Temperature and field dependence of MgB_2 energy gaps from tunneling spectra

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Abstract

We have synthesized MgB_2/Pb planar junctions to study the temperature and field dependence of the superconducting energy gap of MgB_2. The major peak occurs at Δ of about 2 meV, and this corresponds to a $2\Delta/k_BT_c$value of 1.18. While this is significantly smaller than the BCS weak coupling value, there are features in the tunneling spectra indicating the possibility of another larger gap. By fitting the dI/dV curves with a simple model, the larger gap is estimated to be about 4.5 times the smaller gap. The temperature dependence of both gaps is BCS-like, and start to open up at temperatures just below T_c (39.5 K). This confirms that these gaps are indeed bulk properties of MgB_2. The junction is stable only up to a field of 3.2T then "collapsed" into Josephson tunneling for higher fields.

Key words: superconductivity; tunneling; energy gap; Josephson effect; MgB_2

1. Introduction

One interesting feature in the superconductivity of MgB_2 (T_c = 40 K) [1] is the possibility of coexistence of two energy gaps. This immediately leads to many intriguing questions, like whether the two gaps follow Δ_{BCS}(T) and share the same critical temperature. There have been numerous tunneling spectroscopic studies to investigate this phenomenon at low temperatures. Most of these studies are performed with scanning tunneling microscope [2] or point contact [3]. To provide the needed stability for temperature and field dependence studies, we have synthesized planar tunnel junctions on bulk MgB_2 [4] with Pb as the counter electrode.

2. Results and discussion

As indicated in figure 1, the major peak (Δ_1) in most of our junctions occurs consistently around 2 meV. This is significantly smaller than the BCS value. The second gap (Δ_2) appears as a small feature at around 9 meV. For conductance curves when Pb is normal, we can fit the data with a simple model by mixing two BCS density of states (with energy gaps Δ_1 and Δ_2) at a ratio of C. A depairing term Γ is introduced to account for different depairing effects, and barrier strength Z is also included to account for the zero bias offset by Andreev reflection [5]. Thermal broadening is included at the particular temperature of the fitting. C, Γ, and Z are determined by the curve at temperature = 7.78 K above Pb $T_c \approx 7.2$ K. They have the best fitted values of 0.064, 0.95 meV, and 1.33 meV respectively. These values are then fixed for all subsequent fittings at higher temperatures. Δ_1 and Δ_2 are the only adjustable parameters for higher temperature curves.

The temperature dependence of the two energy gaps is shown in the right insert of figure 1. It is clear that both energy gaps follow a BCS-like behavior and both gaps survive up to the bulk T_c of MgB_2. From this we can conclude that the commonly observed small energy gap is not a result of surface degradation, but a true bulk property of MgB_2. $\Delta_1(0)$ and $\Delta_2(0)$ are 1.8 meV and 8.2 meV respectively, and the ratio Δ_2/Δ_1

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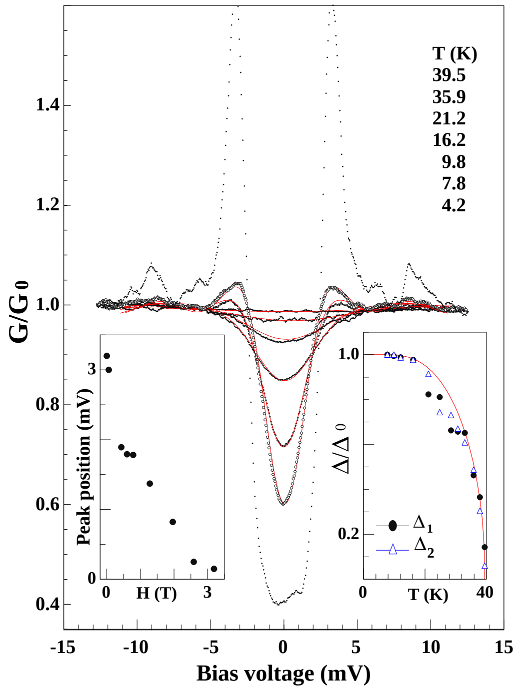

Fig. 1. Temperature dependence of the normalized conductance. The lowest curve at 4.2 K is SIS tunneling, while the others are SIN tunneling. Solid lines are the best fitted curves from which Δ_1 and Δ_2 are determined. Right insert: Temperature dependence of Δ_1 and Δ_2. Δ_0 is the gap value at 7.78 K. Left insert: Field dependence of the major peak position.

is about 4.5 through out the temperature range. This ratio is close to both the theoretically predicted [6] and experimentally suggested [7] values.

The left insert in figure 1 shows the field dependence of the major peak position at 4.2 K. At low fields, this corresponds to the sum of Pb gap (Δ_{Pb}) and Δ_1. It can be seen that there is a discontinuity in the peak position at the critical field of Pb ($H_c(0) \approx 0.08T$), when Pb ceases to be superconducting. The peak position corresponds to Δ_1 at all higher fields. At a field of about 3.2 T most of our junctions "collapse" into Josephson tunneling and the change is not reversible.

The behavior of one of these Josephson junctions is shown in figure 2. The Josephson tunneling is between MgB_2 and Pb. The normal resistance (R_N) varies only very slightly with temperature. I_cR_N is estimated to be about 2.1 mV (insert, Fig. 2) for the curve at 4.2 K. If we assume $I_cR_N \approx \frac{\pi}{e}\frac{\Delta_1\Delta_{Pb}}{\Delta_1+\Delta_{Pb}}$ and $\Delta_{Pb}(at 4.2K) \approx$ 1.08 meV, we can estimate Δ_1 to be 1.75 meV. This is consistent with our result from the quasiparticle tunneling discussed above.

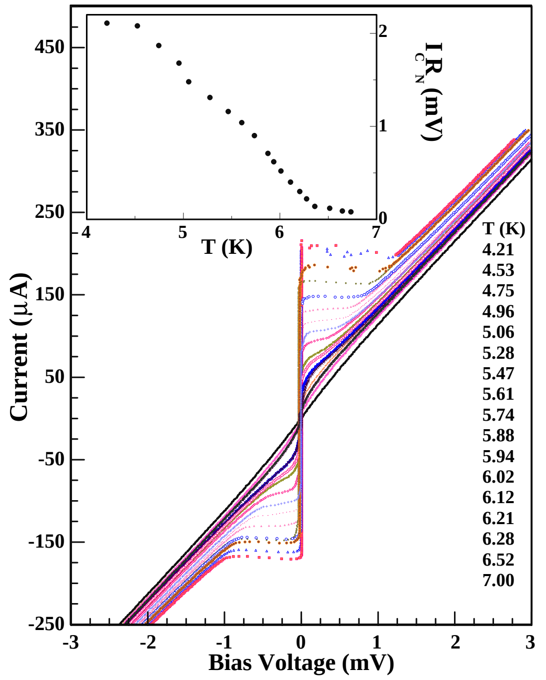

Fig. 2. Josephson tunneling at different temperatures. The listed temperatures are in the same order as the cruves presented. Insert: $I_cR_N vs. T$.

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