Thermal conductivity of overdoped $BaFe_{1.73}Co_{0.27}As_2$ single crystal: Evidence for nodeless multiple superconducting gaps and interband interactions

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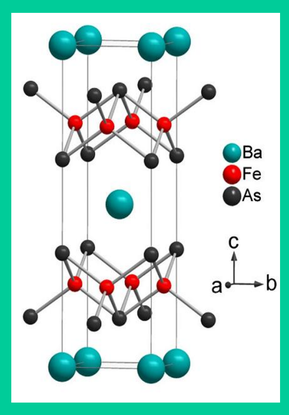
Abstract

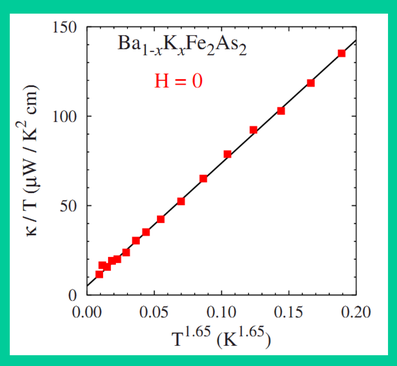
The in-plane thermal conductivity of overdoped iron-arsenide superconductor $BaFe_{1.73}Co_{0.27}As_2$ (T_c = 8.1 K) single crystal was measured down to 80 mK. In zero field, the residual linear term κ_0/T is negligible, suggesting a nodeless superconducting gap in the *ab*-plane. In low magnetic field, κ_0/T increases sharply, very different from conventional *s*-wave superconductors $Ba_{1-x}K_xFe_2As_2$ and $BaFe_{1.9}Ni_{0.1}As_2$ near optimal doping. This anomalous $\kappa_0(H)/T$ may reveals an exotic superconducting gap structure in overdoped $BaFe_{1.73}Co_{0.27}As_2$: the vanishing hole (β) pocket has a much larger gap than the electron (γ and δ) pockets which contain most of the carriers. Such an exotic gap structure is an evidence for superconducting state induced by interband interactions, in which the band with the smaller density of states has a larger gap.

I. Introduction

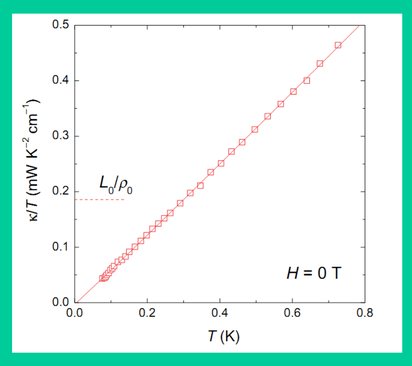


Crystal structures of $BaFe_2As_2$ [1]

- Near optimal doping samples show multiple isotropic nodeless gaps, studied by ARPES and heat transport. [2-4]
- In this work, we measured the overdoped $BaFe_{1.73}Co_{0.27}As_2$ sample to clarify doping evolution of the superconducting gap structure on the electron-doped side of the phase diagram.



$Ba_{1-x}K_xFe_2As_2$ [3]



$BaFe_{1.9}Ni_{0.1}As_2$ [4]

II. Resistivity

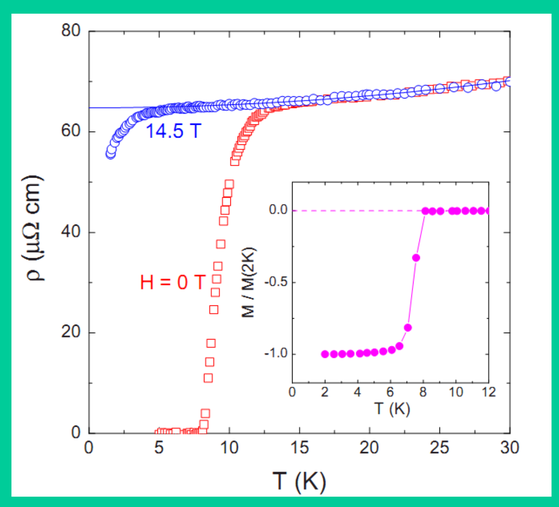


FIG. 1: In-plane resistivity of $BaFe_{1.73}Co_{0.27}As_2$ in H = 0 and 14.5 T. The zero-resistance point of the resistive transition is at T_c = 8.1 K in zero field. Inset: normalized magnetization which shows the diamagnetic superconducting transition.

III. Thermal conductivity

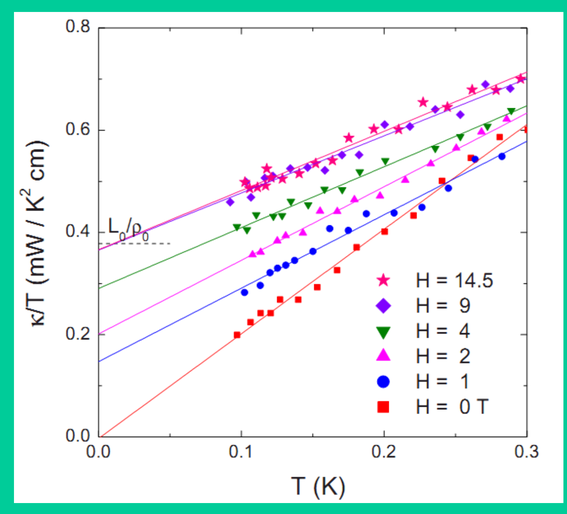


FIG. 2: Low-temperature thermal conductivity of $BaFe_{1.73}Co_{0.27}As_2$ in magnetic fields applied along the *c*-axis (H = 0, 1, 2, 4, 9, and 14.5 T). The solid lines are $\kappa/T = a + bT$ fits. The dashed line is the normal state Wiedemann-Franz law expectation L_0/ρ_0, with L_0 the Lorenz number $L_0 = 2.45 \times 10^{-8}$ W Ω K^{-2}.

IV. Field dependence of thermal conductivity

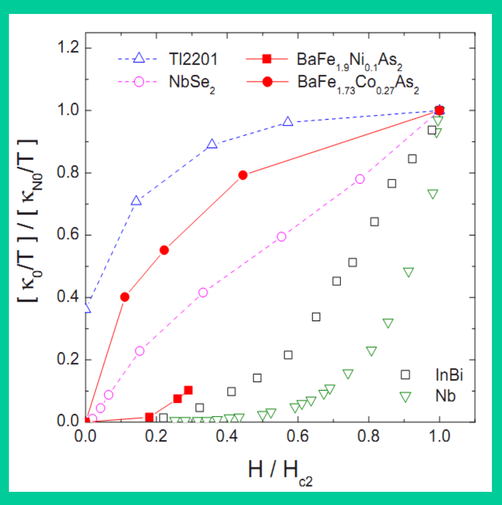
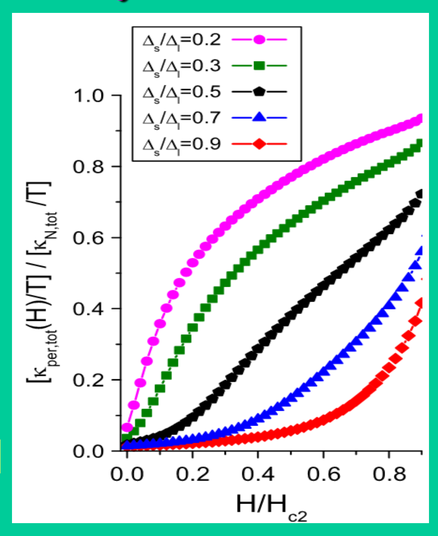


FIG. 3 Normalized residual linear term κ_0/T of $BaFe_{1.73}Co_{0.27}As_2$ as a function of H/H_{c2}. For comparison we also plot Nb (*s*-wave), InBi (dirty *s*-wave), $NbSe_2$ (multi-band *s*-wave), Tl-2201 (*d*-wave) and $BaFe_{1.9}Ni_{0.1}As_2$.

FIG. 4 A calculation of normalized κ_0/T for different gap size ratios. [5] →



- Multi-band *s*-wave $NbSe_2$: the gap on the Γ band is ~1/3 of the gap on the other two band and H first suppresses the superconductivity on the Fermi surface with smaller gap. The even sharper increase in $\kappa_0(H)/T$ in $BaFe_{1.73}Co_{0.27}As_2$ may result from an extreme case of multigap structure, in which the gap of one band is much smaller than others (e.g., 1/4 or 1/5).
- Based on this trend of band-structure evolution from ARPES, there should be a very small hole (β) pocket, together with two large electron (γ and δ) pockets which contain most of the carriers in $BaFe_{1.73}Co_{0.27}As_2$ sample.
- We note a recent calculation of $\kappa_0(H)/T$ with unequal size of isotropic *s*-wave gaps has successfully fit the experimental data and supports our interpretation. [FIG. 4]

IV. Summary

We have used low-temperature thermal conductivity to clearly demonstrate nodeless superconducting gap in overdoped iron-arsenide superconductor $BaFe_{1.73}Co_{0.27}As_2$.
The $\kappa_0(H)/T$ increases sharply at low field and may reveal an exotic superconducting gap structure : the vanishing hole (β) pocket has a much larger gap than the electron (γ and δ) pockets, although the electron pockets have much larger density of states. Such an exotic gap structure is an evidence for the theory of interband superconductivity, thus of great importance to understand the superconducting state in FeAs-based superconductors.

References:

[1] M. Rotter *et al.*, Phys. Rev. Lett. 101, 107006 (2008).
[2] H. Ding *et al.*, EPL 83, 47001 (2008).
[3] X. G. Luo *et al.*, Phys. Rev. B 80, 140503(R) (2009).
[4] L. Ding *et al.*, New J. Phys. 11, 093018 (2009).
[5] Y. Bang, Phys. Rev. Lett. 104, 217001 (2010).

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