Origin of Magnetic Anisotropy of Gd₅Si₂Ge₂ Compound

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The second-order anisotropy constant $K_2$ in polycrystalline Gd₅Si₂Ge₂ 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 Gd₅Si₂Ge₂ 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 Gd₅Si₂Ge₂ compound.

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1. Introduction

Much of the interest in Gd₅Si₂Ge₂ 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 magnetostriiction effects [2–4]. Therefore, one may expect in Gd₅Si₂Ge₂ 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 Gd₅Si₂Ge₂ compounds. In spite of the many works published on Gd₅Si₂Ge₂, 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 Gd₅Si₂Ge₂ is lacking.

In the present paper we report on the magnetic anisotropy of polycrystalline Gd₅Si₂Ge₂ alloys which are investigated by dc and ac SQUID technique.

2. Experimental details

The Gd₅Si₂Ge₂ 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 Rinaki [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 $H_{as}$. This singular point is determined by observing the successive derivatives $d^n M/dH^n$. 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 Gd₅Si₂Ge₂ compounds. Figure 1 shows as an example curves $d^2\chi/dH^2$ 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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(1261)
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

$$H_{an} = 2K_2/M.$$  

(1)

![Graph showing the derivative of the real part of the ac susceptibility plotted versus internal field measured for several temperatures.](image)

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

![Graph showing temperature dependence of the second order anisotropy constants for Gd₅Si₂Ge₂.](image)

**Fig. 2.** Temperature dependence of the second order anisotropy constants for Gd₅Si₂Ge₂.

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:

$$K_2(T) = AM(T)^2 + BM(T)^3.$$  

(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 Gd₅Ge₄. The value of the anisotropy constant $K_2(200\,\text{K})$ 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.

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**References**


