Temperature-dependent $H_{c2}$ anisotropy in MgB$_2$ as inferred from measurements on polycrystals

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74.70.Ad, 74.60.Ec

The recent discovery 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 the anisotropy of its upper critical field. Re-}

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Temperature-dependent $\gamma$ 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 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 we presented anisotropic $H_{c2}$ data for $T \gtrsim 25$ K and extracted a value of $\gamma(25$ K) $\approx 6$. In this report 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 $T \gtrsim 25$ K obtained from the analysis of the temperature-dependent magnetization of randomly (continuously) oriented MgB$_2$ powders are readily available from Ref. 22. Applying the qualitative arguments used in Ref. 22 for $M(T)|_{T_d}$ data to magnetization isotherms, $M(H)|_{T_d}$ 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 $M(H)|_{T_d}$ was presented more than a decade ago and in relation to high temperature copper oxide superconductors. In the case of MgB$_2$ (sintered sample similar to the one used in Ref. 22) 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 the 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 $H \geq H_{c2}^{max}$ 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 and wire segments we will use the $H_{c2}(T)$ data for wire segments 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 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. 2 together with the data from Ref. 22. Our data show a similar, but somewhat less pronounced, temperature dependence of the anisotropy: $\gamma$ 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 $RRR$ ($RRR \geq 20$) MgB$_2$ samples is temperature dependent. $\gamma$ 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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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 $\frac{d^2M}{dH^2}$ curves, $H_{c2}^{\text{min}}$ 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 $M(H)|T$, astericks - 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.