Phase-Sensitive measurements on the corner junction of iron-based superconductor BaFe\textsubscript{1.8}Co\textsubscript{0.2}As\textsubscript{2}

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We have made a phase-sensitive measurement on the corner junction of the iron-based superconductor BaFe\textsubscript{1.8}Co\textsubscript{0.2}As\textsubscript{2}, and observed the typical Fraunhofer-like diffraction pattern. The result suggests that there is no phase shift between the \textit{a-c} face and \textit{b-c} face of a crystal, which indicates that the superconducting wavefunction of the iron based superconductor is different from that of a cuprate superconductor.

The iron-based high \(T_c\) superconductors discovered several months ago have become the focus of interest in condensed-matter physics because they have displayed the high \(T_c\) up to 55K so far\textsuperscript{1} and included a magnetic element in the crystalline structure. The similarities between the iron-based and cuprate superconductors, i.e. the layered crystal structure, the approximate 2D conduction layer\textsuperscript{2,3}, closeness to a long range antiferromagnetic order\textsuperscript{4}, all suggest that the iron-based superconductors may have the same superconducting mechanism as the cuprate superconductor’s. Recent heat capacity measurement\textsuperscript{5} and photoemission spectroscopy\textsuperscript{6} measurements seem to favor this opinion. However, some other recent experiments such as ARPES\textsuperscript{7,8,9}, infrared spectrum\textsuperscript{10}, etc., would rather support that the iron-based superconductors act more like a conventional superconductor with regard to pairing behavior. Meanwhile, there are two different kinds of theories in the effort of trying to disclose the underlying superconducting mechanism: one is based on the strong-coupling approach\textsuperscript{11,12,13}, which emphasizes on-site correlations applicable to the high \(T_c\) cuprate superconductors; the another is based on the weak-coupling approach\textsuperscript{14,15,16}, which emphasizes itinerant-electron physics. The debates indicate that there is the need of much more work to do to determine the superconducting wavefunction as well as its underlying mechanism in the iron-based superconductor, among which the phase-sensitive experiment is obviously one of the most important works drawing much attention.

The first phase-sensitive experiment on cuprate superconductor was reported in 1993\textsuperscript{17}. Since then, phase-sensitive experiments based on different configurations especially the corner junction\textsuperscript{18,19,20,21,22,23} have played an important role in studying the high \(T_c\) cuprate superconductors, and it has been regarded as the most direct and key tool in studying some intrinsic properties of the superconducting wavefunction. Till now, it is still the only one tool to directly detect the superconducting phase.

For an ideal corner junction based on a conventional superconductor, its critical current as a function of magnetic field is represented in the following form\textsuperscript{19} (shown in Fig.1a):

\[
I_c = I_0 \left| \frac{\sin(\pi\Phi/\Phi_0)}{(\pi\Phi/\Phi_0)} \right|
\]

where \(\Phi=Blt\) is the total magnetic flux threading it, \(l\) is the length of the corner junction, \(t\) is magnetic barrier thickness, \(\Phi_0\) is the flux quantum. It reaches a peak at zero magnetic field.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig1.png}
\caption{The schematic map of the diffraction pattern on a corner junction: (a) with zero phase shift; (b) with \(\pi\) phase shift.}
\end{figure}

For a corner junction based on cuprate superconductor, its critical current is represented in the different form\textsuperscript{19} (shown...
in Fig. 1b):

\[ I_c = I_0 \left| \frac{\sin^2(\pi \Phi / 2 \Phi_0)}{(\pi \Phi / 2 \Phi_0)} \right|. \]

Obviously, at zero applied magnetic field, there is a minimum in the curve of critical current, because the \( \pi \) phase difference of the superconducting wavefunction between the two faces of the crystal corner leads to a destructive interference of superconducting current.

Therefore, the diffraction pattern of the critical current of corner junction could be used as typical and direct evidence, which indicates whether or not the wavefunction of a superconductor is like that of the cuprate superconductor. In this letter, we present the phase-sensitive measurement on the corner junction of the iron-based superconductor BaFe\(_{1.8}\)Co\(_{0.2}\)As\(_2\). To our knowledge, this is the first phase-sensitive experiment on the iron-based superconductors.

The electrical characters of our corner junction is shown in Fig. 2, the I-V curve (Fig. 2a) exhibits a typical resistively shunted current-voltage character, which should be expected from superconductor-normal metal-superconductor (SNS) junction with a high quality. The very sharp transition in the dynamic resistance curve (Fig. 2b) makes it feasible to detect the critical current precisely.

![Image](image.png)

FIG. 2: The electrical characters of the corner junction at 1.8K: (a) Current-Voltage curve (b) Dynamic resistance vs voltage.

We fabricated single crystal BaFe\(_{1.8}\)Co\(_{0.2}\)As\(_2\) into corner junctions in the way described in Ref [17]. Our single crystals with \( T_c = 22 \)K was obtained by flux-melt technique similar as described in [24]. All of the samples are cleaved into small, thin sheets with the typical thicknesses of 20 ~ 40\( \mu \)m; and all the faces used for corner junction are cleavage planes, smooth and flat. After masking the sample (leaving the corner face and all the faces used for corner junction are cleavage planes), we sputter about 40nm Au on the sample, then continue to sputter 300nm Pb over the Au layer. The typical lengths of both sides of the corner junctions in our experiment are 100 ~ 200\( \mu \)m, and the geometric asymmetry of the corner junctions are less than 15\% (According to Ref [18], the small asymmetry will not affect the final conclusion). Critical current of our junctions used for measurement at 2 K is 20\( \mu \)A ~ 3mA which is feasible to measure at low temperature. We manufactured two superconductor cans with inner layer of Pb and outer layer of Nb in order to make sure of the good shielding effect. Measurement was taken in the temperature range of 1.8K ~ 4.2K which is far below the transition temperatures of Nb and Pb.

![Image](image.png)

FIG. 3: The Fraunhofer diffraction pattern of the critical current as a function of magnetic field taken at 1.8K. Magnetic field is applied by a self-made NbTi superconducting coil, the maximum scanning range of magnetic field is -800mG ~ 800mG, limited by the Joule heat in contacts.

Magnetic field modulation of the critical current is shown in Fig. 3. It displays a typical, symmetric Fraunhofer diffraction pattern, completely different from that of the corner junction of cuprate superconductors, which shows a minimum instead of a maximum at zero field. The diffraction pattern of our edge junction is the same as that of our corner junction. Symmetric Fraunhofer diffraction pattern of the corner junction indicates that there is no phase shift between the a-c face and b-c face of the corner. The possibility of flux trapping in the corner could be ruled out [18], because this diffraction pattern can be repeatedly demonstrated in different samples and in the same sample during several different thermal cyclings between the measurement temperature and 25K.

It should be mentioned hereby that, there has been a common belief of which the \( \pi \) phase shift is a direct evidence for d-wave pairing symmetry, and on the other hand, the zero phase shift is that for s-wave pairing symmetry [19] [22]. Therefore, the result that we have reported here seems to support s-wave pairing symmetry. However, some other points of view [27] is questioning about the ground theory [25] [26] of the above belief, and since the aim of this letter is to report the experimental result, we will leave the theoretical debate open for further research.

In summary, we did phase-sensitive experiment in the iron-based superconductor BaFe\(_{1.8}\)Co\(_{0.2}\)As\(_2\), the typical Fraunhofer diffraction pattern shows that the critical current is max-
imum at zero magnetic field, which means there is no phase shift between the $a$-$c$ face and $b$-$c$ face of the crystal corner. This indicates that the superconducting wavefunction of the iron based superconductor is definitely not like that of a cuprate superconductor.

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