



High-resolution ARPES study of electron-doped Fe-based superconductor $\text{BaFe}_{1.85}\text{Co}_{0.15}\text{As}_2$

T. Kawahara^{a,*}, K. Terashima^b, Y. Sekiba^a, J.H. Bowen^c, K. Nakayama^a, T. Sato^{a,d}, P. Richard^e, Y.-M. Xu^f, L.J. Li^g, G.H. Cao^g, Z.-A. Xu^g, H. Ding^c, T. Takahashi^{a,e}

^a Department of Physics, Tohoku University, Sendai 980-8578, Japan

^b UVSOR Facility, Institute for Molecular Science, Okazaki 444-8585, Japan

^c Beijing National Laboratory for Condensed Matter Physics and Institute of Physics, Chinese Academy of Science, Beijing 100190, China

^d TRI-P, Japan Science and Technology Agency (JST), Kawaguchi 332-0012, Japan

^e WPI Research Center, Advanced Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan

^f Department of Physics, Boston College, Chestnut Hill, Massachusetts 02467, USA

^g Department of Physics, Zhejiang University, Hangzhou 310027, China

ARTICLE INFO

Article history:

Accepted 17 November 2009

Available online 26 November 2009

Keywords:

Iron-based superconductor
Superconducting gap
ARPES

ABSTRACT

We have performed high-resolution angle-resolved photoemission spectroscopy of an electron-doped iron-based superconductor $\text{BaFe}_{1.85}\text{Co}_{0.15}\text{As}_2$, and experimentally determined the Fermi-surface, the band structure and the superconducting gap. We found an isotropic s-wave-like superconducting gap on a hole pocket centered at the Γ point and on electron pockets at the M point. The superconducting gap magnitude is significantly enhanced on the Fermi-surfaces connected by the antiferromagnetic wave vector, suggesting the importance of an interband interaction on the pairing mechanism.

© 2009 Elsevier B.V. All rights reserved.

1. Introduction

The recent discovery of iron-based superconductor $\text{LaFeAsO}_{1-x}\text{F}_x$ ($T_c = 26$ K) [1] has triggered intensive debates on its superconducting (SC) mechanism. There are mainly four types of crystal structures in iron-based superconductors, called the 1111, 122, 111 and 11 systems. The electronic structure has been actively studied in the 122 system since large high-quality single crystal-line samples are available. The parent compound of the Ba122 system (BaFe_2As_2) is an antiferromagnetic metal and it becomes a superconductor by both electron- and hole-doping. Investigation of the electronic structure in the hole- and electron-doped systems plays an important role to understand the mechanism of high- T_c superconductivity. So far, angle-resolved photoemission spectroscopy (ARPES) studies have been mainly carried out on the hole-doped system, and they have revealed (i) the isotropic nodeless SC gaps, (ii) the Fermi-surface (FS) dependence of the SC gap and (iii) the strong pairing on the nearly nested FS pockets [2,3]. On the other hand, very few ARPES studies have been reported on the electron-doped counterpart. It is of particular importance to perform ARPES measurements on the electron-doped system to

find the universality of the electronic structure responsible for the occurrence of superconductivity.

In this paper, we report ARPES results on the optimally electron-doped $\text{BaFe}_{1.85}\text{Co}_{0.15}\text{As}_2$. We observed the k - and T -dependences of the SC gap on each FS. We compare the ARPES results between the electron- and hole-doped compounds to discuss the universality of the SC mechanism.

2. Material and methods

High-quality single crystals of $\text{BaFe}_{1.85}\text{Co}_{0.15}\text{As}_2$ were grown by the self-flux method. ARPES measurements were performed using a VG-SCIENTA SES2002 spectrometer with a high-flux discharge lamp and a toroidal grating monochromator. We used the He I α resonance line (21.218 eV). The energy resolution was set to 4 and 15 meV for the measurement of the SC gap and the band dispersion, respectively. The angular resolution was set to 0.2°.

3. Results and discussion

The ARPES intensity at the Fermi level (E_F) of $\text{BaFe}_{1.85}\text{Co}_{0.15}\text{As}_2$ plotted as a function of the in-plane wave vector is shown in Fig. 1a. A circular and an elongated intensity pattern centered at the Γ and M points are observed, and they are attributed to hole- and electron-like bands [4]. In Fig. 1b, we show an ARPES intensity

* Corresponding author. Address: Photoemission Solid State Physics Laboratory, Department of Physics, Tohoku University, Aramaki-Aza-Aoba 6-3, Aoba-Ku, Sendai, Miyagi 980-8578, Japan. Tel.: +81 22 795 6477; fax: +81 22 795 3104.

E-mail address: t.kawahara@arpes.phys.tohoku.ac.jp (T. Kawahara).

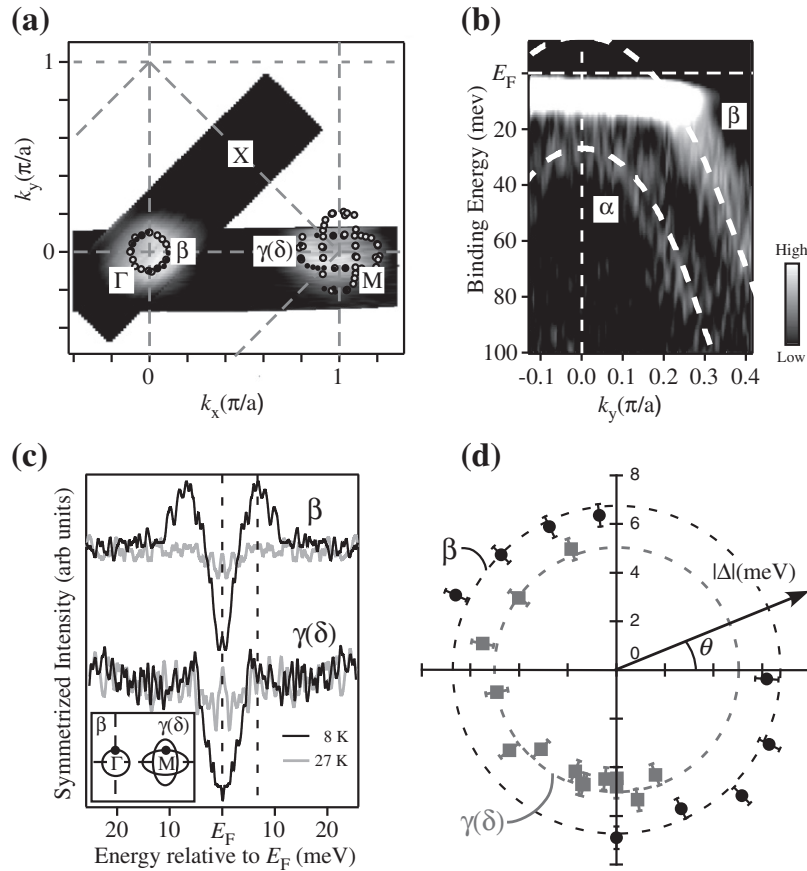


Fig. 1. (a) ARPES intensity at E_F of $\text{BaFe}_{1.85}\text{Co}_{0.15}\text{As}_2$ ($T_c = 25.5$ K) plotted as a function of the two-dimensional wave vector measured at 8 K. The intensity at E_F is obtained by integrating the spectra within 5 meV with respect to E_F . Filled circles in (a) show the k_F positions determined by tracing the experimental band dispersion, while open circles are symmetrized k_F points obtained by assuming a four-fold symmetry with respect to the Γ and M point, respectively. (b) Second derivative plot of EDCs along the Γ – M direction at 8 K as a function of wave vector and binding energy. Dashed lines are guidelines for the energy dispersion. (c) Temperature dependence of the ARPES spectrum measured at $T = 8$ and 27 K at the k_F point on the β and $\gamma(\delta)$ FS (black dots in inset). Symmetrized EDCs were divided by those at $T = 33$ K. (d) SC gap values at 8 K as a function of FS angle θ extracted from the EDCs shown on the polar plot, for the β and $\gamma(\delta)$ FSs (black and gray dots, respectively). Dashed circles represent the averaged gap value.

plot measured along the Γ – M direction. Two holelike bands are clearly visible. The inner band, which is assigned to the α band [2,3], sinks significantly (~ 30 meV) and does not create a small FS pocket as observed in the hole-doped samples, confirming the electron doping by the Co substitution. The outer band (the β band) crosses E_F , creating a hole pocket at the Γ point. As clearly seen in Fig. 1a, the β hole pocket is nearly nested with the electron pockets, in sharp contrast to the observation of a good FS nesting between the α hole pocket and the electron pockets in the hole-doped $\text{Ba}_{0.6}\text{K}_{0.4}\text{Fe}_2\text{As}_2$.

As seen in Fig. 1c, we clearly observe a SC gap below T_c on each FS. The spectral shapes on each FS are basically similar whereas there are some important differences: the SC gap on the $\gamma(\delta)$ FS has a weaker coherence-peak weight and a smaller SC-gap size as compared to those on the β FS, demonstrating the FS-sheet dependence of the SC gap. We also notice that the weight of the coherence peak is much weaker than that of the hole-doped $\text{Ba}_{0.6}\text{K}_{0.4}\text{Fe}_2\text{As}_2$ [2,3], possibly owing to a lower superfluid density due to a lower T_c value (25.5 vs. 37 K) and disorder scattering induced by the Co substitution.

The estimated k -dependence of the SC gap magnitude is shown in Fig. 1d, where the FS angle θ denotes the angle between the k_F – Γ (or M) line and the ΓM line. The SC gap on each FS is nearly constant, indicating an isotropic s -wave nature. On the other hand, the average gap values of the hole and electron pockets are different

(6.6 and 5.0 meV, respectively), again confirming the FS-dependent nature of the SC gap.

From a direct comparison of the ARPES data on the electron- and hole-doped SC samples, we conclude that (i) the SC gap opens on multiple FSs centered at the Γ and M points, (ii) the SC gap is nodeless and exhibits a nearly isotropic behavior on each FS, and (iii) the pairing strength, as reflected by the ratio of $2\Delta/k_B T_c$, is related to the FS nesting condition between the electron and hole pockets. In hole-doped $\text{Ba}_{0.6}\text{K}_{0.4}\text{Fe}_2\text{As}_2$ [2,3] the interband scattering *via* the wavevector $Q \sim (\pi, \pi)$ would enhance the pairing amplitude of the α and $\gamma(\delta)$ FSs, resulting in large $2\Delta/k_B T_c$ values of 7.2–7.7, while the poorly-nested β FS has a value of 3.6, close to the weak-coupling regime. Remarkably, in electron-doped $\text{BaFe}_{1.85}\text{Co}_{0.15}\text{As}_2$, the β (but not α) is connected to the $\gamma(\delta)$ FSs by the same Q vector and possess strong-coupling $2\Delta/k_B T_c$ values of 5.9, suggesting an enhancement of the pairing amplitude due to inter-pocket scattering on the nearly nested FSs. The observation that the pairing strength of the β band increases from 3.6 in the optimally hole-doped sample to 5.9 in the optimally electron-doped sample strongly suggests that the coupling strength is more related to the nesting condition among the FSs than to the orbital characters themselves. All these experimental observations suggest that inter-pocket scattering and FS nesting are critical aspects of the pairing mechanism of the iron-based superconductors.

4. Conclusion

We have performed high-resolution ARPES on optimally electron-doped $\text{BaFe}_{1.85}\text{Co}_{0.15}\text{As}_2$ ($T_c = 25.5$ K) and revealed FS-dependent isotropic nodeless SC gaps and strong pairing on nearly nested FS-sheets.

References

- [1] Y. Kamihara et al., *J. Am. Chem. Soc.* 130 (2008) 3296.
- [2] H. Ding et al., *Europhys. Lett.* 83 (2008) 47001.
- [3] K. Nakayama et al., *Europhys. Lett.* 85 (2009) 67002.
- [4] K. Terashima et al., *Proc. Nat. Acad. Sci.* 106 (2009) 7330.