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Optical conductivity in the "hot spots" model of the pseudogap state

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Abstract

We consider a two-dimensional model of the pseudogap state, based on the scenario of strong electron scattering by fluctuations of "dielectric" (AFM, CDW) short-range order, dominating within the regions around "hot spots" on the Fermi surface. A system of recurrence equations is constructed both for one-particle Green's function and vertex part, describing electron interaction with an external field, which takes into account *all* Feynman graphs for electron scattering these (Gaussian) fluctuations. The results of detailed calculations of optical conductivity are presented for different geometries (topologies) of the Fermi surface, demonstrating both the effects of pseudogap formation and localization effects.

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In the model of "nearly antiferromagnetic" Fermi-liquid, which is actively used to explain the microscopic nature of HTSC, effective electron interaction with spin-fluctuations of AFM short-range order is usually described by the dynamic spin susceptibility having a sharp maximum at the wave vector $\mathbf{Q} = (\pi/a, \pi/a)$ of antiferromagnetic ordering in dielectric phase, and characterized by correlation length ξ an frequency ω_{sf} of spin fluctuations. Strong scattering by fluctuations with $\mathbf{q} \sim \mathbf{Q}$ leads to two "types" of quasiparticles—"hot" one with momenta in the vicinity of "hot spots" on the Fermi surface and "cold" with momenta around the parts of the Fermi surface around Brillouin zone diagonals [1,2]. For high enough temperatures $\pi T \gg \omega_{sf}$ we can neglect the spin dynamics [2], and use the static approximation. We assume the usual spectrum of free ("bare") quasiparticles [2],

$$\xi_{\mathbf{p}} = -2t(\cos p_x a + \cos p_y a) - 4t' \cos p_x a \cos p_y a - \mu \quad (1)$$

characterized by t—the transfer integral between nearest neighbors, and t'—the transfer integral for second nearest neighbors on the square lattice, and different values of the chemical potential μ.

In Ref. [3] we have performed a detailed analysis of higher-order contributions for electron self-energy and obtained "nearly" exact recursion relation for the one-electron Green's function [5]), giving an effective algorithm for numerical computations and taking into account *all* Feynman diagrams of perturbation series over an effective interaction with spin fluctuations, characterized by an effective amplitude (energy) Δ, determining the pseudogap width. Our solution for one-particle Green's function is exact in the limit of $\xi \to \infty$ [4,2]. It is also exact in a trivial limit of $\xi \to 0$. For all intermediate values of ξ it gives apparently very good interpolation, being practically exact for certain geometries of the Fermi surface [3].

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To calculate optical conductivity we need the knowledge of the vertex part, describing electromagnetic response of the system. This vertex can be determined using the method suggested for the similar one-dimensional problem in Ref. [6]. Details of this recursion procedure which also takes into account *all* perturbation theory diagrams (with different diagram combinatorics—commensurate [3], spin-fermion [2] or standard ladder [6,7]) for two-dimensional case can be found in Ref. [7].

Optical conductivity and some other characteristics of the model were computed using standard expressions via Green's functions and vertex [8] for different values of parameters, determining the "bare" quasiparticle spectrum and for fixed value of $\Delta = t$. Some of our results [7] are presented in Figs. 1 and 2, where conductivity is measured in units of the universal conductivity in two-dimensions $\sigma_0 = \frac{e^2}{\hbar} = 2.5 \times 10^{-4}\ \Omega^{-1}$ and the density of states—in units of $1/ta^2$. Typical picture is that of rather wide maximum of $\mathrm{Re}\sigma(\omega)$ for $\omega \sim 2\Delta$, due to absorption through pseudogap and localization maximum at small frequencies (disappearing in "ladder" approximation). It should be noted that maximum due to pseudogap absorption remains even in case of only slight manifestation of the pseudogap in the density of states. Introduction of additional dephasing scattering rate γ due to inelastic processes leads to the appearance of narrow Drude-like peak at small frequencies as shown in Fig. 2. These results are somehow similar to those obtained in earlier simplified approach [9]. Note that the qualitative behavior of optical conductivity observed in Ref. [10] for NdCeCuO is in complete agreement with results shown in Fig. 2.

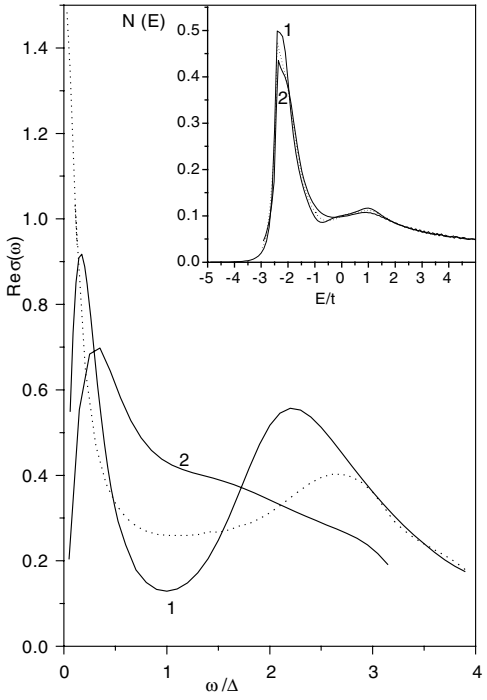

Fig. 1. Real part of optical conductivity for $t'/t = -0.4$ and $\mu/t = 0$ for $a/\xi = 0.1$ and different combinatorics of diagrams: 1—spin-fermion combinatorics; 2—commensurate case. Dashed line—"ladder" approximation. At the insert-corresponding densities of states.

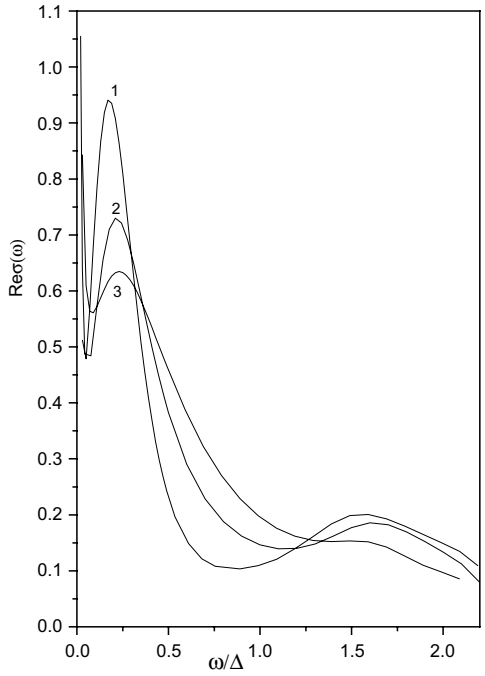

Fig. 2. Real part of optical conductivity in spin-fermion model for $t'/t = -0.4$ and $\mu/t = -1.3$ (typical for high-temperatures superconductors) and different values of correlation length a/ξ: 0.05–1; 0.1–2; 0.2–3. Inelastic dephasing rate $\gamma/t = 0.005$.

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