Point-contact spectroscopy of MgB_2 in high magnetic fields

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Abstract

The point-contact spectroscopy data reveal the existence of two distinct superconducting energy gaps in the Andreev reflection of quasiparticles between MgB_2 and a copper counterelectrode. Above the gap energies reproducible nonlinearities are observed at the characteristic phonon energies of MgB_2. The strength and position of the observed nonlinearities due to the electron-phonon interaction do not reveal any renormalization when the point contact undergoes the transition from the superconducting to the normal state.

Key words: Point-contact spectroscopy; MgB_2; two-band superconductivity; electron-phonon interaction

After more than a year of intensive studies of the superconductivity in MgB_2 experimental results converge to a model of the superconducting state with a multiband electronic structure, proposed by Liu *et al.* [1]. The existence of two superconducting energy gaps in the excitation spectrum has been experimentally evidenced by different techniques [2,3]. Moreover, these density-functional calculations of Liu *et al.* [1] predict an anisotropy in the electron-phonon interaction (EPI) mediating superconductivity, with strongly anharmonic coupling between the E_{2g} phonons near 60 meV and the 2D Fermi sheets ($p_{x,y}$ orbitals) with the large superconducting energy gap Δ_L. Accordingly, the transition to the superconducting state in MgB_2 is supposed to be accompanied with 12 % hardening of this mode. The phonon density of states (PDOS) of MgB_2 has been observed by neutron scattering experiments [4] up to energies of 100 meV. In the point contacts revealing clearly two superconducting gaps we study the electron-phonon interaction as seen in nonlinearities in the current-voltage characteristics $d^2V/dI^2(V)$.

In our previous work [3] on point-contact spectroscopy in MgB_2 we have shown in a direct way the presence of two superconducting energy gaps closing at the same bulk T_c, supporting the two-band model of superconductivity in MgB_2. The measurements here presented have been performed on polycrystalline MgB_2 samples from the same batch with $T_c = 39.3$ K. A standard lock-in technique at 400 Hz was used to measure the differential resistance $dV/dI(V)$ and second derivative $d^2V/dI^2(V)$ as a function of applied voltage on the point contacts. The microconstrictions were prepared by pressing a copper tip on the freshly polished surface of the superconductor with a special approaching system.

Typical examples of the point-contact spectra obtained for various Cu-MgB_2 point contacts are shown on Figure 1. The spectrum 1 reveals a clear two-gap structure with $\Delta_S = 2.8$ meV for the small gap on the 3D sheets of the Fermi surface (FS) and $\Delta_L = 7$ meV for the large one on the 2D sheets. The contribution from the 2D FS is diminished in spectrum 2 and almost not present in curve 3. Only the point-contact current flowing to the *ab* planes of MgB_2 can probe the large gap. It is only randomly present in the measurements on polycrystals. The MgB_2 point contact spectra can be quantitatively described by the sum of the two point contact conductances (BTK model, for details see [3])

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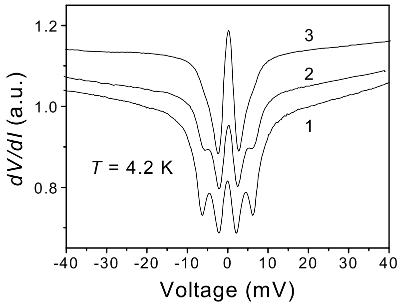

Fig. 1. $dV/dI(V)$ spectra of the Cu-MgB_2 contacts with different weights of the two superconducting gaps.

due to the 3D and 2D FS sheets, respectively. Approximatively, the small (large) gap can be estimated from the half distance between the first (second) minima around the zero bias in the $dV/dI(V)$ spectrum. We note also a linearly increasing bacground in all three presented spectra - typical feature of the point contacts with more direct than tunneling conductance. All that suggests a good quality of the contacts with a ballistic transport of the current.

As reviewed by Yanson in Ref.[5] the point-contact spectroscopy is capable to study the electron-phonon interaction in superconductors either via inelastic quasiparticle scattering on phonons (similarly to the classical point-contact spectroscopy on normal metals), or via the energy dependent superconducting energy gap present in the elastic component of the excess current (due to the Andreev reflection on the boundary between the superconductor and normal metal). The latter mechanism prevails in the strong coupling superconductors and is analogous to the tunneling spectroscopy. The first mechanism requires clean ballistic contacts and reveals about the same spectrum in the superconducting as well as in normal state. In both mechanisms the second derivative of the $I - V$ curves $d^2V/dI^2(V)$ is proportional to the electron-phonon interaction (EPI) function.

Figure 2 shows the d^2V/dI^2 spectra of the point contact 2 from Fig. 1 with significant two gap features. Now the spectra are shown in a voltage (energy) scale up to 120 mV. They were measured below and above the superconducting transition $T_c(H)$. The top panel shows d^2V/dI^2 curves measured in a fixed magnetic field of 9 Tesla at different temperatures. The bottom panel displays field dependencies of d^2V/dI^2 curves at a fixed temperature of $T = 30$ K. The dotted lines in both panels represent the spectra in the normal state (see $H-T$ diagram in [6]). All spectra show nonlinearities up to 120 mV. Namely, we have observed smeared maxima near 15 and 35 mV, a more pronounced peak at 60 mV and two broadened peaks at 80 and 90 mV.

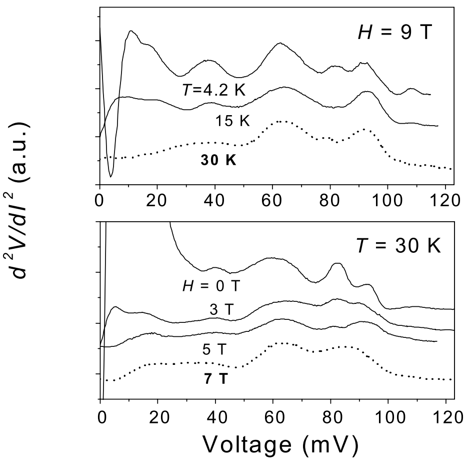

Fig. 2. Point-contact spectra $d^2V/dI^2(V)$ measured at different temperatures and magnetic fields below and above the superconducting transition (dotted lines).

Similar point-contact spectra have been measured in the superconducting state by Bobrov et al. [7]. The nonlinearities shown in Fig. 2 are positioned at energies in agreement with the phonon density of states data [4]. Nevertheless, we have not observed the predicted significant increase of the electron-phonon interaction of the 60 meV peak compared with the other phonon modes. Moreover, there is no change of the position and intensity of the EPI structure when the contact is driven to the normal state by increasing temperature and magnetic field. Similar behavior has been observed on another contacts with a smaller contribution of the large gap. We note that Raman studies [8] have also not seen any hardening of E_{2g} mode below T_c.

In conclusion, our results do not indicate particularly strong EPI to any phonon mode in MgB_2. Further investigations, particularly on the single crystals, are needed.

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