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Point Contact Spectroscopy Measurements of $Ba(Fe_{0.96}Co_{0.04})_2As_2$ Single Crystals

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Point contact spectroscopy results are presented on the electron underdoped $Ba(Fe_{0.96}Co_{0.04})_2As_2$ single crystals. Two superconducting energy gaps with coupling values $2\Delta_1 \sim kT_c \approx 2.55$ and $2\Delta_2 \sim kT_c \approx 11$ at $T_c = 15.5$ K have been observed in the point contact spectra. The temperature dependence of the normal state background of the point contact spectra observed between T_c and T_N indicates antiferromagnetic origin of the V-shaped minimum at zero bias.

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1. Introduction

Superconductivity in the pnictides, similarly to the cuprates is obtained by doping a parental antiferromagnetic material. The highest $T_c \approx 55$ K is obtained in the optimally doped REFeAsO(F), with RE = Gd, Nd or Sm. Another group is the structurally simpler and less anisotropic AFe_2As_2 with A = Ba, Sr and Ca [1]. The multiband superconductivity with interband interactions leading to an exotic *s*-wave pairing with a sign reversal of the order parameter between different Fermi surface sheets [2] stands among the hot candidates to explain the high-T_c superconductivity in pnictides. Very important issues are the value and the symmetry of the superconducting energy gap(s). After two years it seems that the situation in the hole-doped $Ba_{1-x}K_xFe_2As_2$ is well resolved. Most of the measurements including our point contact spectroscopy [3] agree on the existence of multiple nodeless gaps in the excitation spectrum. The gaps have two sizes — the small one with a strength up to the BCS weak coupling limit and the large one with a very strong coupling with $2\Delta/k_BT_c > 6$–8. In the electron doped $Ba(Fe_{1-x}Co_x)_2As_2$ systems contradicting results are published [4–6]. The most of the experiments including ours [4] find only a single gap with a strong coupling strength in optimally doped $Ba(Fe_{0.3}Co_{0.7})_2As_2$ samples.

In this paper our recent point contact spectroscopy results are presented on the electron underdoped $Ba(Fe_{0.96}Co_{0.04})_2As_2$ single crystals with $T_c = 15$ K [7]. We investigated the evolution of the point contact Andreev-reflection (PCAR) spectra up to temperatures near T_N which is about 47 K for our sample [7].

The point contact spectra measured between a normal metal and a superconductor consists of the Andreev reflection contribution and the tunneling contribution. At $T = 0$ due to the excess current of PCAR the conductance inside the gap is twice higher than the value outside. The tunneling contribution yields a peak at the gap edge and a reduced conductance inside. PCAR conductance can be compared with the Blonder–Tinkham–Klapwijk (BTK) model [8] using as input parameters the energy gap Δ, the parameter z (measure for the strength of the interface barrier) and a parameter Γ for the spectral broadening. For a multigap superconductor the PC conductance can be expressed as a weighted sum of partial BTK conductances.

2. Results

Typical PCAR spectra obtained on Pt–$Ba(Fe_{0.96}Co_{0.04})_2As_2$ heterocontacts at $T = 4.2$ K are shown in Fig. 1 by solid lines. The spectra 1 and 2 reveal double enhanced conductances at energies ∓ 7 mV and below ∓ 2 mV. These features, typical for two-gap superconductors have been observed in the both principal *c*- and *ab*-crystallographic directions. The spectra 1 and 2 are normalized to their respective normal state forms and fitted to the two-gap BTK model (open symbols) with the resulting gap values: $\Delta_1 \approx 2$ meV and $\Delta_2 \approx 9$ meV (curve 1) and $\Delta_1 \approx 1.8$ meV and $\Delta_2 \approx 7.3$ meV (curve 2) determined at a rather poor spectral resolution due to the high values of the smearing parameters $\Gamma_1 \sim \Delta_1$ and $\Gamma_2 \sim 0.5\Delta_2$. The weight of the contribution of the band with a small gap to the overall BTK conductance was $\alpha \approx 0.3$ for the both curves. The enhanced PCAR spectra with peaks at the superconducting gap(s) have been observed only in the highly transparent contacts ($z \to 0$), and this structure occurred on a strongly temperature dependent and asymmetric V-shaped background (Fig. 2a). On the majority of the contacts in *c*-direction only a V-shaped background has been observed (curve 3).

Figure 2 shows the temperature dependence of the spectrum 2 from Fig. 1. The main part (a) shows the raw data without normalization. The temperature dependence of the zero-bias conductance (ZBC) of the PC spectra is plotted in Fig. 2b. At increased temperatures the suppression of the two-gap structure is accompanied by deepening of the V-shaped background at zero bias.

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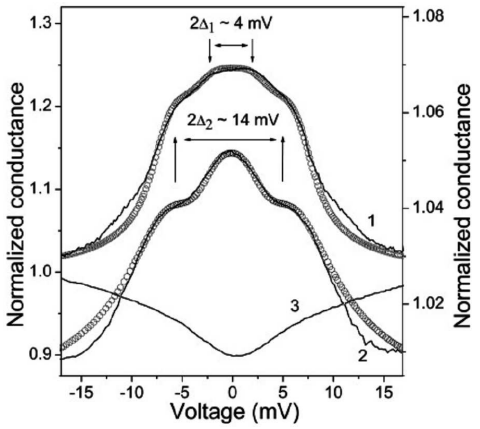

Fig. 1. PCAR spectra measured on Pt–$Ba(Fe_{0.6}Co_{0.4})_2As_2$ (solid lines) heterocontacts at 4.2 K. Spectra 1 (left scale) and 2 (right scale) are normalized to their respective normal state and fitted to the two gap BTK model (symbols). Curve 3 plots a V-shaped conductance measured typically in c-direction.

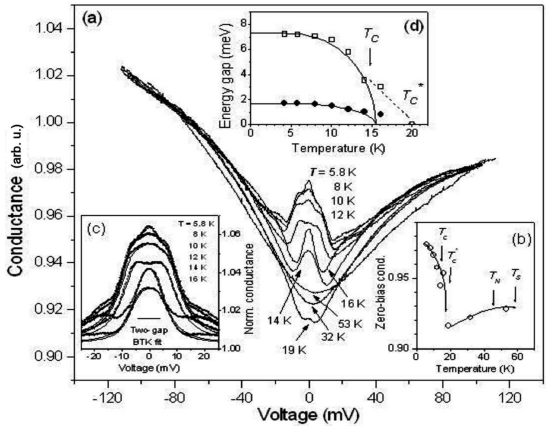

Fig. 2. (a) Temperature dependence of the spectrum 2 from Fig. 1 (lines) measured up to $T = 53$ K. (b) Temperature dependence of the zero bias conductance. The arrows indicate critical temperatures of the superconducting and magnetic transitions. (c) Temperature dependence of the PCAR spectra normalized to the spectra measured at $T = 19$ K — solid lines. Fits to the two-band BTK model — symbols. (d) The temperature dependences of Δ_1 and Δ_2 from fitting — symbols. BCS type $\Delta(T)$ dependences — lines.

Afterwards at $T \approx 19$ K the superconductivity is suppressed and the minimum at zero bias is smeared and filled smoothly up to $T \approx 50$ K, where a saturating tendency is visible. In $Ba(Fe_{0.96}Co_{0.04})_2As_2$ the superconducting transition is followed by the antiferromagnetic/paramagnetic (AFM/PM) one at $T_N \approx 47$ K and at $T_s \approx 60$ K by the structural transition [7]. The presence of these transitions can be followed on the temperature dependence of ZBC (arrows in Fig. 2b). Thus, the V-shape background of the PCAR spectra can be a spectroscopic reflection of a reduced DOS due to the AFM gap. Figure 2c shows the spectra from the main part after their normalization to the spectrum measured at $T = 19$ K (lines). Fitting curves for the two-gap BTK model are shown by symbols. During the fits the parameters α, Γ and z have been kept constant. Figure 2d shows the resulting temperature dependence of Δ's by symbols. When comparing our data points with the BCS-type $\Delta(T)$ dependence (lines) one can see that T_c should be around 15–16 K, in agreement with the bulk resistivity measurements [7], but instead of that the gaps are still present up to about 19 K. This is probably due to a proximity of a minority phase with higher T_c.

3. Conclusions

We can conclude that the underdoped $Ba(Fe_{0.96}Co_{0.04})_2As_2$ pnictide appears as the multiband systems with two superconducting energy gaps which corresponds to the coupling strengths of $2\Delta_1/kT_c \approx 2.6$ and $2\Delta_2/kT_c \approx 11$ with $T_c = 15.5$ K. Although the s-wave two-gap BTK formula has been successfully used to fit our PC data due to small spectral resolution the possibility of an unconventional pairing symmetry cannot be completely ruled out.

Acknowledgments

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