TWO-PROTRUSION STM ON AN ANISOTROPIC SUPERCONDUCTOR

JEFF M. BYERS* and MICHAEL E. FLATTÉ†

* Naval Research Laboratory, Washington, D.C. 20375, U.S.A.
† Division of Applied Sciences, Harvard University, Cambridge, MA 02138, U.S.A.

Abstract—The differential conductance of an STM with two atomically sharp protrusions separated by at least several atomic spacings depends on the electronic transport in the sample between those protrusions. This allows direct probing of any gap anisotropy experienced by propagating quasiparticles.

Keywords: scanning tunneling spectroscopy, high-temperature superconductivity.

We propose an experiment which should provide detailed angular information about local transport on a superconducting sample. The apparatus consists of a spatially extended STM tip, manufactured with two protrusions each ending in a single atom. Here we point out that new information is obtainable when these protrusions are separated by more than 10 Å. Such two-protrusion tips are often found by chance. Atomic-scale tunneling from more than one site has been proposed as a probe of local transport [1,2], but these proposals require two separate contacts. It should be noted that probing electronic properties by scattering electrons off an impurity has already had some success [3,4].

On a homogeneous sample the transport quantities of interest would determine the desired separation of protrusions on the STM contact. Measurements of quantities with long length scales (100–1000 Å) such as mean free paths, transitions from ballistic to diffusive propagation, low-T c coherence lengths, charge-density-wave correlation lengths, and angularly anisotropic density-of-states effects [4] would most benefit from the increased signal of the two-protrusion configuration relative to the two-contact configuration. The two-protrusion configuration has a higher signal than the two-contact configuration because the interference term between the two tips is of lower order in the tunneling matrix elements. However, to make such an experiment feasible the sample would have to be rotated or several domains which differ by their crystallographic orientation would have to be examined. Normalizing the signal for comparison among the different orientations could be done by comparing currents across the voltage range.

For the two-protrusion STM the differential conductivity is

\[
\frac{dI}{dV} \propto \text{Im} \tilde{g}(x_1, x_1; 0) \text{Im} \tilde{G}(r_1, r_1; V) + \text{Im} \tilde{g}(x_2, x_2; 0) \text{Im} \tilde{G}(r_2, r_2; V) + \text{Im} \tilde{g}(x_1, x_2; 0) \text{Im} \tilde{G}(r_1, r_2; V) + \text{Im} \tilde{g}(x_2, x_1; 0) \text{Im} \tilde{G}(r_2, r_1; V)
\]

(1)

where \( \tilde{G} \) and \( \tilde{g} \) are the Green functions in the sample and tip respectively, convoluted with the tip shape. The first two terms describe direct tunneling through the two protrusions, but the last two terms are interference terms between the two protrusions.

We apply eqn (1) to transport on Bi₂Sr₂CaCu₂O₈. In a heuristic sense, gap anisotropy produces an angularly-dependent density of states, which can be qualitatively different at different energies. For a \( d_{x²-y²} \) gap, which has four nodes, at voltages much less than the gap quasiparticles can only travel in the real-space directions roughly parallel to node momenta, yielding “channels” of conductance [1]. At voltages slightly higher than the gap maximum there are more states for momenta near the gap maximum, so the channels would appear rotated by 45°. By examining transport at different energies a two-protrusion STM has the capability of measuring gap anisotropy via short-length scale transport measurements.
Fig. 2. Similar to Fig. 1, but only one quadrant and $eV = 0.1\Delta$.

REFERENCES