Possible quasi-one-dimensional fermi surface in LSCO: phenomenological study

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Abstract

Motivated by recent angle resolved photoemission spectroscopy in $La_{2-x}Sr_xCuO_4$, we propose a novel picture that a quasi-one-dimensional Fermi surface is realized in each CuO_2 plane and is stacked alternately along c-axis.

Keywords: LSCO; Fermi surface; incommensurate antiferromagnetism

Recently, Ino *et al.*[1] have performed angle resolved photoemission spectroscopy (ARPES) on $La_{2-x}Sr_xCuO_4$ (LSCO) for several hole densities, δ[2]; they have observed the Fermi surface (FS) near $(\pi, 0)$ and $(0, \pi)$ in $0.05 \leq \delta \leq 0.30$, but not near $(\pi/2, \pi/2)$ especially at low δ ($\lesssim$0.15). Assuming a two-dimensional FS (2dFS) satisfying the Luttinger sum rule, they have suggested the shape of the FS at several δ: with increasing δ, the 'hole-like' FS centered at (π, π) evolves into the 'electron-like' FS centered at $(0, 0)$ around $\delta \sim 0.20$. In the previous mean field theory of the t-J model[3], this change of the topology of the FS has been reproduced. However, detailed comparisons with the theory and the experiments appear to indicate difficulties to reproduce the shape of the FS at each δ by using the standard method where bare hopping integrals, t (between the nearest neighbor (n.n.) sites), $t^{'}$ (the second ones) and $t^{''}$ (the third ones), are taken as fitting parameters.

In this paper, for the farther understanding of the shape of the FS, we propose a novel picture that quasi-one-dimensional FS (q-1dFS) is realized in each CuO_2 plane and is stacked alternately along c-axis. We show that the FS observed by ARPES can be regarded as consisting of two orthogonal q-1dFSs. Following the picture of the q-1dFS, we also explore the wavevector of incommensurate antiferromagnetism (IC-AF). Details will be published elsewhere[4].

We first assume that either of two kinds of the q-1dFSs, q-1dFS(x) or q-1dFS(y), is realized in each CuO_2 plane and is stacked alternately along c-axis as shown in Fig. 1. We denote the dispersion for the q-1dFS(x) (q-1dFS(y)) by $\xi^{\rm A}_{\boldsymbol{k}}$ ($\xi^{\rm B}_{\boldsymbol{k}}$). Since there is a small, but not negligible, interlayer hopping integral[5], $\tilde{t}_\perp$, two dispersions, $\xi^{\rm A}_{\boldsymbol{k}}$ and $\xi^{\rm B}_{\boldsymbol{k}}$, hybridize to form

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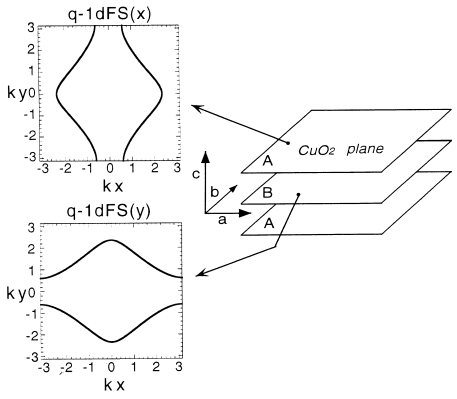

Fig. 1. Proposed quasi-one-dimensional (q-1d) FSs, q-1dFS(x) and q-1dFS(y), and their alternate stacking along c-axis.

$$\xi^{\pm}_{\boldsymbol{k}} = \frac{\xi^{\rm A}_{\boldsymbol{k}} + \xi^{\rm B}_{\boldsymbol{k}} \pm \sqrt{(\xi^{\rm A}_{\boldsymbol{k}} - \xi^{\rm B}_{\boldsymbol{k}})^2 + 4\epsilon^2_{\boldsymbol{k}}}}{2} \qquad (1)$$

where $\epsilon_{\boldsymbol{k}} = 8\tilde{t}_\perp \cos\frac{k_x}{2}\cos\frac{k_y}{2}\cos\frac{k_z}{2}$, whose form factor comes from the fact that Cu sites on the n.n. CuO_2 planes are relatively displaced by [1/2, 1/2, 1/2]. As shown in Fig. 2, the FS consists of the 'outer FS' formed by $\xi^-_{\boldsymbol{k}}$ and the 'inner FS' by $\xi^+_{\boldsymbol{k}}$. Since there is a dispersion along k_z-direction, the 'inner FS' and the 'outer FS' sensitively change with k_z, but not the 'outer FS' near $(\pi, 0)$ and $(0, \pi)$ where $\epsilon_{\boldsymbol{k}} = 0$. Thus, if ARPES spectrum is somewhat integrated along k_z-direction, the FS will be blurred except for the 'outer FS' near $(\pi, 0)$ and $(0, \pi)$. This interpretation is consistent with ARPES data. Therefore we can regard the FS observed by ARPES as consisting of the q-1dFS(x) and the q-1dFS(y).

Following the picture of the q-1dFS, we examine an interesting phenomenon that the wavevectors of IC-AF do not lie on the symmetry axes ($k_x = \pm\pi$ or $k_y = \pm\pi$) but slightly deviate from that[7,8]. Fitting the q-1dFS near $(\pi, 0)$ or $(0, \pi)$ to the observed FS segment, we calculate static spin susceptibility, $\chi_0(\boldsymbol{q})$. We find that the wavevector of IC-AF can be understood in terms of fermiology and that its shift from the symmetry axis comes from orthorhombicity of the crystal structure.

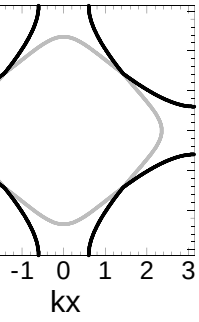

Fig. 2. Theoretical FS at $k_z = \pi$ consisting of the 'outer FS' (solid line) and the 'inner FS' (gray line).

In summary, we have proposed for LSCO a novel picture that a q-1dFS is realized in each CuO_2 plane and is stacked alternately along c-axis. We have shown that the observed FS by ARPES can be regarded as consisting of the q-1dFS(x) and the q-1dFS(y). We believe that the successful understanding of the wavevector of IC-AF in the present context supports our picture of the q-1dFS.

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