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Magnetization and time dependent effects in $ErCo_3Ga_2$

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Abstract

Recently, unusual magnetic properties have been reported on the $ErCo_3Ga_2$ compound. In this paper, we report on the measurements of magnetization, ac susceptibility, and the time dependence of magnetization on polycrystalline samples of $ErCo_3Ga_2$. The field cooled (FC) samples show negative magnetization with a minimum at 25 K in low magnetic fields. The FC magnetization becomes positive above 150 K. The FC and ZFC magnetizations meet at 150 K as the temperature increases. For magnetic fields above 5000 G, the FC and ZFC magnetizations are the same in the entire temperature range from 5 K to 300 K. The ac susceptibility shows a peak around 20 K. We have found that for $T<150$ K, the magnetization in a constant magnetic field at constant temperature increases with time and does not attain a constant value over 64 h. The increase in magnetization is linear on the log(time) scale. The magnetic properties suggest a spin glass-type transition below 150 K and a strong temperature dependent magnetic anisotropy.

1. Introduction

The ternary RM_3Ga_2 compounds (where R = rare earth, M = Co, Ni) were studied first by Fremy *et al.* [1] using X-ray diffraction. More recently, the structure and magnetic properties of RCo_3Ga_2 (R = Tb, Y and Er) were investigated by Felner *et al.* [2] and Rousti and Yakinthos [3]. These compounds crystallize in a hexagonal structure belonging to the *P6/mmm* space group. Magnetic and Mössbaur studies suggest two magnetic transitions in $TbCo_3Ga_2$ at 20 K and 200 K whereas YCo_3Ga_2 has a magnetic transition below 85 K [2]. The magnetic properties of $ErCo_3Ga_2$ are unusual. At low applied magnetic fields, the field cooled magnetization of $ErCo_3Ga_2$ as a function of temperature exhibits a minimum with negative magnetization values [3]. Rousti and Yakinthos [3] determined a compensation point $T_0 = 120$ K for $ErCo_3Ga_2$. They also found that magnetization at 4.2 K in an applied field increases with time. The magnetic structure of these systems are unknown.

We are pursuing magnetic and time dependent studies on these unusual RCo_3Ga_2 compounds. In this short paper, we present the results of magnetization, ac susceptibility and time dependence of magnetization measurements on the $ErCo_3Ga_2$ compound.

2. Experimental details

The polycrystalline samples of $ErCo_3Ga_2$ were prepared by repeated arc-melting of stoichiometric quantities of the constituent metals under an argon atmosphere. The nominal purity of these metals was 99.9% for Er (Cerac Inc.) and 99.99% for Co and Ga (Johnson Matthey Electronics). The weight losses during arc melting were negligible. The arc melted buttons were annealed in a vacuum at 900 °C for 5 days. A SQUID magnetometer (Quantum Design, CA) was used for magnetization and time dependent magnetization measurements. The ac susceptibility was measured using the mutual induction method at a frequency of 80 Hz and an ac field with rms value of 1.5 G.

3. Results and discussion

The temperature dependence of magnetization for $ErCo_3Ga_2$ in an applied magnetic field is shown in Fig. 1. The zero field cooled (ZFC) and field cooled (FC) samples show a positive magnetization value down to a temperature of 150 K. Below $T_f = 150$ K, the FC and ZFC magnetizations separate and FC magnetization becomes negative and has a minimum at 25 K. This behavior persists for an applied magnetic field value of up to 2 kG. For an applied magnetic field of 5 kG, the ZFC and FC magnetizations are positive and fall on the same curve as shown in Fig. 1. These results are qualitatively similar to those of Rousti and Yakinthos [3]. In the case of $ErCo_3Ga_2$, there are two magnetic atoms, Er and Co. If one replaces magnetic Er with non-magnetic Y, one may be able to isolate the magnetism of Co sublattice. For this purpose, we have

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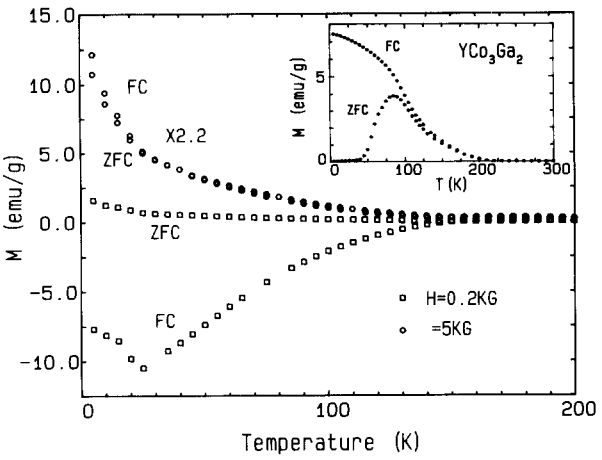

Fig. 1. The magnetization (M) as a function of temperature (T) in various constant magnetic fields for $ErCo_3Ga_2$. The symbols ZFC and FC mean zero field cooled and field cooled samples, respectively. The inset shows magnetization (M) versus temperature (T) for YCo_3Ga_2.

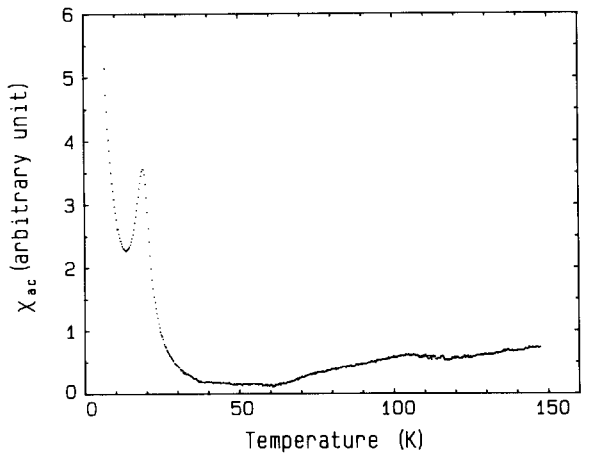

Fig. 2. The ac susceptibility (χ_{ac}) as a function of temperature (T) for $ErCo_3Ga_2$.

measured the XFC and FC magnetization of YCo_3Ga_2 in an applied magnetic field of 0.2 kG shown in the inset of Fig. 1. We observed a maximum in the ZFC data at 85 K, and the ZFC and FC magnetizations merge at $T_f = 160$ K. This behavior appears to be that of a spin glass. The spin glass freezing temperature, $T_f = 160$ K, for YCo_3Ga_2 is very close to the temperature $T_f = 150$ K for $ErCo_3Ga_2$ where the ZFC and FC magnetization curves merge (Fig. 1). Therefore, one may conclude that the spin glass type ordering of the Co sublattice may be taking place in $ErCo_3Ga_2$ below $T_f = 150$ K.

The ac susceptibility of $ErCo_3Ga_2$ as a function of temperature is presented in Fig. 2. The main feature of χ_{ac} data is a sharp rise below 25 K with a peak in χ_{ac} at $T_c = 20$ K. This peak in χ_{ac} is very close to the negative minimum temperature in the magnetization data (Fig. 1). This sharp peak in χ_{ac} at 20 K appears to be due to a ferromagnetic or ferrimagnetic ordering. It is probable that the Er sublattice orders ferro- or ferrimagnetically below 20 K. No such magnetic transition is observed in YCo_3Ga_2. Based on the magnetization and χ_{ac} data, it appears that the Co and Er sublattices order independently below $T_f = 150$ K and below $T_c = 20$ K.

The magnetization hysteresis loops of $ErCo_3Ga_2$ at 5 K, 50 K and 200 K after zero field cooling are presented in Fig. 3. The isotherms at 5 K and 50 K are symmetric around zero field. The remanence values are 12.16 emu/g and 7.45 emu/g and the coercive fields are 1.76 kG and 2.97 kG for 5 K and 50 K isotherms, respectively. For the 200 K isotherm, magnetization increases linearly with increasing magnetic field. The remanent magnetization decreases with increasing temperature and goes through a minimum at 20 K; at the same time the coercive field increases with temperature and reaches a maximum around 20 K and stays fairly constant up to 100 K, then decreases to zero around 150 K. The shape of the hysteresis loop changes at 20 K. These observations again suggest that there are two magnetic phases. One magnetic phase exists below 20 K and the other between 20 K and 150 K. The system is paramagnetic above 150 K.

The time dependence of magnetization at a constant temperature and applied magnetic field is very unusual. These measurements were taken for samples cooled to a constant temperature below $T = 150$ K in zero field. Then a constant magnetic field was applied and the magnetization was measured as a function of time. Typical magnetization versus ln(time) curves are presented in Fig. 4(a) for the temperature of 30 K and various applied magnetic fields. The magnetization increases with time and does not saturate even over a period of 64 h (not shown here). The magnetization increase is logarithmic in time as seen in Fig. 4(a).

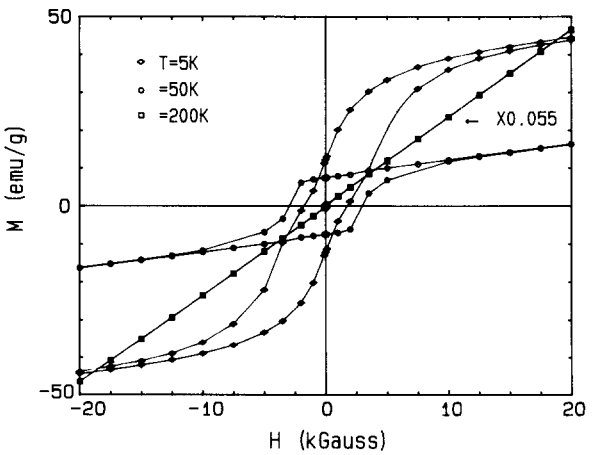

Fig. 3. The magnetization (M) as a function of the applied magnetic field (H) at several temperatures for $ErCo_3Ga_2$.

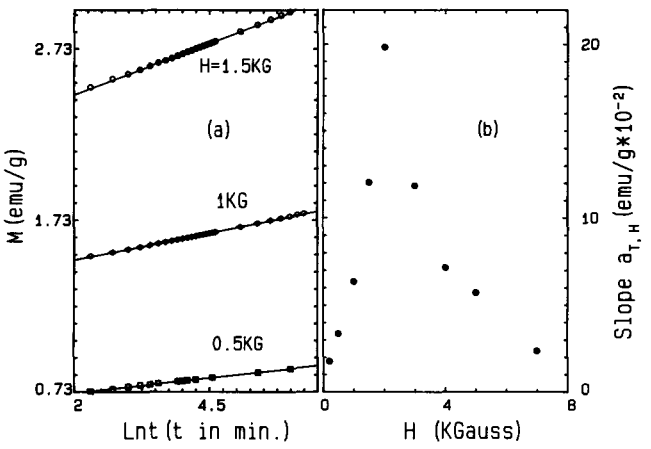

Fig. 4. (a) The magnetization (M) as a function of ln$t$ at a constant temperature of 30 K and various magnetic fields. (b) The slope "a" (slope of M versus ln$t$ curves) as a function of the applied magnetic field (H). The temperature was kept constant at 30 K.

The magnetization versus time curve follows the relationship

$$M_{T,H}(t) = M_{T,H}(0) + a_{T,H} \ln t \quad (1)$$

where $M_{T,H}(0)$ is the magnetization at initial time at temperature T and applied magnetic field H. The slope of the M versus ln t curve, $a_{T,H}$, is positive for $ErCo_3Ga_2$ (for $T < 150$ K) and depends on temperature and applied magnetic field. In Fig. 4(b), we present the slope of the M versus ln t curve as a function of the applied magnetic field at a constant temperature of 30 K. We find the value of the slope $a_{T,H}$ increases with magnetic field and reaches a maximum around 2 kG and then decreases with increasing field to about zero around 8 kG.

In summary, our preliminary study of the magnetic properties of $ErCo_3Ga_2$ suggests that there is a spin glass type transition below $T_f = 150$ K. This is most likely due to the Co magnetic sublattice. We observe another magnetic transition below $T_c = 20$ K due to ferro- or ferrimagnetic ordering of the Er sublattice. The negative magnetization in FC samples at low magnetic fields for temperatures below 150 K is an indication of magnetic anisotropy with strong temperature dependence. The increase in magnetization with time in a constant magnetic field is very curious. This is a preliminary report. We are presently engaged in a detailed study of the temperature and field dependence of the slope $a_{T,H}$ of the M versus ln t data. Neutron diffraction studies on $ErCo_3Ga_2$ are also being carried out to gain further insight in the nature of the magnetic ordering.

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