Direct Determination of Fermi Surface Topology on Iron-Chalcogenide Superconductor by Angle-Resolved Photo-emission Spectroscopy

By using angle-resolved photoemission spectroscopy (ARPES), we have investigated the electronic structure of the iron-chalcogenide superconductor $Fe_{1.03}Te_{0.7}Se_{0.3}$, which is a family of the recently discovered iron-based high-T_c superconductors. We clearly observed a hole-like and an electron-like Fermi surface (FS) at the Brillouin zone center and corner, respectively. These FSs are closely connected by the momentum transfer of $Q = (\pi, \pi)$. The present results provide experimental evidence for the similarity of the FS topology between iron-chalcogenide and iron-arsenide superconductors, and suggest the importance of inter-FS scattering for superconductivity.

The recent discovery of high-T_c superconductivity in the iron-based compound $LaFeAsO_{1-x}F_x$ [1] has attracted great attention. Owing to intensive research, a variety of related compounds containing an iron-arsenide (FeAs) or iron-chalcogenide (FeS, FeSe, and FeTe) layer have been discovered. While the details of the superconducting (SC) mechanism in these iron-based superconductors are still highly controversial, recent ARPES studies on FeAs superconductors have revealed a large SC-gap opening on the hole and electron FSs connected by the $Q \sim (\pi, \pi)$ wave vector, suggesting that the inter-FS scattering enhances the SC pairing [2-4]. Since the parent compounds of FeAs superconductors show antiferromagnetic (AF) order with the $Q_{AF} = (\pi, \pi)$ wave vector, the remnant AF fluctuation with a similar wave vector may be responsible for the SC pairing. However, the universality of the inter-FS scattering via Q_{AF} in all iron-based superconductors is still unclear. In particular, the FS topology of the iron-chalcogenide superconductor is highly controversial. Although band calculations for the stoichiometric compound (i.e. $Fe_1Te_{1-x}Se_x$) have predicted that the FS shape is very similar to that of FeAs compounds [5], a remarkably different FS may emerge in practice ($Fe_{1+y}Te_{1-x}Se_x$; $y \neq 0$) due to the electron doping with excess Fe atoms (y) [6]. This controversy is due to the lack of experimental data on the FS of SC samples of $Fe_{1+y}Te_{1-x}Se_x$.

To elucidate the FS topology of iron-chalcogenide superconductor and clarify the SC mechanism, we have performed high-resolution ARPES of $Fe_{1.03}Te_{0.7}Se_{0.3}$ (T_c = 13 K) at BL-28A [7].

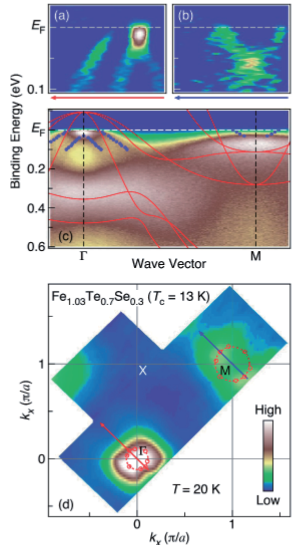

Figure 1
(a) and (b) Second-derivative plot of momentum distribution curves at 20 K measured with $h\nu$ = 44 eV on $Fe_{1.03}Te_{0.7}Se_{0.3}$ (T_c = 13 K) along the red and blue arrows in (d), respectively. (c) ARPES intensity plot along the Γ-M high symmetry line together with the calculated bands for FeTe (red curves). Near-E_F band dispersions extracted from (a) and (b) are also shown by blue dots. (d) ARPES intensity plot at E_F as a function of two-dimensional wave vector. Solid and dashed circles show experimentally determined Fermi wave vectors and schematic FSs, respectively.

Figures 1(a) and (b) show the band dispersion in the vicinity of the Fermi level (E_F) of $Fe_{1.03}Te_{0.7}Se_{0.3}$ measured around the Γ and M points of the Brillouin zone, respectively. As clearly seen in Fig. 1(a), there are two hole bands centered at the Γ point. The outer band creates a hole-like FS, while the inner one does not cross E_F. Around the M point [Fig. 1(b)], there is a shallow electron band which crosses E_F. The band dispersion measured along the Γ-M line is plotted in Fig. 1(c) compared with the band calculations for stoichiometric FeTe (red curves) [5]. The observed overall band structure appears to basically track the calculations. In Fig. 1(d), the ARPES intensity at E_F is plotted as a function of two-dimensional wave vector. The FSs centered at the Γ and the M points are clearly identified, corresponding to the hole and electron pockets, respectively. These experimental facts show that the FS topology in iron-chalcogenide superconductors is qualitatively similar to that in FeAs superconductors, indicating that the effect of electron doping by excess Fe atoms was overestimated in a recent theoretical study [6], which predicted the appearance of a large square-type FS both at the Γ and X points due to the chemical potential shift. The presence of hole-like and electron-like FSs well connected by the $Q_{AF} = (\pi, \pi)$ wave vector strongly suggests that electron pairs formed on the hole-like (electron-like) FS are scattered onto the electron-like (hole-like) FS by the AF spin fluctuations. The enhanced inter-FS scattering would lead to an increase of effective pairing interaction. The present results thus suggest that common AF spin fluctuations play an important role for the occurrence of superconductivity between iron-arsenide and iron-chalcogenide superconductors.

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