The Nature of the Cooper Pair Electrons on High \( T_c \) Copper Oxides

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Abstract: Sanderson electronegativity equalization principle is used to research into the effect of chemical bonding on the feature of elements properties change and its results change on copper oxide superconductivity. The origin of Cooper pair electrons in copper oxides is studied with the superconducting properties. The conclusion is that the Cooper pair electrons of high \( T_c \) copper oxides originate the non-bonded electrons of the bearing superconducting elements.

Key words: High \( T_c \) copper oxide, Cooper pair electron origin, electronegativity equalization principle, non-bond electrons.

1. Introduction

A experiment conducted the study and concluded that under the critical temperature of superconductivity, the carriers in high \( T_c \) copper oxide superconductors are combined in pairs to form the coherent superconductivity states \([1]\), and the characteristics of Cooper pairing are also proved by a series of experiments, like direct current (DC) and alternating current (AC) Josephson effect \([2]\), Andreev reflection current \([3]\) and electron-hole mixture resolution in photoemission spectroscopy \([4]\). Electron bounding mechanism of high \( T_c \) copper oxide superconductors evolves into a key to probe into mechanism of superconductivity. All the elements in high \( T_c \) copper oxide superconductors are formed by chemical bonding causing great changes in the element nature, which, in turn, exerts great impact on the features of superconductivity. Quantum chemical bond theory is a crucial theory origin from the application of quantum mechanics to chemical bonding among elements \([5]\).

And quantum chemical bonding has already been successful applied to the researches into elements bonding and matter nature in such fields as chemistry, biology and material science.

Quantum chemical bond theory is mainly concerned with the Pauling quantum chemical bonding theory \([5]\) and Sanderson electronegativity equalization principle \([6]\), with the former (Pauling) directed at researches into the characteristics when the elements formation chemical bond and the latter (Sanderson) at researches into interrelations with the electronegativity equalization after the elements formation.

2. Methods

In light of the characteristics of the high \( T_c \) copper oxide superconductors’ superconductivity and properties of superconductors, the \( \mu_B \) (\( \mu_B \) is Coulomb’s interaction between the bonded electrons) of the crystal lattice stability is correlated with the bonded electrons to satisfy the condition of \( \mu_B > \lambda_B \) (\( \lambda_B \) is the coupling constant of the bonded electrons and phonons) while \( \lambda_C \) (\( \lambda_C \) is the coupling constant of formation Cooper pairs electrons and phonons) is correlated with non-bonded
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electrons to satisfy the condition of \( \lambda_C > \mu_C \) (\( \mu_C \) is Coulomb’s interaction between the Cooper pairs electrons) [7]. Due to the chemical bond formation of the elements in the high \( T_c \) copper oxide superconductors, the N(O) (N(O) is a kind of the density of the Bloch of one spin per unity energy at the Fermi surface) and \( V/V_{KK} \) (average, the matrix element and \( V_{KK} \) can be replaced by a constant average matrix element, for pairs making transition in the region \(-\hbar \omega < \epsilon < \hbar \omega \) and by zero outside this region, where, \( \omega \) is the average phonon frequency) will have special change, and the electron media phonon can generate high \( T_c \) superconductivity [7].

As Cu and O on the CuO\(_2\) plane of the high \( T_c \) copper oxide superconductors have obvious isotope effects and they are inter-correlated, the phonons of Cu and O on CuO\(_2\) plane participate in the electrons phonons coupling [8].

Because of chemical bond formation of Cu and O on CuO\(_2\) plane, the \( f_{\text{Cu}} = f_O \) (\( f_{\text{Cu}} \) is the force of the bonded electrons exerted with Cu element while \( f_O \) is the force of the bonded electrons exerted with O element) is obtained. The bonded electrons are not beneficial to the superconductivity. The coupling electrons of Cu and O on CuO\(_2\) plane are the locality of non-bonded electrons [8].

3. Discussion

Sanderson [6] pointed out that in the process of formation of polyatom into the material of polyelectro, the differences of electronegativity of the elements in each part of the system made electrons transfer from the region of low electronegativity to the region of high electronegativity (that is, electrons transferred from the region of high chemical potential to the region of low chemical potential) to make the electronegativity of each element in the substances forming the system of polyelectron tend to become balanced.

That is:

\[
x_a = x_b = \cdots = x
\]

where \( x_a \) and \( x_b \) represent the electronegativity of different elements.

Besides, there are the constraint conditions of electric charge:

\[
\sum_a q_a = Q
\]

where \( x \) and \( Q \) are the electronegativity and the total charge of the system.

Among the superconductors formed by bonds between the elements, heterogeneity was formed because of the existence of the following conditions:

1. The atomic natures of forming the superconductors and the distributions were different;
2. The atoms of forming the superconductors were the same but the bonding ways were different and distributions were different, too;
3. The atoms of forming the superconductors were the same and the ways of bonding were also same but the crystal forms were different.

According to the principle of the balance of electronegativity between different regions, to obtain:

\[
x'_x = x'_y = \cdots = x'
\]

\( x'_x, x'_y, \ldots \) were the regional electronegativity in different regions.

In the same region:

\[
x_a = x_p = \cdots = x_t
\]

\[
x'_a = x'_p = \cdots = x'_t
\]

\[
x''_a = x''_p = \cdots = x''_t
\]

\( x_a, x'_a, \ldots, x''_a, x_b, x'_b, \ldots, x''_b \) were the electronegativity of the elements in different regions.

But there were not always equality between \( x_a, x'_a, \ldots, x''_a \) or \( x_b, x'_b, \ldots, x''_b \).

In the structure of the high \( T_c \) copper oxidized superconductors, their crystals were divided into conducting layers and carrier bank layers according to the different electric properties. But the same crystals have:

\[
x_{\text{conducting layer}} = x_{\text{carrier bank}}
\]

Based on quantum chemical bond theory, we learn that on CuO\(_2\) plane of high \( T_c \) copper oxide, electrons transfer between elements Cu and O, with element O attracting more electrons for its high electronegativity and element Cu losing more electrons for its low
electronegativity, thus forming a powerful interrelated Coulomb system. From Sanderson electronegativity equalization principle, the forces of the bonding electrons by bonding elements Cu and O are equal:

$$f_{Cu^2+} = f_{O^2-}$$

(8)

From Debye vibration model:

$$\nu = \frac{1}{2\pi} \sqrt{\frac{f}{m}}$$

(9)

$$\nu$$ stands for Oscillator frequency, $$f$$ for the force acted on oscillator and $$m$$ for oscillator mass. And:

$$\frac{m_{Cu}}{m_{O}} = 4$$

(10)

Therefore, the electrons of Cooper pairs bonded by electron-media phonon are only the localized electrons in conformity with $$\nu_{Cu^2+} \approx \nu_{O}$$ resulted from the different forces of Cu$$^{2+}$$, O.

From this, we can draw the conclusion that in copper oxide formed with chemical bond, the bonded electrons are not built with the conditions for the formation of Cooper pairs electrons and only the localized nonbonding electrons can form Cooper electron pairs [7].

The crystalline imperfections of CuO$_2$ plane outer also affect CuO$_2$ atomic layer flatness and make electrons scatter. Fig. 1 shows the TI of TI-2223 sample with different qualities [9]. The residual state density of the untreated samples are 0.3 N ($N_{res} = 0.3$ N) [9], while the Nres of the treated samples reduced to 0.17 N [9]. Partial TI and Ca in this chemical mixture changed positions, causing lattice distortion.

Impurity scattering reduces $$T_c$$ and its relation with $$N_{res}$$ is shown in Fig. 2.

The experimental data are the result of above mentioned TI-2223, and it basically conforms with the prediction of theoretical model of d-wave.

The anisotropy that the superconduction relaxation rate changes with temperature, temperature change of the ratio of Cu and O relaxation rate, and temperature change of $$T_2$$, all points to show that wave function of copper oxide superconductors is d-wave.

Fig. 3 shows the temperature change of relaxation rate anisotropy of copper oxide superconducting
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Fig. 3  Temperature change of $T_1$ anisotropy. The curve is the theoretical result of Bulut and Scalapino on d-wave.

Fig. 4  Change of $1/T_{2G}$ in YBa$_2$Cu$_4$O$_8$ with temperature (white circles). The curve is the theoretical results Bulut and Scalapino on s-wave and d-wave.

Fig. 4 shows the temperature change of $1/T_{2G}$ [11]. $T_{2G}$ mainly catches $\Delta(Q)$ data, so it remains unchanged in superconducting. This indicates that energy gap function is d-wave as in s-wave superconducting $1/T_{2G}$ shows a clear drop with the decrease of temperature.

4. Conclusions

Through analysis, the nature of the Cooper pair electrons of high $T_c$ copper oxides with Sanderson electronegativity equalization principle. An important conclusion is obtained that Cooper pair electrons of high $T_c$ copper oxides originate the non-bonded electrons of the bearing superconducting elements. The conclusion is discussed with the superconducting properties. This conclusion presents a new notion and a new approach to an insight into the mechanism superconducting of high $T_c$ copper oxides.

References