SNS behavior in a $(TMTSF)_2ClO_4$ bicrystal junction

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Abstract

I-V measurements were taken on a crossed bicrystal of the molecular superconductor $(TMTSF)_2ClO_4$. Strong evidence for spin triplet pairing has accumulated recently for this material. We interpret our conductance vs. bias as representing an SNS junction between two triplet superconductors. A superconducting energy gap of 2Δ=0.5 meV ($\sim 4.2 k_B T_c$) was measured. A large zero bias conductance peak is also observed, due to Andreev bound states at the NS interface(s). We have also prepared linear ClO_4-ClO_4 and ClO_4-PF_6 bicrystals for similar studies. The relevance of our results to the pairing symmetry of this triplet superconductor is discussed.

Key words: organic superconductor ; triplet ; tunneling

Molecular organic superconductivity is almost a quarter century old, yet the nature of the pairing remains ill-defined. In the quasi-1-D, TMTSF-based crystals, a history of suspicion regarding spin-triplet pairing symmetry dates back to the early 1980's. While some early experiments pointed to conventional behavior (critical fields, specific heat), others suggested otherwise (defect studies, NMR). The issue of unconventionality was revived in the mid-90's with upper critical field studies under accurately aligned conditions [1],[2], motivated by theoretical predictions of unconventional superconductivity [3],[4]. These studies found a very large in-plane large H_{c2}, several times the Pauli limit, suggestive, again, of triplet pairing [5]. Subsequent Knight shift [6] and thermal conductance [7] experiments support, or at least are consistent with, this scenario.

It is generally accepted that the most direct probe of the superconducting energy gap is tunneling, which has therefore been used to characterize the magnitude and k-dependence, or symmetry, of Δ in virtually every superconducting system known. A notable exception is TMTSF. There have of course been tunneling experiments on this system, but these have provided no consensus on the energy gap magnitude, and no information at all on the symmetry. There may be several reasons for this dearth of important data. Perhaps the most important is a somewhat perplexing poor surface quality, which to date has precluded reliable STM or ARPES results. Also, previous tunnel barriers were formed between the organic and a conventional superconductor (SNS' or SIS'), or with a normal metal electrode (NIS). Here, we report I-V characteristics across a barrier between two $(TMTSF)_2ClO_4$ organic superconductors (SNS), potentially providing missing information on the pairing symmetry.

Eight leads were attached to a bicrystal as shown in Fig. 1. Current-voltage measurements were made in several modes, including static, swept and pulsed (to check for heating) I-V and V-I, dynamic dV/dI-V, and mixed static/dynamic. Data were taken in a dilution refrigerator and later a ^{3}He refrigerator.

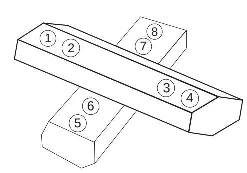

Fig. 1. Schematic of sample with contacts.

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In Fig. 2, we plot the measured conductance dI/dV across the barrier (I=1,5; V=4,8). Two main attributes of these data are (1) a gap-like feature near V=±0.5 mV, the magnitude and bias of which decrease with increasing temperature, and (2) a large conductance peak centered at V=0 (zero bias, ZBCP).

In an SNS junction, the voltage separation between the ±0.5meV features measures 4Δ. For the given T_c, BCS predicts a gap of $2\Delta = 3.52\ k_B T_c = 0.42$ meV. Our low temperature value is about 15 percent larger, implying strong coupling. This interpretation is based on the following facts. When the sample is cooled below T_c, the junction resistance exhibits metallic dependence to 10mK. This suggests two possibilities: the inter-sample junction is metallic in nature, such that the system is an SNS proximity-coupled, or weak-link junction, or we have a superconducting short. Certain experiments, such as microwave irradiated transport or weak magnetic field studies, can distinguish among these possibilities. This sample did not survive movement to appropriate probes for such studies, which must await future bicrystal samples.

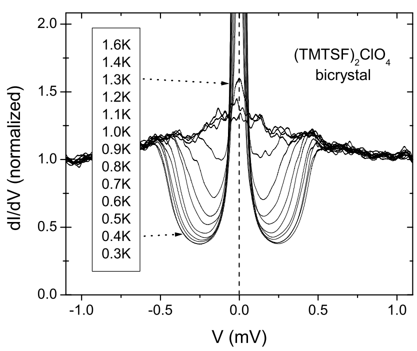

Fig. 2. Normalized differential conductance across the bicrystal junction, at several temperatures from above to below T_c. The zero bias peak reaches a value of ∼ 10 on this scale.

Additional support for SNS comes from measurements of the individual crystals. Fig. 3 shows I-V and dI/dV for one of these, using four contacts in a linear arrangement (leads 1,2,3,4). A conventional critical current is seen, while the conductance is featureless near 0.5mV (aside from the ZBCP which naturally arises from the zero resistance state).

We interpret the ZBCP as arising from Andreev bound states at the junction interface, resulting from a superconducting order parameter sign change on the anisotropic Fermi surface. This in turn is a manifestation of $l > 0$ pairing. Given the warped, quasi-1D nature, *p*-wave triplet pairing is most consistent with the data, as opposed to *f*-wave triplet or *d*-wave singlet. More thorough analyses, including magnetic field studies, will be provided in a separate publication.

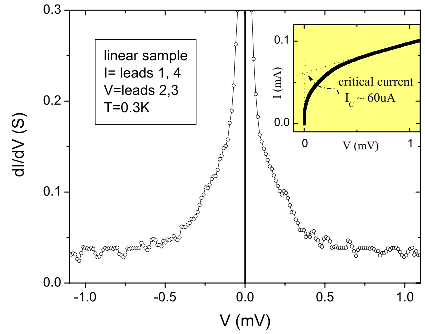

Fig. 3. Conductance of one piece of the bicrystal, showing conventional critical current (inset), and no gap-like structure.

In conclusion, we have prepared $(TMTSF)_2X$ bicrystals in various geometries in order to obtain tunnel junctions appropriate to study core superconducting properties. We reported here inter-crystal junction results on a crossed $X=ClO_4$ bicrystal, where we obtained an accurate measurement of the BCS-like energy gap, 2Δ=0.50 meV. We observed a very large zero bias conductance peak across the junction, which we attribute to Andreev bound quasiparticle states at NS interface(s). For presumed interlayer transbarrier transport, this result suggests a triplet superconducting state with *p*-wave symmetry. Further studies on other geometries, in magnetic fields, and using mixed X/X' samples will help to solidify the symmetry.

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