f, which depends on the applied field H. The H-T_f lines determined by the susceptibility and viscosity measurements are different from each other.

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