HIGH RESOLUTION-ANGLE RESOLVED PHOTOEMISSION STUDIES
OF HIGH TEMPERATURE SUPERCONDUCTORS

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HIGH RESOLUTION-ANGLE RESOLVED PHOTOEMISSION STUDIES OF HIGH TEMPERATURE SUPERCONDUCTORS

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Recent photoemission studies of Y 123 and Bi 2212 performed with high energy and angular resolution have provided detailed information on the nature of the states near the Fermi level. Measurements of the superconducting gap, band dispersion, and the density of states near the Fermi level in the normal state all support a Fermi liquid description of these materials.

1. INTRODUCTION

Historically, photoemission has had mixed success in determining the electronic structure of the high temperature superconductors. More recently, it has been shown¹ that it is important to cleave $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (Y 123) samples at low temperature to ensure that the surface probed by photoemission is characteristic of the bulk. The $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_8$ (Bi 2212) class of superconductors is much more stable at elevated temperature, but reduced temperatures prolong the useful life of a surface. Additionally, reduced Fermi level broadening is important in studying the details of band dispersion near the Fermi level. Spectra can be further simplified by angular (k space) resolution, high kinetic energy resolution, or the application of all three at the same time.

2. EXPERIMENTAL

Measurements were done at the Synchrotron Radiation Center^{*}, Stoughton, Wisconsin on the Ames/Montana State-ERG/Seya beamline². The photoemission spectrometer has two degree angular resolution and is capable of 20 meV electron resolution. The combined system resolution in Figs. 3 and 4 was 32 meV.

3. RESULTS

The spectra in Fig. 1 are taken in normal emission. In this geometry a shift in the binding energy of a peak as a function of photon energy represents dispersion along the direction normal to the ab plane. As can be seen in Fig. 1a for Bi 2212, there is minimal dispersion. The primary effects are a small shift of the 3.5 eV peak to lower binding energy

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FIGURE 1
Photoemission energy distribution curves taken in normal emission for Bi 2212 (a) and Y 123 (b). The samples were cleaved and maintained at 20K. The spectra are normalized to incident photon flux.

with increasing photon energy and a larger shift of the 4.8 eV peak to higher binding energy. The small amount of dispersion in the z direction is not surprising in this highly two dimensional material. Dispersion in less well defined peaks is masked by the very strong intensity modulations due to matrix element effects. The enhancement near the Fermi level and at 1.5 eV for photon energies near 18 eV are only one of the strong selection rule effects.

Fig. 1b is a similar set of spectra for Y 123. Again, the two dimensionality of this material results in minimal dispersion in this geometry. There are indications of dispersion lower in the valence band, but the dominant features are the very strong matrix element effects. From these spectra, and others taken at other emission angles, it is clear that the strong enhancement of the 1.25 eV peak at a 22 eV photon energy is a matrix element effect and not an oxygen resonance.

Dispersion is much larger along directions in the ab plane. Fig. 2 are spectra for different emission angles and hence different k values along approximately the Γ -S direction. An initial state at 1.25 eV splits with one branch remaining at about 1.25 eV and the other moving deeper away from the zone center. Additional dispersion is seen in the lower part of the valence band. Finally, a band is seen dispersing through the Fermi level. In both Fig. 1 and 2, because of the moderate resolution (150 meV), emission near the Fermi level is largest when the band is actually well below E_F . High resolution data taken at the same time as the spectra in Fig. 2 show that the Fermi level crossing is at 12 degrees.

FIGURE 2
Angle resolved photoemission spectra along approximately the Γ -S direction, normalized to incident photon flux. The angle is relative to the sample normal.

For Bi 2212, emission near the Fermi level can be seen in much greater detail in the high resolution spectra of Fig. 3. As predicted by all band structure calculations, there is

FIGURE 3

High resolution angle resolved spectra along approximately the Γ -M direction, normalized to incident flux.

minimal emission from the Fermi level near the zone center. The structure that is seen near normal emission in the figure probably comes from randomly oriented damaged areas at the edges of the sample. Increasing angles sample a line near the zone diagonal (Γ -M). A band is seen dispersing towards the Fermi level from at least 300 meV below E_F and then moving away from the Fermi level. This follows the calculated band³ qualitatively but the measured band appears much closer to the Fermi level than predicted. This is in qualitative agreement with Takahashi et.al.⁴

The measurements shown in Fig. 3 were taken at 20K, and the shape of the band near the Fermi level is distorted by the existence of a superconducting gap. Data reported in Ref. 5 were taken along a line parallel to that of Fig. 3, and include a point which is one of the few places where a band in the normal state crosses the Fermi level. The spectra⁵ in the normal and superconducting state are shown in

the upper part of Fig. 4. Modeling these spectra gave $2\Delta/kT_c = 7$, twice the weak coupling BCS value. In the bottom half of Fig. 4, the same normal state spectrum is compared to a platinum foil on the sample holder. The instrumental resolution (32 meV) is comparable to the Fermi level width at this temperature (34 meV). The measured Fermi levels are equivalent to within the resolution and noise of the experiment. A report by these authors of a more extensive experiment on the normal state Fermi level properties is in preparation, with the goal of placing quantitative limits on the possible value of RVB parameters.

FIGURE 4

Upper: High resolution spectra showing modifications to the density at the Fermi level as a result of a superconducting gap. The solid curve is for 20K, and the dotted curve is for 90K; above the T_c of 82K. Lower: The same normal state density compared to a Pt density of states (solid line) at 90K.

4. CONCLUSIONS

High energy and angular resolution combined with low temperature is giving an increasingly detailed picture of the high temperature superconductors. Some of the detail, such as

the importance of matrix element effects, means a complete angle resolved study of the valence bands will be very time consuming. Fortunately, increased resolution simplifies other parts of the study. We have determined that bands cross the Fermi level at relatively few points in the zone. By isolating those points from the background we have determined the superconducting gap, and determined that the spectral density in the normal state looks like an ordinary metal. Increasingly, Y 123 and Bi 2212 are looking like traditional Fermi liquid materials.

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