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Unexpected two-fold symmetry of the electronic structure in heavily overdoped Bi2201 observed by angle-resolved photoemission spectroscopy

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High transition-temperature (T_C) cuprate superconductors have attracted much interest since their discovery in 1986 for their high T_C as well as unusual physical properties such as a pseudogap [1] and a Nematicity [2]. Superconductivity occurs in the CuO_2 plane and the Cu $3d_{x^2-y^2}$ state forms the Fermi surface (FS). It has been widely believed that the CuO_2 plane is four-fold symmetric so far. Recently, however, symmetry reduction of the electronic structure has been reported in Bi-based cuprate superconductors [2,3]. Note that the breaking of the four-fold rotational symmetry or nematicity has been also found in the electronic structure of iron-based superconductors [4]. Although the nematicity in electron liquid has attracted much interest, the rotational symmetry breaking in the electronic structure of high-T_C cuprate superconductors has not been directly clarified yet.

In this study, we examined the symmetry of the electronic structure of the cuprate superconductors using high-resolution angle-resolved photoemission spectroscopy (ARPES). Here, as a suitable system for this study, we have selected heavily overdoped Bi-based high-*T*c cuprates, $(Bi,Pb)_2Sr_2CuO_{6+\delta}$ (Pb-Bi2201) because it has a single CuO_2 plane in the unit cell and the superstructure reflections are suppressed by Pb doping. Furthermore, the pseudogap disappears in the heavily overdoped sample and one can clearly see the entire FS in the normal state.

By mechanically rotating the sample, we found the difference of nodal distances for the two nodal directions (#1 and #2 in the inset of Fig. 1(a)) at the Fermi level (E_F). The two-fold symmetry was obvious if we compared the observed FS with the four-fold symmetric theoretical FS given by the tight-binding model. In addition, the ARPES spectral intensities at the E_F were different for these two nodal directions. To further examine many-body interactions, we have evaluated self-energies ($\Sigma^{(\#1)}, \Sigma^{(\#2)}$) as shown in Figs. 1(a) and 1(b) along the two nodal directions #1 and #2 in the inset of Fig. 1(a). Since the experimentally extracted real and imaginary parts of the self-energies satisfy the Kramers-Kronig relation, the two-fold anisotropy should be intrinsic, indicating that the many-body interactions such as the electron-electron and the electron-boson (phonon) interactions are anisotropic in these two nodal directions. Note that the observed symmetry breaking of the electronic structure is independent of temperature in the range used in this study (20 – 260 K).

The two-fold symmetry of the electronic structures in the heavily overdoped Pb-Bi2201 may be related to a charge order formation in heavily overdoped Pb-Bi2201 as observed by resonant inelastic X-ray scattering [5]. Our results provide an insight for the intriguing physical properties such as the nematicity [2]

and the ferromagnetic fluctuation [6] of the heavily overdoped Bi2201.

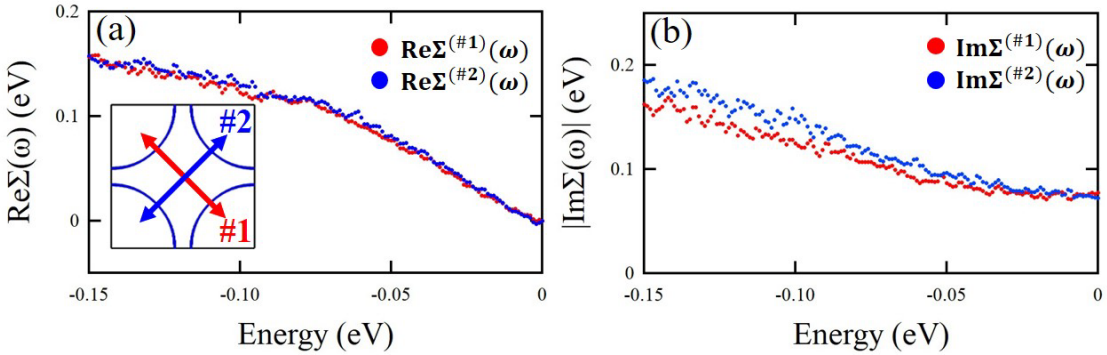

FIGURE 1. (a), (b) Experimentally obtained self-energy (Σ) along the orthogonal two nodal directions. Red and blue dots indicate $\Sigma^{(\#1)}$ and $\Sigma^{(\#2)}$ extracted from #1 and #2 directions as shown in the inset of panel (a) respectively.

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