MAGNETIC RESONANT MODE IN THE SINGLE-LAYER HIGH TEMPERATURE SUPERCONDUCTOR $Tl_2Ba_2CuO_{6+\delta}$

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Electronic conduction in the copper oxide high temperature superconductors takes place predominantly in structural units of chemical composition CuO_2, in which copper and oxygen atoms form an approximately square planar arrangement. Most theoretical models of high temperature superconductivity are therefore based on a two-dimensional square lattice. In real materials, however, deviations from this simple situation are nearly always present. For instance, buckling distortions of the CuO_2 layers that are found in many copper oxides are thought to have a significant influence on the electronic structure and on the superconducting transition temperature T_c. Interlayer interactions in materials with closely spaced CuO_2 layers (forming bi- or trilayer units) or additional copper oxide chains in the crystal structure present further complications whose influence on the superconducting properties remains a subject of debate. Experiments on $Tl_2Ba_2CuO_{6+\delta}$, a material with unbuckled, widely spaced CuO_2 layers and a maximum T_c around 90 K, have therefore played a pivotal role in resolving some issues central to our understanding of these materials.

Inelastic neutron scattering experiments in high-T_C cuprates have revealed a magnetic resonant mode characteristic of only the superconducting state at the antiferromagnetic (AF) wavevector $\mathbf{Q}_{AF}$. Since its discovery [1], this collective mode has been extensively investigated in the bilayer copper oxide $Yba_2Cu_3O_{6+\delta}$, as well as in $Bi_2Sr_2CaCu_2O_{8+\delta}$ (BSCO) another bilayer compound [2]. At all doping levels, strong line shape anomalies of this collective spin excitation below T_c bear witness to a substantial interaction with charged quasiparticles. Conversely, anomalies in the quasiparticle spectra observed by photoemission, optical conductivity, tunneling, and Raman scattering techniques have been interpreted as evidence of coupling to the neutron mode. In the copper oxides the intriguing correspondence between anomalous features in the spectra of spin and charge excitations has stimulated spin fluctuation based pairing scenarios. All of these considerations are, however, only viable if the resonant spin excitation turns out to be a general feature of the various crystallographically distinct families of superconducting copper oxides. The failure to detect such an excitation in the single-layer compound $La_{2-x}Sr_xCuO_{4+\delta}$, despite much experimental effort, has therefore hampered a unified phenomenology of the copper oxides, and the prospect that the mode could be a spectral feature specific to bilayer materials has cast a cloud over models in which spin excitations play a central role.

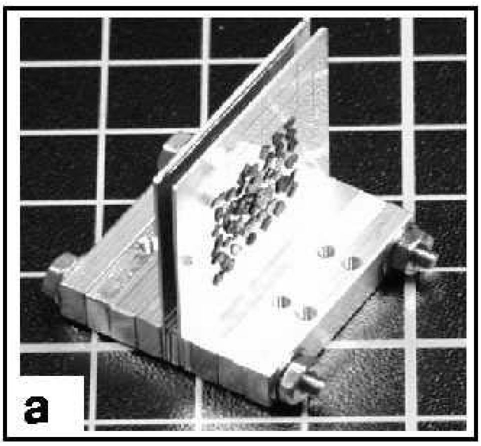

Figure 1. Photograph of a part of the array of co-oriented $Tl_2Ba_2CuO_{6+\delta}$ single crystals, glued onto Al plates. The equivalent single crystal has a mosaicity of 1.5° (from [3]).

We therefore recently focused our effort on the magnetic excitations on the one layer system, $Tl_2Ba_2CuO_{6+\delta}$, with $T_C \cong 90$ K. The crystal growth of the Tl-based copper oxide superconductors suffers from technical difficulties arising from the toxicity of Tl, and only single crystals with moderate volumes of about ~ 0.5-3 mm^3 can be obtained through a CuO-rich flux technique at the Institute of Solid State Physics in Chernogolovka (Russia). To obtain the required single crystals volume of ~ 0.1 cm^3 in order to perform inelastic neutron scattering, an array of more than 300 co-aligned single crystals had been assembled at the Max-Planck-Institut in Stuttgart (see photo Fig.1) [3]. Before alignment, the magnetic susceptibilities of all crystals were measured as a function of temperature. The crystallographic axes of the individual crystals in the array were aligned with an accuracy of about 1.5°. The array of figure 1 is equivalent to a standard single crystal on which we could measured low energy transverse acoustic phonons accurately.

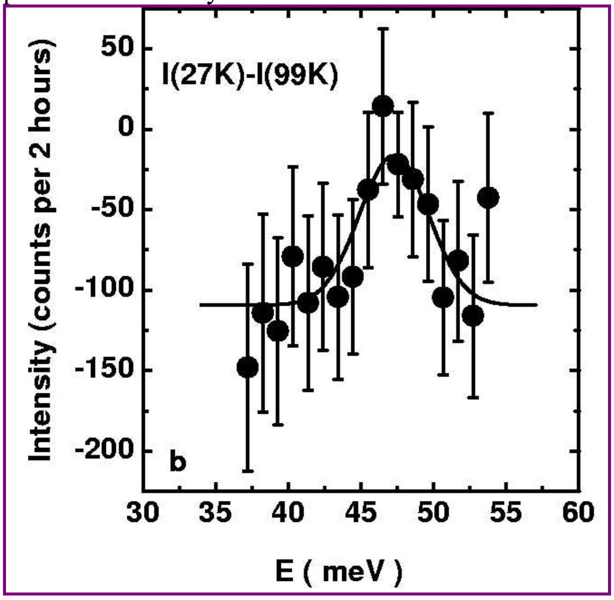

Figure 2. Difference between constant-**Q** scans measured at T=99 K (> T_c) and T=27 K (< T_c) at the antiferromagnetic wave-vector (from [3]).

Using high-flux triple axis spectrometer 2T at LLB, we were able to observe a resonance peak for this array [3]. Constant-energy scans above T_c show a featureless background that gradually decreases in an energy- and **Q**-independent fashion as the temperature is lowered. In the superconducting state, a sharp peak centered at $\mathbf{Q}_{AF}$ appears on top of this background. As expected for magnetic scattering that is uncorrelated from layer to layer, the peak intensities measured at two inequivalent *L*-positions are identical within the errors. The identification of this peak with the magnetic resonant mode is further supported by comparing constant-**Q** scans at $\mathbf{Q} = \mathbf{Q}_{AF}$ above and below T_c. Figure 2 shows that difference: it typically exhibits the characteristic signature of the resonant mode, albeit at an energy of 47 meV that is somewhat larger than the mode energy in the bilayer compounds.

In many aspects, the resonant mode in $Tl_2Ba_2CuO_{6+\delta}$ shows strong similarities with that observed in $YBCO_7$. In both cases, the mode is limited by the resolution in energy and exhibits the same extension in q-space. Further, the resonance peak spectral weight per CuO_2 layer, defined as $\int d\omega d^3\mathbf{Q}\, \mathrm{Im}\chi^{res}(\mathbf{Q},\omega)$, equals $(0.02\mu_B^2/eV)$ for both of these systems. In BSCO, where the resonance q-width along the diagonal (110) direction is about twice as large, the spectral weight is larger, but the energy integrated intensity at the AF wavevector, normalized to one CuO_2 layer, is almost identical for the three different cuprates.

The result of our experiment on single-layer $Tl_2Ba_2CuO_{6+\delta}$ (whose T_c ~ 90 K is closely similar to that of optimally doped $Yba_2Cu_3O_{6+\delta}$ and $Bi_2Sr_2CaCu_2O_{8+\delta}$ implies that strong magnetic interactions between closely spaced CuO_2 layers are not required for the formation of the resonant mode. The different form of the spin excitation spectrum of $La_{2-x}Sr_xCuO_{4+\delta}$ may be due to the proximity of a competing instability that could also be responsible for the anomalously low $T_c \leq 40K$. The magnetic resonance is therefore a generic feature of high-T_c cuprates, at least for systems with a maximum T_C^{max} of around 90 K. The resonant mode occurs at an energy E_r always lower than twice the superconducting gap $E_r < 2\Delta_{max}$ ~70 meV ~ 9 k_BT_c, which has been deduced either by photoemission measurements in BSCO or by the position of the B_{1g} mode in Raman scattering; the latter has been measured for all cuprates. This agrees with models which interpret the resonant mode as a magnetic collective mode of the $d_{x^2-y^2}$-wave superconducting state below the electron-hole continuum.

The most important implication of the findings reported here regards the unified phenomenological picture recently developed for spin and charge spectroscopies of the copper oxides. The spectral anomalies that have been interpreted as evidence of coupling to the collective spin excitation are present in single-layer $Tl_2Ba_2CuO_{6+\delta}$, and equally pronounced as in analogous data on bilayer materials. If the mode had turned out to be absent (or its spectral weight substantially diminished) in $Tl_2Ba_2CuO_{6+\delta}$, this model would have become untenable. As it has survived this crucial test, it is now time to quantitatively refine this approach and to fully evaluate its implications for the mechanism of high temperature superconductivity

References

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