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MAGNETIZATION AND SUSCEPTIBILITY OF $Sn_{1-x}Gd_xTe$ *

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The magnetization and magnetic susceptibility of Bridgman-grown $Sn_{1-x}Gd_xTe$ with values of x up to 0.09 have been measured over a temperature range from 2 to 300 K and in magnetic fields up to 5.5 T. The magnetic susceptibility data followed the Curie–Weiss relation with a small Curie temperature that indicated a weak antiferromagnetic coupling among Gd ions. The magnetic field dependence of the magnetization was fitted to a modified Brillouin function with parameter values that agreed fairly well with those from Curie–Weiss plots. The value of the exchange parameter was larger than in $Pb_{1-x}Gd_xTe$. The samples were p-type with carrier concentrations up to 1.3×10^{21} cm^{-3}. The ferromagnetic or spin-glass phase due to the RKKY interaction was not observed.

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1. Introduction

Magnetic properties of rare-earth-doped IV–VI chalcogenides have been studied recently in $Pb_{1-x}Gd_xTe$ and $Pb_{1-x}Eu_xTe$ [1, 2]. Here we are reporting results on $Sn_{1-x}Gd_xTe$. Since the f-shell of Gd is more localized and shielded in comparison with the d-shells of transition metal ions, one would expect a smaller exchange interaction in rare-earth-doped diluted magnetic semiconductors (DMS). The high carrier concentration might cause a ferromagnetic ordering, as in $Pb_{1-x-y}Sn_yMn_xTe$ [3].

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1. Experiment

The samples of $Sn_{1-x}Gd_xTe$ were cut from boules grown by the Bridgman technique. The x_v values determined by electron microprobe analysis and the hole concentrations (both with an accuracy of about 20%, including variation throughout the sample) are given in Table I.

TABLE I

Susceptibility fitting parameters and carrier concentrations

Sample	x_v	$\bar{x}$	T (K) fit range	θ(K)	χ_0(emu/g)	J/k_B(K)	$p(10^{20}cm^{-3})$
A	0.09	0.074	20–300	5.22	-5×10^{-7}	0.56	1.58
B	0.08	0.057	20–300	6.04	-5×10^{-7}	0.84	4.07
C	0.06	0.043	20–300	4.19	-5×10^{-7}	0.77	5.60
D	0.05	0.039	20–300	3.46	-5×10^{-7}	0.69	5.60
E	0.01	0.011	10–125	0.51	-1×10^{-6}	0.36	10.0
F	0.006	0.005	10–125	0.63	-7.7×10^{-7}	0.93	12.6

The magnetization measurements from 0.005 to 5.5 T were carried out at the University of Maryland using a SQUID magnetometer system. In order to determine the susceptibility the measurements were carried out at four fields between 0.005 and 0.05 T, and the susceptibility was determined by a linear least-squares fit.

3. Results and discussion

The susceptibility data have been fitted to the Curie–Weiss law

$$\chi = \frac{P_1}{T+\theta} + \chi_0, \tag{1}$$

where T is the absolute temperature, P_1 is the Curie constant, θ is the Curie temperature, and χ_0 is the diamagnetic susceptibility of the host lattice. P_1 and θ were fitting parameters, χ_0 was assumed -5×10^{-7} emu/g in samples with $p < 10^{21}$ cm^{-3} and was fitted in samples with $p > 10^{21}$ cm^{-3}. The effective content of Gd ions, $\bar{x}$, and the nearest neighbor exchange parameter, J/k_B (k_B is the Boltzmann constant), were determined from P_1 and θ, with estimated errors of about 10% and 20%, respectively, as described in Ref. [2].

The experimental results and fits are shown in Fig. 1. The fitting parameters are given in Table I.

The magnetization as a function of magnetic field is shown in Fig. 2 for a sample with $x_v = 0.05$ (sample D). In all samples the magnetization was fitted to a modified Brillouin function of the form

$$M = Sg\mu_B\bar{x}N_0B_S(\zeta) + \chi_0H, \tag{2}$$

where $\zeta = Sg\mu_BH/k_B(T+T_0)$ and $B_S(\zeta)$ is a Brillouin function. S is the magnetic ion spin, g is the g-factor of magnetic ion, μ_B is the Bohr magneton, and N_0

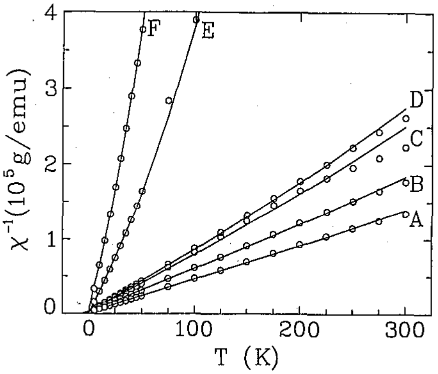

Fig. 1. Inverse susceptibility vs. temperature for $Sn_{1-x}Gd_xTe$. Solid lines are fits to the Curie–Weiss law (see Table I).

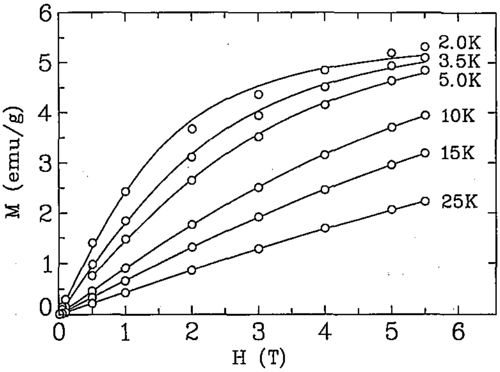

Fig. 2. Magnetization vs. magnetic field for $Sn_{1-x}Gd_xTe$ with $x_v = 0.05$. Solid lines are fits to a modified Brillouin function.

is the number of cation sites per gram. For Gd $g = 2$ and $S = 7/2$. $\bar{x}$ and T_0 were fitting parameters. The solid lines in Fig. 2 are given by Eq. (2). The fitting parameter values are given in Table II. The values of θ and T_0 agree fairly well. The temperature dependence of $\bar{x}$ and T_0 is stronger than in $Pb_{1-x}Eu_xTe$ [2].

We see that the exchange interaction is antiferromagnetic. From the susceptibility and magnetization data we obtained the average value $J/k_B = 0.7 \pm 0.2$ K. This is smaller than for the Mn-based chalcogenides, as expected in case of rare-earth ions, and larger than for $Pb_{1-x}Gd_xTe$ and $Pb_{1-x}Eu_xTe$, in agreement with the smaller cation–anion spacing in the SnTe-based compounds (see Ref. [4]).

TABLE II
Magnetization fitting parameters for $Sn_{1-x}Gd_xTe$ with $x_v = 0.05$

T(K)	$\overline{x}$	T_0	J/k_B(K)
2	0.035	2.08	0.47
2.5	0.035	2.30	0.51
3	0.036	2.44	0.54
3.5	0.036	2.54	0.56
5	0.037	2.95	0.62
10	0.040	3.82	0.75
15	0.037	2.20	0.47
25	0.040	3.53	0.71

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References

[1] M.Górska, J.R. Anderson, Z. Gołacki, *Mat. Res. Soc. Symp. Proc.* **89**, 119 (1987).

[2] M. Górska, J.R. Anderson, G. Kido, Z. Gołacki, *Solid State Commun.* **75**, 363 (1990).

[3] T. Story, G. Karczewski, L. Świerkowski, M. Górska, R.R. Gałązka, *Semicond. Sci. Technol.* **5**, S138 (1990).

[4] M. Górska, J.R. Anderson, *Phys. Rev. B* **38**, 9120 (1988).