Evidence for superconductivity in the boron layers of MgB_2

Ken'ichi Takahashi [a], Mingxiang Xu [b], Hideaki Kitazawa [b], Takekazu Ishida [a,1]

[a] *Department of Physics and Electronics, Osaka Prefecture University, Sakai, Osaka 599-8531, Japan*

[b] *Nanomaterials Laboratory, National Institute for Materials Science (NIMS), 1-2-1 Sengen, Tsukuba, Ibaraki 305-0047, Japan*

Abstract

We examine the superconducting anisotropy $\gamma = \sqrt{m_c/m_{ab}}$ of a metallic high-T_c superconductor MgB_2 by measuring the magnetic torque of a single crystal. The anisotropy γ does not depend sensitively on the applied magnetic field at 10 K. We obtain the anisotropy parameter $\gamma = 4.31 \pm 0.14$. The torque curve shows the sharp hysteresis peak when the field is applied parallel to the boron layers. We consider that this comes from the intrinsic pinning and is direct evidence for the occurrence of superconductivity in the boron layers. This is consistent with what the band calculations predict in the electronic states.

Key words: torque; anisotropy; MgB_2; layered superconductor

1. Introduction

Since MgB_2 [1] has a high critical temperature (40 K) and is easily processed, it is expected to utilize for various applications. Therefore, many groups involve in studying fundamental properties of MgB_2. An anisotropy parameter $\gamma = \sqrt{m_c/m_{ab}}$ of MgB_2 is very important, but it varies from 1.2 to 9 in the literature [3]. The discrepancy of γ partly comes from the use of the polycrystals. Melting point of magnesium is 650℃, while that of boron is 2550℃. This makes it difficult to grow a single crystal.

Magnetic torque is a useful tool to investigate anisotropy. We have developed an automatic torque magnetometer, and have used to investigate the electronic anisotropy of high-T_c cuprates [4]. According to Kortus *et al.* [2], MgB_2 consists of boron layers which are responsible for superconductivity. If a layered superconductivity comes out in MgB_2, an intrinsic pinning would appear in the torque signal. Angst *et al.* [6] reported that γ depends on H and T.

In this paper, we report the anisotropy and the intrinsic pinning of single crystalline MgB_2.

2. Experiment

Xu *et al.* succeeded to synthesize a single crystal of MgB_2 by using a vapor transport method, of which the details were reported elsewhere [5]. The starting materials (Mg (99.99%) chunk and B (99.9%) chunk) were sealed in a molybdenum crucible. The crucible was heated to 1400℃ at a rate of 200℃/h, and kept for two hours. After that, it was cooled to 1000℃ at a rate of 1000℃/h, and was restored to room temperature. The onset temperature of samples was 38.6K.

Our torque magnetometer can change a magnetic field continuously from −60 kG to +60 kG in the temperature range from 4 K to 300 K. This instrument controls a sample direction by an optical position sensor, and rotates a torque sensing part by a stepping motor. We can get the torque signal from a current through a feedback coil. A sample temperature was fixed to 10 K while the applied magnetic field was varied from 10 kG to 60 kG. The angular step was 0.5° in torque curves.

[1] Corresponding author. Department of Physics and Electronics, Osaka Prefecture University, Sakai, Osaka 599-8531, Japan. E-mail: ishida@center.osakafu-u.ac.jp

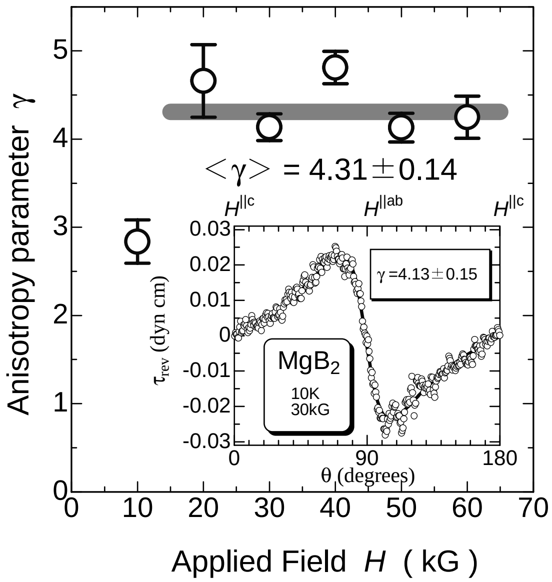

Fig. 1. Inset is the reversible torque curve at 10 K in 30 kG. The fitted line by the Kogan equation is also indicated. Main panel is γ for the several different fields H.

3. Results and Discussion

Reversible torque is $\tau_{rev}(\theta) = (\tau_{inc}(\theta) + \tau_{dec}(\theta))/2$ and irreversible torque is $\tau_{irr}(\theta) = (\tau_{dec}(\theta) - \tau_{inc}(\theta))/2$, where $\tau_{inc}(\theta)$ and $\tau_{dec}(\theta)$ are torque signals for increasing and decreasing angle, respectively. In the inset of Fig. 1, the reversible torque is analyzed by Kogan equation

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

where $\epsilon(\theta) = (\sin^2\theta + \gamma^2\cos^2\theta)^{1/2}$. We used a fixed parameter $\eta H_{c2}^{//c}$(=60 kG) at 10 K [5]. The main panel is γ in the applied magnetic fields H (10, 20, 30, 40, 50, 60 kG). We find that γ is almost constant in fields larger than 20 kG, where the averaged $<\gamma>$ is 4.31 ± 0.14. In 10 kG, γ ($= 2.84 \pm 0.25$) is the smallest because a remarkable hysteresis appears at angles near $\theta = 90°$ (see Fig. 2). The tiny hysteresis exists even in 20 kG near 90°.

This hysteresis comes from intrinsic pinning originating from a boron layer superconductivity. Tachiki and Takahashi [8] reported the fundamental pinning force drastically decreased when ξ_c/a_c exceeded unity. However, the weakly pinning phenomenon were observed in 2H-$NbSe_2$($\xi_c/a_c > 1$) [9]. Our torque magnetometer is also sensitive enough to see a subtle intrinsic pinning expected in MgB_2.

A prefactor $\{\phi_0 HV(\gamma^2-1)\}/16\pi\lambda^2\gamma^{1/3}$ gives $m \sim 5$ μg by assuming λ =85 nm [3], ρ =2.63 g/cm^3, and $\gamma = 4.31$. This is almost the same with the calculation from the sample size.

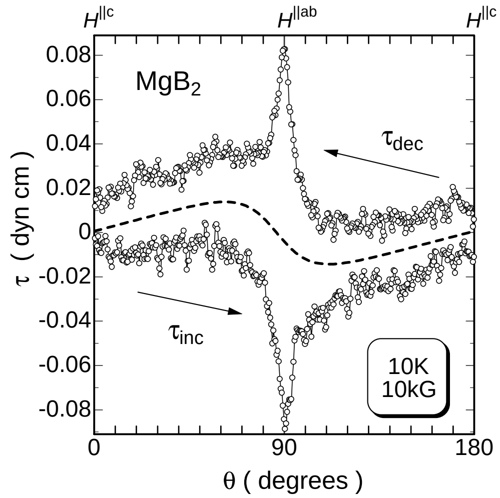

Fig. 2. This is magnetic torque curve at (10 K, 10 kG). The dashed curve is reversible torque. The sharp hysteresis is looked at angles near $\theta = 90°$.

In conclusion, the anisotropy parameter γ is constant in fields larger than 20 kG, and the averaged $<\gamma>$ is 4.31±0.14. We consider that a sharp hysteresis in 10 kG is from the intrinsic pinning, and is evidence for a layered superconductivity in the boron layers of MgB_2.

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