Comparative Study on the Anisotropic Properties of MgB_2

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Abstract

The anisotropy of upper critical field of MgB_2 has been studied on single crystals and poly-crystals by both transport and magnetic measurements. The angular dependence of H_{c2} shows deviation from the anisotropic Ginzburg-Landau model at lower temperatures. The value of anisotropy parameter is temperature and sample dependent, and is about 3 and 4.5 for single and poly crystals, respectively, at temperatures near T_c. However, $H^c_{c2}(T)$ are almost the same for all samples. These features could be an indication of anisotropic s-wave superconductivity with pancake-like energy gap or resulted from the different impurity levels in these samples. The anisotropy of H_{c2} in *ab*-plane has also been measured and we set an upper bound of 1% for the in-plane anisotropy.

Key words: MgB_2 ;anisotropy ;upper critical field ;

1. Intruduction

MgB_2 has stimulated intense researches all over the world for its highest T_c among intermetallic componds and simple structure. Its superconducting mechanism, two gap structure, anisotropic properties, surface superconductivity are issues of recent interests. Among these issues, the anisotropy of upper critical field is very important for both superconducting mechanism and applications of MgB_2. However, the anisotropy of MgB_2 is still under debate due to the span of anisotropy parameter $\gamma = H^{ab}_{c2}/H^c_{c2}$ from 1.1 to 13 [1]. It is not very clear why γ depends on temperature and samples [2]. It is also not clear whether the anisotropic behavior of MgB_2 obeys the anisotropic Ginzburg-Landau relation or not. In this paper, we report our comparative studies on γ for single crystals and poly-crystals by both transport and magnetic measurements. We also report in-plane anisotropy of H_{c2} by carefully aligning the magnetic field in the plane.

2. Experimental

The single crystals of MgB_2 are synthesized under high pressure and its crystallinity has been checked by Laue x-ray photograph. The Laue x-ray diffraction shows a clear six-fold partten. The superconducting transition temperature (T_c) of single crystalline samples are 36-38 K and the transition width (ΔT_c) is smaller than 0.3 K. The single crystalline samples are thin platlets with thickness of about 25 μm. The dense poly-crystalline samples are prepared by directly reacting Mg and B in Ta tube without pressure. T_c is about 38.5 K and the transition is very sharp (0.2 K). The upper critical fields are determined by transport measurements using standard four-probe method and by SQUID magnetometer. For transport measurements of the anisotropy of H_{c2}, we use a two-axis sample rotator and a vector magnet system with maximum fields

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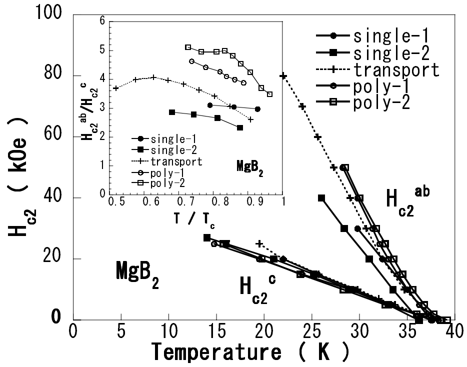

Fig. 1. Temperature dependence of the upper critical field H_{c2}^{ab} and H_{c2}^{c}. Inset shows the temperature dependence of anisotropy parameter $\gamma = H_{c2}^{ab}/H_{c2}^{c}$ for different samples.

of 50 kOe and 30 kOe for transverse and longitudinal directions, respectively.

3. Results and Discussion

Figure 1 shows the temperature dependence of upper critical fields obtained from $R-T$ and $M-T$ curves. For single crystalline sample, H_{c2} are determined by the onset of diamagnetic transition or the kink points of $R-T$ curves [3]. For poly-crystalline samples, the H_{c2}^{c} and H_{c2}^{ab} are estimated by the kink of the slope of $M-T$ curves proposed by Bud'ko *et al.* [4]. The inset of Fig. 1 shows the temperature dependence of the anisotropy parameter $\gamma = H_{c2}^{ab}/H_{c2}^{c}$. H_{c2}^{c} and H_{c2}^{ab} have different temperature dependence and hence γ is also temperature-dependent, which implies a breakdown of the anisotropy of the band effective mass or may be related to the anisotropy of the energy gap structure of MgB_2. $H_{c2}^{ab}(T)$ is obviously sample-dependent while $H_{c2}^{c}(T)$ is almost independent of samples. These features may be resulted from two origins: (1) The pancake-like energy gap anisotropy proposed by Posazhennikova *et al.* [5], which may result in larger change of H_{c2}^{ab} while smaller change of H_{c2}^{c} for samples with different γ values and can result in temperature-dependent γ. (2) Difference in impurity levels, which can also result in this phenomenon because H_{c2}^{c} only depends on ξ_{ab} while H_{c2}^{ab} depends on both ξ_{ab} and ξ_c. So if only ξ_c is different for different sample, H_{c2}^{ab} and γ will change and H_{c2}^{c} will not change for samples with different impurity levels.

To check the anisotropic behavior of H_{c2}, we have measured the angular dependence, $H_{c2}(\theta)$, at different temperatures as shown in Fig. 2. Here θ is the angle of the field from the c-axis. At temperatures near T_c, the $H_{c2}(\theta)$ can be fitted by anisotropic GL relation, while at lower temperatures, it deviates from the GL theory.

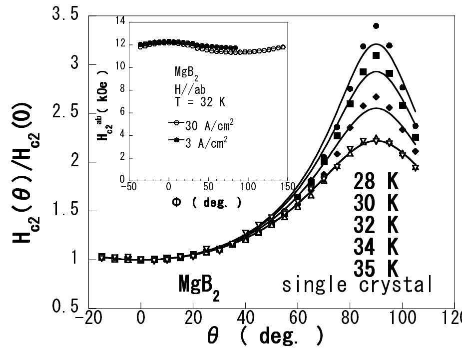

Fig. 2. Angle dependence of normalized upper critical field $H_{c2}(\theta)$ at different temperatures determined by the peak of the derivative of $R-H$ curves. Solid lines are the best fitting by GL model with $\gamma = 3.21, 2.93, 2.55, 2.22, 2.22$. Inset shows the angle dependence of H_{c2}^{ab} in ab-plane at 32 K determined by $R-H$ curves with different transporting currents.

The peak at 90^o is sharper than GL theory, which may be resulted from the effect of special energy gap structure of MgB_2 or just the effect of surface superconductivity on the determination of H_{c2}[6].

We also measured the in-plane anisotropy of the upper critical field, $H_{c2}(\phi)$, by carefully aligning the magnetic field exactly in the *ab*-plane for each ϕ. The current is passed along the *a*-axis, where we define the direction of the in-plane field $\phi = 0^o$. The inset of Fig. 2 shows $H_{c2}(\phi)$ at $T = 32K$ for two different current densities. As is evident from the figure, the dominant component of $H_{c2}(\phi)$ has a two-fold symmetry rather than the six-fold symmetry expected from the hexagonal crystal structure. The two-fold symmetry is due to the Lorentz force as evidenced by the current density dependence and the minimum of $H_{c2}(\phi)$ for a field perpendicular to the current. After subtracting the two-fold symmetry component, the six fold-symmetry component is less than 1%. It should be noted that a clear anisotropy of $H_{c2}(\phi)$ more than 30% in hexagonal material Cs_xWO_3 is reported in high quality single crystals [7].

This work is supported by Grant-Aid for Scientific Research from Ministry of Education, Culture, Sports, Science and Technology.

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