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Point-Contact Tunnelling Measurements of Tl-Pb-Ca-Pr-Sr-Cu-O

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Abstract. We report point-contact tunnelling measurements of the high-T_c superconductor $(Tl_{0.5}Pb_{0.5})(Ca_{0.8}Pr_{0.2})Sr_2Cu_2O_y$. The *I-V* characteristics clearly show an energy gap and are qualitatively similar to those of a classical S-I-S tunnel junction with $2\Delta/k_bT_c$ of 5.1.

1. Introduction

Electron tunnelling is a powerful technique for studying the density of states of a superconductor. The point-contact method of tunnel junction fabrication developed by Levinstein and Kunzler (1966) uses a sharpened metal tip, heavily anodised to form an insulating barrier, in contact with a small region on the surface of a bulk sample. Anodising of the tip is not necessary for point-contact junctions formed on high-temperature superconductors since these have insulating surface layers possibly caused by carbonate contamination due to reaction with atmospheric carbon dioxide (Egdell *et al* 1990) or by atomic segregation during annealing (Gavaler *et al* 1988) . Their surface layers are much thicker than their short coherence lengths (Wonltungton *et al* 1987) and so impede attempts to vacuum-tunnel using a scanning tunnelling microscope (STM) but allows a point-contact tunnel junction to be formed by carefully pushing the tip into the surface layer until the layer is thin enough for a measurable tunnel current to flow.

2. Experiment

The necessary fine-control of a point-contact has been obtained by manipulating a tip with three-degrees of freedom using a single, cylindrical, piezoelectric transducer, the design being similar to that of many contemporary STMs (Binnig and Smith 1986). Course approach of the tip to the sample is achieved at 4.2K by using a 7μm/turn differential screw and differential spring system. Despite vibration isolation, the cryostat contacts are found to be rather unstable; a particular current-voltage characteristic may remain stable for several minutes and then change unpredictably. For this reason four-terminal measurements of the tip-sample current are made using a microcomputer controlled voltage-biased source and data acquisition system. Sets of identical *I-V* characteristics may later be averaged and differentiated numerically to obtain the dynamic conductance. The conductance of more stable junctions may be measured directly using a lock-in amplifier technique in which the bias is slowly swept over the range of interest.

3. Results

We report measurements on a sample of high-quality, single-phase, polycrystaline ceramic with composition $(Tl_{0.5}Pb_{0.5})(Ca_{0.8}Pr_{0.2})Sr_2Cu_2O_y$ and T_c (zero resistance) of 106 K (Liu *et al* 1989) using an electrochemically etched tantalum tip. The conductance often varied smoothly with voltage with no evidence of a gap-like structure. However, fine adjustment of the contact produced *I-V* characteristics with the attributes of a good superconducting tunnel junction, i.e.

- low-conductance in a region about zero-bias
- conductance overshoots at the edge of this region
- symmetry in the voltage at which the overshoots occur

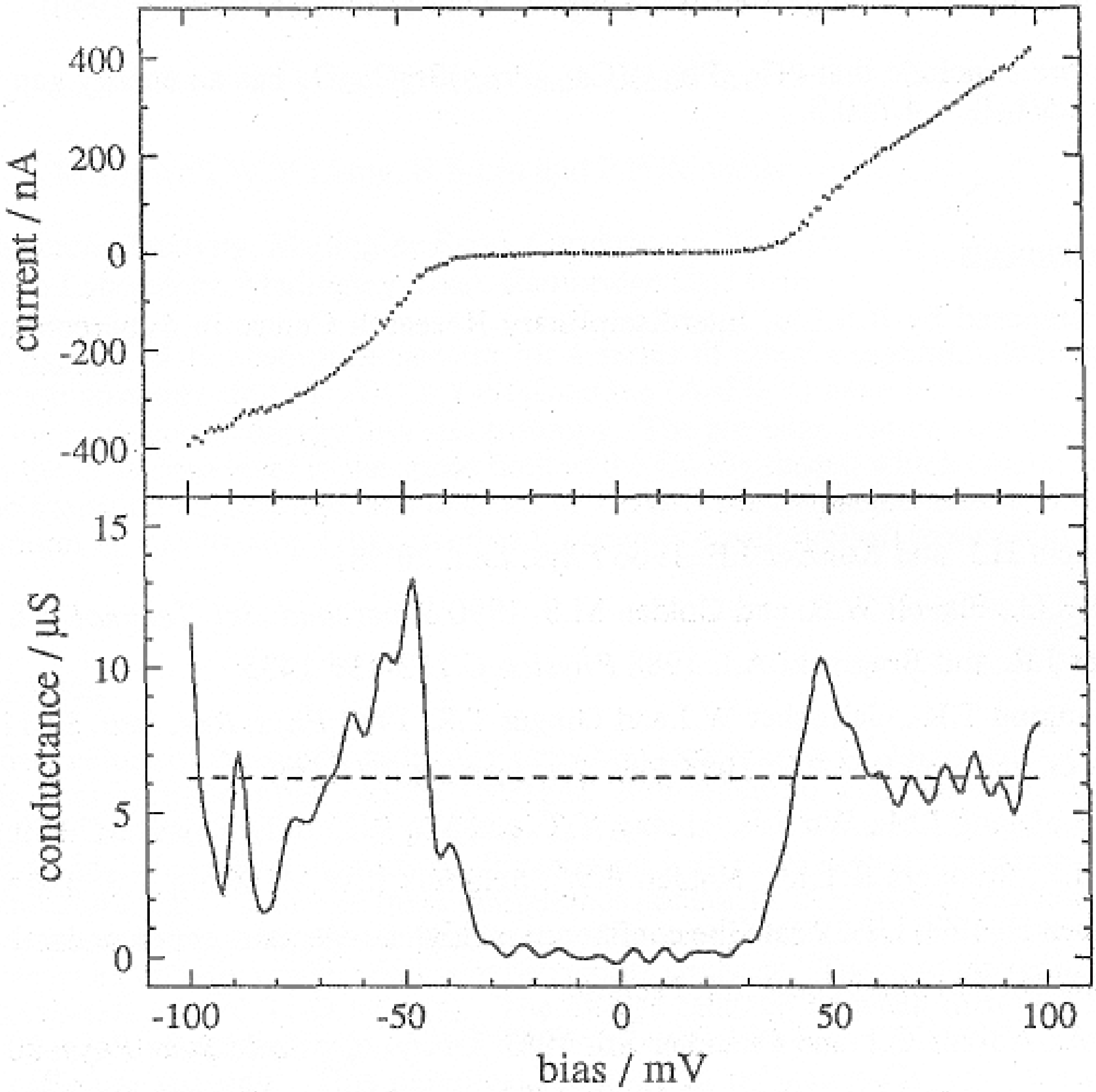

Figure 1 The *I-V* and conductivity (*dI/dV*) curves of a Ta point-contact onto $(Tl_{0.5}Pb_{0.5})(Ca_{0.8}Pr_{0.2})Sr_2Cu_2O_y$. The dashed line shows the estimated background conductance.

The above curves are carefully calibrated and the zero-bias conductance was unmeasurable – less than 2% of the beyond-gap conductance. Features both inside and outside the gap region are attributed to noise. The conductance maxima occur at ±48±1 mV and the conductance crosses the estimated background value (dotted line in Figure 1) at ±43±1 mV. We use the latter as a measure of $\Delta_1+\Delta_2$. Comparison with the BCS density of states shows a slight broadening though this is much smaller than in many reports (Wnuk *et al.*1990).

There are two possible interpretations :

(a) The structure results from S-I-S tunnelling between superconducting tantalum and the high-T_c material. In this case we obtain $\Delta \approx 43\pm1$ meV and $2\Delta/k_bT_c \approx 9.4\pm0.3$.

(b) We are observing tunnelling between two grains of the high-temperature superconductor, one of which is in good contact with the tip and the other is part of the bulk ceramic. The tunnelling barrier is between the grains. This model gives an energy gap of 21.5 meV and $2\Delta/k_bT_c$ of 4.7±0.3, a value which is in agreement with our earlier work on $Y_1Ba_2Cu_3O_y$ (Edgar et al 1988) where we find $2\Delta/k_bT_c \approx 5$.

A similar model was used by Viera *et al* (1989) to explain the observation of S-I-S characteristics when tunnelling from a normal Pt-Rh into $Tl_2Ba_2Ca_2Cu_3O_{10+\delta}$. This explanation is also supported by the majority of good tunnelling experiments which report values of $2\Delta/k_bT_c$ in the range 4-6 for the high-T_c superconductors (Kirtley 1990).

We therefore conclude that $(Tl_{0.5}Pb_{0.5})(Ca_{0.8}Pr_{0.2})Sr_2Cu_2O_y$ has an energy gap of 21.5 meV and $2\Delta/k_bT_c \approx 4.7\pm0.3$.

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