MAJOR PARAMETERS OF HIGH Tc OXIDES

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ABSTRACT

The major normal and superconducting parameters of several cuprate superconductors are evaluated and discussed. The effects of the two-gap structure in YBa2Cu3O7 are especially emphasized.

Introduction

The problem of evaluation of the major normal and superconducting parameters of the doped high Tc oxides such as La-Sr-Cu-O and Y-Ba-Cu-O is of definite interest. This problem has been studied by the authors in [1-3]. In this paper we are going to discuss the main results and present some new ones. We are going to stress the unique features of the new materials.

Normal Parameters

Our approach is based on Fermiology of the new materials. For La-Sr-Cu-O we used the expressions:

\[ m^* = \left( \frac{\hbar^2}{\pi k_B^2 d_y} \right) \gamma \]
\[ E_F = \left( \frac{\pi^2 k_B^2}{3\hbar} \right) \gamma \] (1)

Here \( d_y \) is the interlayer distance, \( \gamma \) is the Sommerfeld constant at \( T = 0 \) k and \( n \) is the carrier concentration. The effective mass \( m^* \) is defined by the relation \( m^* = (2\pi)^{-1} \frac{dE}{d\epsilon} \) ("cyclotron mass"; the integration is taken over the Fermi circle, that is over the cross-section of the Fermi surface, by the plane \( p_x = p_y \) constant). The expressions (1) have been derived under the assumption that the Fermi surface is cylindrical. The topology of the Fermi surface for Y-Ba-Cu-O is more complicated (see below). The normal parameters for the cuprates are summarized in Table I. One can see directly from Table I that the oxides are characterized by small values of the Fermi energy, \( E_F \), and the Fermi velocity \( v_F \). We think that these features are key properties of the new materials.

Superconducting Parameters

The new superconductors have a start coherence length (see Table II). This is a direct consequences of one small values of the Fermi velocity and can be seen from the relation \( \xi_0 = \frac{\hbar v_F}{2\pi k_B T_C} \) of course, large values of \( T_C \) also lead to a decrease in \( \xi_0 \) but the small value of \( v_F \) is also a crucial fact.

The small value of \( \xi_0 \) results in a large value of \( H_{c2} \) (see Table II; \( H_{c2} \) is calculated from the expression \( H_{c2} = \frac{\chi_0}{3} \xi_0^2 \)) and in a large value of the surface impedance \( Z \), which is proportional to the quantity \( (\delta / \xi_0)^2 \)

Two Gap Structure

A small value of the coherence length leads to the unique opportunity to observe a two-gap structure. It has been predicted in our papers [1-2] and has been verified in recent experiments [5]. Unlike the conventional superconductors, the criterion \( 1 \geq \xi_0 \) can be easily satisfied for the oxides. This criterion along with the existence of two different overlapping energy bands are the conditions for the appearance of a two-gap structure. Such a situation occurs in the Y-Ba-Cu-O system. This approach leads to a complete description of chain structure. Its function is two-fold:

1. Chains provide doping of CuO planes and
2. They form an additional superconducting subsystem.

Each of two subsystems (bands) is characterized by its own energy gap and coherence length. The Fermi surface for Y-Ba-Cu-O consists of a cylindrical part and a set of planes perpendicular to the axis \( p_x \) and \( p_y \).

Two gap superconductors are described by 3 coupling constants \( \lambda_{ab}, \lambda_{ba} \) and \( \lambda_{ab} \) \( (\lambda_{ab} \) corresponds to the interband transitions). Note that the presence of the two-gap structure is favorable for superconductivity, regardless of the high \( \lambda_{ab} \) (see e.g. [1]).

The values of the energy gaps \( \Delta_0(0) \) and \( \Delta_0(0) \) can be determined from NMR and tunneling data and they are presented in table II.

The problem of temperature dependence of the energy gaps is of definite interest (particularly, in the region near \( T_C \)); this dependence affects the thermodynamic, transport and the electromagnetic properties. It has the form \( \Delta(T) = \Delta_0 (1 - T/T_C)^{1/2} \). According to BCS theory which describes the one-gap superconductor in a weak coupling
approximation $\alpha = 3.06$. Strong coupling leads to a larger value of $\alpha$.

The values of $\alpha_i$ for the smallest gap in the Y-Ba-Cu-O system can be obtained from an analysis of the thermal conductivity data [6]. A major contribution to the thermal flow in cuprates comes from the lattice term $\kappa_{\text{phon}}$. According to [7] the ratio $\kappa^0_{\text{phon}}(T) / \kappa^0_{\text{phon}}(T)$ is a universal function $F(b^2)$ of the parameter $b^2 = \Delta_b(T)/T$, where $\Delta_b$ is the smaller gap and $\Delta_b << \Delta_c$ for a more detailed analysis see [7]. Using the expression for $F(b^2)$ and the data [6], we calculated the value of $\Delta_b$: $\Delta_b \sim 2$. Therefore $\alpha_b$ is less than $\alpha_{\text{BCS}}$. A more detailed evaluation will be described elsewhere.

**Strength of the Coupling**

According to the approach developed by the authors jointly with M. Morawitz [1,8], high $T_c$ is due to the interaction of the carriers with the peculiar acoustic plasmon branch ("electronic" sound). Note that the acoustic nature of the plasmon branch makes plasmons in the layered oxides similar to phonons, so that we can talk about a generalized mechanism of high $T_c$. The interaction with low frequency modes which leads to high $T_c$ implies strong coupling to these modes. The evaluation of the strength of the coupling (see table 3.4) confirms this conclusion. The evaluation is based on the relation $\lambda = [y(\omega) / y(T_c)] - 1$, see e.g. Refs. [1] and on the analysis of the heat capacity data [9]. The value of the coupling constant $\lambda$ for La-Sr-Cu-O is large (see Table II) (note for comparison, that the value of $\lambda$ for Pb which is a conventional strong coupled superconductor is 1.4).

It is important to note that for the two gap superconductor such as Y-Ba-Cu-O, the analysis of the strength of the coupling should be carried out with considerable care. This is connected with the presence of 3 coupling constants and their values can be entirely different (see Table II).

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**TABLE I** Normal state parameters of conventional metals and the cuprates

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Conventional</th>
<th>LaSrCuO</th>
<th>YBaCuO</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m^*$</td>
<td>1-15$m_e$</td>
<td>5$m_e$</td>
<td>5$m_e$, 25$m_e$</td>
</tr>
<tr>
<td>$E_F$(eV)</td>
<td>5-10eV</td>
<td>0.1eV</td>
<td>0.3eV</td>
</tr>
<tr>
<td>$k_F$(cm$^{-1}$)</td>
<td>$-10^8$</td>
<td>$3.5 \times 10^7$</td>
<td>$5 \times 10^7$</td>
</tr>
<tr>
<td>$v_F$(cm-sec)</td>
<td>$1.2 \times 10^8$</td>
<td>$8 \times 10^6$</td>
<td>$10^7$, $2 \times 10^6$</td>
</tr>
</tbody>
</table>

**TABLE II** Superconducting parameters of conventional metals and the cuprates

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Conventional</th>
<th>LaSrCuO</th>
<th>YBaCuO</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_c$</td>
<td>$&lt; 23K$</td>
<td>40K</td>
<td>95K</td>
</tr>
<tr>
<td>$2\Delta/k_BT_c$</td>
<td>$&lt; 4.4$</td>
<td>$\sim 5$</td>
<td>5-8, 2-3.5</td>
</tr>
<tr>
<td>$\Delta/E_F$</td>
<td>$10^{-4}$</td>
<td>$10^{-1}$</td>
<td>$2 \times 10^{-1}$, $10^{-1}$</td>
</tr>
<tr>
<td>$\lambda_{\text{el-ph}}$</td>
<td>$&lt; 2$</td>
<td>$2.5$</td>
<td>$&gt; 1 &lt; 0.5 &lt; 0$</td>
</tr>
<tr>
<td>$\xi_0$(\AA)</td>
<td>$10^3-10^4$</td>
<td>20</td>
<td>15, 7</td>
</tr>
<tr>
<td>$H_{c2}(T)$</td>
<td>$&lt; 60T$</td>
<td>$&lt; 90T$</td>
<td>140T, 280T</td>
</tr>
</tbody>
</table>

6. J. Cohn et al., to be published.