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Effect of anisotropy strength on phase transitions in random anisotropy magnets

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ac susceptibility and magnetization measurements are reported for a number of Gd and Tb based glasses. Raman magnetic anisotropy effects are observed in both the Gd and Tb glasses. The Gd glasses show a transition to an infinite susceptibility state and in some cases a further transition to an hysteretic state at low temperatures in which field-cooling and magnetic viscosity effects are observed. The Tb glass shows only a small speromagnetic peak at low temperatures. The ratio of anisotropy strength to exchange was varied in the Gd glasses by alloying, and the effect of this on the resulting magnetic states is discussed.

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INTRODUCTION

Rare-earth-rich metallic glasses show a variety of interesting magnetic properties due to the presence of a random magnetic anisotropy (RMA). The simplest Hamiltonian incorporating this RMA may be written [1]

$$H = -J \sum_{ij} \vec{J}_i \cdot \vec{J}_j - D \sum_i (\hat{n}_i \cdot \vec{J}_i)^2$$

where the first term represents the exchange of strength $J > 0$; i.e., ferromagnetic, and the second term represents the RMA of strength $D > 0$; i.e., uniaxial. $\hat{n}_i$ is a unit vector which varies at random from site to site describing the uniaxial anisotropy. Aharony and Pytte [AP] have determined the magnetic equation of state for a system with this Hamiltonian in the limit of small D/J and small H/M [3]. In this model the RMA is strong enough to destroy the magnetic order but does not destroy the infinite susceptibility. Recently we have reported [2] on an infinite susceptibility state in $Gd_{72}Ga_{18}B_{10}$ and the onset of hysteresis at low temperatures.

For Gd, an S-state ion, the single-ion anisotropy strength is expected to be very small. However for Tb and other rare-earth ions, D is expected to be quite large so that the theory of AP is not likely to be applicable. In our Gd-rich alloys we find an effective anisotropy constant (K) which is orders of magnitude larger than crystalline Gd. In addition we have found that K can be changed in these glasses by varying the glass formers. In this paper we report on the effects of changing the anisotropy strength on the phase transitions occurring in $Gd_{72}Ga_{18}T_{10}$ where T = B, Ni, Al and $Gd_{58}T_{32}B_{10}$ where T = Ga, Ni, Al and $Tb_{72}Ga_{18}B_{10}$.

EXPERIMENTAL DETAILS

The amorphous alloys of this work were prepared by the splat-cooling technique. X-ray diffractograms were taken on all of the samples and no evidence of crystalline phases was found. Also the measured AC susceptibility, χ_{AC} (= dM/dH_a; H_a is the applied field) showed no structure above the transition temperature which one observes if there are crystalline Gd-rich phases present. The samples were in the form of strips of dimensions $\sim$ 4 mm x 1 mm oriented in order to reduce demagnetizing effects. The AC susceptibility was measured in the temperature range 4.2 — 300 K at a frequency of 280 Hz in RMS applied fields of less than 0.01 Oe. The high-field magnetization data were measured in fields up to 80 kOe using a superconducting solenoid and vibrating sample magnetometer at temperatures of 4.2 K and above.

RESULTS

χ_{AC} curves for the series $Gd_{58}T_{32}B_{10}$ where T = Ga, Ni, and Al are shown in Fig. 1 and are limited by the demagnetization factor, N, below a certain temperature T_c. The true susceptibility χ (= dM/dH; $H = H_a - NM$) therefore diverges below T_c. In addition both the Ni and Al glasses show a further transition at some lower temperature T_h to an hysteretic phase. T_h was calculated from the construction shown in Fig. 1c. An infinite susceptibility phase was also observed in each of the glasses of the series $Gd_{72}Ga_{18}T_{10}$ where T = B, Ni, Al and all of these alloys show a transition to an hysteretic phase at low temperatures. In contrast χ_{AC} for the glass $Tb_{72}Ga_{18}B_{10}$ is not limited by the demagnetization factor but rather shows a small peak (Fig. 1) indicating a transition to a speromagnetic state. The speromagnetic state is a frozen-in random spin structure much like a spin-glass state; the difference is that the former is produced by the presence of an RMA while the latter is produced by the presence of antiferromagnetic interactions. The temperatures T_c and T_h for each of these alloy series are summarized in Table 1.

The effective anisotropy constant (K) values for each of these alloys were calculated from their high-field magnetization curves using the magnetization area method. [4] Examples of the magnetization curves for the $Gd_{58}T_{32}B_{10}$ glasses and the $Tb_{72}Ga_{18}B_{10}$ glass are shown in Fig. 2. Also magnetic isotherms in the form of Arrott plots are shown in Fig. 3 for the $Gd_{58}Al_{32}B_{10}$ glass. The exchange strength J_1 (= zJ where z is the coordination number) was calculated using mean field theory from T_c for both Gd series and from T_h for the Tb glass. Defining $D_1 = K/nk_B$ where n is the number density of mag-

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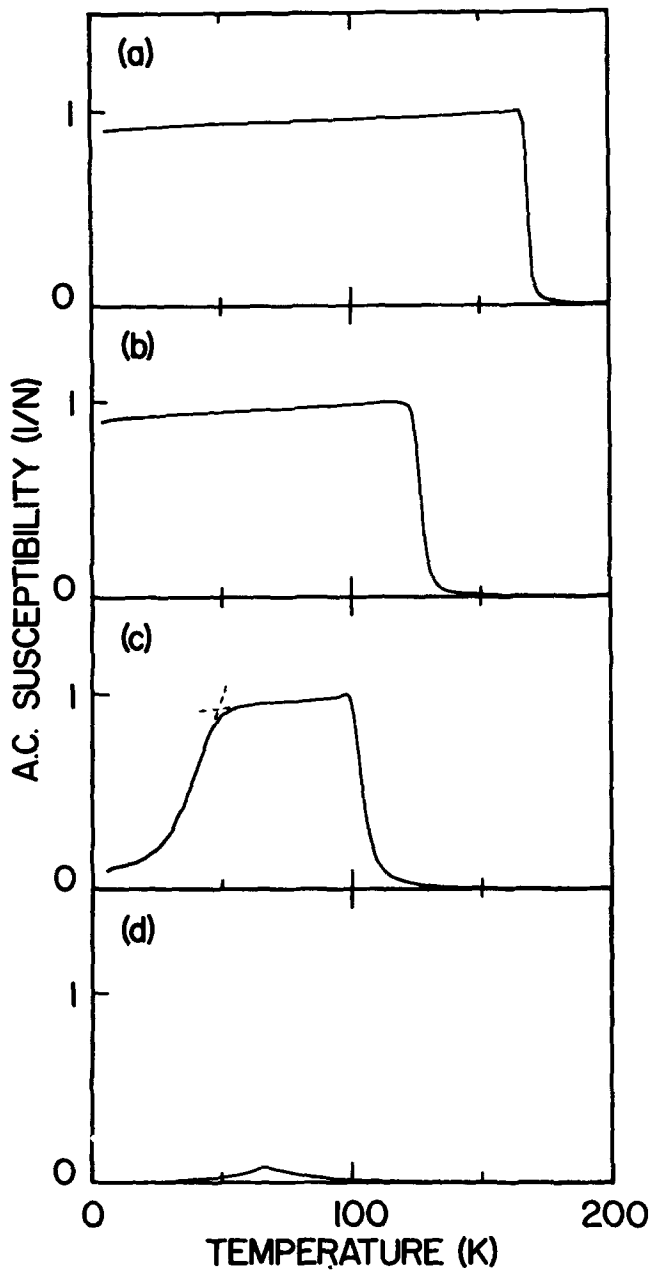

Fig. 1. The AC susceptibility of the series $Gd_{58}T_{32}B_{10}$ where T is (a) Ga, (b) Ni, (c) Al; and also (d) $Tb_{72}Ga_{18}B_{10}$.

netic ions, the resulting D_1 and J_1 values are summarized in Table 1.

We have also observed field-cooling and magnetic viscosity effects in the hysteretic state of many of these glasses. These effects will be discussed in a later publication.

DISCUSSION

The source of RMA in the Tb glass is the random electric field gradients generated by the positional disorder of the Tb ions. The source of this anisotropy in the Gd glasses is somewhat uncertain but a possibility is exchange anisotropy of the type discussed by Fert and Levy [5].

From Table 1 the overall effect of increasing D_1/J_1 in both Gd series is first to introduce a low temperature hysteretic transition at temperature T_h. As D_1/J_1 is increased further T_h is moved to higher temperatures.

Also, as shown in Fig. 2, as D_1/J_1 increases the magnetization decreases monotonically. For a speromagnetic system which has been perturbed by the field into an asperomagnetic state with a hemispherical fan, the magnetization would be gJ/2 per spin ($M/M_0 = \frac{1}{2}$). Fig. 2 thus suggests that the magnetic

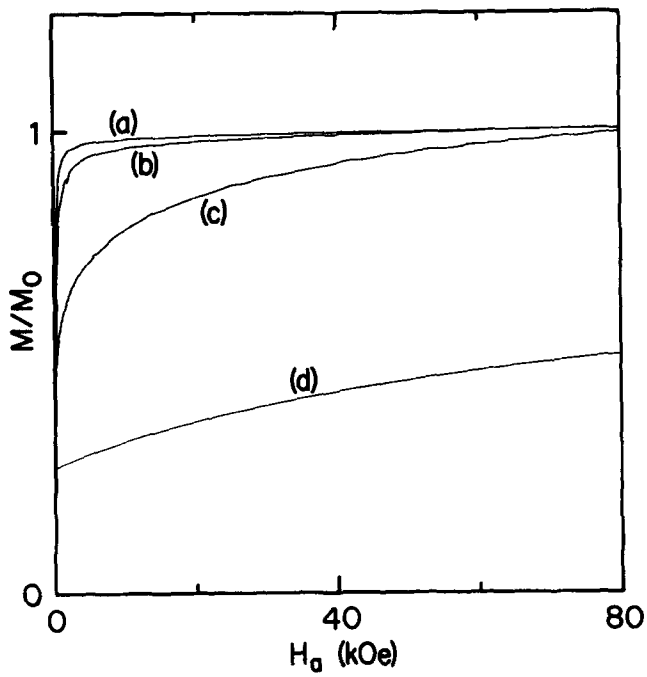

Fig. 2. High-field magnetization curves for the series $Gd_{58}T_{32}B_{10}$ where T is (a) Ga, (b) Ni, (c) Al; and also (d) $Tb_{72}Ga_{18}B_{10}$. M_0 is the saturation magnetization corresponding to the complete alignment of the spins.

TABLE 1

	T_c(K)	T_h(K)	D_1(K)	J_1(K)	D_1/J_1
$Gd_{58}Ga_{32}B_{10}$	166	-	0.61	15.8	0.04
$Gd_{58}Ni_{32}B_{10}$	124	9	0.93	8.9	0.105
$Gd_{58}Al_{32}B_{10}$	98	50	4.75	9.7	0.49
$Gd_{72}Ga_{18}B_{10}$	123	41	2.90	11.7	0.25
$Gd_{72}Ga_{18}Ni_{10}$	116	26	3.22	11.0	0.29
$Gd_{72}Ga_{18}Al_{10}$	127	27	3.15	12.1	0.26
$Tb_{72}Ga_{18}B_{10}$	-	66	11.6	2.36	4.92

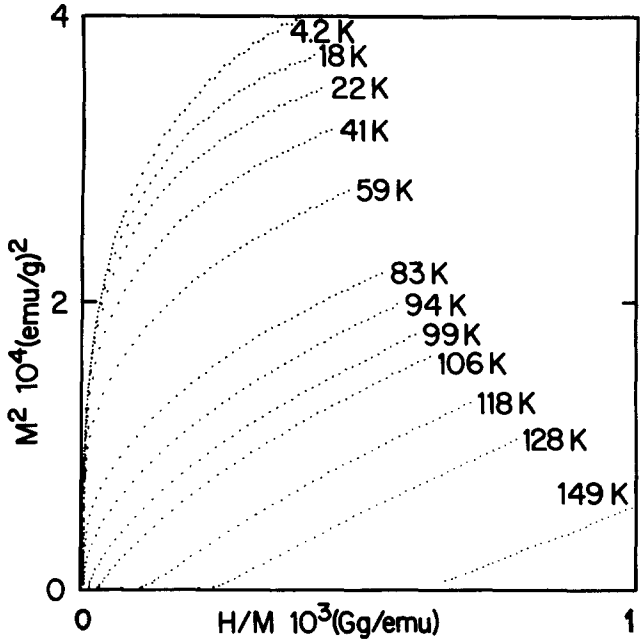

Fig. 3. Magnetic isotherms in the form of Arrott plots for $Gd_{58}Al_{32}B_{10}$. Here H is the applied field. Correcting for demagnetizing effects (see text) results in a very small shift of the curves to the left (0.006 x 10^3 Gg/emu).

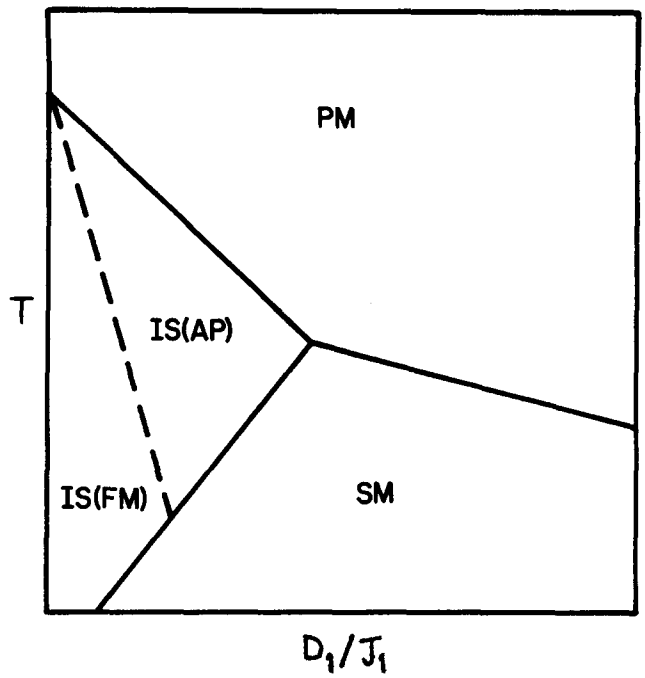

Fig. 4. Schematic phase diagram for a RMA system. The abbreviations are PM - paramagnetic; SM - speromagnetic; IS(AP) - Aharony and Pytte infinite susceptibility state; IS(FM) - infinite susceptibility ferromagnetic state with a domain structure.

state is increasingly driven towards speromagnetism as D_1/J_1 increases. The increase in T_h with D_1/J_1 is evidence that thermal excitations of spins over anisotropy barriers are required to break up the low temperature hysteretic state.

At large D_1/J_1 values the infinite susceptibility state is suppressed and there is a direct transition from the paramagnetic state to the speromagnetic state as is evidenced by the Tb glass.

With these data we can suggest a qualitative phase diagram as shown in Fig. 4. The dashed line indicates the possibility of a phase boundary between an infinite susceptibility phase with no order (IS(AP)) and an infinite susceptibility phase with ferromagnetic domains (IS(FM)). The speromagnetic phase may also become an hysteretic ferromagnet at low D_1/J_1 but we have not indicated this possibility in the phase diagram.

In future work we intend to make alloys whose D_1/J_1 values approach the tricritical point in the phase diagram and also to explore the possibility of a phase boundary in the infinite susceptibility part of the phase diagram. We are pursuing a critical exponent analysis of several of these alloys at present.

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