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STM study of novel resonances in $Bi_2Sr_2CaCu_2O_{8+\delta}$

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Abstract

Low temperature scanning tunneling microscopy (STM) of various samples of the high temperature superconductor $Bi_2Sr_2CaCu_2O_{8+\delta}$ consistently reveals the presence of quasi-particle scattering resonances, similar both spectroscopically and spatially to those observed around Zn atoms in Zn-doped BSCCO. As the resonances appear at energies indicative of nearly unitary scattering (~0.5 meV) and are always accompanied by topographic depression of the surface Bi atom around which they are centered, we postulate that the source of scattering may be Cu vacancies in the CuO_2 plane. Such resonances should thus provide a simpler test case for theoretical models than those created by Zn or Ni substitution.

Keywords: STM; STS; $Bi_2Sr_2CaCu_2O_{8+\delta}$; Quasi-particle scattering resonances; Vacancy

In previous STM studies of $Bi_2Sr_2CaCu_2O_{8+\delta}$ (BSCCO) we have shown that Zn and Ni impurities generate scattering resonances [1], confirming several early predictions about the existence of such states [2] and inspiring further theoretical investigations of the effects of scattering [3]. One commonly made assumption in such studies, and in studies of the effects of scattering on, for example, transport properties [4], is that the scattering is in the unitary limit.

We here report the results of STM measurements of a new kind of scattering resonance, similar to those found surrounding Zn and Ni atoms, yet with a resonance energy close to the Fermi energy, indicating it is very near the unitary limit. We postulate, for reasons described below, that these resonances are generated by Cu vacancies and hence refer to them as "vacancy resonances". We have observed vacancy resonances in all of the BSCCO samples that we have studied thus far, including oxygen underdoped, optimally doped and overdoped, and including samples which were not impurity doped as well as those doped with Ni and Zn. For space considerations we here show only data taken from an as grown crystal (i.e. nearly optimally doped), grown by the floating zone technique and doped with 0.2% of Ni atoms (T_c of 85 K).

Our method of study follows that described in detail in previous papers [1]. We make use of both the topographic imaging capability of the STM and its ability map the electronic local density of states (LDOS) on the surface at energy $E = eV$ by measuring the differential tunneling conductance G at sample bias V as a function of position.

Typical spectra taken at the center of a vacancy resonance (an example of which is presented in Fig. 1) are strongly reminiscent of results obtained on Zn resonances, characterized by the suppression of the coherence peaks and the presence of a strong peak slightly below the Fermi energy (typically ~0.5 meV). Although this peak is the dominant one in the spectrum, it is not the only one, with at least one weaker shadow resonance appearing at positive sample bias (appearing as a shoulder on the larger peak).

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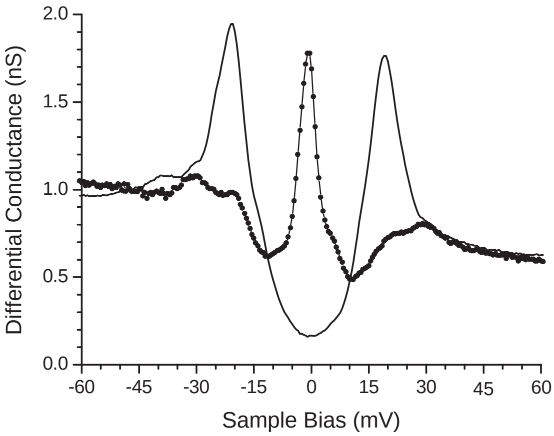

Fig. 1. Differential conductance spectrum from the center of a vacancy resonance in the Ni doped sample, obtained at 4.2 K using a lock-in technique. The junction resistance was set to 1 GΩ at $V_{\mathrm{sample}} = -200$ mV, and the 447.3 Hz lock-in modulation had an amplitude of 500 μV_{rms}.

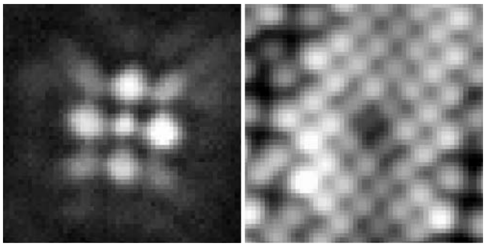

Fig. 2. Simultaneously obtained (a) LDOS map and (b) topography of a 32 Å square region, centered on a single vacancy resonance.

An LDOS map (taken at the resonance energy of -0.5 meV) and the associated topography of a 32 Å region surrounding a single vacancy resonance, are shown in Fig. 2. The map shows that, just as for Zn, the center of the resonance is "bright" at the resonance energy (i.e. the resonance is strongest at the spatial center of the resonant state) as are four spots at roughly the locations of the next nearest Bi atoms (or Cu atoms in the CuO_2 plane)—along the gap nodal direction. Four weaker resonance spots appear near the third nearest neighbor atom locations along the gap maximum direction. Although we describe the resonance peak locations as being associated with atoms, we stress that they do not lie directly above the atoms.

In contrast to these common features, the topography (Fig. 2b) shows a thus far unique attribute of the vacancy resonances—a topographic depression of the center and nearest neighbor surface Bi atoms (by ~ 0.5 and ~ 0.2 Å, respectively). Due to the nature of STM topography, it is impossible to determine whether this observation is caused by a physical depression of these atoms or by a loss of spectral weight at these locations, but either way it reflects a significant perturbation to the local environment. Coupled with the fact that the resonance energy (~ -0.5 meV) is even closer to the Fermi energy than that observed in Zn resonances (~ -1.5 meV) it is apparent that the source of scattering in these resonances is very strong (unitary). This is one reason why we hypothesize that the scattering is due to Cu vacancies. Further evidence comes from the fact that we observe these resonances in a wide variety of samples, including those in which no intentional impurities have been added. Regardless of their source, however, these resonances provide those wishing to study unitary scattering in the high temperature superconductors with a new experimental benchmark.

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