BL-1

Optimization of self-energy in high-T_c cuprate superconductor $La_{2-x}Sr_xCuO_4$

H. Oda[a], H. Iwasawa[b,c], T. Miyashita[a], S. Ozawa[a], A. Kimura[a], R. Yano[d],

S. Kashiwaya[d], T. Sasagawa[e], S. Kumar[c], E. F. Schwier[c], K. Shimada[c]

[a]*Graduate School of Science, Hiroshima University, Japan*
[b]*National Institutes for Quantum and Radiological Science and Technology, Japan*
[c]*Hiroshima Synchrotron Radiation Center, Hiroshima University, Japan*
[d]*Department of Applied Physics, Graduate School of Engineering, Nagoya University, Japan*
[e]*Materials and Structures Laboratory, Tokyo Institute of Technology, Japan*

Keywords: Cuprate, ARPES

For the revealing mechanism of high-temperature superconductivity in cuprates, many-body interactions have been extensively investigated by angle-resolved photoemission spectroscopy (ARPES). However, it had been challenging to obtain high-quality ARPES spectra from crystal systems having strong three-dimensionality such as $La_{2-x}Sr_xCuO_4$ (LSCO) due to the roughness of a cleavage plane. On the other hand, in recent years, spectral quality has been improved as developing experimental equipment and performance, enabling us to obtain fine electronic states and study many-body interactions even in three-dimensional systems. Indeed, a recent ARPES study on an overdoped LSCO (x=0.23) examined quasiparticle scattering rate $\Gamma(\omega)=2\mathrm{Im}\Sigma(\omega)$ as expressed by using the imaginary part of the self-energy, and claimed its energy dependence deviates from the Fermi liquid behavior [1]. However, since the analysis of the scattering rate is based on only electron-electron interaction, it is necessary to consider other many-body interactions such as electron-boson interaction (boson: phonon or magnon, etc.), which dominates the quasiparticle scattering in the vicinity of the Fermi level. In this work, we have thus examined the band structure in a wide energy range on an optimally doped LSCO using a high-resolution ARPES to understand the role of many-body interactions in this system.

High-quality single crystals of optimally doped LSCO (x=0.155, $T_c \sim 39$ K) were prepared by the traveling-solvent floating-zone technique. ARPES experiments were measured at the linear undulator beamline (BL-1) of Hiroshima Synchrotron Radiation Center (HiSOR) using an R4000 electron analyzer (Scienta Omicron). Clean surfaces of the samples were obtained by cleaving *in situ* under ultra-high-vacuum conditions (4×10^{-9} Pa) at a low temperature (~27 K). Present ARPES data were taken with the photon energy of 70 eV at 27 K in the *s*-polarization geometry.

Figure 1(a) shows the ARPES image of the optimally doped LSCO taken along the nodal direction, where the circles represent the band dispersions determined by fitting momentum distribution curves (MDCs). The ARPES dispersion was then compared with the calculated dispersion by the tight-binding (TB) model [2], as shown in Fig. 1(b). Assuming the TB model dispersion as a non-interacting or bare band, we found that the experimental dispersions show a larger effective mass in the vicinity of the Fermi level, while a smaller one in the higher energy region. This dispersion behavior is an indication of the high-energy anomaly widely observed in the strongly correlated electron systems. Moreover, we found that the maximum of the real part of the self-energy locates at around 0.3 eV, which agrees well with the energy-scale of the antiferromagnetic spin fluctuations as reported by resonant inelastic X-ray scattering (RIXS) measurements [3]. Our results thus indicate that the antiferromagnetic spin fluctuations play an important role in large energy-scale band renormalization effects in LSCO.

To visualize the renormalization effects more clearly, we extracted the real and imaginary parts of the self-energy as shown in Figs. 1(c) and 1(d), respectively. Here, we first fitted the experimental results (circles) by the model self-energies, including the electron-phonon interaction, the electron-electron interaction, and the final-states effects with the impurity scattering [4]. Then, using the obtained fitting

parameters, we calculated the real-part of the self-energy. As clearly seen in Figs. 1(c) and 1(d), the real and imaginary part of the self-energy shows the excellent agreement between the experimental and fitting results. The present results thus validate the experimentally induced self-energy and allow us to evaluate the coupling strength of the many-body interactions quantitatively. In this talk, we will discuss the coupling strength of the electron-electron and electron interaction in cuprate systems. Also, we will introduce a new analysis method based on machine learning for deducing an optimized self-energy and bare band.

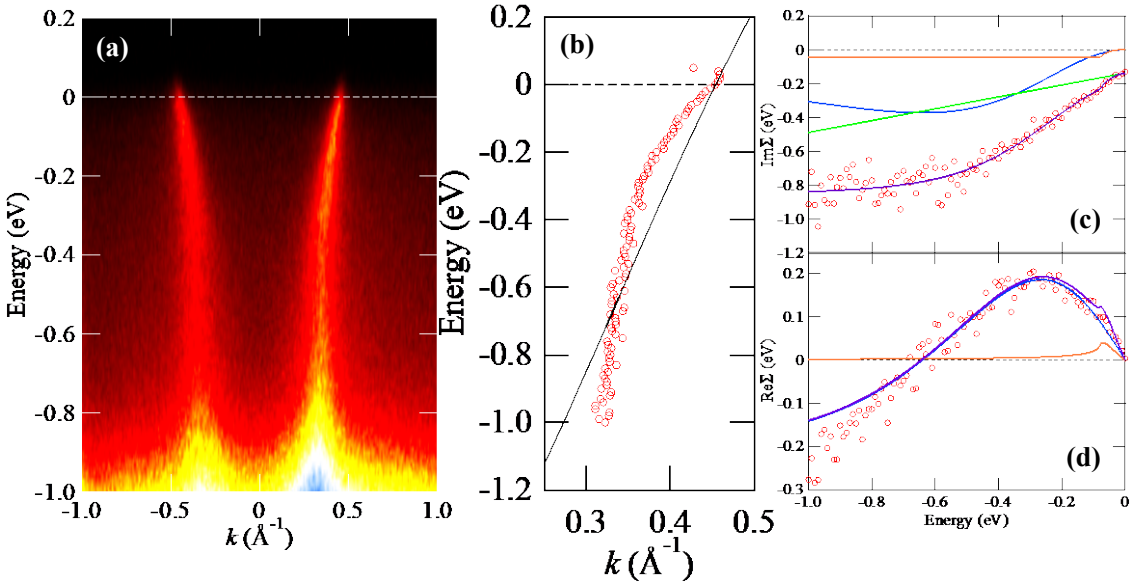

Figure 1. (a) APRES image of optimally doped LSCO taken along the nodal direction at a photon energy of 70 eV below 27 K with *s*-polarization geometry. (b) Comparison of the MDC-derived band dispersion (circles) and TB model (solid line) band dispersion. (c) and (d) Imaginary and real parts of the self-energy, respectively: ARPES self-energy (circles) and model self-energy (solid line) including the electron-phonon interaction (orange line), the electron-electron interaction (blue line), and the final states effects with the impurity scattering (green line).

REFERENCES

[1] J. Chang *et al*., Nat. Commun. **4**, 2559 (2013).
[2] R. S. Markiewicz *et al.*, Phys. Rev. B **72**, 054519 (2005).
[3] M. P. M. Dean *et al.*, Nat. Mater. **12**, 1019 (2013).
[4] H. Hayashi *et al.*, Phys. Rev. B **87**, 035140 (2013).