Intrinsic Tunneling or Joule Heating?

Symmetric peaks in *tunneling* conductance are generally attributed to a superconducting energy gap Δ_s or normal state pseudogap Δ_p in the electronic density of states (DOS). Recently Yurgens *et al.* [1] ascribed to Δ_s and Δ_p two peaks in the c-axis differential conductance of Bi2201-La mesas. The authors [1] ruled out a precursor Cooper pair scenario, while mechanisms based on van Hove singularity in the DOS, or on the resonant tunneling between CuO_2 planes, were outlined as possible explanations of Δ_p. I will show that a Joule heating of mesas may cause I-V nonlinearities similar to those in [1].

This approach provides a natural explanation of another finding of Yurgens *et al.* [1], the similarity between temperatures at which Δ_p vanishes in Bi2201 and Bi2212 despite a threefold difference in their T_c. Moreover, in addition to the resemblances noted in [1], strikingly similar (to those applied to Bi2212) levels of dissipation (estimated as VI/A) are required to achieve the characteristic features of the I-V of Bi2201 at the same temperature, 4.2–4.5 K [Figs. 1 and 2(a) of [1]], namely, 0.1, 2, and 8 kW/cm^2 for the end of the multivalued part of I-V, and those ascribed in [1] to Δ_s and Δ_p, respectively ($A \simeq 30\ \mu\mathrm{m}^2$ is the mesa area in [1]). The relevance of heating in Bi2212 is experimentally confirmed by different methods; notably, significant overheating of the mesa's surface was reported by [2,3] even in the multivalued part of $I(V)$. I believe that the character of Joule heating of a sample with typical c-axis $R(T)$ dependence (inset of Fig. 1) may be responsible for those similarities.

Here I will show that the "tunneling characteristics" from Fig. 4 of [1] could be reproduced qualitatively *and* quantitatively using experimental out-of-plane normal state resistance $R_c(T)$ of the same sample (Fig. 4 in [1]) and assuming that the heating of the mesa caused by the Joule dissipation is the *only* reason for effects observed at high bias. Using *Newton's Law of Cooling* (1701), the temperature of a thin mesa is given by

$$T = T_0 + IV/(Ah), \qquad (1)$$

where T_0 is the temperature of a coolant medium (liquid or gas) and h is the heat transfer coefficient. According to Eq. (1), monitoring $I(V)$ at a certain bath temperature T_0 results in a sample temperature rise that entails nonlinearity in $I = V/R_c(T)$ which is gaplike if $\partial R/\partial T < 0$. Thus constructed dI/dV curves resemble those presented in Fig. 4 of [1] and reveal *quantitatively* similar variation of conductance. This similarity allows for an estimate of the inverse heat transfer coefficient $(hA)^{-1} \simeq 62.5$ K/mW and overheating at high bias, $\sim$80 K for $T_0 = 200$ K; the set of curves accounting for this coefficient is shown in Fig. 1. As is clearly seen from Fig. 1, the "heating" spectra taken at $T_0 < T^*$ reveal a "pseudogap" which disappears entirely when $T_0 \geq T^*$. Thus Eq. (1) provides a natural explanation of some of the puzzling findings of [1].

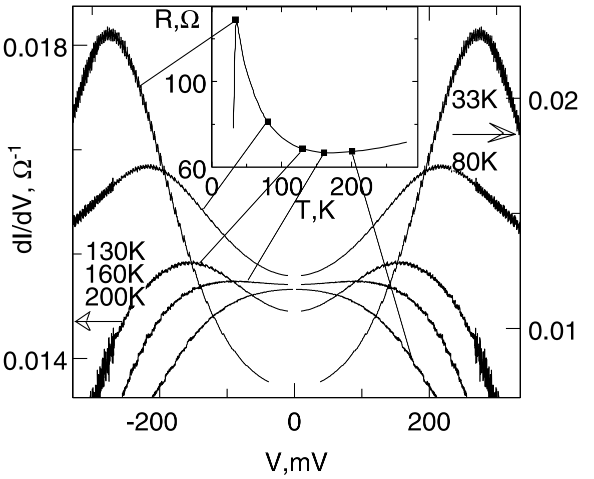

FIG. 1. dI/dV obtained from $R_c(T)$ of [1] (shown in the inset) assuming Joule heating origin of $I(V)$ nonlinearities.

To conclude, the nonlinear I-V characteristics observed in Bi2201 by Yurgens *et al.* [1] at high voltages are related to the temperature dependence of the *normal* state c-axis resistance, rather than to a (pseudo)gap in the tunneling DOS. As far as the unusual $R_c(T)$ itself is concerned, the explanation in the framework of the bipolaron model of cuprates [4] was supported experimentally [5,6].

Although only normal state data were considered here, there is no doubt that heating plays an even greater role at $T < 30$ K, so that heating issues have to be accounted for in analysis of the low temperature data also [7]. As for the low-bias results, these might be less affected by heating. One example is the puzzling correlation between the "subgap resistance" obtained in zero field and R_c of a single sample, in conditions where its superconductivity is destroyed by high magnetic fields [8]. In my opinion, both reflect the normal state resistance in the absence of superconductivity described in [5,6].

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[1] A. Yurgens *et al.*, Phys. Rev. Lett. **90**, 147005 (2003).
[2] C. E. Gough *et al.*, cond-mat/0001365.
[3] V. N. Zavaritsky, J. Supercond. **15**, 567 (2002).
[4] A. S. Alexandrov *et al.*, Phys. Rev. Lett. **77**, 4796 (1996).
[5] V. N. Zavaritsky *et al.*, Europhys. Lett. **51**, 334 (2000).
[6] V. N. Zverev and D. V. Shovkun, JETP Lett. **72**, 73 (2000).
[7] V. N. Zavaritsky, Physica (Amsterdam) **404C**, 440 (2004).
[8] A. Yurgens *et al.*, Phys. Rev. Lett. **79**, 5122 (1997).