Temperature dependence of the magnetic penetration depth and multicomponent order parameter in the $YBa_2Cu_3O_{7-\delta}$

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Abstract We have analyzed the temperature dependencies of the superfluid density in $YBa_2Cu_3O_7$ along a- and b- crystallographic axes using the multicomponent order parameter for the superconducting gap. Estimated values of the gap components for the d-wave and the isotropic s-wave are Δ_d=29meV and Δ_s=5meV correspondently. Band structure parameters were taken accordingly ARPES and neutron scattering data.
Keywords: Superconductivity, multicomponent order parameter, superfluid density

Introduction

Intensive studies of HTSC cuprates by different experimental methods displayed the unbelievable complexity of these materials [1]. Telplov et al. [2,3] at early stages of HTSC activity have demonstrated that even most perfect compounds $TmBa_2Cu_4O_8$ show an anomalies in Tm –NMR line width at $T<T^*$. Afterwards, Mьller and Keller [4] pointed some evidence that HTSC cuprates are unconventional superconductors with multicomponent order parameter. For now this intriguing phenomena is under debate of many studies [5,6]. In this paper we focus on the temperature dependence of the superfluid density in orthorhombic $YBa_2Cu_3O_{6.98}$ reported in [7] and show that this data allows us to extract the relative value of s- and d- component of superconducting gap. It is clear that in addition to other possibilities to measure the multicomponent order parameter (via ARPES [8], by neutron scattering [9,10] tunneling experiments [11,12], or via Raman [13] spectroscopy) it will give us a new information about the nature of interactions yielding the superconducting pairing.

Temperature dependencies of the superfluid density

Our calculations are based on the energy dispersion for carriers in CuO_2 plane, which has been extracted from ARPES data [9]. The general expression for the superfluid density was discussed for details in paper [14]. It is written as follows

$$\frac{1}{\lambda^2} = 4\pi\left(\frac{e}{c\hbar}\right)^2\left\{\sum_k \frac{\partial\varepsilon_k}{\partial k_x}\left[\frac{|\Delta_k|^2}{E_k^2}\frac{\partial\varepsilon_k}{\partial k_x} - \frac{(\varepsilon_k-\mu)}{2E_k^2}\frac{\partial|\Delta_k|^2}{\partial k_x}\right]\left[\frac{1}{E_k} - \frac{\partial}{\partial E_k}\right]\tanh\left(\frac{E_k}{2k_BT}\right)\right\}. \quad (1)$$

Here it is assumed that the field is applied along the x-axis in CuO_2-plane (ab). ε_k is the energy dispersion for quasiparticles in the normal state, μ – chemical potential, $E_k = \sqrt{(\varepsilon_k-\mu)^2+|\Delta_k|^2}$ – Bogolubov's quasiparticles energy in the superconducting state, Δ_k is the energy gap, which depends on wave vector and temperature. Energy dispersion has been taken in form [9]: