Low temperature magnetization and exchange interaction in $Sn_{1-x}Gd_xTe$

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Abstract

We report magnetization measurements performed at 20 mK on three Bridgman grown samples of $Sn_{1-x}Gd_xTe$. Magnetization steps (or ramps) from pairs with $J = -0.38$ K are present in the experimental traces of all three samples. In one of the samples, however, there's another ramp that, if attributed to another kind of Gd-pairs, would give $J' = -1.3$ K. The coexistence of these two "exchange constants" in a sample seems to contradict a recent interpretation for the exchange mechanisms in this material.

Key words: exchange interaction; $Sn_{1-x}Gd_xTe$; dilute magnetic semiconductors

The magnetization of three $Sn_{1-x}Gd_xTe$ samples (labeled 1, 2 and 2A) was measured using SQUID, at 2 K, a vibrating sample magnetometer (VSM), at 0.6 and 1.6 K, and a force magnetometer, at 20 mK. Samples 2 and 2A were from the same Bridgman ingots but sample 2A was annealed in Sn atmosphere. The Gd concentration, x, was determined from the saturation moments measured at $H = 160$ kOe for samples 2 and 2A and at $H = 70$ kOe for sample 1. Spin $S = 7/2$ and $g = 2$ were assumed and the results for x were x(1) = 0.0084, x(2) = 0.045 and x(2A) = 0.045.

The low field susceptibility was also measured, showing a normal paramagnetic behavior for all three samples. The values of x from fits to the Curie-Weiss law were consistent with the values given above. Microprobe analysis resulted in average concentrations x(1) = 0.0082, x(2A) = 0.052 and x(2) = 0.047, with deviations up to 20%, 30% and 90%, respectively, from these average values.

An overall view of the experimental results is shown in Fig. 1. The traces of M at 20 mK exhibit similar features for samples 1 and 2A. An initial fast rise of M at low fields is followed by a ramp which ends near 45 kOe. This ramp may be attributed to pairs (two spins coupled by an exchange constant J). Between 45 and 60 kOe there is another smaller ramp, corresponding to the completion of the alignment of the magnetic

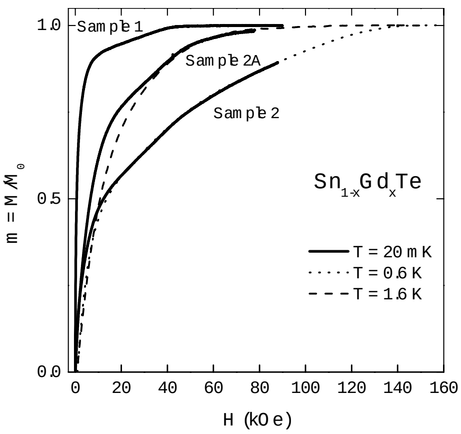

Fig. 1. Magnetization curves for samples 1 (x = 0.0084), 2 (x = 0.045) and 2A (x = 0.045) measured at 20 mK (full lines). For samples 2 and 2A the 20 mK traces were calibrated using the high field magnetization traces (dot and dashed lines) measured with a VSM. For all traces, the magnetization M was normalized to its saturation value M_0.

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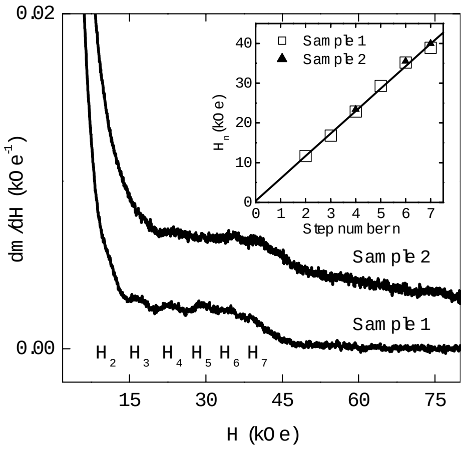

Fig. 2. Numerical derivative of the magnetization curves measured at $T = 20$ mK for samples 1 and 2. Insert: the fields H_n at the MST's from pairs as a function of the step number n.

moments of the triplets (three spins coupled by J). After 60 kOe both samples are practically saturated.

The first ramp observed for samples 1 and 2A (up to 40 kOe) is also present in both magnetization traces of sample 2. The significant difference in sample 2A is the presence of another larger and rounded ramp which extends up to about 140 kOe (from the 0.6 K trace).

For pairs with $S = 7/2$ with isotropic AF exchange, seven magnetization steps (MST) are predicted at $H_n = 2n|J|/g\mu_B$ with $n = 1, 2, \ldots, 7$. These MST's are not easily discernable in the M-traces. Nevertheless, they can be seen as broad peaks in the numerically obtained susceptibility (dm/dH) shown in Figure 2. The five broad and equidistant peaks for sample 1 correspond to the 3th through 7th MST's steps from pairs. The second MST, near 11 kOe, manifests itself as a shoulder on the fast drop of dm/dH at low H. For sample 2, the peaks are much broader, but the 4th and the two last peaks (6th and 7th) are well observed. For sample 2A, the the dm/dH trace (not shown) shows no distinguishable peaks, only a plateau ending at $H =$ 45 kOe. From the field positions of the peaks observed for samples 1 and 2 (see inset in Fig. 2) we obtained for the exchange constant $J = -0.38 \pm 0.01$ K.

In the field range of the larger ramp, dm/dH for sample 2 shows a continuous decrease up to 140 kOe without any structure of peaks. If this ramp is attributed to another type of Gd-pairs, the corresponding exchange constant can be estimated from the end of the ramp. The result is $J' = -1.35 \pm 0.05$ K.

Computer simulations of M for samples 1 and 2A were performed assuming a single dominant exchange constant, with the value J as determined above, and random distribution.[1] By assigning J to the nearest-neighbor constant J_1, a good match between simulated and experimental curves is obtained for both samples, particularly for the sizes of the ramps due to pairs and triplets. On the other hand, the magnetization of sample 2 (non-annealed), could not be simulated by any simple cluster model with two exchange constants.

The simulations, for samples 1 and 2A, have also shown that the initial rise of M is much slower than predicted for $T = 20$ mK, the difference being more pronounced for sample 2A. This result, as well as the large broadening of the observed MST's, may be due to the existence of smaller AF exchange constants from distant-neighbors.

In a recent publication[2], it has been claimed that the strength of the AF exchange interaction in $Sn_{1-x}Gd_xTe$ depends both on x and the carrier concentration. The conclusion was based on exchange constants for different samples which were mainly around a minimum of ≈ -0.4 K and a maximum ≈ -1 K. The results presented here were obtained in much lower temperatures, which emphasize the structure of the magnetization traces. A magnetization ramp consistent with an exchange constant $J' = -1.3$ K, comparable to the reported maximum, has been found in sample 2. However, in the same sample, Gd-pairs with $J = -0.38$ K are also present. The coexistence of this two "exchange constants" in a single sample seems to question the validity of the interpretation given in Ref. [2].

Gd-pairs with $J = -0.38$ K were present also in the two other samples. This exchange constant shows no relevant change with x, and is probably the nearest-neighbor exchange constant J_1. The attribution of the larger ramp to another kind of Gd-pair, however, is not certain. The non-annealed sample in which it was observed is very inhomogeneous (as revealed by the microprobe) and the Gd distribution may be not random. Consequently, it's possible that larger Gd-clusters (coupled by J_1), which saturate only at larger fields, are present giving rise to the observed ramp.

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