Effect of Zn and Ni impurities on the quasiparticle renormalization in $Bi_2Sr_2CaCu_2O_{8+\delta}$

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Abstract

The Cu substitution by Zn and Ni impurities and its influence on the mass renormalization effects in angle resolved photoelectron spectra (ARPES) of $Bi_2Sr_2CaCu_2O_{8+\delta}$ is addressed. We show that the nonmagnetic Zn atoms have much stronger effect both in nodal and antinodal parts of the Brillouin zone than magnetic Ni. The observed changes are consistent with the behaviour of the spin resonance mode as seen by inelastic neutron scattering in YBCO-123. This strongly suggests that the "peak-dip-hump" and the "kink" in ARPES on the one side and neutron resonance on the other are closely related features.
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Since their discovery in the single-particle spectral function of a high-T_C superconductor the anomalous renormalization effects are believed to be crucial for understanding the phenomenon of high-T_C superconductivity. Along the nodal direction of the Brillouin zone (BZ) renormalization effects are represented by the so called "kink" [1–3]. In the vicinity of the $(\pi, 0)$ point of the BZ the renormalization is noticeably stronger and makes itself evident even in the lineshape of the spectral function $A(\mathbf{k}, \omega)$ [4–6]. Now it is widely accepted that the coupling to a collective mode [7,8] is the reason for these anomalies. However the mode origin remains a current controversy between the two most frequently proposed candidates which are phonons and magnetic excitations. As follows from the inelastic neutron scattering experiments (INS), doping different types of impurities into the CuO_2 plane [10,9] distinctly modifies the spectrum of magnetic excitations. Therefore, if it is the coupling to magnetic excitations that causes the aforementioned effects, the corresponding changes should also be detected in ARPES spectra. To check for this we studied three high quality samples: nearly optimally doped pure BSCCO ($T_C = 92$ K), 1% Zn ($T_C = 86$ K), and 2% Ni ($T_C = 87$ K) substituted BSCCO. Basing on FS areas, the hole doping level for the samples was found to be identical within 2%. The ARPES experiments were carried out at the U125/1-PGM beam line (BESSY) using a SCIENTA SES100 spectrometer. The data were collected from freshly cleaved surfaces at $T = 30$ K with overall energy and angular resolution of 20 meV and 0.2°, respectively.

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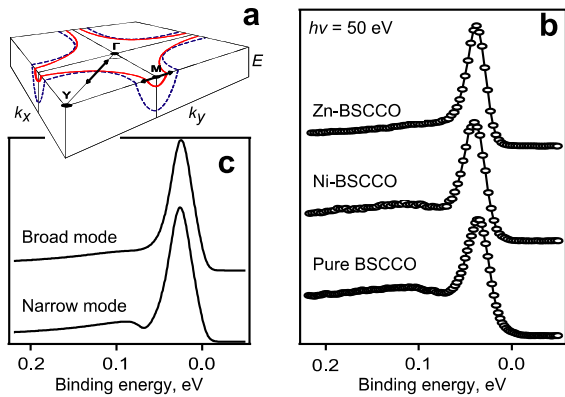*E-mail address:* v.zabolotnyy@ifw-dresden.de (V.B. Zabolotnyy).

Fig. 1. (a) BSCCO band structure. The red solid line corresponds to the antibonding band, the blue dashed one – to the bonding band. (b) Experimental spectra taken at $(\pi,0)$ point. (c) Model spectra, when coupled to a narrow (2 meV) and broad (20 meV) collective mode.

Fig. 2. Experimental dispersions along the BZ diagonal.

The two regions of the BZ that we concentrated on, the nodal and the antinodal one, are schematically shown by two double headed arrows in Fig. 1a.

In the Fig. 1b we plot ARPES spectra measured at the $(\pi, 0)$ point of the BZ. To exclude the effects of bilayer splitting on the line-shape, these spectra were measured with excitation energy of 50 eV, when the photoemission from the bonding band is suppressed due to matrix elements effects [11]. The remarkable feature of these spectra is the presence of a "dip" at binding energy of about 60–70 meV and its gradual vanishing when going from a pure to Zn substituted sample. We find that such behaviour can be well understood in terms of coupling of the electrons to a mode whose width is affected by incorporated impurities. This corresponds exactly to the behavior of the spin resonance mode as observed by INS [9]: While for the pure sample the mode is resolution limited, for 1% Zn substituted YBCO its FWHM reaches 10 meV. Furthermore, INS data implies that magnetic Ni has weaker impact on the spin resonance than Zn, since 3% of Ni atoms result in approximately the same broadening of the resonance along momentum and energy axes as 1% of Zn [10]. Therefore such a broadening of the resonance would result in a smearing of the features in the self energy and, consequently, lead to a smearing of the dip itself. In Fig. 1c we illustrate this by a simple simulation where the effects of the coupling to the mode were modelled by a smeared step-like increase of the imaginary part of self energy.

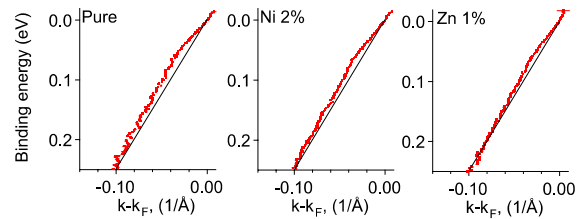To investigate the effects of impurities along the nodal direction we measured the renormalized band dispersion strictly along the BZ diagonal. The simplest way to "quantify" the strength of renormalization is to consider the deviation of the dispersion from the straight line, namely, the area enclosed between the line and the dispersion curve (Fig. 2). Although, like for the antinode, for the nodal direction Zn atoms have the strongest impact, it cannot be simply accounted for by the broadening of spin resonance, since the resonance mode with momentum $Q = (\pi, \pi)$ may not effectively scatter the nodal quasiparticles. To properly account for this, one likely needs to consider not only the spin resonance but the whole magnetic spectrum, in particular, the new resonance feature peaked at 54 meV and Q_{IC}^* [12,13]. However, the behaviour of this new resonance with impurity substitution still has to be clarified.

To conclude, we show that while both types of impurities suppress the renormalization effects, the Zn atoms have stronger effect both in nodal and antinodal regions of the BZ.

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