LATTICE DYNAMICS AND ELECTRON PAIRING IN HIGH TEMPERATURE SUPERCONDUCTORS

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Abstract: Angle resolved photoemission spectroscopy combined with isotope substitution (^{16}O ^{18}O) sample preparation method is used to probe the effect of the lattice degrees of freedom on the electron dynamics of optimally doped $Bi_2Sr_2CaC_2O_{8+\delta}$ high temperature superconductors, as a function of momentum and temperature. Our data show that the lattice dynamics strongly renormalizes the electron dispersion and the photoemission line shapes. The renormalization is enhanced near the anti-nodal region and in the superconducting state, i.e. as the superconducting gap opens up. This unusual behavior is direct evidence that the electron-phonon interaction is correlated with the electron pairing in the high temperature superconductivity.

Key words: Electron-lattice interaction, phonons, Spin Peierls, Angle Resolved Photoemission spectroscopy, Isotope Substitution

1. INTRODUCTION

One of the ongoing debates in the field of high temperature superconductors is whether the lattice degrees of freedom are responsible for some of the unusual electronic properties of the cuprates. While many experiments have pointed out that the lattice is heavily involved in several properties of the cuprate superconductors [1], the lack of experiments probing directly the electronic response to the lattice has kept the debate open. In addition, the absence of a pronounced conventional isotope effect

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[2] on the critical temperature (T_c) [3, 4] has reinforced the belief that the magnetic interaction is the main player instead. However, the meaning of this small isotope coefficient of T_c is unclear since even for conventional superconductors screening can induce small and/or negative value of the isotope coefficient [5]. Indeed, there are several experiments suggesting the presence of a strong electron-phonon interaction in the cuprates, for example the observation of a phonon "kink" in the quasiparticle dispersion measured by photoemission spectroscopy [6], the presence of a very large isotope effect on the pseudogap formation temperature [7,8] and the magnetic susceptibility [9], and the observation of an anomalous isotope effect on the in-plane far-infrared optical conductivity [10].

2. ISOTOPE EFFECT ON THE ELECTRON DYNAMICS

To probe directly the response of the electronic degrees of freedom to the lattice degrees of freedom we propose a novel experiment where Angle Resolved Photoemission Spectroscopy (ARPES) is combined with oxygen isotope substitution on high temperature superconductors. This allows monitoring how changes in the lattice induce changes in the electronic structure. While ARPES in fact is the only technique that probes the electronic structure in a momentum resolved manner, isotope substitution control the lattice degrees of freedom.

ARPES data were collected at beamline 10.0.1 of the Advance Light Source using a SCIENTA 2000 analyzer on optimally doped oxygen isotope substituted $Bi_2Sr_2CaC_2O_{8+\delta}$ (Bi2212) (T_c=92K) superconductors. Upon isotope substitution ($^{16}O\rightarrow^{18}O$), T_c changes to 91K. The details of isotope substitution are described elsewhere [11]. The energy resolution was of 15 meV FWHM and the angular resolution of 0.15 degree, corresponding to momentum resolution better than 0.01 π/a. The vacuum during the measurement was better than 5 x 10^{-11} Torr. The photon energy was 33 eV. Data were collected for scans parallel to the nodal cut ΓY, (0, 0) to (π, π), of the Brillouin zone, at two different temperatures, below (25K) and above (100K) T_c. Each cut is assigned a cut number, which is the angle offset from the nodal direction. For example, cut 0 will mean a nodal cut, and cut 6 will mean a cut 6 degrees displaced from the nodal cut.

In Figure 1 we show the raw ARPES data as image plots, for several cuts in the momentum space, from the nodal ΓY (panel a0 and b0) to half way towards the M point (π, 0) (panels a6 and b6), for the two isotope substituted samples. The color scale represents the photoelectron intensity versus the momentum and binding energy, with maximum in black and minimum in