Angle-Resolved Photoemission Study on Strongly Correlated Electron Materials

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Strongly correlated electron materials has attracted more attentions in the last few decades because of their unusual and fascinating properties such as high-T_c superconductivity, giant magnetoresistance, heavy fermion and so on. Those unique properties can offer a route toward the next-generation devices. We investigate the mechanism of the physical properties as well as the electronic structure of those materials by using angle-resolved photoemission spectroscopy (ARPES), a powerful tool in studying the electronic structure of complex materials, based on synchrotron radiation.

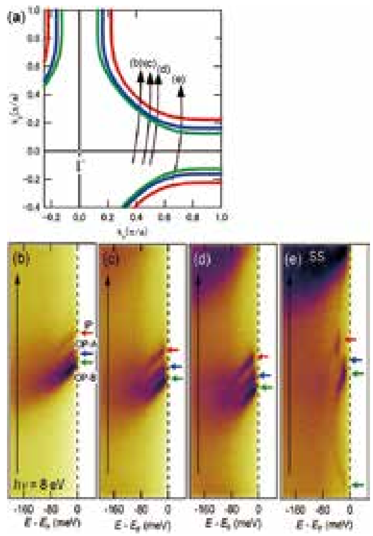

Figure 1. ARPES intensity plot of slightly-overdoped Bi2223 taken with $h\nu$ = 8 eV along FS.

Selected Publications

- K. Tanaka, T. Yoshida, A. Fujimori, D. H. Lu, Z.-X. Shen, X.-J. Zhou, H. Eisaki, Z. Hussain, S. Uchida, Y. Aiura, K. Ono, T. Sugaya, T. Mizuno and I. Terasaki, "Effects of Next-Nearest-Neighbor Hopping *t'* on the Electronic Structure of Cuprates," *Phys. Rev. B* **70**, 092503 (4 pages) (2004).
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1. Triple-Layer Splitting in Slightly-Overdoped $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ Observed by ARPES

It has been known that one of the most efficient ways to increase the critical temperature (T_c) of high-T_c cuprate superconductors (HTSCs) is to increase the number of neighboring CuO_2 planes (n). T_c generally increases from single-layer (n = 1), double-layer (n = 2), to tri-layer (n = 3) and then decreases for $n \geq 4$. Several mechanisms have been proposed to explain the n dependence of T_c. According to the tunneling mechanism of Cooper pairs between the CuO_2 planes, $T_{c,max}$ should increase with increasing n. However if one takes into account the charge imbalance between the planes and the existence of competing order, $T_{c,max}$ takes a maximum at n = 3 in agreement with experiment. Meanwhile, T_c shows tendency to increase with next-nearest-neighbor Cu–Cu hopping parameter t, which increases with the number of CuO_2 planes. Also, T_c increases with decreasing degree of out-of-plane disorder. So far, which governs the n dependence of $T_{c,max}$ has been unclear because of the lack of detailed knowledge about the electronic structure of the multi-layer cuprates.

In the case of Bi-based HTSCs, the optimum T_c ($T_{c,max}$) increases from the single-layer $Bi_2Sr_2CuO_{6+\delta}$ (Bi2201, $T_{c,max}$ = 35 K), the double-layer $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212, $T_{c,max}$ = 95 K) to the tri-layer $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ (Bi2223, $T_{c,max}$ = 110 K). Angle-resolved photoemission spectroscopy (ARPES) studies of double-layer Bi2212 and four-layer $Ba_2Ca_3Cu_4O_8F_2$ (F0234) have revealed the splitting of band dispersions and Fermi surfaces (FSs). In Bi2212, hybridization between the two CuO_2 planes causes splitting into the bonding and anti-bonding bands. The ARPES study on F0234 has indicated two energy bands due to the different hole concentrations of the outer CuO_2 planes and the inner CuO_2 planes, and correspondingly two FS sheets have been observed. In the previous ARPES results on the tri-layer Bi2223 have revealed only two FSs originated different hole concentrations of inner (IP) and outer (OP) CuO_2 planes and band splitting has not been observed. In the present study, we performed detailed low-photon-energy dependent ARPES study of slightly-overdoped Bi2223 in the superconducting states (T = 12 K) at UVSOR BL7U, and successfully observed the third band dispersion originated by the band splitting.

In Figures. 1(b)~(e), we plot ARPES intensity taken with $h\nu$ = 8 eV along FS, where the momentum positions in the k-space are shown in Figure 1(a). Three different band dispersions have been clearly observed as indicated by three arrows. By comparing the band positions in the momentum space to previous report, we have found that the band located in the center indicated by blue arrow is the newly observed band. Here, it should be noted that the intensity of each band strongly depended on the energy of incident photons and this results could not be obtained if the synchrotron light source was not used where the photon energy of the measurements is tunable.

In Figure 2, the symmetrized ARPES intensity against the Fermi level around $k_x \sim 0.54$ ($Å^{-1}$) is plotted. It clearly shows that three bands have different superconducting gaps.

The present results give us the following important messages. First, there is strong interaction between CuO_2 planes in Bi2223. Since this interaction has not been observed in four-layer F0234, it can be a critical factor to achieve the highest T_c. Second, it is not obvious why three bands show different superconducting gap size. To clarify the relationship between the interaction between CuO_2 planes and high-T_c superconductivity, it is necessary to perform temperature dependent measurements along the FS to define the Fermi arc region which should strongly contribute to the superconductivity.

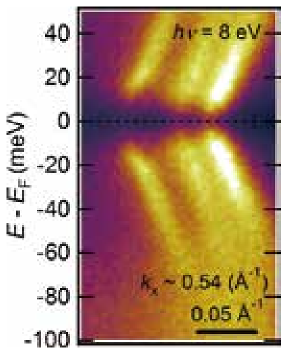

Figure 2. The symmetrized ARPES intensity against the Fermi level around $k_x \sim 0.54$ ($Å^{-1}$).

2. Development of New Spin-Resolved ARPES

UVSOR Facility in Institute for Molecular Science equipped two public undulator-beamlines for ARPES, one was BL5U in the photon energy $h\nu$ region of 20–200 eV and the other BL7U of $h\nu$ = 6–40 eV. Since the monochromator of BL5U was an old-style spherical grating type SGMTRAIN constructed in 1990s and the throughput intensity and energy resolution were poor, the whole beamline has been replaced to state-of-the-art monochromator and end station. The new beamline has been opened to users from FY2016. The newly developed electron lens system successfully achieved ~100 times better momentum resolution perpendicular to slit direction compared to the conventional ARPES. Together with the image-spin detection, which is under development, one should be able to obtain spin information of materials with much higher efficiency than the conventional spin-resolved ARPES.

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