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Magnetoresistance Study of $CeSi_{2-x}Ga_x$

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Abstract

Magnetoresistance measurements on $CeSi_{2-x}Ga_x$, x = 0.7, 1.0 and 1.3 were carried out in the temperature range 3K – 125K and in fields upto 80 kOe. The data gives a clear evidence of competition between Kondo and RKKY interactions as the temperature is lowered in these ferromagnetic Kondo systems. As the Ga concentration is increased the Kondo interaction strengthen at the expense of magnetic interactions which is consistent with Doniach's diagram. This has been interpreted as an electronically driven volume transition as a function of Ga doping.

INTRODUCTION

Cerium, in its intermetallic compounds and alloys exhibits various types of anomalous ground states that are closely linked with the hybridization strength between the conduction electrons and the Ce 4f electrons. The two processes viz, interatomic RKKY interaction and the single site Kondo interaction compete with each other in cerium Kondo lattice compounds. Dominance of one over the other leads to either magnetically ordered or a non magnetic ground state. Cerium silicides with either hole doping ($CeSi_x$ /1/, Ce $(SiAl)_2$ /2/) or isoelectronic substitution ($Ce(SiGe)_2$ /3/) exhibit a vide variety of ground states. In $CeSi_{2-x}Ga_x$, the system evolves from non-magnetic – ferromagnetic - antiferromagnetic ground state associated with a structural transition from tetragonal - hexagonal structure near the ferro - antiferro magnetic transition /4/. In the concentration range $0.7 \leq x \leq 1.3$ the compounds order ferromagnetically with transition temperature decreasing with increasing x. Magnetic and transport properties of these compounds indicate a strong competition between the intersite RKKY and the single site Kondo interactions /4/. The specific heat for x = 0.7 sample shows a sharp schottky anomaly which broadens up with considerable decrease in intensity for x = 1.0 and 1.3. These measurements indicate a competition between Kondo and RKKY interactions in this system. We report here our results of magnetoresistance measurements carried out on the polycrystalline samples of $CeSi_{2-x}Ga_x$.

EXPERIMENTAL

The samples of desired composition were prepared by arc melting different constituents, taken in stoichiometric proportion, in an argon atmosphere using a Centorr Tri Arc furnace. The samples were checked by x-ray diffraction for their phase purity. All the compounds were single phase with tetragonal structure (sp. gr. $I4_1/amd$). The calculated lattice constants were a = 4.24 Å, c = 14.07 Å for x = 0.7, a = 4.24 Å, c = 14.10 Å for x = 1.0 and a = 4.24 Å, c = 14.12 Å for x = 1.3. Magnetoresistance measurements were done on an automated magnetoresistance setup at IUC-DAEF, Indore in the temperature range 3 K to 300K and with applied fields up to 80 kOe.

RESULTS AND DISCUSSION

The results of zero field resistivity (ρ) for the series $CeSi_{2-x}Ga_x$, x = 0.7, 1.0 and 1.3 in the temperature interval are presented in Fig. 1.

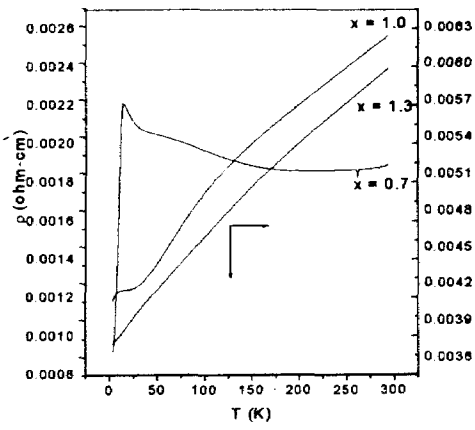

Figure 1: Zero field resistivity plots for $CeSi_{2-x}Ga_x$

For $CeSi_{1.3}Ga_{0.7}$, the resistivity is typically Kondo lattice type exhibiting a double hump structure i.e. a first maximum at about T_M = 14K followed by a minimum at 35K and a second maximum at 60K which is due to combined effect of crystalline electric field and Kondo effect. There is a complete change in behaviour of resistivity for CeSiGa (x = 1.0). In this case the minimum in resistivity occurs at 25K while for $CeSi_{0.7}Ga_{1.3}$ it shifts to 3K or below. Normally this would indicate a decrease in Kondo temperature however the Kondo temperatures calculated from neutron line widths /4/ point to the contrary. The ferromagnetic ordering temperature also decreases with increasing Ga concentration and this goes well with the fact that in this series the Kondo

interactions strengthen at the expense of RKKY interactions with increase in Ga concentration.
In order further confirm this viewpoint we have carried out magnetoresistance ($\Delta\rho/\rho$) measurements and the results of this study are presented in Fig. 2.

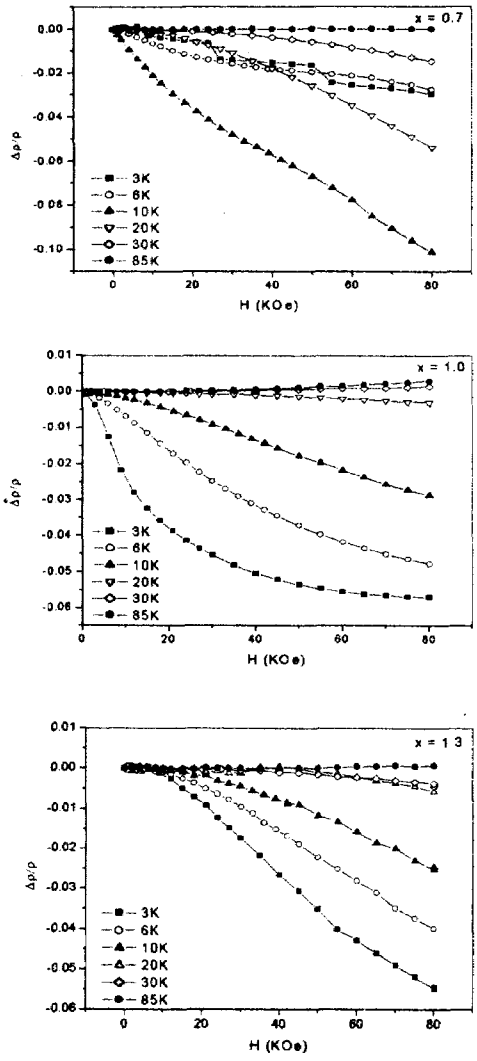

Figure 2: Magnetoresistance data on $CeSi_{2-x}Ga_x$

For $CeSi_{1.3}Ga_{0.7}$, $\Delta\rho/\rho$ at 30K i. e. around the Kondo minimum exhibits quadratic dependence on H as expected for a single ion Kondo effect, while below T_c = 11K its behaviour mimicks that of a ferromagnetic material. In the case of CeSiGa, the quadratic behaviour of $\Delta\rho/\rho$ extends roughly down to 10K below which it is like that of a magnetically ordered system consistent with the ferromagnetic ground state of the material with T_c = 8K. Further addition of Ga at $CeSi_{0.7}Ga_{1.3}$ results in a quadratic behaviour of $\Delta\rho/\rho$ down to 3K indicating that Kondo interactions are dominant even down to this temperature. This clearly indicates that with increase in Ga concentration the strength of Kondo interactions increases over the strength of RKKY interactions. It may be noted that small positive values of $\Delta\rho/\rho$ for CeSiGa and $CeSi_{0.7}Ga_{1.3}$ at 85K may be due to antiferromagnetic fluctuations. This is in good agreement with the fact that both these materials have negative values of paramagnetic Curie temperatures /4/.

The behaviour of cerium based Kondo systems depend largely upon two effects. The volume effect where the size of the ligand ion is changed which either reduces or increases the Ce-Ce bond distance or the electronic concentration effect where in the ionic radii of ligand is nearly same but its outer electronic configuration is changed. This changes the electron density of states at Fermi level and thereby the k-f hybridization (k is the symbol used for conduction electron). Substitution of Ga for Si can bring about both effects. The lattice parameters indicate a systematic increase in cell volume with Ga concentration. If increase in cell volume was only the cause than it should have strengthened the magnetic order as in the case of Ce $(SiGe)_2$ /3/. However in the case of $Ce(SiGa)_2$, Ga substitution at first introduces a ferromagnetic order ($CeSi_{1.3}Ga_{0.7}$) but further addition of Ga weakens the RKKY interactions responsible for magnetic order and strengthens the Kondo interactions. This clearly indicates that change in outer electronic configuration of Ga with respect to Si also plays a major role. Therefore both the change in ligand size as well as the change in outer electronic configuration are responsible for the observed properties.

CONCLUSIONS

Magnetoresistance of ferromagnetic Kondo compounds belonging to $CeSi_{2-x}Ga_x$ has been studied. The results indicate that the Kondo interactions dominate over the RKKY interactions. This can be said to be due to an electronically driven volume transition.

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