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Optical Conductivity in a Simple Model of the Pseudogap State

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We present calculation of optical conductivity in a simple model of electronic spectrum of two-dimensional system with "hot patches" on the Fermi surface, leading to non Fermi-liquid renormalization of the spectral density (pseudogap) on these patches. Based upon "nearly"-exact solution for the two-particle Green's function it is shown that this model qualitatively reproduces basic anomalies of optical experiments in the pseudogap state of copper oxides.

We assume that pseudogap anomalies are mainly due to fluctuations of antiferromagnetic short-range order, as in the "hot-spots" model [1]. In this model it is possible to obtain "nearly" exact solution for the electronic spectrum, based upon complete summation of all the relevant Feynman diagrams, describing electron interaction with antiferromagnetic fluctuations [1,2], generalizing to two dimensions the earlier solution of a similar one-dimensional problem [3–5]. Here we consider much simplified "hot patches" model of the pseudogap state proposed in Ref.[7], which is physically quite close to "hot spots" model. Following Ref. [7] we assume that the Fermi surface of two-dimensional electronic system has flat (nesting) patches of finite width along $(0,\pi)$ and symmetric directions in the Brillouin zone. Fluctuations of short-range order are assumed to be static and Gaussian with correlation function of the form [2,7]:

$$S(\mathbf{q})=\frac{1}{\pi^2}\frac{\xi^{-1}}{(q_x-Q_x)^2+\xi^{-2}}\frac{\xi^{-1}}{(q_y-Q_y)^2+\xi^{-2}} \quad (1)$$

where either $Q_x=\pm 2p_F$, $Q_y=0$ or $Q_y=\pm 2p_F$, $Q_x=0$ for incommensurate fluctuations, $\mathbf{Q}=(\pi/a,\pi/a)$ for commensurate case. We shall assume that these fluctuations interact only with electrons from the "hot" (nesting) patches of the Fermi surface. Effective interaction of these electrons with fluctuations we shall model as $(2\pi)^2\Delta^2 S(\mathbf{q})$, where Δ is of dimensions of energy and defines the characteristic width of the pseudogap. On "cold" patches we shall assume the existence of some weak static scattering of arbitrary nature with appropriate scattering rate described by phenomenological parameter γ.

In the limit of $\xi\to\infty$ this model can be solved exactly summing all perturbation series diagram for both one – particle and two – particle Green's functions, by method used in Refs.[3,7], while for finite ξ it can be "nearly" exactly solved (cf.[1,2]) by the method of Refs. [4,5]. Spectral density and density of states for this model were obtained in Ref. [7] and demonstrated non Fermi-liquid pseudogap behavior on "hot" patches of the Fermi surface. Conductivity in this model is determined by additive contributions from "hot" and "cold" patches. For its real part we obtain:

$$Re\sigma(\omega)=\frac{4\alpha}{\pi}Re\sigma_\Delta(\omega)+(1-\frac{4\alpha}{\pi})Re\sigma_D(\omega) \quad (2)$$

$$Re\sigma_\Delta(\omega)=\frac{\omega_p^2}{4}\frac{\Delta}{\omega^2}\int_0^{\omega^2/4\Delta^2}d\zeta\, exp(-\zeta)\frac{\zeta}{\sqrt{\frac{\omega^2}{4\Delta^2}-\zeta}} \quad (3)$$

where ω_p – is plasma frequency and

$$Re\sigma_D(\omega)=\frac{\omega_p^2}{4\pi}\frac{\gamma}{\omega^2+\gamma^2} \quad (4)$$

–is the usual Drude–like conductivity from "cold" patches. Parameter α defines the angular size of "hot" patches [7].

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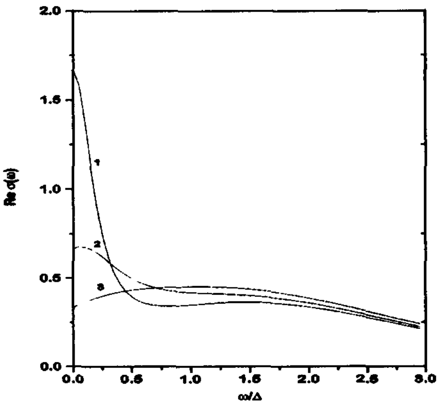

Figure 1. Real part of conductivity in the model with infinite correlation length. Conductivity is in units of $\omega_p^2/4\pi\Delta$. Incommensurate fluctuations, $\alpha = \pi/6$. (1)—$\gamma/\Delta = 0.2$; (2)—$\gamma/\Delta = 0.5$; (3)—$\gamma/\Delta = 1.0$.

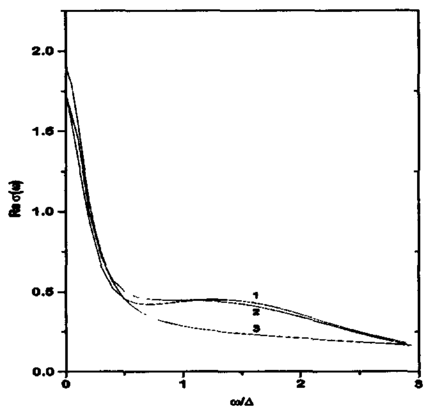

Figure 2. Real part of conductivity as a function of correlation length for the fixed value of $\gamma = 0.2\Delta$. Commensurate fluctuations, $\alpha = \pi/6$. (1)—$v_F\xi^{-1}/\Delta = 1.0$; (2)—$v_F\xi^{-1}/\Delta = 0.5$; (3)—$v_F\kappa/\Delta = 0$.

In Fig.1 we present the frequency dependence of the real part of conductivity, calculated from (2), (3) for different values of γ. As the scattering rate γ on "cold" patches grows, the Drude-like peak at small frequencies is dumped. More realistic case of finite correlation length of "antiferromagnetic" short-range order fluctuations ξ in (1) can be analyzed by the method of Refs.[4,5], which allows to find "nearly exact" [2] solution of the problem. For one-electron Green's function on "hot" patches we obtain the recurrence relation (continuous fraction representation) similar to that obtained in Ref. [4]). For the vertex-part, determining density-density response function (two-particle Green's function) on "hot" patches, we have recurrence relations of Ref. [5] (see also [1]). "Hot" patches contribition to conductivity $Re\sigma_\Delta(\omega)$ in (2) can be calculated as in Ref. [5]. In Fig.2 we show the frequency dependence of the real part of conductivity obtained in this way for different values of correlation length ξ for the case of commensurate fluctuations. Similar data for incommensurate case and spin-fluctuation model can be found in Ref. [6]. Real part of conductivity is characterized by rather narrow Drude-like peak for small frequencies $\omega < \gamma$ due to "cold" patches on the Fermi surface and relatively flat maximum for frequencies $\omega \sim 2\Delta$, corresponding to the absorption through the pseudogap which opens on "hot" patches. Dependence on correlation length is rather weak.

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