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Origin of Magnetic Anisotropy of $Gd_5Si_2Ge_2$ Compound

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The second-order anisotropy constant K_2 in polycrystalline $Gd_5Si_2Ge_2$ giant magnetocaloric material was measured as a function of temperature by the modified singular point detection technique. Although the structural, electrical, thermal, magnetic and magnetocaloric properties of the $Gd_5Si_2Ge_2$ have been rather well investigated experimentally, magnetic anisotropy of this system is almost unknown. The singularity indicating the anisotropy field was determined analyzing ac susceptibility data taking into account several features of the magnetization curve. The temperature dependence of the anisotropy fields was measured from 4.2 K up to the Curie temperature. The observed relationship between $K_2(T)/K_2(0)$ and magnetization $M(T)/M(0)$ was explained assuming dipolar origin of magnetic anisotropy of $Gd_5Si_2Ge_2$ compound.

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1. Introduction

Much of the interest in $Gd_5Si_2Ge_2$ compounds is related to their giant magnetocaloric effect [1]. These materials exhibit the magnetocaloric effect of 2–10 times larger than that of the best known magnetic refrigeration materials (for example gadolinium). It makes them, at present, the best material for magnetic refrigeration. Past studies have also shown several unique properties of these alloys such as a giant magnetoresistance (GMR) and a large magnetostriction effects [2–4]. Therefore, one may expect in $Gd_5Si_2Ge_2$ the strong coupling of the lattice to magnetic moments in contrast to the usually observed weak spin–lattice interactions in gadolinium-based magnetic compounds. This coupling should also have strong effect on magnetic anisotropy of $Gd_5Si_2Ge_2$ compounds. In spite of the many works published on $Gd_5Si_2Ge_2$, to the best of our knowledge, apart from the paper [5] (see also [6]) reporting value of the anisotropy constant for $T = 260$ K the information on magnetic anisotropy of $Gd_5Si_2Ge_2$ is lacking.

In the present paper we report on the magnetic anisotropy of polycrystalline $Gd_5Si_2Ge_2$ alloys which are investigated by dc and ac SQUID technique.

2. Experimental details

The $Gd_5Si_2Ge_2$ alloy was prepared in induction vacuum furnace (at the vacuum of 10^{-6} Torr) using ceramic crucible with a double lining from tungsten and tantalum. The obtained melted alloy was heated for 1 h in a high-temperature furnace at the temperature of 1600 °C under protective atmosphere of Ar, and then it was rapidly cooled down to the room temperature. The structure of the samples was characterized by using X-ray powder diffraction. X-ray diffraction patterns did not show any extra lines and were successfully indexed in the hexagonal $P112_1/a$ space group. The magnetic anisotropy was investigated by the use of the singular point detection technique developed by Asti and Rinaldi [7] (see also review paper [8]). This powerful technique was developed for the study of singularities in magnetization process when it reaches saturation at the anisotropy field H_{an}. This singular point is determined by observing the successive derivatives d^nM/dH^n. The measurements are usually performed in pulsed magnetic field. In this paper a modification of the singular point detection technique proposed by Turilli [9] was used. The modification consists in detection of the singular points analyzing the ac susceptibility in longitudinal geometry (ac field parallel to static field H). Magnetization and ac susceptibility measurements were carried out by a 7 T superconducting quantum interference device SQUID magnetometer (Quantum Design MPMS-XL).

3. Results and discussion

The modified singular point detection technique was applied to determine the magnetic uniaxial anisotropy constant $K_2(T)$ of $Gd_5Si_2Ge_2$ compounds. Figure 1 shows as an example curves $d\chi'/dH$ versus the internal field H ($H = H_{ext} - NM$, where N is the demagnetizing factor of the sample and M is the saturation

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magnetization) measured at various temperatures. Singularities indicating the anisotropy field H_{an} are clearly detectable and displayed observations confirm that the applied method is a suitable tool for measuring the magnetic anisotropy in this class of magnets. The anisotropy field is related to the anisotropy constant K_2 through the dependence

$$H_{an} = 2K_2/M. \tag{1}$$

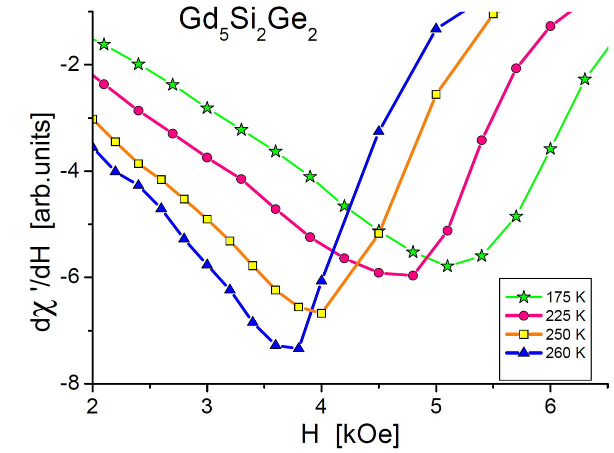

Fig. 1. The derivative of the real part of the ac susceptibility plotted versus internal field measured for several temperatures.

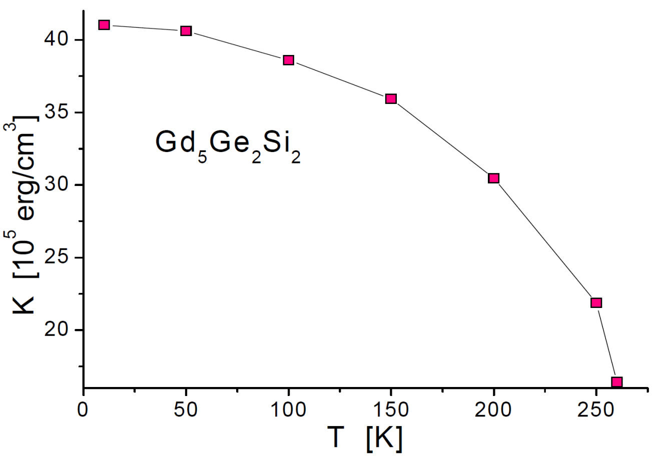

Fig. 2. Temperature dependence of the second order anisotropy constants for $Gd_5Si_2Ge_2$.

Using this formula, one can calculate the temperature dependence of the anisotropy constant $K_2(T)$. The obtained results are presented in Fig. 2. The analysis of the experimental data was performed by fitting them to the following equation:

$$K_2(T) = AM(T)^2 + BM(T)^3. \tag{2}$$

This equation describes two main contributions to the anisotropy constant. The first term describes dipolar mechanism and the second term — the single-ion mechanism described by Callen and Callen model [10]. The performed fitting leads to the conclusion that the first term dominates, while the contribution of the second term is less than 10%. This conclusion is similar to that proposed [11] for Gd_5Ge_4. The value of the anisotropy constant K_2(260 K) is very near to that reported in [5, 6]. The obtained results confirm that the modified singular point detection technique based on ac susceptibility measurements is a suitable tool for measuring the anisotropy in polycrystalline magnetic alloys.

Acknowledgments

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