Temperature dependence of magnetic torque for a single crystal MgB_2 in 10 kG

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Abstract

We have investigated the magnetic torque of MgB_2 by using a torque magnetometer consisting of a 4-K closed cycle refrigerator and a variable field permanent magnet. Single crystals of MgB_2 have been synthesized by the vapor transport method. We examie the mass anisotropy $\gamma = \sqrt{m_c/m_{ab}}$ by analyzing the magnetic torque curves of MgB_2. We discuss that γ is not sensitive to temperature in a constant field 10 kG.

Key words: torque; anisotropy; MgB_2; refrigerator

1. Introduction

It has been amazing that a metallic magnesium diboride MgB_2 became superconducting at a temperature higher than what the conventional BCS theory predicts [1]. Actually, MgB_2 is a superconductor of $T_c = 40$ K. Since this material is metallic and is not so expensive, it seems to be very promising to the various applications.

One of the basic material parameters of a superconductor is certainly an anisotropy parameter. It is desirable to carry out the experiments with single crystals, but it is very difficult to grow a MgB_2 single crystal because of a comlicated phase diagram of the Mg-B system. Therefore, most of the preceeding experiments have been limited to the polycrystalline samples. It is also not unveiled how the nature of the multibands and the multigaps influences the anisotropy [2].

In the present study, we carry out the systematic torque measurements to reveal the temperature dependence of γ by using a single crystalline MgB_2.

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2. Experimental

Xu *et al*. [3] succeeded in synthesizing a single crystal of MgB_2 by the vapor transport method. They reported that the onset temperature of superconductivity was 38.6K. The starting materials of Mg (99.99%) chips and a B (99.9%) chunk were sealed in a molybdenum crucible by electron beam welding. The crucible was first heated to 1400°C at a rate of 200°C/h, was kept for 2 hours, then was cooled slowly to 1000°C at a rate of 5°C/h, and was finally cooled to room temperature by switching off the furnace.

We used a torque magnetometer on the basis of a 4-K closed cycle refrigerator and a variable field permanent magnet [5]. The temperature of a top-loading insert is controlled by the two-independent PID controllers in the temperature regime from 300 K down to 1.5 K with a typical stablity of ±0.01 K. A torque sensor consists of the four piezoresistors on a silicon cantilever. The torque can be measured as an off-balance signal of the Wheatstone brige. We carried out the torque measurements with sample and without sample for a long term, i.e., the experiments last continueously more than 15 days without supplying any liquid helium. The tem-

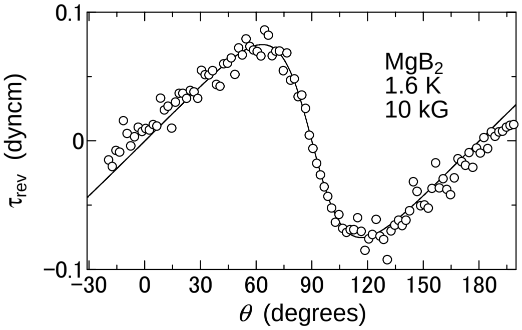

Fig. 1. The reversible torque τ_{rev} of MgB_2 as a function of angle θ at 10 kG (1.6K).

peratures were scaned from 1.6 to 45 K. A typical temperature step was 0.5 K, and the angular step was 0.5 degrees. The applied field was fixed to the maximum value (10 kG).

3. Results and Discussions

We measured the torque of single crystalline MgB_2 as a function of angle in 10 kG. The reversible torque was obtaind as $\tau_{rev}(\theta) = [\tau_{inc}(\theta) + \tau_{dec}(\theta)]/2$ where $\tau_{inc}(\theta)$ and $\tau_{dec}(\theta)$ are the torques as a function of increasing and decreasing angle, respectively.

In Fig. 1, we show the reversible torque τ_{rev} of MgB_2 at 10 kG (1.6 K). In the three-dimensional anisotropic London model in the mixed state, the angular dependence of the torque is given by Kogan [6] as

$$\tau_{rev}(\theta) = \frac{\phi_0 HV}{16\pi\lambda^2}\frac{\gamma^2-1}{\gamma^{1/3}}\frac{\sin 2\theta}{\epsilon(\theta)}\ln\left(\frac{\gamma\eta H_{c2}^{\perp ab}}{H\epsilon(\theta)}\right), \quad (1)$$

where $\epsilon(\theta)$ is $\epsilon(\theta) = (\sin^2\theta + \gamma^2\cos^2\theta)^{1/2}$, θ is the angle between the applied field and the c axis, γ is the anisotropy parameter, $H_{c2}^{\perp ab}$ is the critical field perpendicular to the ab plane, and V is a sample volume.

In Fig. 2, we show γ as a function of T. The anisotropy parameter is fairly independent of temperature. We obtained $\gamma = 2.43 \pm 0.02$ by averaging at temperatures below 25 K. This is in marked contrast with the temmperature dependent γ reported by Angst et al. [4].

In Fig. 3, we show the prefactor $\tau_0 = \phi_0 HV/16\pi\lambda^2$ $(\gamma^2-1)/\gamma^{1/3}$ as a function of T. The line is an empirical formula $\tau_0(T) = \tau_0(1-(T/T_c)^2)^\alpha$ to guide eyes where $\tau_0 = 5.54 \times 10^{-2}$ dyncm, $T_c = 33$ K, and $\alpha = 5.23 \times 10^{-1}$.

We consider that evidence for the existence of the multigaps cannot be seen as far as the temerature dependences of γ and τ_0.

In conlusion, the electric anisotropy γ of MgB_2 is rather independent of temperature. We did not find evidence for the appearances of the multigaps in MgB_2.

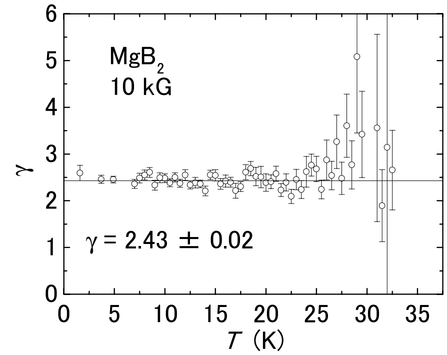

Fig. 2. Temperature dependence of the upper critical field anisotropy H_{c2}

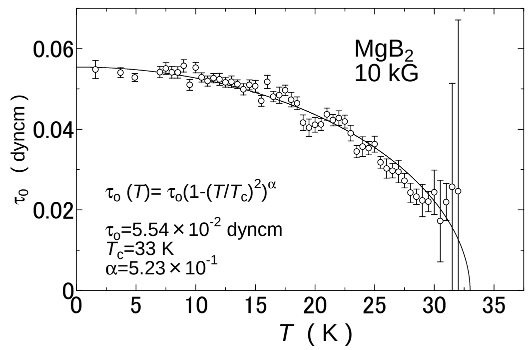

Fig. 3. A prefactor $\tau_0 = \phi_0 HV(\gamma^2-1)/16\pi\lambda^2\gamma^{1/3}$ of the Kogan formula as a function of T

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