CHAPTER 8

CONCLUSIONS

Sadly, little information about the physics of high-temperature superconductors can be concluded from the original work described in this dissertation. The conclusions that can be drawn are more in the nature of suggested improvements for future experiments. Before presenting these suggestions the results of tunnelling experiments on high-T_c superconductors will be briefly summarised. These results fall a long way short of the stated aim of this work - to measure the excitation density of states of high-temperature superconductors - and are not unique, since all characteristics seen in this work have also been observed and reported by other groups.

8.1 Summary

To start on a positive note, evidence for an energy gap has been observed, if infrequently, in all the high-T_c superconducting materials studied. However, the tunnelling characteristics were all complicated by the presence of non-ideal features that prevented confident quantitative estimation of the gap value. In particular, samples of ceramic $YBa_2Cu_3O_y$ were dominated by a V-shaped conductance background and only weak gap-like features were seen. The gap was clearer and the background less prominent in the tunnelling characteristics of a $Bi_2Sr_2CaCu_2O_8$ single crystal. However, samples of this type were difficult to work with due to their small size, and only one crystal out of the many examined exhibited gap-like tunnelling characteristics. This single successful result appears to have arisen through the serendipitous formation of an SIS junction rather than by improved experimental technique. The relatively more ideal characteristics of this single-crystal point contact permitted estimation of a gap ratio of 5–7.5. Although there is little confidence in this value, due to use of the sample's bulk transition temperature and uncertainty in the exact junction configuration, it is larger than predicted by BCS theory and agrees with most reports in the literature (figure 4.18).

The tunnelling characteristics of both ceramic $(Tl,Pb)(Ca,Pr)Sr_2Cu_2O_y$ and thin-film $YBa_2Cu_3O_y$ samples were dominated by Coulomb gap and staircase structure (i.e., charging or SET effects). This is believed to be due to the formation, by an isolated conducting particle positioned between the point-contact tip and the bulk electrode, of two small tunnel junctions in series. Although much of the surface of these samples was normal, evidence was seen for an energy gap. However, an unambiguous estimation of the gap value was not possible with the simplified models used in this work.

8.2 Recommendations for Future Work

In discussing possible improvements to the point-contact apparatus at the end of chapter 7, the advantages of a recently built STM were described. It would clearly be sensible to use this, and its associated control and data-acquisition electronics, in any future point-contact tunnelling studies of high-temperature superconductors. Following the discussion in section 4.5, the author believes that a facility to cleave samples *in situ* at low temperature (< 70 K) is essential in such work; this appears to be the only way to guarantee that surfaces examined by a point contact are representative of the bulk.

The discussion in section 6.3.6 suggests that electrochemically etched tungsten is susceptible to charging effects and should not be used as a point-contact or STM tip in spectroscopic studies. Although the Coulomb staircase behaviour described in sections 7.3.3–4 is believed to be due to isolated particles at the surface of the sample, one cannot rule out the possibility that these are also tip-induced artefacts. This uncertainty should be resolved by repeating the experiments with more suitable, mechanically sharpened tips. In retrospect, it is clear that whilst performing the majority of experiments described in this dissertation the author was insufficiently aware of the importance of charging effects. In particular, the voltage ramp applied to the junction was usually too small, so only the first (positive and negative) steps of a Coulomb staircase were seen and measured. This resulted in incorrect or ambiguous interpretation of some data (e.g., figure 7.21). To help distinguish between simple SIN tunnelling and charging effects, and to permit full analysis of the latter, the junction voltage should be swept over at least three times the bias of the lowest-energy conductance peaks. This is the practice recommended for future work.

To avoid SET effects ceramic samples should not be used. These are also very inhomogeneous in composition and cleaving may expose defect-rich grain boundaries rather than bulk material. The results of section 7.3.4 indicate that $YBa_2Cu_3O_y$ thin films also suffer from SET effects. For this reason it is suggested that future work should concentrate on single-crystal samples. Moreover, attempts should be made to fabricate junctions with tunnelling in the *ab*-plane of these crystals*, since results are generally superior to those of *c*-axis tunnelling, probably due to the longer coherence

* Possibly using the crossed-crystal technique of Wnuk *et al*. (1991) and variants thereof.

length. The Bi-Sr-Ca-Cu-O family of high-T_c superconductors would be a suitable initial focus for these studies, since these seem to produce more BCS-like tunnelling characteristics and single crystals can now be grown to a considerable size (e.g., $5 \times 5 \times 0.5\ \mathrm{mm}^3$, Tanaka *et al*. 1989). Establishing a source of high-quality single-crystal samples should be given higher priority in future work.