Designing Phase-sensitive Tests for Fe-based Superconductors

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August 15, 2013 (HP63). Four years after the discovery of the new family of high-T_c Fe-based superconductors (FeBS) [1] their pairing symmetry is still under dispute [2]. While most researchers favor the so-called $s_{\pm}$ pairing, whereupon the sign of the order parameters changes between the hole and the electron bands [3], some advocate [4] the more conventional anisotropic s-wave pairing. In the high-T_c cuprates, the real deal-breaker were phase-sensitive Josephson-junction-based experiments that have proved the sign change of the order parameter upon a 90^o degree rotation[1]. Unfortunately, the main contenders in the FeBS, the s_{++} and the $s_{\pm}$ states, have the same rotational symmetry, and if one wants to detect a sign change of the order parameter one has to design nontrivial Josephson junction (JJ) loops that would pick up selectively different superconducting bands, so that the current in one contact would be dominated by the carriers having one sign of the order parameter, and in the other by carriers with the opposite sign. Several designs aimed at exploiting particular Fermi surface topology of FeBS have been suggested [5,6], but they appeared to be too complicated to be realized in practice. In our recent work [7] we have suggested three experimental designs, all of them much simpler than all proposed previously and which could be accessible by available sample fabrication techniques.

While previous designs were trying to differentiate the contacts mainly by the current direction, we decided to exploit the fact that even and individual JJ can be tuned, by varying the thickness of the barrier, to probe one or another group of electrons. The summary of suggested three experimental designs to test pairing symmetry in FeBS is given in Figure1 and briefly discussed below.

[1] Orthogonal faces of high-T_c single crystal were weakly connected with conventional s-wave superconductor to form a dc SQUID and detect the phase difference by interferometry.

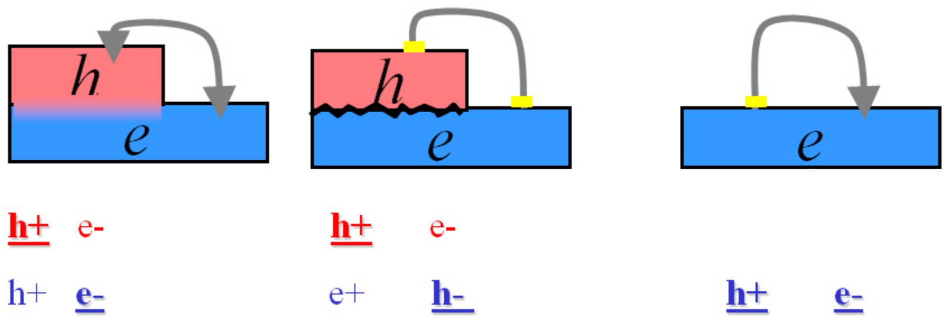

Fig. 1. Suggested experimental designs of Josephson π-loops: epitaxial sandwich (left); rough sandwich (middle); single sample (right). Yellow rectangles denote tunnel junctions, where electrons normal to the interface have an exponentially big advantage over those with a finite momentum parallel to the interface. Gray triangles denote point contacts, where electrons with any values of momenta parallel to the interface contribute roughly equally to the total current. Hole- and electron doped films are shown by red (blue) colors.

(a) Epitaxial sandwich (Fig.1, left). Momentum conservation requires that the sign of the order parameter for the states with the same lateral momentum will be the same. Two point contacts made out of a conventional superconductor are attached to the two films. As argued in [7], the current from the electron doped film into the point contact will be dominated by the electron Fermi surfaces, simply because these carriers dominate the bulk, while the current from the hole-doped film will be dominated by holes. If s_{+-} pairing occurs in FeBS, these two currents will thus have the opposite signs, or the phase shift of π.

(b) Rough sandwich (Fig.1, middle). Contacts to a conventional superconductor are attached via thick tunneling barrier. Since there is no momentum conservation, the energy of the interface will be minimized if the majority carrier in both slabs will have the same sign of the order parameter. The current in both contacts is dominated by the electronic states near the zone center (that is to say, with no kinetic energy expended on the lateral motion), which in FeBS are holes and, as a result, one achieves a Josephson loop with a π shift between the contacts [7].

(c) Single sample (Fig.1, right). Here a single sample (electron-doped FeBS) is attached to a conventional superconductor by two contacts of different nature. The current in a planar thick-barrier tunnel junction is dominated by electrons, while the current in a point contact - by holes, thus again creating a π shift.

In all three designs discussed above a π shift shows up as a minimum of a critical current of a two-junction interferometer at zero value of external magnetic flux (the so-called π-SQUID behavior), in contrast to a maximum in a conventional SQUID.

To summarize, three experimental designs are suggested in [7] in order to test pairing symmetry in FeBS. These designs involve Josephson two-junction interferometers where current in different contacts is dominated by different type of carriers, electrons or holes. If pairing symmetry is of the s_{+-} -type, a Josephson π-loop is realized (π-SQUID), while in the more conventional s_{++} case the standard SQUID behavior is expected. The suggested designs should be accessible by available fabrication techniques and should allow to probe pairing symmetry in FeBS. This highlight was invited by SNF editor to attract the attention of experimentalists to ref. [7].

References

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