MAGNETOCALORIC EFFECT OF THE SINGLE CRYSTAL AND NANOCRYSTALLINE RFe_{11}Ti COMPOUNDS WITH HAVY RARE-EARTH METALS

T.I.Ivanova\textsuperscript{a*}, YU.S. Koshkidko\textsuperscript{b}, K.P. Skokov\textsuperscript{b}, D.YU. Karpenkov\textsuperscript{b}, A.YU. Karpenkov\textsuperscript{b}, YU.G. Pastushenkov\textsuperscript{b}, S.A.Nikitin\textsuperscript{a}

\textit{a. Moscow State University, Faculty of Physics, Moscow, Russian Federation}
\textit{b. Tver State University, Faculty of Physics, Tver, Russian Federation}

1Corresponding author: Dr. Tatiana Ivanova, e-mail: ivanova@phys.msu.ru, fax: +7-495-9328820

Abstract

The results of investigation of magnetocaloric effect in microcrystalline and nanocrystalline TbFe_{11}Ti and GdFe_{11}Ti intermetallic compounds are presented. It was found that the dependence between the reduction of the grain size below a single domain size and value of magnetocaloric effect has a complicated nature. Appearance of this dependence has been explained by the influence of intergrain exchange interaction in nanocrystalline alloys.

Keywords: magnetocaloric effect; nanocrystalline rare-earth compounds;

1. Introduction

Nanocrystalline intermetallics and alloys are novel materials which provide great opportunities for researchers to develop many important technical applications such as magnetic refrigerators, magnetic recording etc. The interest in research on nanocrystalline rare-earth intermetallic compounds has increased considerably since it was found that these compounds are suitable materials for magnetic refrigerant over a large temperature span. Magnetic refrigeration based on the magnetocaloric effect (MCE). The MCE is a magneto-thermodynamic phenomenon, in which a reversible change in temperature of a material is caused by exposing this material to a changing magnetic field under adiabatic conditions. Here, we report a result of the experimental MCE research for the microcrystalline and nanocrystalline TbFe_{11}Ti and GdFe_{11}Ti compounds.

The magnetic properties of TbFe_{11}Ti and GdFe_{11}Ti compounds have been studied earlier [1–5]. As it is known, the magnetocaloric effect has maximum magnitude in the area of the magnetic phase transitions. These compounds have the Curie temperatures near room temperatures, which allow hoping for occurrence a considerable MCE in the region of the magnetic phase transitions and for theirs applications in cryogenic magnetic refrigerator devices. Besides, the RFe_{11}Ti compounds with ThMn_{12} crystalline structure have a wide homogeneity region.

2. Experimental.

The measurements were performed on the single crystals and noncrystalline of the RFe_{11}Ti compounds, where R =Gd,Tb. The cast alloys were prepared by means of high-frequency induction melting in the atmosphere of pure argon. The method of synthesis made it possible to obtain coarse-grained ingots. The single crystal grains were separated from these ingots.

The rapidly quenched alloys were prepared by crystallization of the melt on the horizontally rotating copper disk, which has the linear velocity of about 6.53 m/s.
The method of X-ray diffraction analysis was used to attest the obtaining nano- and micro-crystalline samples.

The dimensions of grain were determined by the methods of atomic-power microscopy. Measurements of MCE have been carried out by a direct method by means of the copper-constantan thermocouple, which was placed in the sample surrounded by an adiabatic envelope. The values of MCE (∆T) were defined in the range of temperatures 80 – 700 K and in the static magnetic fields up to 18.5 kOe.

The observation of domain, micro- and nanostructure of the cast and rapidly quenched samples were performed using optical microscopy (magnification up to 1000) and atomic force microscopy (magnification up to 50000).

3. Results and discussion

The domain structure of TbFe$_{11}$Ti single crystals was studied using the magnetooptical Kerr method. Microstructure of the nanocrystalline TbFe$_{11}$Ti sample was observed by methods of the atomic force microscopy. The obtained results represent in Fig.1 (a) and Fig. 1(b) respectively.

As shown in Fig. 1(a) and Fig. 1(b) grain size of the cast alloys approximately equal to 200 microns, while the nanoparticle size of rapidly quenched alloys approximately equal to 50 nanometer.

The microstructure image of nanocrystalline GdFe$_{11}$Ti sample (not shown) received by methods of atomic force microscopy similar to the one of nanocrystalline TbFe$_{11}$Ti alloy. The nanoparticle size of the GdFe$_{11}$Ti alloy was estimated to be ≈ 80-100 nanometers.

![Kerr microscopy images showing the domain and crystalline structure of microcrystalline TbFe$_{11}$Ti alloys (a) and atomic force microscopy images showing microstructure of nanocrystalline TbFe$_{11}$Ti alloys (b).](image)

Fig. 1 shows the magnetocaloric effect change versus temperature curves for TbFe$_{11}$Ti single crystals and for nanocrystalline state TbFe$_{11}$Ti alloy. The obtained results indicate that the MCE maximum of micro- and nanocrystalline samples of TbFe$_{11}$Ti alloy equal to 1.23 K and 0.91 K respectively. Furthermore, the shift of the MCE maximum approximately on 15 K towards low temperatures is observed for the nanocrystalline sample.

Temperature dependence of the magnetocaloric effect in magnetic field 18.3 kOe is shown in Fig. 3 for the GdFe$_{11}$Ti single crystals and for nanocrystalline state GdFe$_{11}$Ti alloy. As seen from Fig. 3, the MCE...
maximum of the single crystal GdFe\(_{11}\)Ti alloy equal to 1.47 K while the one for nanocrystalline state GdFe\(_{11}\)Ti sample to become substantially smaller \(\Delta T \approx 0.8\) K. Besides, the MCE nanocrystalline maximum shifts almost by 100 K with regard to the one for the GdFe\(_{11}\)Ti single crystal.

All of the above experimental results show that the value of magnetocaloric effect of the TbFe\(_{11}\)Ti and GdFe\(_{11}\)Ti alloys essentially depends on the grain size. The change of MCE in nanocrystalline alloys can be explained by the influence of intergrain exchange interaction. It is known when the exchange interaction between grains with a size below the single-domain particle size takes place; these grains participate in the formation of interaction domains [6, 7]. Our analysis of MCE and the magnetic microstructure evolution of the rapidly quenched alloys in dependence on the grain size shows that for alloys with grain size more than 200 nm no interaction domains and no changes in the magnitude of MCE are observed. But, below critical grain size about 150 nm the interaction domains appear in a specimen and the change of MCE become essential.

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**References**


