Angle-Resolved Photoemission Study on Strongly Correlated Electron Materials

UVSOR Facility
Division of Advanced Solid State Physics

TANAKA, Kiyohisa
Associate Professor
[k-tanaka@ims.ac.jp]

Education

1990 B.S. The University of Tokyo
2005 Ph.D. The University of Tokyo

Professional Employment

2005 Postdoctoral Fellow, Stanford University and Lawrence Berkeley National Laboratory
2008 Assistant Professor, Osaka University
2013 Associate Professor, Osaka University
2014 Associate Professor, Institute for Molecular Science
Associate Professor, The Graduate University for Advanced Studies

Member

Assistant Professor
MATSUNAMI, Masaharu

Graduate Student
HAJIRI, Tetsuya*
MITAMURA, Masaki*
TSUIKI, Emiri*
KATO, Masaki
KANEKO, Masaki*
MOMIYAMA, Haruya*

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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.

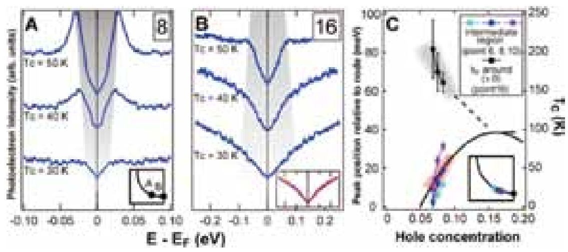

Figure 1. The symmetrized ARPES spectra of heavily underdoped Bi2212 at (A) the tip of the Fermi Arc region and (B) the antinodal region. Their corresponding locations on the Fermi surface are shown in the inset of (A).

Selected Publications

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1. ARPES Study on High-T_c Cuprate Superconductors

Two decades after the discovery of first high temperature superconductors, the microscopic mechanism of high-T_c superconductivity remains elusive. In conventional superconductors, it has been well established that electrons form so-called Cooper pairs to give rise to superconductivity. The pair binding manifests itself as an energy gap in many spectroscopic measurements. This energy gap, known as superconducting gap, appears at the superconducting transition temperature T_c where the resistance also vanishes. For high temperature superconductors, the story is more complicated. Over a wide region of compositions and temperatures, there exists an energy gap well above T_c. This energy gap is called "pseudogap," because there is no direct correlation to the superconducting transition. The origin of this pseudogap and its relation to the superconducting gap are believed to hold the key for understanding the mechanism of high-T_c superconductivity—one of the outstanding problems in condensed matter physics. In this regard, we performed ARPES measurements on the highly underdoped cuprate superconductor $Bi_2Sr_2Ca_{1-x}Y_xCu_2O_{8+\delta}$ (Bi2212) to clarify the doping dependence of the gap structure. Through a systematic study of heavily underdoped Bi2212 samples with T_c = 30, 40, and 50K, two distinct energy gaps along the Fermi surface were identified in different parts of the momentum space: A small gap along with a sharp coherence peak near the nodal region and a relatively large gap near the antinodal region. Remarkably, these two energy gaps exhibit opposite trends with doping as shown in Figure 1A and 1B. Panel A displays the data taken at the tip of the "Fermi-Arc"—the region along the Fermi surface where a coherence peak is observed, while panel B shows the data from the antinodal region. As indicated by the shaded area, the gap associated with the Fermi Arc region is reduced as the doping level and T_c decrease, while the gap in the antinodal region increases. The complete doping evolution of these two energy gaps is summarized in panel C. The doping dependence of the gap magnitude in the antinodal region (black circles and dashed line) is consistent with the well-studied pseudogap behavior. The unexpected doping evolution of the gap in the Fermi Arc region (colored symbols and solid line), on the other hand, is the new discovery of this work. Based on these observations, we proposes a picture of two energy gaps coexisting in different regions of the momentum space. The gap associated with the Fermi Arc region is most likely the superconducting gap as evidenced by the existence of a coherence peak in ARPES spectra and a positive correlation between the gap magnitude and T_c. The pseudogap in the antinodal region may, however, arise from another mechanism such as Umklapp scattering by the antiferromagnetic correlations or competing states, such as stripes, polaronic behavior, or a charge-density-wave. This two-gap scenario not only provides natural explanation of the new ARPES results, but also resolves the contradictory results on the superconducting gap deduced from different experimental techniques.

This two-gap scenario has two important implications that could be important for developing a microscopic theory of high-T_c superconductivity. First, the pseudogap near the antinodal region in these deeply underdoped samples is unlikely a precursor state of the superconducting state, as had been suggested previously. Instead, it is more likely a state that competes with the superconducting state. Second, these data suggest that the weakened superconductivity in the underdoped regime arises not only from the loss of phase coherence associated with the decrease in the superfluid density but also due to the weakening of the pairing amplitude. In this case, a mechanism for the superconducting gap reduction could be related to the shrinkage of the coherent Fermi surface with less doping, leading to a smaller phase space for pairing.

2. Development of New Spin-Resolved ARPES

UVSOR Facility in Institute for Molecular Science equips two public undulator-beamlines for ARPES, one is 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 is an old-style spherical grating type SGMTRAIN constructed in 1990s and the throughput intensity and energy resolution are poor, the beamline was planned to be replaced to state-of-the-art monochromator and end station. Then we designed a new spin and angle-resolved photoemission spectroscopy instrument with variable photon energy and polarization. We employed a Monk-Gillieson-type variableline-spacing plane-grating monochromator covering the photon energy of 20–200 eV. The end station shown in Figure 2 will equip a VLEED spin detector for spin-resolved ARPES. The beamline is constructed in FY2013–FY2014 and will be opened to users from FY2015.

Figure 2. Picture of the new spin-resolved ARPES end station of BL5U, UVSOR-III.

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* carrying out graduate research on Cooperative Education Program of IMS with Nagoya University