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Magnetic Properties of Cr–C and Cr–Zr Amorphous Alloys*

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Synopsis

Cr–C and Cr–Zr amorphous alloys were prepared by a high-rate dc sputtering method. From the measurements of the magnetization as a function of magnetic field and the temperature dependence of susceptibility, it is concluded that the present amorphous alloys have no localized magnetic moment, and then no spin-glass behavior. The magnitude of susceptibility of Cr–C amorphous alloys is larger than that of Cr–Zr ones at the same composition. The temperature dependence of susceptibility of Cr–20 %C amorphous alloy shows a slight increase at low temperatures. This increase would not be attributed to the magnetic impurities but to the enhancement of the repulsive Coulomb force due to randomness of the amorphous structure.

Introduction

Magnetic properties of amorphous alloys composed of the transition metals have been investigated extensively because they are important materials for practical and fundamental researches. In the amorphous state, Co and Ni-based amorphous alloys are considered as strong ferromagnets, that is, the one d-band is partly empty and their magnetic properties show a rather simple concentration dependence. With

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increasing content of the glass former element, both the Curie temperature and the magnetic moment decrease. A spin-glass behavior in Co-metal alloy systems such as Co-Sn has been observed around the critical concentration range of disappearance of ferromagnetism[1].

In the case of Ni-based amorphous alloys, the Curie temperature and the magnetic moment drastically decreases with increasing content of the glass former element, and almost all amorphous alloys become paramagnetic above 20 %.

The magnetic properties of Fe-based amorphous alloys with early transition metals are very peculiar, that is, the spin-glass behavior is often observed in the dilute concentration range of the additional element(Fe-Zr[2] and Fe-Hf[3]). It should be noted that Fe-Y amorphous alloys have no magnetic long range order in the whole range of composition. Some other Fe-metal amorphous alloys show a re-entrant spin-glass behavior in the wide range of composition (Fe-Ce[4], Fe-La[5] and Fe-Lu[6]). In the high concentration range, these Fe-metal amorphous alloys also show a spin-glass behavior in the vicinity of the critical concentration of disappearance of ferromagnetism.

Mn and Cr metals are antiferromagnetic. Mn-metal and Mn-metalloid amorphous alloy systems have been also investigated. Several ferromagnetic Heusler alloys do not become ferromagnets but spin glasses[7] due to the frustration of Mn moment in the amorphous structure, that is, the distribution of Mn-Mn distances result in the distribution of exchange interactions between positive and negative and the spin glass state is easily created. On the other hand, there is no systematic study on the magnetic properties of Cr-based binary amorphous alloys as far as we know. It is interesting to study whether these amorphous alloys exhibit a spin-glass behavior or not, and the difference in the magnetic properties between Cr-metal and Cr-metalloid amorphous alloys. In the present study, Cr-C and Cr-Zr amorphous alloys are selected as representative amorphous alloys and their magnetic properties are investigated.

Experimental

The alloy targets were prepared by arc-melting using starting materials. The purity of Cr, C and Zr is 99.999, 99.999 and 99.9 wt%, respectively. The preparation of amorphous alloys was made by high-rate dc sputtering. The argon gas pressure during sputtering was 40 m Torr and the water-cooled Cu plate was used as a substrate. The sputtering needed about 2.5 days in order to obtain the bulk sample about 0.3mm thick. The Cu substrate was dissolved away at 100°C in a solution of H_2SO_4(27 cc)+CrO_3(500 g)+H_2O(1000 cc). The amorphous state was confirmed by conventional X-ray diffraction.

The magnetization at 4.2 K up to 60 kOe and the temperature dependence of susceptibility were measured by an induction method using a superconducting magnet.

Results and discussion

Figure 1 shows the magnetic field dependence of magnetization of Cr-C and Cr-Zr amorphous alloys. These results indicate a linear relationship up to 60 kOe at 4.2 K, suggesting that there is no localized magnetic moment. The temperature dependence of susceptibility is shown in Fig.2, together with that of a pure crystalline Cr[8]. The values of these amorphous alloys are about two times that of the pure Cr. Almost all curves slightly depend on the temperature, and the data on Cr-20 %C amorphous alloy shows a clear dependence. There are small amount of magnetic impurities in the starting Zr. It has been pointed out that these impurities are likely to localize in Cr-based crystalline alloys[9] and Zr-based amorphous alloys[10]. However, it should be noted that Cr-20 %Zr and Cr-30 %Zr amorphous alloys do not show such a distinct increase of susceptibility at low temperatures, indicating no localized magnetic moment. Furthermore, the susceptibility of Cr-Zr amorphous alloys is smaller than that of Cr-C ones. Figure 3 shows the concentration dependence of the susceptibility of Cr-C and Cr-Zr amorphous alloys at 4.2 K. The linear dependence is observed in the latter alloy system, and the remarkable increase is observed at low concentration range in the former alloy system. Although, Cr-based amorphous alloys have no localized magnetic moment in the concentration range investigated in the present study, it is been confirmed that the susceptibility of Cr-C(metalloid) amorphous alloys is larger than that of Cr-Zr(metal) alloys.

The temperature dependence of susceptibility of a paramagnetic materials is given by the following equation;

$$\chi(T) = \chi_0 - \chi_1 T^2 \quad (1),$$

where χ_0 is the temperature independent terms such as the Larmor diamagnetism, Van Vleck paramagnetism and so on, and χ_1 is comprised of the first and second energy derivatives of the density of states.

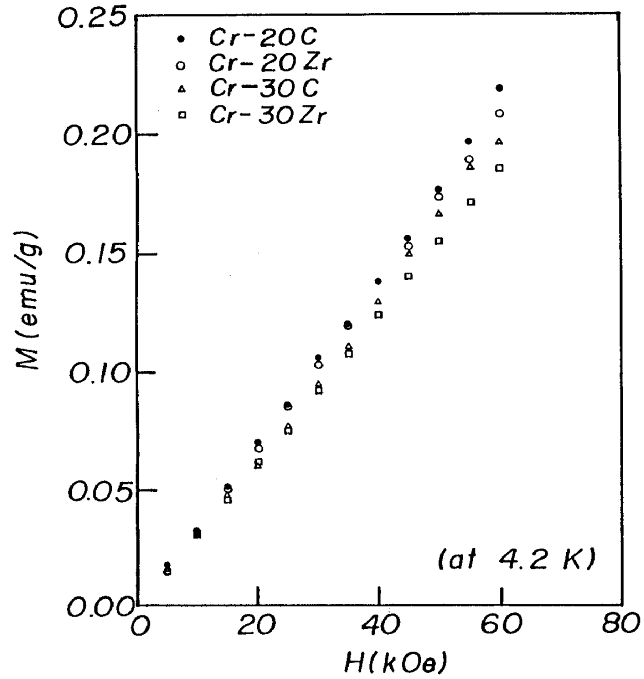

Fig.1 Magnetization vs. applied magnetic field plots for Cr-C and Cr-Zr amorphous alloys.

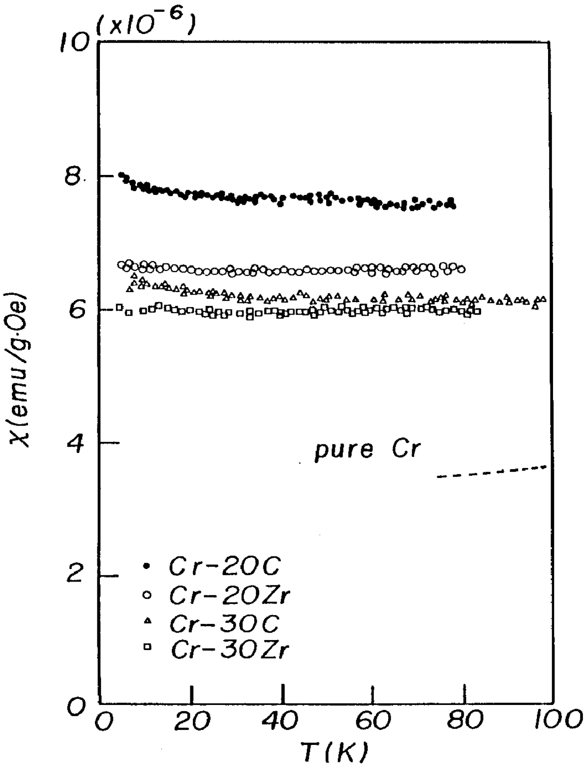

Fig.2 Temperature dependence of the susceptibility of Cr-C and Cr-Zr amorphous alloys.

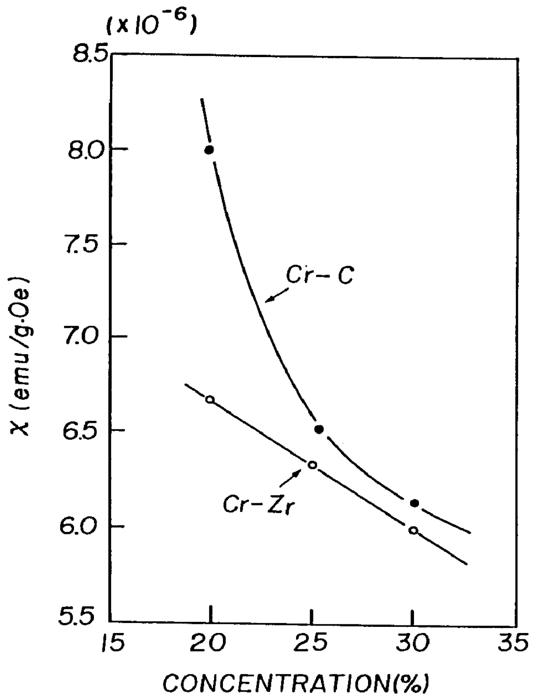

Fig.3 Concentration dependence of the susceptibility at 4.2 K for Cr-C and Cr-Zr amorphous alloys.

According to Eq.(1), the temperature dependence curve of the susceptibility of paramagnetic materials would become slightly convex upward. In fact, $Al_{60}Si_{25}Cr_{15}$ amorphous alloy exhibits such a temperature dependence[11]. However, the present result of Cr-20 %C amorphous alloy is the opposite tendency as seen from the figure. Recently, it has been pointed out that the randomness enhances the repulsive electron-electron Coulomb force[12]. In the circumstances, the magnetism is enhanced and a remarkable decrease occurs at low temperatures in χ^{-1} vs. $T^{1/2}$ plot[12]. Therefore, the large value of susceptibility and its temperature dependence at low temperatures is explained by taking into account this enhancement.

Summary

In order to confirm the existence of spin-glass behavior and to see the difference of the magnetic properties between Cr-metal and Cr-metalloid amorphous alloys, Cr-Zr and Cr-C amorphous alloys have been investigated. The main results are summarized as follows;

a) There is no localized magnetic moment, and then no spin-glass behavior is observed in these two amorphous alloy systems.

b) The magnetic susceptibility of Cr–C amorphous alloys is larger than that of Cr–Zr ones.

c) The increase of the susceptibility at low temperatures for Cr–20%C amorphous alloy would be not correlated to the magnetic impurities but to the enhancement of the repulsive electro-electron Coulomb force.

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