Doping-induced change in the interlayer transport mechanism of Bi-2212

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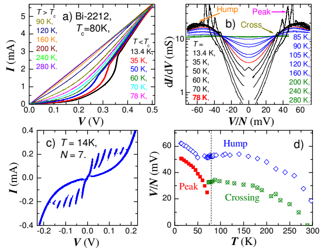
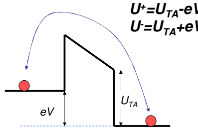
Characteristic features of intrinsic tunneling characteristics: Peak, Hump, Crossing point



Thermal-Activation analysis

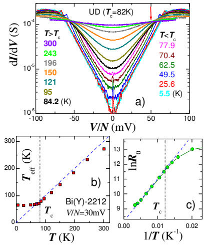


$$I_{TA} \propto n(T)\, e^{-U_{TA}/k_BT} \sinh\frac{eV}{2k_BT}$$

$$\frac{\mathrm{d}I}{\mathrm{d}V}(T,V) \propto \frac{n(T)}{T}\, e^{-U_{TA}/k_BT} \cosh\frac{eV}{2k_BT}$$

at finite bias: the slope of ln(d*I*/d*V*)] ~e/2k_BT
at zero bias: R_0 / *T* ~exp[U_{TA}/k_BT]

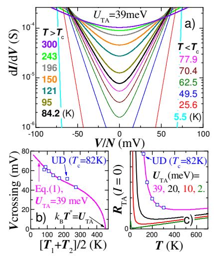
Crossover from thermal activation – to – quantum tunneling transport at Tc in underdoped Bi-2212



Below Tc:
the curves remain parallel, but the energy scale decreases

Above Tc:
the slope monotonously decreases with T, but the energy scale remains constant

Comparison with numerical simulations:

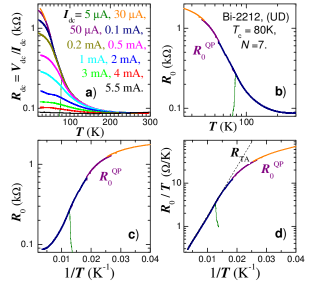


n(T) **= const**

Reproduces dI/dV at *T* > T_c, without fitting parameters

- $R_0(T)$
- the slope of d*I*/d*V*(*V*)
- the crossing point

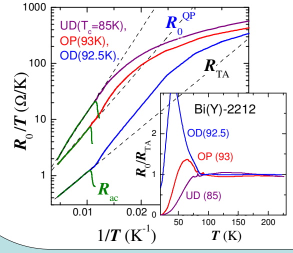
Analysis of zero-bias resistance



d-wave gap: power law?

Pure Thermal Act. Arrhenius law

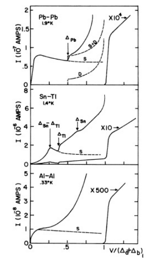
Observation of the excess/negative quasiparticle resistance in the superconducting state



- OD: excess QP resistance at *T*<T_c, consistent with single QP tunneling

- UD: negative excess QP resistance at *T*<T_c ⇨ pair tunneling contribution

Multi-particle tunneling

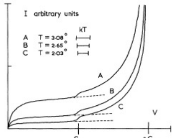


creases rapidly with *V*. On subtracting the theoretical SPT curves from the experimental curves at various temperatures, we find that this excess current is temperature independent and that it actually varies exponentially with *V*.

B.N.Taylor and E.Burstein, Excess currents in electron tunneling between superconductors. Phys.Rev.Lett. 10 (1962) 14

FIG. 1. Current-voltage curves for Pb-Pb, Sn-Tl, and Al-Al. The solid lines represent the experimental data and the dashed lines marked S represent theoretical SPT curves. For Pb-Pb, the theoretical DPT curve, marked D, and the sum of the SPT and DPT curves, marked S+D, are shown also.

FIG. 1. Tunneling in a Pb-Pb junction showing the temperature independence of the two-particle contribution. Currents below $V = 4\epsilon_{Pb}$ have an exponential dependence on temperature and are due to thermally excited electrons only.



C.J.Adkins
Multi-particle tunneling between superconductors, Rev.Mod.Phys. 36 (1964) 211

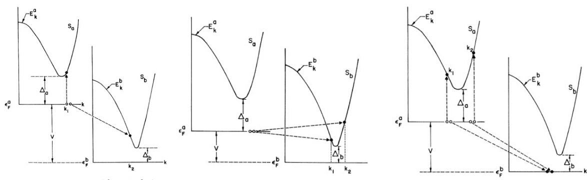


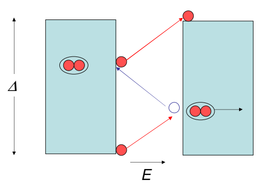
FIG. 1. Schematic quasi-particle spectra for two superconductors illustrating conventional single-particle tunneling.

FIG. 2. Two processes contributing to the double-particle tunneling process between two superconductors.

J.R.Schrieffer and J.W.Wilkins, Two-particle tunneling processes between superconductors. Phys.Rev.Lett. 10 (1962) 17

Elastic process, Cooper pair dissociation

Multiple Andreev reflection



E.N.Bratus', et al., Phys.Rev.Lett. 74 (1995) 2110

Inelastic traversing of the gap:

Incoherent: *I* ~ V^a

Coherent: assisted by time-dependent phase difference due to AC - Josephson effect: *I ~ exp(bV).*

Disappears at T_c together with the phase coherence

Conclusions

We observed a remarkable crossover at T_c in interlayer transport of underdoped Bi-2212: from Thermal-Activation type at *T*>T_c to Quantum Tunneling type at *T*<T_c.

Surprisingly, the crossover is most pronounced in UD-Bi2212 with smooth and featureless superconducting transition.

Our data indicate that not only the electronic structure, but also the c-axis *transport mechanism* changes with doping: from coherent and directional *single* QP tunneling in overdoped, to progressively increasing *pair* contribution in underdoped Bi-2212.

The latter is apparent only in the phase coherent state at *T*<T_c, is almost *T*-independent, and is consistent with multiple Andreev reflection mechanism of the interlayer transport.

Trivial TA behavior in the whole normal state *T*>T_c (no gap, no angular dependence no fitting parameters):
Is the c-axis Pseudogap a pairing gap?

More on arXiv:0801.2921