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Investigation of the Local Superconducting Properties at Grain Boundaries in High- T_c Superconductors

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INVESTIGATION OF THE LOCAL SUPERCONDUCTING PROPERTIES AT GRAIN BOUNDARIES IN HIGH- T_c SUPERCONDUCTORS

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Developing an atomic scale study of the structure-property relationships of grain boundaries in high- T_c superconductors is essential to understand their current dissipation mechanism and for incorporating these materials into viable devices. Thin $\text{YBa}_2\text{Cu}_3\text{O}_{7.8}$ films have been deposited by pulsed laser deposition (PLD) on SrTiO_3 symmetric bicrystals. Transport measurements in a magnetic field have been conducted across the grain boundaries through a wide bridge. The data obtained are consistent with microstructural observation in a VG Microscopes HB603 U and a VG HB501 UX dedicated STEM. Of particular interest in the study of high- T_c materials is the use of EELS, which can highlight the presence of non-superconducting regions through interpretation of the onset positions and fine-structure (ELNES) of characteristic core-edge features ^{1,2,3}.

The $V(I)$ curves recorded across a 24° boundary for several magnetic fields (fig. 1 - left) show an onset critical current density followed by a linear differential ohmic behavior which gives a negative intercept. The small $J_c(B)$ arises from a small fraction of strong links, the linear differential resistivity regime represents the grain boundary resistance, and the rapid rise at high current densities is due to the properties of the grains. To explain these properties, a model, where the grain boundary is composed of equally sized and spaced dislocation cores separated by a very small fraction of much stronger links which might carry either the depairing current or the J_c of the grains or a stronger Josephson current is shown in the center of fig. 1. The depairing current case seems very unlikely due to the observed field dependence. The simulated graph obtained for this model, for a situation where the area fraction $x=0.005$, and J_c is the observed $J_c(B)$ of the grains (fig. 1 - right), exhibits qualitatively similar behavior to the data on the left, (right). The imperfect fit suggests that the exact nature of these strong links is most likely a much stronger Josephson current.

The model proposed from the transport properties data is consistent with Z-contrast image of a 30° grain boundary (fig. 2) which shows an asymmetric segment on the left, containing a slightly distorted unit cell, and a small symmetric segment on the right. According to EELS measurements at such boundaries, the symmetry of the boundary seems to play an important role in determining superconducting properties. The ELNES oxygen K edge has been recorded across symmetric and asymmetric boundaries (fig. 3). The intensity of the oxygen K pre-edge which is related to the hole concentration doesn't change at symmetric boundaries but disappears at asymmetric boundaries. This result suggest that the presence of a very small fraction of symmetric cells in a predominantly asymmetric boundary might be the stronger links of the model proposed.

This preliminary investigation has shown that the study of the grain boundary electronic microstructure in parallel with transport properties study should lead us to a better understanding of the transport properties of the superconducting materials. In particular, it has been shown that transport measurements are consistent with a model where the grain boundaries are composed of weak links separated by a very small fraction of much stronger links although more boundaries need to be studied to draw definitive conclusions and determine the real nature of these strong links.

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FIG. 1. (left) $V(I)$ curves for several magnetic fields. The small $J_c(B)$ arises from the strong links, the linear differential resistivity regime represents the grain boundary resistance, and the rapid rise at high current densities is due to the properties of the grains. (center) In the proposed model, the grain boundary is composed of equally sized and spaced dislocation cores separated by a very small fraction of strong links. (right) The simulated graph exhibits qualitatively similar behavior to the data on the left, for a situation where the fraction $x=0.005$, and J_c is the observed $J_c(B)$ of the grains.

FIG. 2. Z-contrast image of a 30° grain boundary showing an asymmetric segment on the left, containing a distorted unit cell, and a small symmetric segment on the right.

FIG. 3. EELS oxygen K edge across boundaries. The hole concentration profile obtained from the pre-edge shows a radically different behavior between asymmetric and symmetric boundaries. It disappears at the asymmetric boundary.

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