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HIGH FIELD MAGNETIZATION OF $Sn_{1-x}Gd_xTe$

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The magnetization of p-type $Sn_{1-x}Gd_xTe$ with x up to 0.045 and the hole concentration, p, varying from 2.7 to 8.3×10^{20} cm^{-3} has been measured in magnetic fields up to 27 T, at the temperatures 4.2 and 1.3 K. The data were fitted to a magnetization equation with single-ion and pair terms. From comparison of the exchange parameters determined from the high-field magnetization with those previously obtained from the high-temperature magnetic susceptibility it was found that in samples with $p > 5\times10^{20}$ cm^{-3} the exchange was of a short-range type, while in samples with a lower carrier concentration the long-range exchange mechanism was observed.

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1. Introduction

Recently, a new model of the exchange interaction in $Sn_{1-x}Gd_xTe$ has been proposed. In this model the exchange interaction is a long-range oscillatory function of the distance between magnetic ions, with the amplitude strongly dependent on the relative position of the Fermi level and the Gd 5d level [1–5]. The mechanism becomes effective when the difference of these two energies becomes small, i.e., in the so-called resonance conditions. From measurements of the high-temperature low-field magnetic susceptibility we found that in specific samples the paramagnetic Curie temperature, θ, increased substantially with a decrease in the hole concentration [1–4]. If we assume a short-range exchange interaction with the nearest neighbors (NN) only, the increase in θ would indicate a similar increase in the NN exchange parameter, J. In order to determine whether the observed large, antiferromagnetic θ was indeed due to an increase in the NN exchange or rather to an onset of the long-range exchange mechanism we measured the high-field magnetization of p-type $Sn_{1-x}Gd_xTe$ samples with x up to 0.045 and the hole concentration varying from 2.7 to 8.3×10^{20} cm^{-3}. In such samples we observed previously the most prominent influence of the carrier concentration on magnetic properties.

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2. Experiment

The samples were grown at the Institute of Physics, PAS, by the Bridgman technique and the Gd content was determined by electron microprobe and X-ray Debye method with an accuracy of about 30%. To change the concentration of carriers some of the samples were annealed in Sn or Te atmosphere. Hall effect measurements at 4.2 K and 77 K were used to determine the carrier concentrations and mobilities. There was a very little difference in the concentration values at 77 and 4.2 K.

Magnetization measurements were carried out using a Vibrating Sample Magnetometer at the National High Magnetic Field Laboratory. The steady fields up to 27 T were produced by a resistive magnet. The errors in magnetization were typically about 3%.

3. Results and discussion

In Fig. 1 we show the high-field magnetization for $Sn_{1-x}Gd_xTe$ samples with x values between 0.028 and 0.045 and different carrier concentrations (open circles). The lower concentrations ($p = 3.1$ and 2.7×10^{20} cm^{-3}) correspond to the resonant condition, the higher ones to the situation when the Fermi energy is located well below the $5d$ level of gadolinium. The solid lines are fits to the data with an expression which includes a Brillouin function plus an explicit term for the magnetization due to magnetic-ion pairs [6]. The expression contains three fitting parameters: the number of separate magnetic ions, x_s, the number of magnetic ions in pairs, $x_{\rm p}$, and the pair exchange parameter, $J/k_{\rm B}$. The contribution from higher clusters has been neglected, as non-significant in samples with $x < 0.05$. As the lattice diamagnetic susceptibility we used our measured value of the low-temperature susceptibility of SnTe, $\chi_0 = -4 \times 10^{-7}$ emu/g [7]. The errors in parameters were about 20% for $x_{\rm s}$ and $x_{\rm p}$, and 30% for $J/k_{\rm B}$. A summary of fitting parameters is given in Table together with the theoretical $x_{\rm s}$ and $x_{\rm p}$ values for random distribution of magnetic ions.

In our earlier high-temperature susceptibility measurements we observed an increase in the absolute value of the paramagnetic Curie temperature, θ, with a decrease in carrier concentration, by a factor of 6 [1–4]. The exchange parameters deduced from θ, in the molecular field approximation, by assuming interactions with the nearest neighbors only, are shown in Table (for details of the method see Ref. [6]).

Analyzing the results collected in Table we see that the model of short-range interactions may be applied to the samples in non-resonant conditions only. In that case the fitted value of the pair exchange constant agrees with that obtained from the high-temperature susceptibility measurements for the nearest neighbors. Also, the assumption of random distribution of magnetic ions is not too bad, though the experimental values for pairs are too large.

On the contrary, for samples in the resonance conditions the short-range interaction model fails. If the value of the pair exchange constant were of the order of that obtained from the susceptibility measurements for nearest neighbors, presented in Table, we should observe magnetization steps, at least at the lowest temperature, 1.3 K. This is not the case, as can be seen in Fig. 1. The absolute

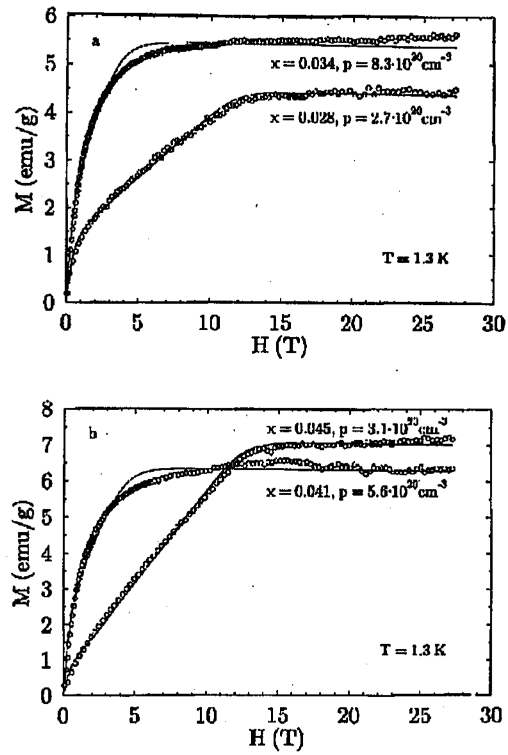

Fig. 1. Magnetization vs. magnetic field of $Sn_{1-x}Gd_xTe$ samples with different carrier concentrations, at 1.3 K. Solid lines are fits to the magnetization single-ion and pair expression. (a) $x_{av} = 0.031$, (b) $x_{av} = 0.043$.

TABLE

Magnetization and susceptibility fitting parameters.

T [K]	x	p [10^{20} cm^{-3}]	$x_s{}^a$	$x_p{}^a$	$x_s{}^c$	$x_p{}^c$	$J/k_B{}^a$ [K]	$J/k_B{}^b$ [K]
4.2	0.034	8.3	0.021	0.013	0.025	0.009	−0.55	−0.34
1.3	0.034	8.3	0.018	0.016	0.025	0.009	−0.42	
4.2	0.028	2.7	0.011	0.017	0.022	0.006	−1.09	−3.46
1.3	0.028	2.7	0.010	0.018	0.022	0.006	−1.06	
4.2	0.042	5.6	0.024	0.018	0.030	0.012	−0.71	−0.69
1.3	0.041	5.6	0.021	0.020	0.030	0.011	−0.46	
4.2	0.044	3.1	0.008	0.036	0.031	0.013	−1.11	−3.97
1.3	0.045	3.1	0.007	0.038	0.032	0.013	−1.13	

[a]High-field magnetization fit, [b]high-temperature susceptibility fit, [c]random distribution.

values of J obtained from the high-field magnetization are three times smaller than those obtained from the susceptibility data. Moreover, the numbers of singles and pairs obtained from fits are far from random distribution, showing very little single magnetic ions. That indicates that in such samples θ should be averaged over more than the first coordination zone; that would result in smaller values of J and explain the low number of non-interacting singles.

In conclusion, the non-applicability of the short-range model to the description of the high-field magnetization data for samples in resonant conditions strongly supports our model introduced previously in which the long-range interactions mediated by the free carriers play the basic role [1–5].

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