Specific heat of ceramic and single crystal MgB_2

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Abstract

The two–gap structure of MgB_2 gives rise to unusual thermodynamic properties which depart markedly from the single–gap BCS model, both in their temperature– and field–dependence. We report measurements of the specific heat up to 16 T on ceramic and single crystal samples, which demonstrate these effects in bulk. The low–temperature mixed–state specific heat reveals a field–dependent anisotropy, and points to the existence of unusually large vortices, in agreement with local density–of–states measurements by scanning tunneling spectroscopy. It is finally shown that a suitable irradiation process nearly doubles H_{c2} in the bulk.

Key words:
MgB_2; specific heat; single crystal; irradiation

1. Introduction

The two–gap model to explain the unusual superconducting properties of MgB_2, first introduced theoretically [1,2], soon found wide support, in particular from bulk determinations based on the specific heat (C) [3,4]. Figure 1 shows the large excess specific heat at $T \ll T_c$ which is the signature of the smaller gap Δ_π on the π–band, the reduced jump at T_c associated with the larger gap Δ_σ on the σ–band, and the excellent fit given by the two–gap model with $\Delta_\sigma/\Delta_\pi \approx 3$ [3,4]. The smaller gap defines both a new temperature scale below T_c ($T_c^\pi \approx 10$ K) and and a new field scale below H_{c2} ($H_{c2}^\pi \approx 0.4$ T) at which a large fraction of the π–band carriers become normal, thus giving rise to a fast increase of C/T followed by a saturation at a value that represents the contribution of the π–band DOS, $\approx \gamma_N/2$ (Fig. 2). This is consistent with recent STS data [5]. The thermodynamics of the π–band carriers differs so much from the classic behavior above the crossovers T_c^π or H_{c2}^π, that for this subset we may talk about "superconductivity above T_c" or "above H_{c2}".

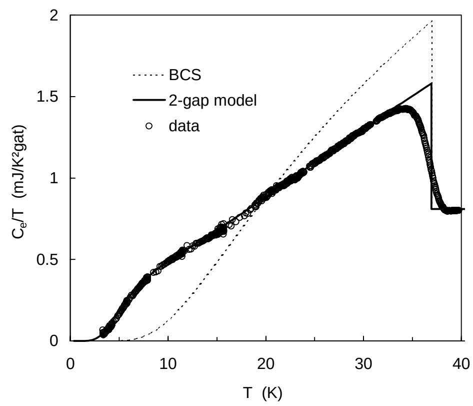

Fig. 1. Electronic specific heat of polycrystalline MgB_2 in zero field, one–gap BCS curve, and two–gap fit [3,4]. The upper critical field for this sample ("pristine sample" of Fig. 4) is $\approx$ 14 to 16 T [4].

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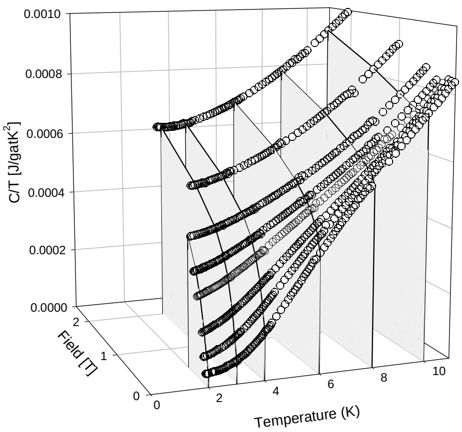

Fig. 2. Total specific heat of polycrystalline MgB_2 at low temperature in fields 0, 0.05, 0.1, 0.2, 0.3, 0.5, 1, and 2 T.

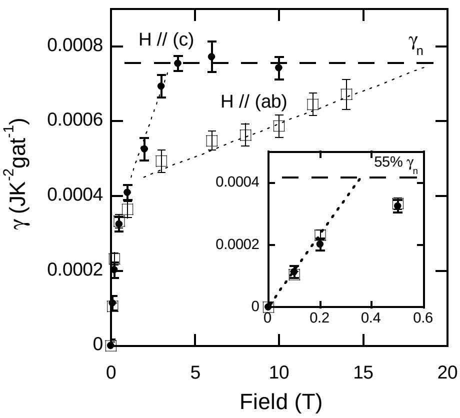

Fig. 3. Coefficient of the mixed–state linear term of the electronic specific heat of single crystal MgB_2 versus field and orientation.

2. Single crystal results

The specific heat of a 39 μg MgB_2 single crystal was measured as a function of $H \parallel (c)$ and $H \parallel (ab)$ near 2–3 K, thus detailing the orientation dependence of H_{c2} [6]. We find that the contribution of the smaller gap is isotropic, and saturates at $\approx 55\%$ of γ_N in the vicinity of $H_{c2}^{\pi} \approx 0.4$ T (Fig. 3 and inset). Beyond this point, the physics depend on the larger gap, since superconducting carriers remaining in the condensate mainly originate from the σ–band. For those carriers, we obtain an anisotropy $\approx 5-6$, as shown by the construction defining the upper critical fields $H_{c2}^{(c)} \approx 3.5$ T and $H_{c2}^{(ab)} \approx 19$ T in Fig. 3. Note that the ratio $H_{c2}^{(ab)}/H_{c2}^{(c)}$ depends on the anisotropy of the Fermi velocity within the σ–band, whereas the ratio $H_{c2}^{(c)}/H_{c2}^{\pi}$ depends on the ratio $(\Delta_\sigma/\Delta_\pi)^2$. These anisotropies are constant in our model, but may appear as one H– and T–dependent effective anisotropy.

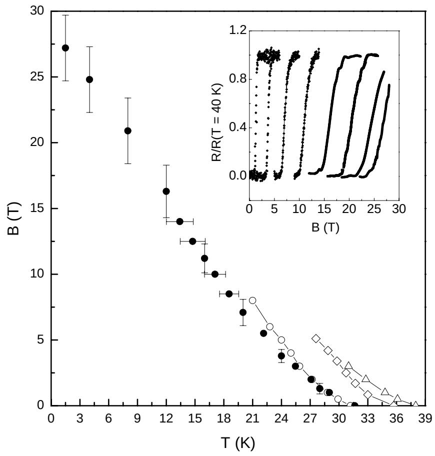

Fig. 4. Upper critical field versus temperature for polycrystalline MgB_2. Onset of the C jump for the pristine sample (△) and after one (◇) and two irradiations (○). (●): midpoint of resistance transitions (see inset) after the second irradiation.

3. Effect of irradiation

Theory predicts that interband scattering will lower T_c down to the point where both gaps merge into a single one; this should occur when $T_c \approx 27$ K [2]. We have studied this effect on polycrystals, and confirm that Δ_σ/Δ_π decreases after irradiation by fast neutrons [7]. However, the smaller gap remains more robust than expected, and Δ_σ/Δ_π still is ≈ 2.1 when $T_c = 30$ K, with almost unchanged weights. Note a remarkable increase of $H_{c2}^{(ab)}(0)$ by a factor of almost two in the disordered state, compared to the pristine sample (Fig. 4).

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