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Dielectric response function in *t–J–V* model

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Abstract

The dielectric response function $\varepsilon(\mathbf{q},\omega)$ has been derived in the frame $t-J-V$ model. In addition to the acoustic plasmon modes, a new collective charge excitation mode has been found. We have shown, that in layered cuprates the inverse dielectric function $1/\varepsilon(\mathbf{q},\omega)$ may be negative in the area which partially overlaps the Fermi surface. Then, the interaction of quasiparticles via plasmon field causes the higher order harmonics in $d_{x^2-y^2}$-wave symmetry of the superconducting gap driven mainly by the superexchange interaction.
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A dielectric response function shows how the Fourier transform of the interaction between quasiparticles changes in the matter with respect to some ideal bare model. Note, the possibility for a negative ε has been explored in a number of studies [1] in order to account for high T_c in cuprates. However, the microscopic origin of the negative ε remains unclear. Therefore, a microscopical study of the dielectric response function in application to high-T_c cuprates is of general interest.

In our study, we start from the Hamiltonian

$$H=\sum t_{ij}\psi_i^{\mathrm{pd},\sigma}\psi_j^{\sigma,\mathrm{pd}}+\frac{1}{2}\sum J_{ij}(\mathbf{S}_i\mathbf{S}_j)+\frac{1}{2}\sum V_{ij}\delta_i\delta_j, \qquad (1)$$

where t_{ij} is a hopping integral, $\psi_i^{\mathrm{pd},\sigma}$ ($\psi_j^{\sigma,\mathrm{pd}}$) are the creation (annihilation) composite Hubbard-like quasiparticle operators, σ is a spin projection. The symbol pd corresponds to a copper–oxygen singlet state with one hole placed on a copper and the second hole distributed on the neighboring oxygen sites. The spin and density operators are expressed by projecting operators as follows: $S_i^+=\psi_i^{\uparrow,\downarrow}$, $S_i^-=\psi_i^{\downarrow,\uparrow}$, $S_i^z=\frac{1}{2}(\psi_i^{\uparrow,\uparrow}-\psi_i^{\downarrow,\downarrow})$, $\delta_i=\psi_i^{\mathrm{pd,pd}}$. Note, the first two terms of the Hamiltonian (1) map on to so-called t–J model. The last term in Eq. (1) accounts for the density–density interaction.

In general case the dynamical charge susceptibility $\chi_{\mathrm{ch}}(\mathbf{q},\omega)$ is written as follows:

$$\chi_{\mathrm{ch}}(\mathbf{q},\omega)=\frac{\chi_{\mathrm{ch}}^{(0)}(\mathbf{q},\omega)}{1+V_{\mathbf{q}}\chi_{\mathrm{ch}}^{(0)}(\mathbf{q},\omega)+\frac{1}{2}\Pi_{\mathrm{ch}}^{(2)}(\mathbf{q},\omega)-((2-P_{\mathrm{pd}})/2)Z_{(\mathrm{ch})}(\mathbf{q},\omega)}, \qquad (2)$$

where

$$\chi_{\mathrm{ch}}^{(0)}(\mathbf{q},\omega)=\frac{1}{N}\sum\left[C_{xx}\frac{n_{\mathbf{k}}-n_{\mathbf{k+q}}}{\omega-E_{\mathbf{k}}+E_{\mathbf{k+q}}}+C_{yy}\frac{n_{\mathbf{k+q}}-n_{\mathbf{k}}}{\omega+E_{\mathbf{k}}-E_{\mathbf{k+q}}}\right]+\frac{1}{N}\sum\left[C_{xy}^{(+)}\frac{P_{\mathrm{pd}}-n_{\mathbf{k+q}}-n_{\mathbf{k}}}{\omega+E_{\mathbf{k}}+E_{\mathbf{k+q}}}+C_{yx}^{(-)}\frac{n_{\mathbf{k}}+n_{\mathbf{k+q}}-P_{\mathrm{pd}}}{\omega-E_{\mathbf{k}}-E_{\mathbf{k+q}}}\right] \qquad (3)$$

and $\Pi_{\mathrm{ch}}(\mathbf{q},\omega)$ and $Z_{\mathrm{ch}}(\mathbf{q},\omega)$ describe the strong correlation effects [2]. For example, $Z_{\mathrm{ch}}(\mathbf{q},\omega)$ has the form

$$Z_{\mathrm{ch}}(\mathbf{q},\omega)=\frac{1}{N}\sum\left[C_{xx}\frac{\omega}{\omega-E_{\mathbf{k}}+E_{\mathbf{k+q}}}+C_{yy}\frac{\omega}{\omega+E_{\mathbf{k}}-E_{\mathbf{k+q}}}\right]+\frac{1}{N}\sum\left[C_{xy}^{(+)}\frac{\omega}{\omega+E_{\mathbf{k}}+E_{\mathbf{k+q}}}+C_{yx}^{(-)}\frac{\omega}{\omega-E_{\mathbf{k}}-E_{\mathbf{k+q}}}\right]. \qquad (4)$$

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