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MAGNETIZATION AND AC-SUSCEPTIBILITY OF AMORPHOUS Mn-Y AND Mn-La ALLOYS

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Abstract. - ac-susceptibility and magnetization were systematically investigated for the amorphous Mn-Y and Mn-La alloys. From the temperature dependence of ac-susceptibility and the temperature and field cooling dependences of magnetization, it is speculated that the alloys exhibit the spin glass characteristics. It is considered that the nearest neighbor atom-atom distance plays an important role to stabilize the spin glass state in these alloys.

1. Introduction

Mn based amorphous binary alloys Mn-X (X denotes a metal atom) exhibit various interesting magnetic properties because of the characteristic magnetic nature of Mn-atoms which depends strongly on their environment and nearest neighbor Mn-Mn distance \( d_{\text{Mn-Mn}} \). That is, the Mn-Mn exchange interaction \( J_{\text{Mn-Mn}} \) oscillates with respect to \( d_{\text{Mn-Mn}} \) [1]. Consequently, the ferromagnetic or antiferromagnetic ordering in several Mn-based crystalline alloys having a definite Mn-Mn distance disappears in the amorphous counterparts due to the fluctuation of Mn-Mn distances. As a result, a spin glass phase appears in some Mn-based amorphous alloys.

In the present study we investigate the magnetic properties of the amorphous Mn-Y and Mn-La alloys and pursue the spin glass feature of these alloys by comparing with the other non-spin glass alloys such as Mn-Sc, Ti, Zr and Nb binary amorphous alloys.

2. Experimental

Amorphous samples \( \text{Mn}_{100-x}Y_x \) and \( \text{Mn}_{100-x}La_x \) were prepared by a high rate dc-sputtering method. The samples were confirmed to be amorphous by X-ray diffraction. The ac susceptibility measurements were performed by a mutual induction ac-bridge method in the temperature range from 4.2 K to 80 K in an ac-magnetic field of 4 Oe at a fixed frequency of 400 Hz. The temperature dependence of the magnetization was also measured by a pendulum type magnetometer between 4.2 K and 300 K in a field of 9.5 kOe.

3. Results and discussion

Figure 1 shows the temperature dependence of the real part of the ac-susceptibility \( \chi' \) for the Mn-Y (Fig. 1a) and Mn-La (Fig. 1b) alloys. Figure 2 shows the temperature dependence of the magnetization for the \( \text{Mn}_{56}Y_{52} \) and \( \text{Mn}_{56}La_{44} \) alloys. In figure 2 the data points marked by A represent the magnetizations measured with increasing temperature without field cooling, while the part B's represent the magnetizations measured with increasing temperature after field cooling in a constant magnetic field of 9.5 kOe from 77 K to

![Fig. 1. - Real part of ac-susceptibility \( \chi' \) as a function of temperature for (a) \( \text{Mn}_{100-x}Y_x \) and (b) \( \text{Mn}_{100-x}La_x \) amorphous alloys.](http://dx.doi.org/10.1051/jphyscol:19888503)

![Fig. 2. - Temperature dependence of magnetization and inverse susceptibility \( 1/(\chi - \chi_0) \) for \( \text{Mn}_{48}Y_{52} \) and \( \text{Mn}_{56}La_{44} \).](http://dx.doi.org/10.1051/jphyscol:19888503)
At 4.2 K. From these experimental results, we can point out the following characteristics: i) the real part of the ac-susceptibility shows a cusp in both the amorphous alloy systems; ii) in both the systems, the large field cooling effect on $\sigma - T$ curve is observed.

The above findings are quite similar to characteristics of the typical spin glasses. It is known that the spin glasses often appear in Mn based amorphous alloys such as Mn-Si and Mn-CuZr [2, 3]. Hauser investigated in detail the origin of the spin glass in these alloys and pointed out that the spin glass properties are governed by the magnitude of the effective moment, $p_{\text{eff}}$ per Mn atom [3].

Susceptibility-temperature curves at a field of 9.5 kOe fit well to the modified Curie-Weiss law, $\chi = \chi_0 + C / (T - \theta)$, for all the present alloys. Where, $\chi_0$ is the temperature independent susceptibility, $C$ the Curie constant and $\theta$ the asymptotic Curie temperature. The typical results of the fitting are shown in figure 2 by the solid lines. The fitting to the Curie-Weiss law indicates that Mn has a localized magnetic moment. From the gradient of $(\chi - \chi_0)^{-1}$ vs. $T$, we have estimated the effective magnetic moment $p_{\text{eff}}$ per Mn atom. The result is shown in figure 3. $p_{\text{eff}}$ values in Mn-Y and Mn-La decrease linearly with increasing Mn content. The same tendency of $p_{\text{eff}}$ vs. Mn content has also been found for the crystalline Mn-W and Mn-Mg alloys by Hauser et al. [3, 4]. The Mn concentration dependence of asymptotic Curie temperature determined from the Curie-Weiss fitting is shown in figure 4. With increasing Mn content, the negative $\theta$ value increases almost linearly, implying that the antiferromagnetic interaction becomes more intensive. When $x = 100$, the antiferromagnetic interaction disappears for both the alloys systems.

Hauser et al. [3, 4] have pointed out that with increasing Mn concentration in Mn-W and Mn-Mg alloys, the interaction between Mn spins becomes more and more antiferromagnetic and the effective local moment $p_{\text{eff}}$ decreases. As seen in figures 3 and 4, the present alloy systems have the same trend as their argument. However, their speculation about spin glasses that a fairly large $p_{\text{eff}}$ value exceeding a threshold value of 3.9 $\mu_B$ is necessary for the appearance of the spin glass state seems to be insufficient for the present alloys. In the present alloys, all the $p_{\text{eff}}$ values are far smaller than 3.9 $\mu_B$, nevertheless the spin glass characteristics can be observed. This suggests that other factors such as Mn-Mn distance, coordination number of Mn-atom and magnetic moment of the guest metal if exists must be taken into account for a full understanding of the appearance of spin glasses.

Among these factors, we may remark that the Mn-Mn distance is an important factor. In table I, the average constituent atom-atom distance determined by the X-ray diffraction is shown for the present spin glass (SG) alloys together with other non-spin glass (NSG) amorphous alloys. It can be said that the spin glass in Mn-based amorphous alloys appears as the average nearest neighbor (nn) distance becomes larger than about 3 Å. The contribution of the nn distance to the spin glass stability seems to be attributed to the Mn-Mn magnetic interaction oscillating with respect to the Mn-Mn distance, then to the competition of the ferromagnetic and antiferromagnetic interactions.

Table I. – Average atom-atom nearest neighbor distance for several amorphous alloys.

<table>
<thead>
<tr>
<th>Alloys</th>
<th>Average nearest neighbor distance</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mn$<em>{48}$Y$</em>{52}$</td>
<td>3.28 Å</td>
<td>SG</td>
</tr>
<tr>
<td>Mn$<em>{41}$La$</em>{59}$</td>
<td>3.73 Å</td>
<td>SG</td>
</tr>
<tr>
<td>Mn$<em>{60}$Sc$</em>{40}$</td>
<td>2.69 Å</td>
<td>NSG</td>
</tr>
<tr>
<td>Mn$<em>{49}$Ti$</em>{51}$</td>
<td>2.69 Å</td>
<td>NSG</td>
</tr>
<tr>
<td>Mn$<em>{48}$Zr$</em>{52}$</td>
<td>2.91 Å</td>
<td>NSG</td>
</tr>
<tr>
<td>Mn$<em>{44}$Nb$</em>{56}$</td>
<td>2.78 Å</td>
<td>NSG</td>
</tr>
</tbody>
</table>