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Inverse photoemission study of $Bi_2Sr_2CaCu_2O_8$

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An inverse photoemission spectrum of $Bi_2Sr_2CaCu_2O_8$ is presented. The spectrum shows a clear Fermi-edge structure in contrast to those reported for $YBa_2Cu_3O_7$ and $La_{1.8}Sr_{0.2}CuO_4$, giving direct evidence for the existence of the Fermi-liquid states in $Bi_2Sr_2CaCu_2O_8$.

The first step to elucidate the mechanism of the high-transition-temperature (high-T_c) superconductivity is understanding the ground-state electronic structure. Photoemission and inverse photoemission spectroscopies have revealed that the electronic structure of high-T_c superconductors is dominated by strong electron correlation.[1,2] The effect of the strong electron correlation clearly appears in the discrepancy between the valence-band photoemission spectrum and the one-electron density of states obtained from band-structure calculations. Photoemission and inverse photoemission spectroscopies have also reported that the density of electronic states at the Fermi level is very small or almost zero.[1-5] This experimental result has been regarded as an indication that a non-BCS-like mechanism may cause high-T_c superconductivity. Recently, however, a substantial density of states at the Fermi level has been observed by photoemission spectroscopies[6,7] of $Bi_2Sr_2CaCu_2O_8$ in contrast to the previous cases for $YBa_2Cu_3O_{7-\delta}$ (Y system) and $La_2CuO_{4-\delta}$ (La system). Since the existence of a Fermi surface in the high-T_c superconductor is crucial in deciding between the high-T_c mechanisms proposed so far, the results of the photoemission experiments[6,7] should be confirmed by other kinds of experiments.

In this Rapid Communication, we present an inverse photoemission spectrum of $Bi_2Sr_2CaCu_2O_8$ which gives direct information about the unoccupied electronic structure. The spectrum shows a clear and substantial spectral intensity just at the Fermi level, supporting the recent photoemission results[6,7] as well as giving direct evidence for the existence of the Fermi-liquid states in the high-T_c superconductor. The observed difference between the present study on the Bi system and the previous ones[8-11] on Y and La systems is also discussed.

The $Bi_2Sr_2CaCu_2O_8$ sample was prepared by sintering a stoichiometric mixture of Bi_2O_3, $SrCO_3$, $CaCO_3$, and CuO powders of 99.99% purity. The x-ray-diffraction measurement showed that the sample was almost single-phase $Bi_2Sr_2CaCu_2O_8$. The resistivity and ac susceptibility measurements of the sample showed a sharp superconducting transition at 80 K and about 95% volume fraction of the superconducting phase at 10 K.

The inverse photoemission measurement was carried out with an inverse photoelectron spectrometer constructed at our laboratory,[12] which has a Pierce-type electron gun with a BaO dispenser cathod and a Geiger-Müller-type (GM) counter. The typical electron current impinging on the sample was about 4 μA. Outcoming photons were focused by a concave mirror into the GM counter which detects photons with an energy of 9.5 ± 0.2 eV by the bandpass filter of a SrF_2 window and iodine gas in it. The overall resolution was estimated to be 0.3–0.4 eV. In order to obtain a clean surface for the measurement, the sample was scraped *in situ* with a diamond file. Scraping was repeated several times until almost no change was found in the spectrum. The sample was kept at room temperature and no spectral change was detected during the measurement. The Fermi level of the sample was referred to that of a silver film deposited onto the sample.

Figure 1 shows an inverse photoemission spectrum of $Bi_2Sr_2CaCu_2O_8$, compared with those of $YBa_2Cu_3O_7$ (Ref. 11) and $La_{1.8}Sr_{0.2}CuO_4$.[8] In the spectrum for $Bi_2Sr_2CaCu_2O_8$, we find four main structures denoted by the letters A–D. At first it is noted that the inverse photoemission spectrum for $Bi_2Sr_2CaCu_2O_8$ has a clear Fermi-edge structure (band A) while it is very weak in $La_{1.8}Sr_{0.2}CuO_4$ and is completely absent in $YBa_2Cu_3O_7$. Thus the present inverse photoemission result strongly supports the recent photoemission measurements[6,7] on

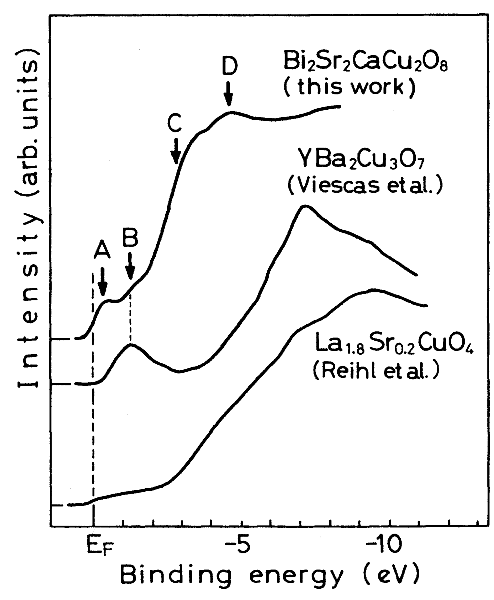

FIG. 1. Inverse photoemission spectra of $Bi_2Sr_2CaCu_2O_8$, $YBa_2Cu_3O_7$ (Ref. 11), and $La_{1.8}Sr_{0.2}CuO_4$ (Ref. 8). Note a clear Fermi-edge structure in the spectrum for $Bi_2Sr_2CaCu_2O_8$ compared with $YBa_2Cu_3O_7$ and $La_{1.8}Sr_{0.2}CuO_4$.

$Bi_2Sr_2CaCu_2O_8$ which have reported a substantial density of states at the Fermi level, in contrast to the Y and La systems. We attribute band A to the doped-hole states with dominant oxygen $2p$ nature. The absence or very weak nature of the Fermi-edge structure in $YBa_2Cu_3O_7$ and $La_{1.8}Sr_{0.2}CuO_4$ may be due to the desorption of oxygen atoms from the sample surface into ultrahigh vacuum in the spectrometer, because the Y and La systems are known to absorb and desorb oxygen more easily than the Bi system. Band B, which appears as a more pronounced structure in the spectrum for $YBa_2Cu_3O_7$, is ascribed to the empty Cu $3d$ state with a small admixture of the O $2p$ state (Cu $3d_{x^2-y^2}$+O $2p_{xy}$). Bands C and D may be due to the Bi $6p$ state.

The observation of a clear Fermi-edge structure in the present inverse photoemission spectroscopy is in good agreement with the electron-energy-loss spectroscopy (EELS),[13] which reported a sharp structure in the spectrum corresponding to the transition from the O $1s$ level to the empty O $2p$ state just above the Fermi level. All these experimental results including the present inverse photoemission and recently reported photoemission studies[6,7] on $Bi_2Sr_2CaCu_2O_8$ as well as the electron-energy-loss spectroscopy[13] strongly indicate the existence of the Fermi-liquid states with dominant O-$2p$ nature in the high-T_c superconductors. This finding gives a certain limitation to modeling the high-T_c mechanism. Superconductivity may be driven by Cooper pairing of the O $2p$ holes in the Fermi-liquid states, probably through the spin or charge fluctuation. The next step to approach the high-T_c mechanism is to determine the symmetry of the orbital of the doped O $2p$ holes.

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