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.

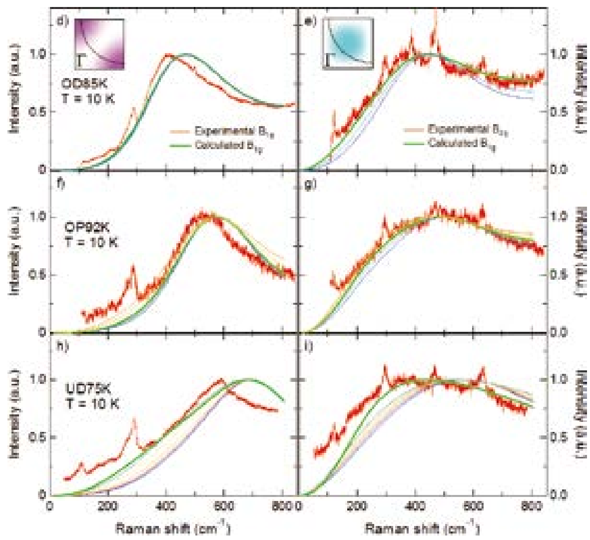

Figure 1. Calculation results of Bi2212 for B_{1g} and B_{2g} ERS spectra using ARPES spectra together with experimental ones.

Selected Publications

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- E. Uykur, K. Tanaka, T. Masui, S. Miyasaka and S. Tajima, "Coexistence of the Pseudogap and the Superconducting Gap Revealed by the *c*-Axis Optical Study of $YBa_2(Cu_{1-x}Zn_x)_3O_{7-\delta}$," *J. Phys. Soc. Jpn.* **82**, 033701 (4 pages) (2013).

1. Quantitative Comparison between ARPES and ERS on High-T_c Cuprate Superconductor

Both of ARPES and electronic Raman scattering (ERS) revealed two energy scales for the gap in different momentum spaces in the cuprates. However, the interpretations were different and the gap values were also different in two experiments. In order to clarify the origin of these discrepancies, we have directly compared experimental ARPES and ERS by using new calculation method of ERS through the Kubo formula.

It is well known that ARPES intensity is a function of matrix element, Fermi Dirac function and a spectral function A(k,ω). On the other hand, the electronic Raman response in the superconducting state can be described by Green's functions using the Kubo susceptibility. Since the imaginary part of Green's function is the spectral function, the electronic Raman responses can be calculated from ARPES spectra.

In this study, we have prepared $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) samples with three doping levels, namely, underdoped (UD75K: T_c = 75 K), optimally doped (OP92K: T_c = 92 K), and overdoped (OD85K: T_c = 85 K) samples and performed ARPES and ERS measurements on the same sample to directly compare the results. From ARPES spectra, we obtained A(k,ω) and calculated ERS spectra and compared to the experimental ERS spectra.

Figure 1 shows the calculated ERS spectra with different intensity distribution of A(k,ω) along the Fermi surface. Compared to the conventional ERS spectral calculation based on kinetic theory, our new calculation results reproduced spectral features much better (not shown). Especially B_{2g} spectra, which are sensitive to the nodal region in the momentum space, were well reproduced. Doping dependence of the best fitted intensity distribution of A(k,ω) shows that the spectral function confined in the nodal region distributes to the antinodal region as the doping level increases.

The peak energies of the calculated Raman spectra were plotted in Figure 2 together with the experimental Raman, ARPES and STM data. From B_{1g} spectra, which are sensitive to the antinodal region in the momentum space, we found that the ARPES antinodal gap is always larger than the experimental B_{1g} peak energy. Since the difference increases with underdoping, this difference is possibly caused by the pseudogap. In Figure 2, we also plotted the pseudogap energy determined by ARPES Bi2212 data taken at 100 K. The pseudogap increases rapidly with underdoping and it seems that the superconducting gap in ARPES is enhanced by underlying-high-energy-pseudogap.

The present results give us the following important messages. First, Raman and ARPES can be understood with the same gap profile. Namely, the nodal slope of gap profiles is doping independent, as reported by ARPES. The apparent doping dependence of the B_{2g} peak energy is caused by the change of spectral weight of A(k,ω) along the Fermi surface. Second, the antinodal gap of ARPES is a superconducting gap that is strongly affected by the pseudogap, whereas the Raman B_{1g} gap is moderately affected. This probe-dependent effect of the pseudogap is the main source for the difference between the Raman B_{1g} gap and the ARPES aninodal gap energies. Third, while the spectral weight of A(k,ω) is confined into the nodal region in the underdoped sample, the antinodal region gains spectral weight with doping and contributes to superconductivity. Although this is similar to the "Fermi arc" picture reported before, the Fermi surface area contributing to superconductivity in our results is larger than the Fermi arc area estimated from the normal state. All these findings reflect the unusual electronic states where superconductivity and pseudogap coexist even at the lowest temperature.

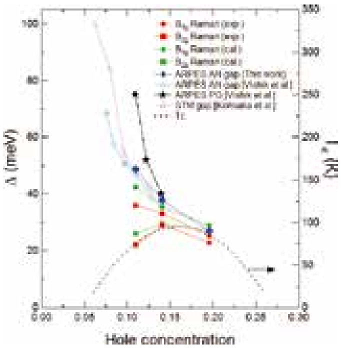

Figure 2. Doping dependence of the peak energies in Bi2212 obtained from ERS calculations in comparison to the experimental data from Raman, ARPES and STM measurements.

2. Development of New Spin-Resolved ARPES

UVSOR Facility in Institute for Molecular Science equips two public undulator-beamlines for ARPES: BL5U in the photon energy $h\nu$ region of 20–200 eV and BL7U of $h\nu$ = 6–40 eV. Since the monochromator of BL5U is an old-style spherical grating type SGM-TRAIN 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 with spin-resolved ARPES. The newly developed electron lens system successfully achieved ~100 times better momentum resolution perpendicular to slit direction compared to the conventional ARPES. The beamline will be open to users from FY2016.

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