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Giant forced magnetostriction in $Tb_{0.2}Gd_{0.8}$ single crystal

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Abstract. The results of investigation of the $Tb_{0.2}Gd_{0.8}$ single crystal forced magnetostriction are presented. Temperature dependences of magnetostriction have been measured from 4 to 300°K in applied magnetic fields up to 14 T. The giant field induced magnetostriction ~ $1.5{\bullet}10^{-3}$ was discovered in the room temperature region in magnetic fields up to 14 T.

1 Introduction

The magnetostriction is the mechanical deformation of magnetic samples due to the changes in the magnetization degree or in the magnetization direction [1]. The rare earth metals (REM) and their alloys form an important class of materials with giant magnetostriction [1-3]. The theory of magnetostriction of REM was developed and formulated by Callen [4] and Clark [5]. Previously, the study of forced magnetostriction was carried out on the polycrystalline and single-crystal samples of REM [6-9] and their alloys [1,2,10-12]. Tb-Gd single crystal alloys are widely used in prototypes of magnetic refrigerators due to giant reversible magnetocaloric effect observed in them near room temperature [13-16]. The volume magnetostriction values are crucial for determination of exchange interactions dependencies on the unit cell volume and on the interatomic distances. Moreower in the modern world, magnetostrictive materials are widely used in wide range of technical devices such as, for example, high power transducers and actuators [1,3,17].

In this work the magnetostriction of $Tb_{0.2}Gd_{0.8}$ single crystal in strong magnetic fields up to 14 T was investigated. This alloy has a relatively high Curie temperature due to high concentration of Gd and giant values of magnetostriction caused by Tb content, which has high values of single-ion magnetostriction. The combination of strong exchange interactions and high magnetostriction in Tb_xGd_{1-x} alloys makes them promising objects in terms of theoretical research and practical applications. For these applications it is essential to know about field and temperature dependences of magnetostriction.

2 Experimental details

We have performed an experimental study of magnetostriction of $Tb_{0.2}Gd_{0.8}$ single crystal in magnetic fields up to 14 T and in temperature range 4.2 K - 300 K.

For a comprehensive study of magnetic and magnetostrictive properties of rare-earth metals and their alloys large single crystals with a perfect crystal structure and a uniform distribution of alloy components on the length and section of the crystal are required. The most suitable for this purpose is the method of pulling crystals from the melt (Czochralski method). For the growth of the single crystal terbium and gadolinium of high purity (99.99 at.%) were used. Terbium and gadolinium form a continuous series of substitutional solid solutions when alloying, which makes distribution of alloy components uniform all over the sample.

Single crystal pulling was carried out at a speed of 0.3 mm per minute and the rotation rate of 20 rpm in a vacuum of 10^{-6} Torr. The grown single crystal has a shape of cylindrical bar of a 6-10 mm diameter and length of 40-60 mm.

For magnetostriction measurements parallelepiped 6*4*4 mm samples were used. Each sample was cut to make surfaces perpendicular to one of the main crystallographic directions. Orientation of the samples was carried out by X-ray diffraction method.

To remove surface-deformed layer after cutting the samples were chemically etched by 30% HNO_3 ethanol solution for depth of approximately 0.2-0.5 mm on each cut side. Then the samples were annealed for 10 hours at a temperature of 800°C in a pure argon atmosphere.

The $Tb_{0.2}Gd_{0.8}$ single crystal has a hexagonal closed packed crystal structure with $P6_3/mmc$ space group.

The measurement of magnetostriction was carried out using the SK-06-030 TY-350 type strain gauge. This type of strain gauge allows to measure the deformation of the sample caused by the simultaneous magnetostrictions in two mutually perpendicular directions. The gauge was glued to the surface of the sample containing c and b crystallographic directions. Magnetostriction measurements were carried out on the PPMS magnetotransport equipment. The measurements were carried out on the $Tb_{0.2}Gd_{0.8}$ single crystal in magnetic fields directed along the ***c*** axis - λ_{cc}, λ_{cb} and

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directed along the ***b*** axis - λ_{bb}, λ_{bc} (the first index indicates the direction of the magnetic field, the second – the direction of magnetostriction measurement).

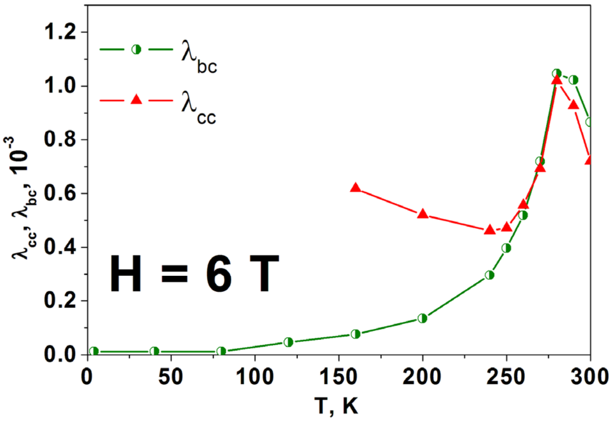

Fig. 1. Temperature dependencies of λ_{cc} and λ_{bc} magnetostrictions in 6 T magnetic field.

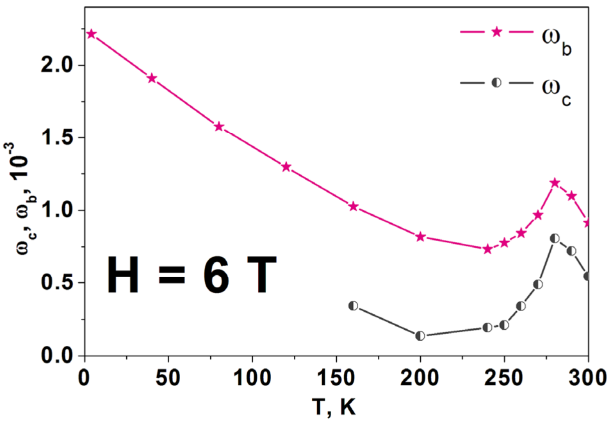

Fig. 2. Temperature dependencies of ω_c and ω_b volume magnetostrictions in 6 T magnetic field.

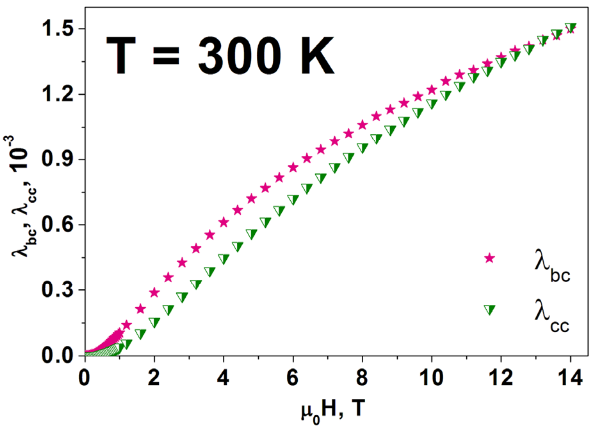

Fig. 3. Field dependencies of λ_{cc} and λ_{bc} magnetostrictions in magnetic field up to 14 T at $T = 300$ K.

3 Results and discussion

The temperature dependencies of λ_{cc} and λ_{bc} magnetostrictions in 6 T magnetic field are shown in fig. 1. These curves have been plotted using experimental data of magnetostriction field dependences measured at constant temperatures. It should be noted that due to strong anisotropy of $Tb_{0.2}Gd_{0.8}$ single crystal (basal plane ***b*** axis is the axis of easy magnetization) λ_{cc} increase with decreasing temperature (fig. 1). The value of λ_{cc} magnetostriction significantly exceeds the value of λ_{bc} in the low temperature region. This effect was also observed before [2]. Temperature dependencies of λ_{cc} and λ_{bc} magnetostrictions in various magnetic fields exhibit maximum near $T_C = 280$ K, the magnetic phase transition temperature of $Tb_{0.2}Gd_{0.8}$ alloy (Curie point). The magnetostriction of $Tb_{0.2}Gd_{0.8}$ single crystal reaches the giant positive values: $\lambda_{bc} \sim 1.5 \cdot 10^{-3}$ in 14 T magnetic field.

We have calculated ω_c and ω_b using experimental values of λ_{cc}, λ_{cb}, λ_{bb} and λ_{bc} and well known equations [11,12,18]:

$$\omega_c = \lambda_{cc} + 2\lambda_{cb}, \quad (1)$$

$$\omega_b = \lambda_{bc} + 2\lambda_{bb}. \quad (2)$$

The temperature dependences of volume magnetostrictions ω_c and ω_b are presented on fig. 2. Temperature dependencies of volume magnetostrictions ω_c and ω_b also exhibit maximum near the magnetic phase transition temperature of $Tb_{0.2}Gd_{0.8}$.

The experimental magnetic field dependences of λ_{cc} and λ_{bc} magnetostriction show an abrupt increase in the area of the magnetic phase transition without saturation up to 14 T magnetic field (fig. 3). It is supposed to calculate the magnetostriction constants for the $Tb_{0.2}Gd_{0.8}$ single crystal using obtained experimental data in the near time. These results suggest that we observe a giant forced magnetostriction. The results obtained in this work indicate that $Tb_{0.2}Gd_{0.8}$ alloy is a promising magnetostrictive material for technical applications.

4 Conclusion

The giant field induced volume magnetostriction exists in the $Tb_{0.2}Gd_{0.8}$ single crystal in the temperature range of ferromagnetic-paramagnetic phase transition (Curie point). However 14 T magnetic field is not enough for saturation of magnetostriction in this single crystal. Therefore the $Tb_{0.2}Gd_{0.8}$ single crystal may be used as magnetostrictive material in various technical devices.

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