Angle-Resolved Photoemission Study on Strongly Correlated Electron Materials

UVSOR Synchrotron Facility
Division of Advanced Solid State Physics

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

Education
2000 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
IDETA, Shin-Ichiro
Graduate Student
KUSUNOKI, Naohiro*
VINCINI, Giulio†

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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.

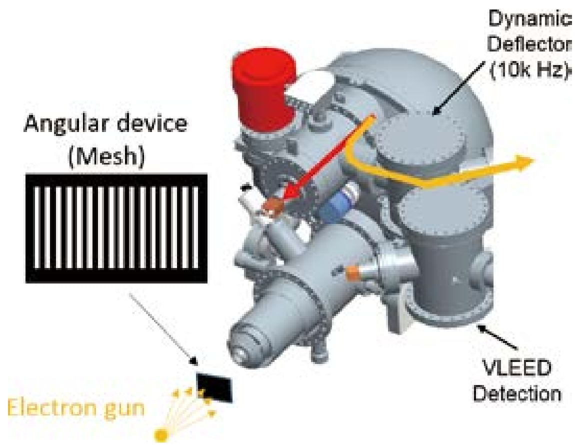

Figure 1. Schematic view of current spun-resolved ARPES system. Red and yellow arrows indicate the electron trajectory of conventional ARPES and spin-resolved ARPES, respectively.

Selected Publications

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1. Development of New Spin-Resolved ARPES

Spintronics is a rapidly emerging field of science and technology that will most likely have a significant impact on the future of all aspects of electronics as we continue to move into the 21st century. Understanding magnetism of surfaces, interfaces, and nanostructures is greatly important for realizing the spintronics which aims to control and use the function of spin as well as the charge of electrons. Spin- and angle-resolved photoemission spectroscopy (spin-resolved ARPES) is one of the most powerful experimental techniques to investigate the magnetic properties of such materials, where one can know the "complete" information; energy, momentum, and spin, on electronic states of materials. Recent development of high energy- and angle-resolution photoelectron analyzer as well as the contemporary light sources such as third generation synchrotron radiation make it possible for the photoemission spectroscopy to investigate not only precise band structures but many body interactions of electrons in solids. However, appending the spin resolution is quite difficult because of an extremely low efficiency (10^{-4}) of Mott-type spin detections, and has not been established. Recently, very-low-energy-electron-diffraction (VLEED-type) spin detector with 100 times higher efficiency than that of conventional Mott-type one has been developed and spin-resolved ARPES has been started to be realized. So far, all the spin-resolved ARPES system in the world is using the single-channel detector and efficiency is still a problem. 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 $h\nu$ = 6–40eV. 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 as high resolution and high flux ARPES beamline from FY2016. The newly developed electron lens system successfully achieved ~100 times better momentum resolution perpendicular to slit direction compared to the conventional ARPES. As a new function for this beamline, we have started high-efficient spin-resolved ARPES project with multi-channel detection as shown in Figure 1 (we call "image-spin" detection). Currently we successfully introduce electrons to the VLEED target position with maintaining the angle information emitted from the sample (Figure 2). If this new image-spin ARPES is realized, efficiency will be better than 100 times and the momentum resolution will be 10 times better than the current spin-resolved ARPES system in the world, which can be a breakthrough in this field.

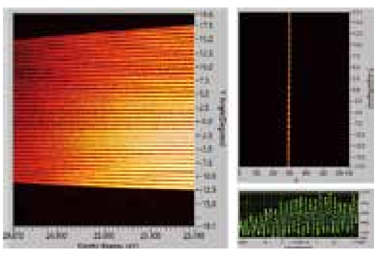

Figure 2. Detector images obtained by the electron trajectory with conventional ARPES (left) and spin-resolved ARPES (right).

2. 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 $n \geq 4$. Although several mechanisms have been proposed to explain the n dependence of T_c, it is still not clear because of the lack of detailed knowledge about the electronic structure of the multi-layer ($n \geq 3$) cuprates. We performed detailed low-photon-energy dependent ARPES study of slightly-overdoped tri-layer $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ (Bi2223, T_c = 110 K) in the superconducting states at UVSOR BL7U, and successfully observed the third band dispersion originated from the band splitting caused by hybridization between the CuO_2 planes. This is the first observation of three bands in Bi2223.[1,2] Surprisingly, each band shows different superconducting gaps as shown in Figure 3. We are performing temperature dependent study of those gaps to clarify which superconducting gap governs the T_c of this system.

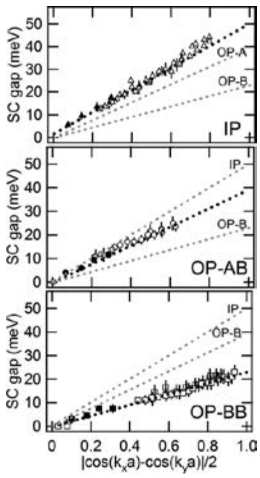

Figure 3. Superconducting gap of each band along the Fermi surface against d-wave form. The dashed lines are guides to the eye indicating the expected momentum dependence of a simple d-wave form.

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

† carrying out graduate research on Cooperative Education Program of IMS with Osaka University