Fermi Surface Topology, Bilayer Splitting, and (π,0) dispersion kinks in Bi2212

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INTRODUCTION

There have been many key developments in our understanding of the E vs. **k** band dispersion in $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) recently, both in the normal and superconducting states. Earlier work of ours [1] was the first to break tradition and indicate that the Fermi Surface (FS) of Bi2212 was not simply a single hole-like pocket centered around the (π,π) points of the Brillouin zone. In particular, we found that a more electron-like portion of the FS was observable at certain photon energies such as 33 eV, in contrast to the standard hole-like FS, which is observed at photon energies near 20 eV. Papers [2] and [3] dealt with this issue and principally contained data from the ALS. The concept of an electron-like FS portion in Bi2212 was supported by additional measurements made by the Stanford group [4]. This Fermi surface topology issue has evolved into the finding of bilayer split bands in the Bi2212 family [6,7]. This discovery explains the observance of two different FS topologies, and has allowed us to unearth new self-energy effects in the E vs. **k** band dispersion near the critical (π,0) point of the Brillouin zone [8,9].

EXPERIMENT

Experiments were carried out at beamline 10.0.1.1 of the Advanced Light Source, and at beamline 5-4 of the Stanford Synchrotron Radiation Laboratory using Scienta SES 200 electron spectrometers. Experiments were conducted at photon energies of 20, 22, 33, and 47eV. The measurements requiring the highest resolution were carried out with a combined experimental energy resolution of 12meV, and a momentum resolution better than $0.01\pi/a$ (where a is the CuO_2 plane lattice constant) along the entrance slit to the spectrometer. Experiments were carried out with the in-plane component of the photon polarization along the (0,0)-(π,0) direction.

RESULTS AND DISCUSSION

The bilayer splitting effect in Bi2212 is expected to occur due to the intracell c-axis coupling between the two CuO_2 layers per unit cell. However, this had not been previously observed, with most experiments indicating that the coupling was zero [5], a possibility consistent with exotic theories of superconductivity such as those favoring the low-dimensional state necessary for spin-charge separation. Simultaneous to the Stanford group's report [6], we made the first measurements of bilayer splitting in a high temperature superconductor, using overdoped Bi2212 samples [7]. We found the splitting to have a maximum value of approximately 100 meV, to be maximal at the (π,0) point of the Brillouin zone, and to be zero along the (π,π) nodal direction. The large value of this splitting relative to other parameters such as the value of the superconducting gap, pseudogap, and some of the magnetic energy scales means that this intracell coupling is strong and should be included in any proper description of the electronic structure. This also should be necessary information for understanding why the T_c of the cuprates depends so strongly upon the number of layers per unit cell. Data showing this splitting is contained in figure 1.

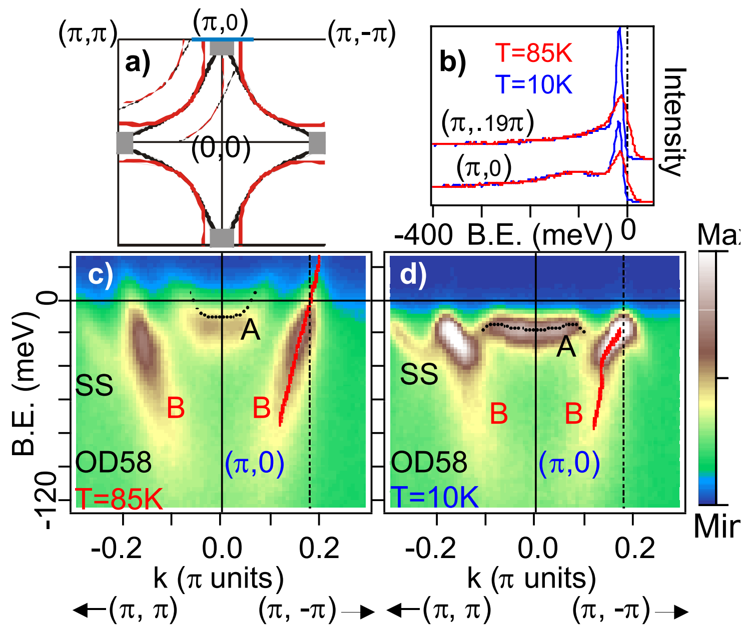

Figure 1. ARPES data in the normal (c) and superconducting state (d) of a T_c=58K overdoped Bi2212 sample, from ref [9]. A and B indicate the antibonding and bonding bands, respectively. The k-space location is along the blue line of panel (a). Panel (b) shows EDCs at two k-space locations.

A later paper of ours made the first extension of the bilayer splitting measurements to optimal and underdoped samples [8]. In these samples, the intrinsic peak broadening is greatly increased, and it is more difficult to separate the contributions of the separate bilayer split bands. By choosing optimal photon energy and polarization conditions we were able to selectively enhance one of the bilayer split bands relative to the other and make an accurate deconvolution. While the decreased c-axis conductivity in underdoped samples led us to expect that the bilayer splitting would be reduced in these samples as well, we found the surprising result that the bilayer splitting energetics are essentially identical for all doping levels [8]. This implies that other effects such as the scattering rate or the opening of the pseudogap must be more relevant to the change in the c-axis conductivity.

The ability to accurately deconvolve the bilayer splitting opened up many more opportunities for research in the critical (π,0) region of the Brillouin zone, where the bilayer splitting is the largest, as well as where the superconducting gap, pseudogap, van-Hove singularity, etc. are all maximal. Earlier measurements had been unknowingly looking at a superposition of the two bands in this region, with misinterpretations arising because of this. For example, there was the very famous peak-dip-hump lineshape at (π,0) observed by many groups in the superconducting state of Bi2212, but not in the normal state. This had been discussed as various types of self-energy effects, including $\alpha^2F(\omega)$ oscillations, coupling to magnetic modes, shake-off effects, etc. Our new data indicates that it is simply an effect of the bilayer splitting [9]. It is present in both the normal and superconducting states (figure 1b), but it was only previously visible in the superconducting state because the broad features present in the normal state pushed the signal below the background.

Even more importantly, the ability to accurately deconvolve the bilayer split bands has allowed us to make the first measurements of a dispersion "kink" near the (π,0) portion of the

Brillouin zone (figure 1d). This result follows up on the pioneering kink studies of cuprates done by the Stanford [10] and other [11,12] groups, except that these previous results were predominantly limited to the nodal region, where the pairing correlations are weakest. We have measured the temperature and momentum dependence of the new (π,0) kink on over and optimally doped samples. We find that the kink strength (but not its energy scale) is a strong function of these parameters. In particular, the kink appears just below T_c, existing only in the superconducting state, while the nodal kink is present both above and below T_c. Also, the kink is localized in a small k-space region near (π,0), with a momentum dependence that closely matches that of the famous "41 meV" magnetic resonance mode observed in inelastic neutron scattering measurements [13]. We argue that these factors point to a likely connection between the (π,0) kink and the magnetic resonance mode, although more work needs to be done to understand the energy scales. If this picture holds together, the kink should be due to electronic coupling to the magnetic resonance and there will be a strong possibility that the pairing of electrons is mediated by this magnetic mode. This should be a very active and important area for future study.

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