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THE INFLUENCE OF CARRIER DENSITY ON THE CRITICAL TEMPERATURE IN LAYERED SUPERCONDUCTORS

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The influence of carrier density on the critical temperature of layered superconductors is studied by using the real dependence of density of states on energy in the framework of ordinary BCS model. It is shown that such a model is in agreement to known experimental data for $La_{2-x}Sr_xCuO_{4-\delta}$ and $YBa_2Cu_3O_y$ superconductors for the dependence of the critical temperature on the dopant concentration and oxygen deficiency, correspondingly.

INTRODUCTION

In connection with the anisotropic structure of high temperature superconductors (HTSC) properties of layered superconductors are widely discussed now. It is already established that the critical temperature of HTSC is very sensibility to the oxygen deficiency or dopant concentration, which determined the occupation of the conductivity band [1,2]. The property of layered superconductors was investigated in the framework of phenomenogical Ginsburg-Landau theory [3] and in the microscopical Eliashberg theory [4, reference therein]. The purpose of the present note is to analyse the critical temperature dependence on carrier density for layered SC. In this connection we will use the ordinary theory BCS taking into account the real dependence of the density of states on energy.

BASIC EQUATION

The dispersion of charge carriers in layered superconductors is given by [5]:

$$\xi(p, p_z) = \frac{p_x^2 + p_y^2}{2m} + 2t(1 - \cos p_z d) - \mu \tag{1}$$

where the first term represent the dispersion along layers, t -is the transfer matrix from plane to plane, μ - chemical potential for the given carrier concentration $n; \hbar = 1$. The equation for the critical temperature [6]

$$q \int_{-\omega_0}^{\omega_0} N(\mu + \xi) \frac{th \frac{\xi}{2T_c}}{2\xi} d\xi = 1 \tag{2}$$

(where q - the attractive constant of between carriers in the frequency interval ω_0 nearly μ, $N(\xi)$ -density of states) must be solved by together with equation for the chemical potential. According to [7] density of states given by the formula:

$$N(\xi) = \frac{m}{d\pi^2} z(\xi) \tag{3}$$

where $z(\xi)$ determined by the formula

$$z(\xi) = \begin{cases} \pi & if \ \xi \geq 4t \\ arccos\left(1 - \dfrac{\xi}{2t}\right) & if \ \xi \leq 4t \end{cases}$$

Relation between carrier concentration and chemical potential under fixed temperature is determined by the equation:

$$n = \frac{mT}{2\pi^2}\left(\frac{\mu-2t}{T}+\frac{1}{\pi}\int_{-\pi}^{\pi}dz\ln\left(1+\exp\frac{(2t(1-\cos z)-\mu)}{T}\right)\right) \tag{4}$$

where $z = p_z d$. In the case degenerated electron gas we can carried out integration in (4) analytically. For $\mu \geq 4t$ equation (4) simplify to:

$$\frac{\mu}{4t} = \frac{\left(1+\frac{n}{n_0}\right)}{2} \tag{5}$$

where $n_0 = \frac{4mt}{\pi d}$. In the case $\mu \leq 4t$ we have next formula:

$$\frac{\mu}{4t} = \frac{1-\cos(z_0(n))}{2} \tag{6}$$

where $z_0(n)$ can be defined by solution of next equation:

$$\frac{n}{n_0} = \frac{(\sin z_0 - z_0 \cos z_0)}{\pi} \tag{7}$$

Equation (6) given us non-appearance form of the $\mu(n)$ function. It is obviously that in all case μ increasing by the increase carrier density n.
Using asymptotical formula for the density of states (3), and using condition BCS $\omega_0 << \mu$, we have get next formula for the critical temperature T_c for the case $\mu \leq 4t$:

$$T_c = T_{c0}\exp\left(\frac{\pi d}{qm}\left(1-\frac{4t}{\mu(n)}\right)\right) \tag{8}$$

For the case $\mu \geq 4t$ critical temperature is equal

$$T_c = T_{c0} \tag{9}$$

where T_{c0}-critical temperature for the two-dimensional superconductors.

RESULT

How following from the formula (7) by increasing μ, T_c is increased and at $\mu \geq 4t$ arise saturation. We can see that for the small chemical potential critical temperature T_c is extremely sensitive to changes in the carrier density and we take this as an indication that our model is also capable of a qualitative description of doping effects.
It is necessary to note that in the case three dimensional SC [6] dependence density of states has a square root character and can be neglected in calculations due to high value of chemical potential. The measurements [8] shows that for the $La_{2-x}Sr_xCuO_4$ at $x = 0.1$ $\mu = 0.046$ eV and at x=0.15 μ=0.1 eV, t=0.015 eV. Fig.1 shows how the carrier concentration and there fore affects the critical temperature. These results support by experimental dates in this system. The cross are data from M.W.Shafer et al as determined chemical method [9]. The hole concentration equals the Sr concentration to about x=0.15. At small x Sr is distributed proportionally and by increasing Sr lead to increasing of the hole concentration in CuO planes [10]. For $x > 0.15$, the only partially position is occupated by the Sr atoms and oxygen vacancies are formed. As result hole concentration n and T_c decreases.

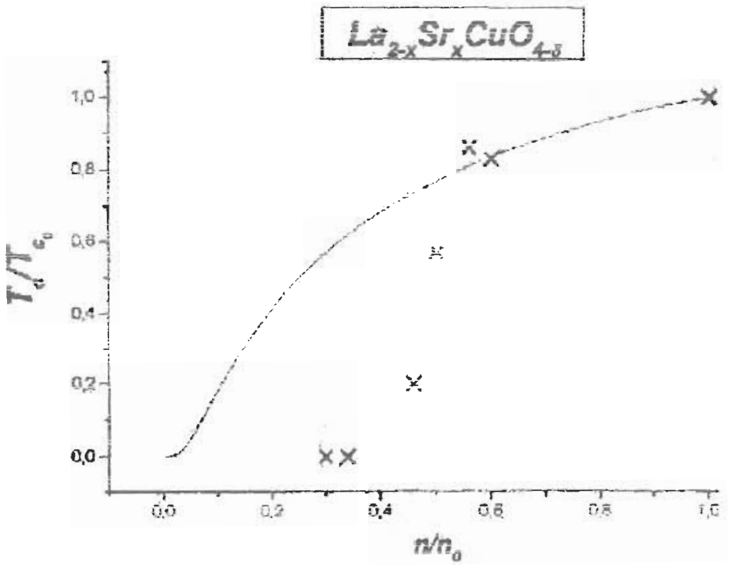

Fig.1.
The dependence of the critical temperature on the carrier concentration for $La_{2-x}Sr_xCuO_{4-\delta}$.

For the $YBa_2Cu_3O_Y$ measurements shows that $\mu = 0.1\text{eV}$, $t = 0.05\text{eV}$ [11]. It means that μ close to the region of rapid change $N(E)$ for small changes in μ or in carrier density. Fig.2 shows T_c/T_{c0} vs the hole concentration. This behavior is an agreement with actual experimental situation in $YBa_2Cu_3O_y$. The experimental results are data from [12] as determined by Hall measurements.

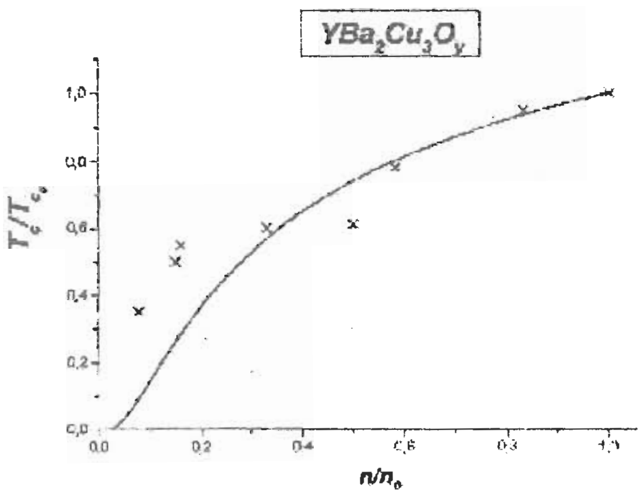

Fig.2.
The dependence of the critical temperature on the carrier concentration for $YBa_2Cu_3O_y$.

CONCLUSION

The special feature of Fermi surface model [1] finally allowed to study the influence of the carrier density on the critical temperature for layered superconductors. It shows a saturation effects in T_c with increasing carrier density which is in qualitative agreement with experimental observation in systems.

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LAYLI İFRATKEÇİRİCİLƏRDƏ DAŞIYICILARIN SIXLIĞININ KRİTİK TEMPERATURA TƏ'SİRİ

İ.N. ƏSGƏRZADƏ

BKŞ modeli daxilində hal sıxlığının enerjidən asılılığını nəzərə almaqla daşıyıcıların sıxlığının kritik temperatura tə'siri öyrənilmişdir. Göstərilmişdir ki, belə model $La_{2-x}Sr_xCu_{4-\delta}$ və $YBa_2Cu_3O_y$ ifratkeçiriciləri üçün kritik temperaturun dopantın və oksigen defisitinin konsentrasiyasından asılılığını göstərən təcrübi nəticələrlə uyğunluq təşkil edir.

ВЛИЯНИЕ ПЛОТНОСТИ НОСИТЕЛЕЙ НА КРИТИЧЕСКУЮ ТЕМПЕРАТУРУ СЛОИСТЫХ СВЕРХПРОВОДНИКОВ

И.Н.АСКЕРЗАДЕ

В рамках обычный теории БКШ с учетом реальной зависимости плотности состояний от энергии исследуется влияние плотности носителей на критическую температуру в слоистых сверхпроводниках. Показано, что зависимость критической температуры от концентрации допанта или кислородного дефицита для $La_{2-x}Sr_xCu_{4-\delta}$ и $YBa_2Cu_3O_y$ сверхпроводников в такой модели находится в хорошем согласии с экспериментальными данными.