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Metamagnetism in $Ce(Ga,Al)_2$

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Abstract. Effect of Al substitution on the magnetic properties of $Ce(Ga_{1-x}Al_x)_2$ ($x = 0$, 0.1 and 0.5) system has been studied. The magnetic state of $CeGa_2$ is found to be FM with a T_C of 8 K, whereas the compounds with $x = 0.1$ and 0.5 are AFM and possess T_N of about 9 K. These two compounds undergo metamagnetic transition and the critical fields are about 1.2 T and 0.5 T, respectively at 2 K. These variations are explained on the basis of helical spin structure in these compounds.

Keywords. Metamagnetism; intermetallics; magnetization; Curie temperature; anisotropy.

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1. Introduction

Intermetallic compounds formed between rare earths (R) and transition metals (TM) have been drawing considerable attention owing to their diverse magnetic properties as well as due to their applications in various fields [1]. One important class of R–TM intermetallics that has become very attractive recently is the metamagnetic systems. In a metamagnetic system the antiferromagnetic (AFM) state changes to ferromagnetic (FM) under the influence of a magnetic field [2].

Magnetization and dc susceptibility measurements on single crystals of $CeGa_2$ have shown that the easy magnetization direction is along the a-axis and that there is no appreciable anisotropy in the ab (basal) plane. The Curie–Weiss law fit of the high temperature susceptibility has resulted in an effective magnetic moment of 2.7 μ_B, which is more than the free Ce^{3+} value. It is known that $CeGa_2$ is at the boundary between FM and AFM state and because of this reason, its magnetic behavior is very sensitive on substitutions at the Ga site [3]. It is also known that Al is able to replace Ga in these compounds over a large concentration range. Al is also found to alter the crystalline electric fields at the rare earth site and thereby influence the anisotropy. Since the metamagnetic transitions can be induced by changes in the anisotropy, we have partially substituted Al at the Ga site in $CeGa_2$. In this paper, we report some of our recent results obtained in the system $Ce(Ga_{1-x}Al_x)_2$ ($x = 0$, 0.1 and 0.5).

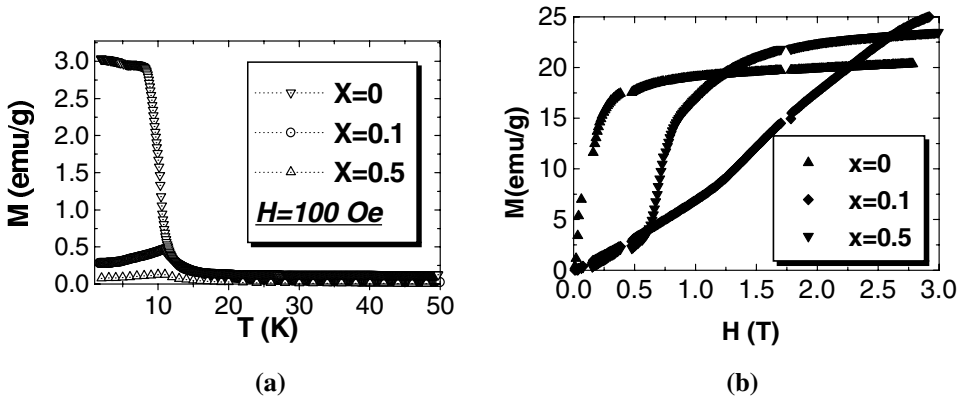

Figure 1. (**a**) M–T (at 100 Oe) and (**b**) M–H (at 2 K) plots of $Ce(Ga_{1-x}Al_x)_2$ compounds.

2. Experimental

All the compounds were prepared by conventional methods. The samples were characterized using the powder X-ray diffractograms using Cu-Kα radiation. The magnetization studies were carried out using an Oxford vibrating sample magnetometer in the temperature range 2–300 K and up to a maximum field of 12 T.

3. Results and discussion

It was found that all the compounds crystallize in single phase with the hexagonal AlB_2 structure. Figure 1a shows the temperature variation of magnetization of $Ce(Ga_{1-x}Al_x)_2$ compounds at 100 Oe. It can be seen that $CeGa_2$ is ferromagnetic with a Curie temperature (T_C) of 8 K. However, the compounds with $x = 0.1$ and 0.5 show AFM behavior with a Néel temperature (T_N) about 9 K. Figure 1b shows the M–H plots of these three compounds at 2 K. The metamagnetic transition in the compounds with $x = 0.1$ and 0.5 can be seen from this figure. The susceptibility in the paramagnetic region for all the three samples obeys the Curie–Weiss behavior. The effective magnetic moment was 2.51 μ_B for $CeGa_2$, whereas the corresponding values were 2.65 and 2.62 μ_B for $x = 0.1$ and 0.5 compounds, respectively. The paramagnetic Curie temperatures were 12 K, -32 K and -28 K for $x = 0$, 0.1 and 0.5 compounds respectively.

It is clear from the figures that Al-substituted compounds are antiferromagnetic whereas $CeGa_2$ is ferromagnetic. The spin arrangement in many uniaxial RGa_2 compounds (like $CeGa_2$) is known to be helical rather than collinear [3]. The structure consists of layers containing magnetic atoms and the coupling within each layer is ferromagnetic giving rise to a net magnetization. The AFM/FM state is determined by the angle (φ) between the spin directions in adjacent layers, which in turn is dependent on the relative strength of exchange interactions within a layer (W_0), and that between first (W_1) and second (W_2) nearest layers [4]. The spin arrangement of the layers in $CeGa_2$ may be expected as $\varphi = 0$,

i.e., a FM state. Due to Al substitution, the anisotropy of the system changes. In addition, the relative strengths of exchange interactions (W) are affected, due to the lattice parameter variations after Al substitution. These two factors lead to a change in the angle φ and a consequent helimagnetic or normal AFM ordering, depending on the value of φ. It has been reported that the bulk magnetic properties of a helimagnet are also similar to that of a simple AFM [4].

This may be the reason for the AFM behavior in the Al-substituted compounds in the present case. However, it was also found that the critical field needed to overcome the AFM is less for CeGaAl, compared to that of $Ce(Ga_{0.9}Al_{0.1})_2$, at the same temperature. Probably this may be related to the fact that the lattice parameters (a and c) change considerably as x is varied from 0 to 0.1, but do not change much when x is increased to 0.5 (in fact c lattice parameter is smaller for $x = 0.5$ than that of $x = 0.1$). This may reflect on the exchange strengths and a consequent destabilization of the AFM state, leading to lower critical fields.

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