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Symmetry reduction in the electronic structure of heavily overdoped Pb-Bi2201 detected by ARPES

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High transition-temperature (T_C) cuprate superconductors have attracted much interest since their discovery in 1986 for their high superconducting transition temperature as well as unusual physical properties such as a pseudogap state and a nematic phase [1,2]. Superconductivity occurs in the CuO_2 plane and the Cu $3d_{x^2-y^2}$ state forms the Fermi surface. One can expect a four-fold symmetry of the Fermi surface because the CuO_2 plane is tetragonal. However, symmetry reduction of the electronic structure has been reported in Bi-based cuprate superconductors recently [2,3]. Similar symmetry reduction or *nematicity* was found in the Fe-based superconductor, the electronic states break the four-fold rotational symmetry of the lattice [4]. Although nematicity in electron liquids has attracted much interest, the rotational symmetry breaking in the electronic states for high-T_C cuprate superconductors has not been clarified yet.

Here, we have examined the symmetry of the electronic structure of heavily overdoped $(Bi,Pb)_2Sr_2CuO_{6+\delta}$ (Pb-Bi2201) (T_C = 6 K) using high-resolution angle-resolved photoemission spectroscopy (ARPES). We selected Bi2201 because it has a single CuO_2 plane and one can exclude the complexity of the electronic structure such as bilayer splitting derived from plural CuO_2 planes. Furthermore, the heavily overdoped sample is favorable because the pseudogap is vanishing and one can clearly detect the Fermi surface in the normal state.

Figures 1(a) and (b) show the Fermi surface measured at $h\nu$ = 22 eV, *s*-polarization, and T = 20 K along two orthogonal nodal directions. We found a clear difference in the nodal distances; $d_1 = (7.948 \pm 0.003) \times 10^{-1}$ Å^{-1} (Fig. 1(a)) and $d_2 = (8.340 \pm 0.003) \times 10^{-1}$ Å^{-1} (Fig. 1(b)). These distances are temperature independent for the temperature range from T = 20 K up to 260 K (Fig. 1(c)). In addition, we have conducted MDC analysis along these two nodal directions and find different quasiparticle lifetime broadening as shown in Fig. 1(d), which is persistent up to 260 K. The situation is similar for the samples with T_C = 4, 6, and 10 K. Our results indicate the reduction of the four-fold symmetry in the electronic states.

In the heavily overdoped region, a charge density wave (CDW) is observed by resonant inelastic X-ray scattering and its onset is well above 250 K [5]. In addition, previous Raman scattering measurements suggest the Pomeranchuk instability and the nematic phase [6]. The previous reports are in line with our findings. Further study is required to reveal how symmetry reduction in the electronic state occurs in the heavily overdoped region. To investigate this issue, we are planning to examine the electronic structure at the endpoint of the hole concentration in the pseudogap state and at the onset of the Lifshitz transition that occurs between the hole-like and electron-like Fermi surfaces.

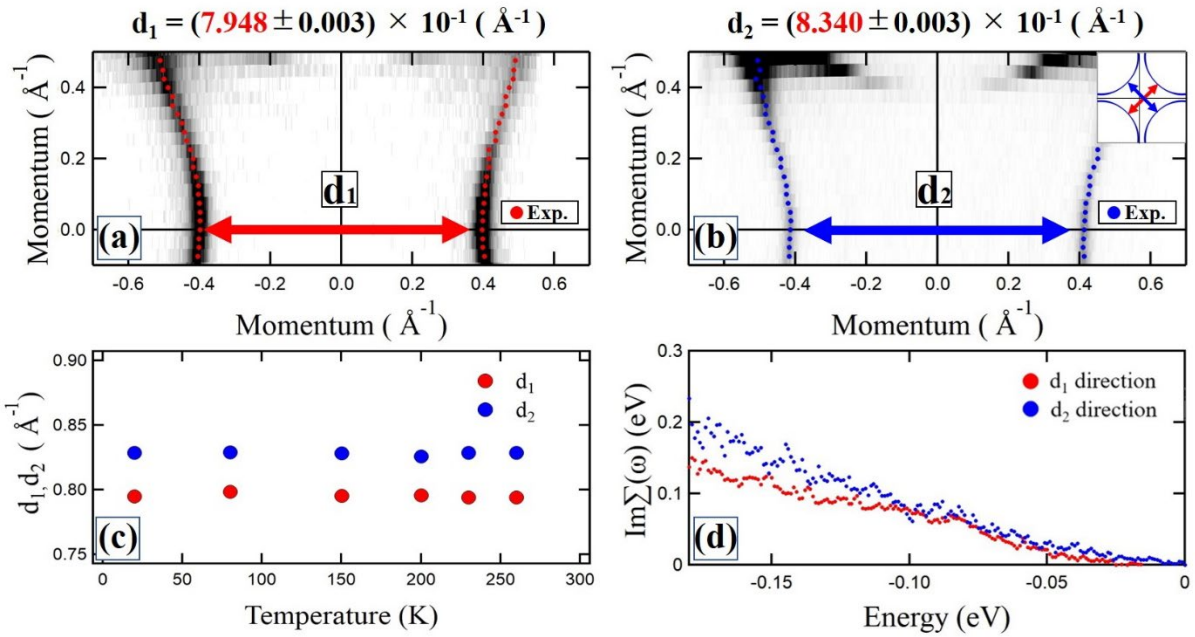

FIGURE 1. (a), (b) Fermi surface observed at $h\nu = 22$ eV, *s*-polarization and $T = 20$ K along the nodal directions shown in the inset of panel (b). The inset displays the Fermi surface centered at the $\bar{\Gamma}$ point. Red and blue dots indicate the Fermi surface points determined from the peaks of the momentum distribution curves. d_1 and d_2 indicate the distance between nodes. (c) Temperature dependence of d_1, d_2. (d) $Im\Sigma$ of the self-energy along d_1 and d_2 nodal directions.

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