



HAL
open science

MAGNETIC AND ELECTRONIC PROPERTIES OF RARE EARTH-RICH METALLIC GLASSES

G. Hadjipanayis, S. Cornelison, D. Sellmyer

► **To cite this version:**

G. Hadjipanayis, S. Cornelison, D. Sellmyer. MAGNETIC AND ELECTRONIC PROPERTIES OF RARE EARTH-RICH METALLIC GLASSES. *Journal de Physique Colloques*, 1980, 41 (C8), pp.C8-642-C8-645. 10.1051/jphyscol:19808161 . jpa-00220262

HAL Id: jpa-00220262

<https://hal.science/jpa-00220262>

Submitted on 4 Feb 2008

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

MAGNETIC AND ELECTRONIC PROPERTIES OF RARE EARTH-RICH METALLIC GLASSES*

G. Hadjipanayis, S.G. Cornelison and D.J. Sellmyer

Behlen Laboratory of Physics, University of Nebraska, Lincoln, Nebraska 68588, U.S.A.

Abstract.- The magnetic and electrical properties of erbium-rich metallic glasses are presented. Magnetic ordering has been observed around 15 K. Below the ordering temperatures a strong local anisotropy develops causing high coercive fields and lack of saturation. The resistivity changes drastically at the ordering temperature and either increases or decreases. The negative temperature coefficients or resistivity at room temperature are explained with the extended Ziman theory. The relationship between the observed kinks in the resistivity curves and the low temperature spin correlations are discussed.

INTRODUCTION

The magnetic properties of the non S-state rare-earth amorphous materials can be discussed by the local random anisotropy model [1]. The balance between magnetic anisotropy and exchange interactions causes a dispersion of the moments and produces the known "speromagnetic" (no net moment) or "asperomagnetic" (net moment) states [2].

In this study we present the magnetic and transport properties of several rare-earth rich metallic glasses. In particular we investigate the effect of the Fermi radius k_F on the resistivity measurements and on the "spin structure." Variation of k_F was achieved by alloying erbium with different transition, noble, and polyvalent metals. An attempt was also made to relate the spin correlations with the observed resistivity kinks that appeared at the magnetic ordering temperatures.

RESULTS

Amorphous samples were prepared by the splat cooling technique. The experimental techniques have been described elsewhere [3]. Magnetic measurements on a large number of rare-earth rich amorphous alloys [3,4,5] show the following features: (i) Some kind of magnetic ordering appears at low temperatures. (ii) The magnetization of the S-state ions (Gd) appears to saturate fairly easy as expected (Fig. 1). In the case of non S-state ions,

(iii) Below the ordering temperature a large magnetic anisotropy develops causing high coercivity and lack of magnetic saturation (Fig. 1). (iv) Strong temperature dependent magnetic aftereffects appear at liquid helium temperatures, suggesting a thermal activation process.

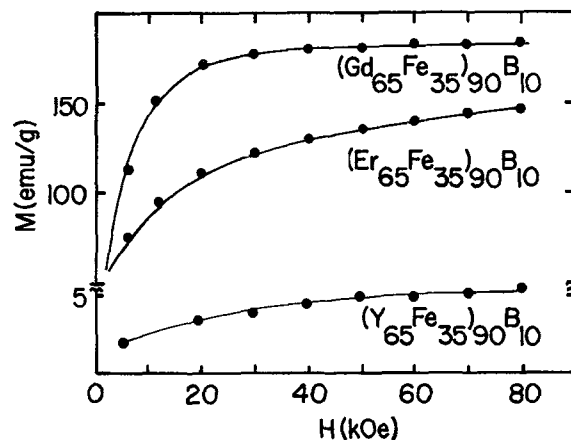


Fig. 1. Magnetization curves for R-Fe-B glasses at 4.2 K

Resistivity measurements in Er-Au glasses showed several kinks at low temperatures (Fig. 2). A complete investigation of these effects has been undertaken in this study where we focus on erbium-based amorphous alloys. The resistivity curves of several of these alloys are shown on Fig. 2. A drastic change in resistivity has been observed at very low temperatures (15 K). However the temperature coefficients of resistivity at 4.2 K and at room temperature change sign in the sequence from Er-Fe to Er-Al.

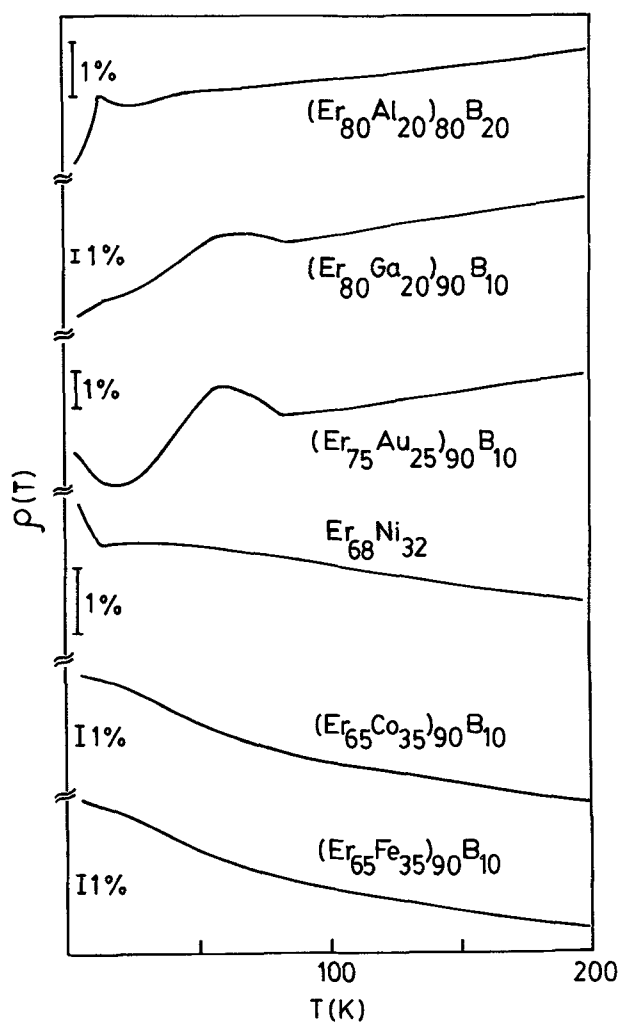


Fig. 2. Electrical resistivity for erbium-rich glasses.

The susceptibility measurements are shown in Fig. 3. A broad maximum has been observed in all samples at very low temperatures. In Er-Ga and Er-Al glasses, the susceptibility drops rapidly below the maximum and "field cooling" effects are noticeable.

High-field magnetization measurements are shown in Fig. 4 for Er-Ga. Magnetic saturation has not occurred even at fields up to 80 kOe. A rough extrapolation of the high-field portion of the magnetization curve at 4.2 K resulted in a value of the spontaneous moment $M_0 \approx 122$ emu/g.

Figure 5 shows the large coercive fields which develop below the ordering temperatures. In Er-Au

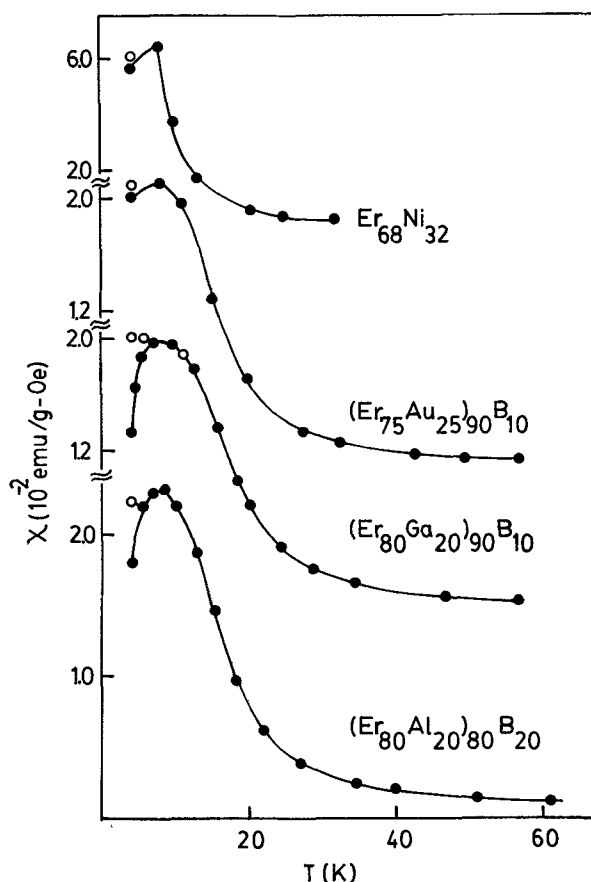


Fig. 3. Magnetic susceptibility for erbium-rich glasses ($H = 700$ Oe)

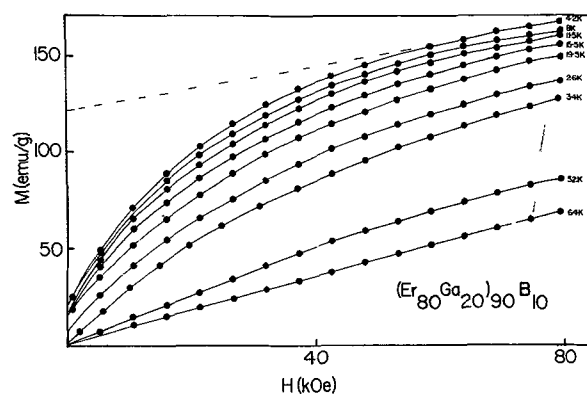


Fig. 4. Magnetization curves for $(Er_{80}Ga_{20})_{90}B_{10}$ glass

and Er-Ga the coercivity remains fairly constant between 10 and 20 K suggesting a quantum mechanical tunneling in this range [6]. For the other two alloys the substantial increase in coercivity which is observed below 10 K is associated with thermal processes.

Metamagnetic behavior has been observed in

Er-Au and Er-Ga in the temperature range of 30-60 K. This is shown on Fig. 6 by the constricted hysteresis loop. It suggests the presence of antiferromagnetic interactions which could be broken up by the applied field.

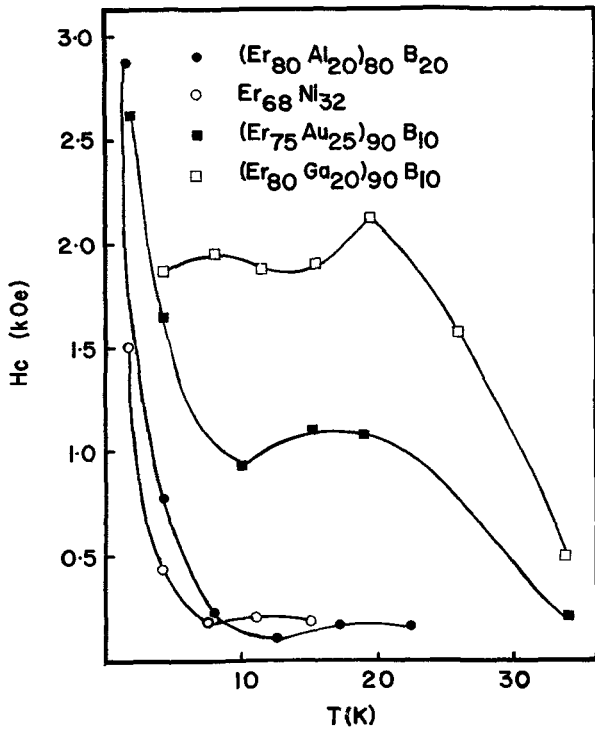


Fig. 5. Temperature dependence of coercivity in erbium-rich glasses

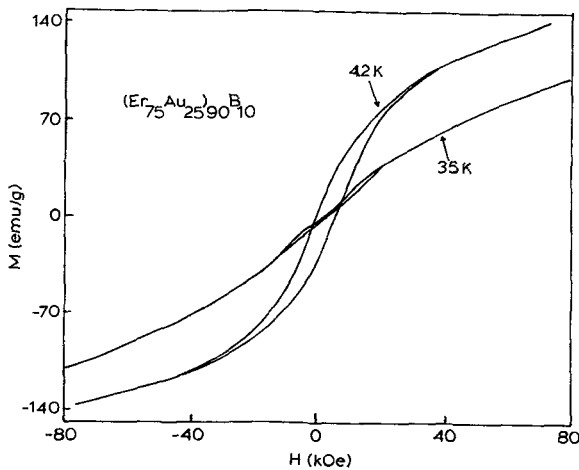


Fig. 6. Hysteresis loops in (Er₈₀Au₂₀)₉₀B₁₀ glass

DISCUSSION

It is evident from the susceptibility curves that magnetic ordering takes place around 15 K for all Er-based alloys. The high-temperature suscep-

tibility data were fit to a Curie-Weiss law and μ_{eff} per Er atom was found to be 11.0, 10 and 8 μ_B for the Er-Au, Er-Ga and Er-Al glasses respectively. The corresponding Curie temperatures were estimated to be 6, 4 and 15 K respectively, indicating ferromagnetic interactions. The values of μ_{eff} determined appear to be slightly different than the expected 9.5 μ_B .

Below the ordering temperatures hysteresis effects appear. The lack of magnetic saturation suggests the presence of a high magnetic anisotropy. The zero field extrapolated values of the moment are about $\frac{1}{2} g\mu_B$ indicating an "asperomagnetic" ordering with the moments spread out into a hemispherical "fan".

The Ziman theory and its extensions [7] are employed to explain the resistivity measurements of amorphous materials. In these theories the resistivity is given by

$$\rho \propto \int_0^{2k_F} S(q)v^2(q)q^3dq \quad (1)$$

where $S(q)$ is the structure factor, $v(q)$ is the Fourier transform of the pseudopotential of a single ion or the single t-matrix for the transition metals and $2k_F$ is the diameter of the Fermi sphere. Because of the q^3 factor, the integral in Eq. (1) heavily weights those values of the integrand near $q=2k_F$. Therefore the temperature dependence of ρ follows the temperature dependence of $S(q)$ near $2k_F$. The first peak of $S(q)$, at the position q_p , becomes lower and broader as temperature increases. Therefore, the position of $2k_F$ with respect to q_p will determine the sign of the high temperature coefficient of resistivity β_h . In Er-Fe, Er-Co and Er-Ni glasses β_h is negative. Thus according to the Ziman theory [7] $q_p = 2k_F$ for these three glasses. This suggests that the number of conduction elec-

trons is the same for the three transition metals, supporting the assumption of Esposito et al. [8]. However in going from Ni to Ga, k_F increases since the number of conduction electrons increase. This suggests that $2k_F > q_p$ which would be consistent with a positive β_h as is observed. These assumptions are confirmed experimentally. In Er-Fe, $2k_F \approx 2.27 \text{ \AA}^{-1}$ and $q_p \approx 2.27 \text{ \AA}^{-1}$. However in Er-Al $2k_F \approx 2.44 \text{ \AA}^{-1}$ and $q_p \approx 2.27 \text{ \AA}^{-1}$.

Magnetic ordering contributes an additional term to resistivity. Asomoza et al. [9] obtained the following expression for the resistivity in the ordered magnetic state:

$$\rho = a + bm(2k_F) \quad (2)$$

where the first term is due to independent scattering by each magnetic ion, the second term is due to coherent exchange scattering and $m(2k_F)$ is the spin correlation function at $2k_F$. This function is given by

$$m(q) = C \sum_{ij} \exp[iq(\vec{R}_i - \vec{R}_j)] \langle \vec{J}_i \cdot \vec{J}_j \rangle \quad (3)$$

If however an asperomagnetic ordering is assumed,

$$\langle J_z \rangle = \mu_1 J, \quad \langle J_x \rangle = \langle J_y \rangle = 0 \quad (4)$$

then

$$m(q) \approx \frac{J}{J+1} \mu_1^2 [S_{11}(q) - 1] \quad (5)$$

where μ_1 is a parameter of local magnetic order and $S_{11}(q)$ is the structure factor of the magnetic ions. As k_F increases, $S_{11}(q)$ and therefore ρ decreases (Eq. 2). This was observed on Fig. 2 where the liquid helium temperature coefficient of resistivity β_1 changes from negative to positive in going from Er-Fe to Er-Al glasses.

The anomaly in $\rho(T)$ at 80 K observed in Er-Au and Er-Ga may be due to local antiferromagnetic spin correlations as expressed in the magnetization of Fig. 6. The antiferromagnetic interactions may arise from subtle local structural effects. This also could give rise to the coer-

civity anomalies observed in Er-Au and Er-Ga in the temperature range of 30 to 60 K.

REFERENCES

*Research supported by NSF Grant DMR 78-10781

- [1] Harris, R., Plischke, M. and Zuckermann, M.J., Phys. Rev. Lett. 31 (1973) 160
- [2] Coey, J.M.D., J. Appl. Phys. 49 (1978) 1646
- [3] Gerber, J.A., Miller, D.J. and Sellmyer, D.J., J. Appl. Phys. 49 (1978) 1699
- [4] Gerber, J.A., Cornelison, S.G., Burmester, W.L. and Sellmyer, D.J., J. Appl. Phys. 50 (1979) 1608
- [5] Sellmyer, D.J., Hadjipanayis, G. and Cornelison, S.G., J. Non-Crystalline Solids (in press)
- [6] Egami, T., Phys. Stat. Sol. (a) 20 (1973) 157
- [7] Faber, T.E. and Ziman, J.M., Phil. Mag. 11 (1965) 153; Cote, P.J. and Meisel, L.V., Phys. Rev. Lett. 39 (1977) 102
- [8] Esposito, E., Ehrenreich, H. and Gellat, C.D., Phys. Rev. B 18 (1978) 3912
- [9] Asomoza, R., Campbell, I.A., Fert, A., Lienard, A. and Rebouillat, J.P., J. Phys. F 9 (1979) 349