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Temperature-dependent H_{c2} anisotropy in MgB_2 as inferred from measurements on polycrystals

Sergey L. Bud'ko and Paul C. Canfield
Ames Laboratory and Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011

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We present data on temperature-dependent anisotropy of the upper critical field of MgB_2 obtained from the analysis of measurements on high-purity, low-resistivity polycrystals. The anisotropy decreases in a monotonic fashion with increase of temperature.

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The recent discovery[1] of superconductivity with a high critical temperature, $T_c \approx 40$ K, in the simple, binary intermetallic compound MgB_2 evoked intense experimental and theoretical studies of the physical properties of this material that resulted in understanding of superconductivity in this material as being of the BCS-type superconductor in which the observed value of T_c is a result of the anisotropy of the electron-phonon coupling and anharmonicity in the relevant (boron E_{2g}) phonon modes.[2–4]

One of the important superconducting properties of MgB_2 is the anisotropy of its upper critical field. Reported values of $\gamma = H_{c2}^{ab}/H_{c2}^{c}$ span between $\gamma \approx 1$ (Ref. 5) and $\gamma = 9-13$.[6] These values were obtained on MgB_2 in different forms and sample quality. For sub-mm single crystallites of magnesium diboride the H_{c2} anisotropy was communicated to be in the range of $\gamma = 1.7-3$.[7–10] Recently the anisotropy of the upper critical field of single crystallites of MgB_2 was studied using torque magnetometry[11] and it was found to be temperature (and applied field) dependent, changing monotonically from $\gamma \approx 2.8$ at 35 K to $\gamma \approx 6$ at 15 K. It has to be mentioned that while these results[11] have an advantage of being obtained by *direct* measurements on small single crystals, the state-of-the-art single crystals[7–12] have their T_c lower ($|\Delta T_c| \gtrsim 1$ K) than that of good polycrystalline samples[13–15] and also have rather moderate values of residual resistivity ratio: $RRR \approx 5-7$ for crystallites as opposed to $RRR \approx 20$ for high-purity polycrystalline samples.

Temperature-dependent γ implies a breakdown of the standard anisotropic Ginzburg-Landau theory with a temperature and field independent effective-mass anisotropy. Temperature-dependent anisotropy of H_{c2}, $\gamma(T)$, has been observed in a number of materials[16–20] and was found to depend on the form and purity of the material. Since establishing the intrinsic anisotropy of the upper critical field for MgB_2 and its temperature dependence is of importance for understanding of the properties of this material, we will present an alternate evaluation of the $\gamma(T)$ behavior in a wide temperature range (1.8–35 K) for samples with optimal $T_c = 39.2-39.4$ K and high residual resistivity ratio ($RRR \gtrsim 20$). The drawback of the approach is that the results are inferred from analysis of the measurements on polycrystalline material, however, this analysis is robust enough to reflect the intrinsic anisotropic properties. In a recent communication[21] we presented anisotropic H_{c2} data for $T \gtrsim 25$ K and extracted a value of $\gamma(25\text{ K}) \approx 6$. In this paper we extend these data so as to determine the full $\gamma(T)$ plot.

Anisotropic $H_{c2}^{min}(T)$ and $H_{c2}^{max}(T)$ data for $T \geqslant 25$ K obtained from the analysis of the temperature-dependent magnetization of randomly (continuously) oriented MgB_2 powders are readily available from Ref. 21. Applying the qualitative arguments used in Ref. 21 for $M(T)|_H$ data to magnetization isotherms, $M(H)|_T$,[22] one would expect to detect an anomaly at H_{c2}^{min}. As in the $M(T)|_H$ case the feature should be present for any continuous (but not necessary random) distribution of grains. Some theoretical discussion, albeit with additional approximations, related to the anomaly in second derivative of $M(H)|_T$ was presented more than a decade ago[23] in relation to high-temperature copper oxide superconductors. In the case of MgB_2 (sintered sample similar to the one used in Ref. 21) the anomaly in the second derivative is clearly seen (see inset to Fig. 1). The temperature-dependent $H_{c2}^{min}(T)$ data between 1.8 K and 35 K was obtained by monitoring this feature at different temperatures (see Fig. 1). The results deduced from the magnetization data taken along different lines in the H-T space are consistent.

Upon application of $H \geqslant H_{c2}^{max}|_T$ all grains in a polycrystalline sample become normal, i.e., $H_{c2}^{max}(T)$ coincides with $H_{c2}(T)$ measured on a polycrystal. Since the polycrystalline H_{c2} is very similar for our sintered pellets[24] and wire segments,[15,25] we will use the $H_{c2}(T)$ data for wire

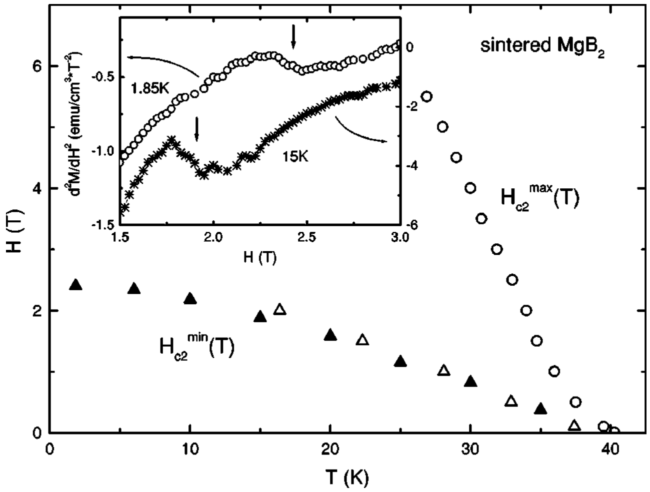

FIG. 1. Anisotropic $H_{c2}(T)$ curves for sintered MgB_2. Open symbols; from $M(T)|_H$, filled triangles; from $M(H)|_T$. Inset: examples of features in smoothed d^2M/dH^2 curves, H_{c2}^{min} are marked with arrows.

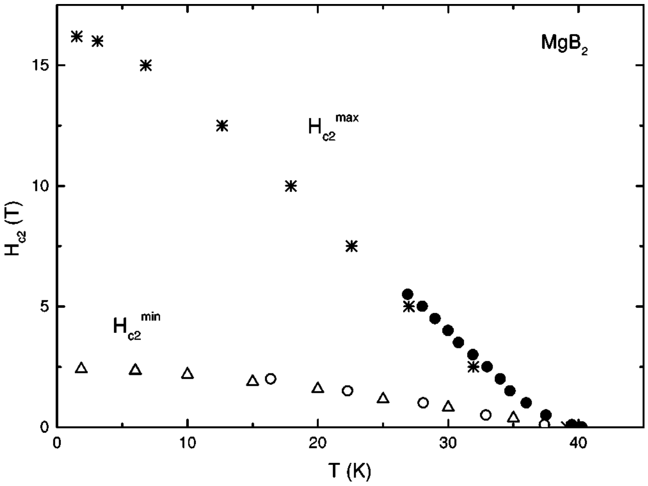

FIG. 2. Combined anisotropic H-T phase diagram for MgB$_2$. Symbols: circles (open and filled); from $M(T)|_H$ (Ref. 21), triangles; from $M(H)|_T$, asterisks; from polycrystalline $H_{c2}(T)$ (Ref. 25).

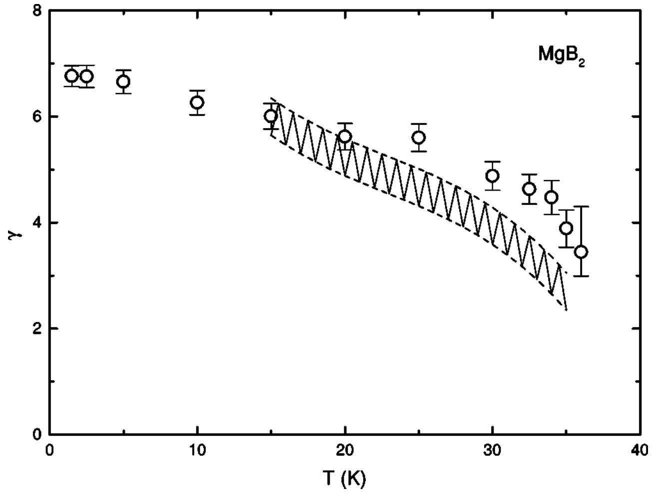

FIG. 3. Temperature-dependent anisotropy of the upper critical field. The range of data from Ref. 11 is shown as a hatched area between dashed lines for comparison.

segments[25] as an approximation for $H_{c2}^{max}(T)$ below 25 K. The data are consistent with the results obtained by analysis of $M(T)|_H$ curves[21] in the shared temperature region (above 25 K). The combined H-T phase diagram for a whole temperature range is presented in Fig. 2. The anisotropy of H_{c2}, $\gamma(T)$, is straightforwardly determined from this phase diagram.

Temperature-dependent anisotropy of the upper critical field of magnesium diboride inferred from the measurements on polycrystalline samples is shown in Fig. 3 together with the data from Ref. 11. Our data show a similar, but somewhat less pronounced, temperature dependence of the anisotropy: γ changes from 3.5 to 7 with decrease of the temperature from 36 K down to 1.8 K. The fact that the two sets of data are qualitatively similar probably points to the intrinsic character of the observed temperature dependence of $\gamma(T)$.

In conclusion, anisotropy of the upper critical field of high-purity, high-T_c ($T_c \approx 39.2$–39.4 K), and high-RRR ($RRR \geqslant 20$) MgB$_2$ samples is temperature dependent. γ decreases monotonically with increase of temperature from $\simeq 7$ ($T = 1.8$ K) to $\simeq 4$ ($T = 35$ K). The data are qualitatively consistent with the results of the measurements on sub-mm single crystals.[11]

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