Spectral properties of incommensurate CDW scattering in cuprates

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Abstract

Motivated by the observation of periodic charge modulations in $Bi_2Sr_2CaCu_2O_{8+\delta}$ by recent STM experiments we show that the associated collective charge dynamics can also account for the peculiar features as seen in ARPES experiments. Especially the famous peak-dip hump structure of the line shape and the related kink in the dispersion can be well described by the coupling of the charge carriers to dynamical incommensurate CDW fluctuations. From a comparison with ARPES data we obtain a mode frequency which decreases towards optimal doping thus strongly supporting the existence of a quantum critical point around this concentration. Finally we extract the temperature dependence of the CDW mode from ARPES experiments and extend this approach in order to include the recently observed bilayer splitting.

Key words: ARPES ;charge-density waves ; quantum critical point

1. Introduction

Numerous experiments now support the existence of a collective mode in the high-T_c materials most prominently exemplified by the appearance of a kink in the electron dispersion near the Fermi surface as seen in angle resolved photoemission spectroscopy (ARPES) (see e.g. [1]). Concerning the origin of the mode the various proposals include a magnetic resonance (see e.g. [2]), the coupling to phonons [1] or incommensurate charge-density waves [3] as the source of the associated strong scattering. Here we are concerned with the latter scenario which is based on the idea that the phase diagram of the cuprates displays a quantum critical point (QCP) located near optimal doping where the corresponding order parameter in the underdoped regime corresponds to the formation of incommensurate charge-density waves [4].

2. Formalism

We consider a system of superconducting (SC) electrons exposed to an effective action

$$S = -\lambda^2 \sum_q \int_0^\beta d\tau_1 \int_0^\beta d\tau_2 \chi_q(\tau_1 - \tau_2)\rho_q(\tau_1)\rho_{-q}(\tau_2)$$

describing the coupling to dynamical incommensurate CDW fluctuations. For simplicity we consider a model susceptibility which is factorized into an ω- and q-dependent part, i.e. $\chi_q(i\omega) = W(i\omega)J(\mathbf{q})$ where $W(\omega) = -\int d\nu g(\nu) 2\nu/(\omega^2 + \nu^2)$ is some distribution of dispersionless propagating bosons and $J(\mathbf{q})$ contains the charge-charge correlations which are enhanced at the four equivalent critical wave vectors $(\pm q_x^c, \pm q_y^c)$.

3. Results

Within the above formalism we have calculated the spectral function at $(\pi, 0)$ for a single energy excitation $(g(\nu) = \delta(\nu - \omega_0))$ and adjusted parameters in order

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to fit (low temperature) ARPES data from Ref. [5] for various concentrations. Fig. (1) shows the results of our fit where we have added a step-like function (constant for all dopings) in order to model the background. Note that our approach is more suitable for the underdoped regime since close to the QCP or for concentrations $x > x_{opt}$ the ICDW fluctuations are expected to become strongly overdamped. However, as can be seen from the inset to Fig. (1) the extracted mode frequency displays a strong softening towards optimal doping which is thus consistent with the existence of a ICDW-QCP around $x = x_{opt}$.

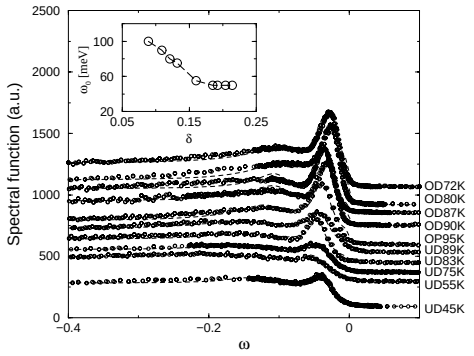

Fig. 1. Fit to ARPES spectra at $(\pi, 0)$ of differently doped Bi2212 samples (OD: overdoped; OP: optimally doped; UD: underdoped). Experimental data are taken from Ref. [5]. The inset reports the extracted mode frequency as a function of doping.

In order to describe the temperature dependence of the spectral line width we have considered a bosonic spectrum which significantly broadens as a function of temperature, i.e. $g(\nu)$ interpolates between a sharp low temperature excitation at ω_0 and marginal Fermi liquid (MFL) behavior at higher temperatures. The corresponding quasiparticle weight is then given by $Z = \left[1 + \frac{\lambda}{\Gamma} \ln \frac{\omega_0 + \Gamma}{\omega_0 - \Gamma}\right]^{-1}$ where Γ denotes the half-width of the bosonic spectrum and λ is a coupling parameter. The T-dependence of Z has been extracted from the ARPES line shape at $(\pi, 0)$ in Ref. [5] which shows a continuous drop in the SC state. From our analysis we thus conclude that already for temperatures $T < T_c$ there is a crossover from mode-type to MFL behavior in the electronic self-energy. We have applied this model to describe the temperature dependence of photoemission spectra in Bi2212 where recent ARPES experiments have succeeded in resolving the bilayer splitting (see e.g. [6,7]). Most interestingly it has been able to show that besides the bonding (BB) and antibonding (AB) band peaks the spectral line shape displays an additional peak-dip-hump feature below T_c.

We have thus extended our calculation and included two layers which are coupled by an anisotropic hopping of the form $t_\perp(k) = t_0[\cos(k_x) - \cos(k_y)]$ as suggested by ARPES experiments [6]. Moreover, since due to the weak interplane screening the interaction between layers is expected to be essentially repulsive, intra- and interlayer CDW susceptibilities are related by $\chi_{inter} = -\chi_{intra}$. Figure (2) shows the resulting spectral functions at $k = \pi(1, 0.1)$ above and below T_c respectively. The peak-dip hump structure in the normal state is now completely due to the bilayer splitting where the broad BB feature is determined by the underlying MFL-type self-energy. However, due to the sharpening of the bosonic spectrum in the SC state there appears a clear signature of an additional peak-dip hump structure where the hump is mainly determined by the bonding band.

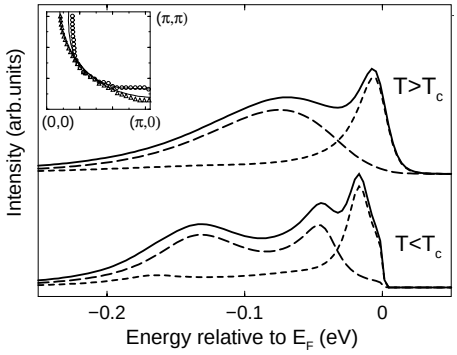

Fig. 2. Spectral line shape at $k = \pi(1, 0.1)$ below and above T_c (solid). Also shown is the contribution from AB (short dashed) and BB (dashed) respectively. The inset displays our tight-binding Fermi surface in comparsion with data from [6].

We have thus shown that dynamical incommensurate CDW scattering can account for the main features as observed in ARPES experiments. However, the sharpening of the spectrum in the SC state and its evolution with doping remain an open and interesting issue for further investigations.

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References

[1] A. Lanzara et al., Nature **412** (2001) 510 .

[2] J. C. Campuzano et al., Phys. Rev. Lett. **83**(1999) 3709 .

[3] G. Seibold and M. Grilli, Phys. Rev. B **63** (2001) 224505 .

[4] C. Castellani et al., Phys. Rev. Lett. **75**, (1995) 4650 .

[5] H. Ding et al., Phys. Rev. Lett. **87**, (2001) 227001 .

[6] D. L. Feng et al., Phys. Rev. Lett. **86**, (2001) 5550 .

[7] A. D. Gromko et al., cond-mat/0205385 .