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Study of Josephson Pair Tunneling for Higher Temperature Superconductor

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ABSTRACT

The optical conductivity measured on a Bi_2 Sr_2 Ca_2 Cu3 O3 polycrystal displays a peak at 450-500cm as bilayer cuprates such as Y Ba, Cu3 Ox, or Bi2 Sr_2 Ca_2 Cu_2 O8. This feature, as well as strong phonon anomalies, are interpreted in the framework of the Josephson superlattice model. This model provides a good fit to both normal and superconducting states with only a few parameters and permits to extraction of the temperature depending on the interlayer Josephson coupling energy. From the multi-layer tight binding sum rule, we estimate the decrease of kinetic energy Δ(HC) — 16m∈ between the normal and superconducting states. This value is of the same order as the Josephson Coupling energy obtained from the fit of the Josephson super lattice model (JSM). This result improves the consistency of the JSM and indicates that the Josephson pair tunneling can account for a significant ingredient for high-temperature superconductivity. In this present paper, we studied Josephson pair tunneling for higher-temperature superconductors(1-20).

Keywords : Josephson Tunneling, Temperature, Superconductor.

I. INTRODUCTION

The electron pairing is due to electron-phonon interaction in conventional super conductor. The mechanism at te origin of high conductor superconductivity in cuprates is still matter of extensive debate. Optical spectroscopy could be useful experimental method to discriminate between interactions responsible of the electron pairing[21-36]. In particular, optical measurements are a good tool to probe typical energy scales involved in pairing mechanisms as done by Timusk et al[37] in 1989, also by Gervais[38] in 2002. Indeed the spectral weight (SW), determined by integrating the real parts of the optical conductivity up to a cut-off frequency $\omega_c, \omega = \int_0^{\omega_c} \sigma,(\omega,T)d\omega$ is expected to follow the Ferrell, Glover and Tinkham(FGT) sum rule, which predicts that the SW lost in the superconducting state $\Delta W(\omega_c, T = T_c) - W(\omega_c, T \ll T_c)$ must be retrieved in the δ(ω) functions centered at zero frequency which represent the superfluid density. The validity of the FGT sum rule can be tested by determining independently $\Delta\omega$

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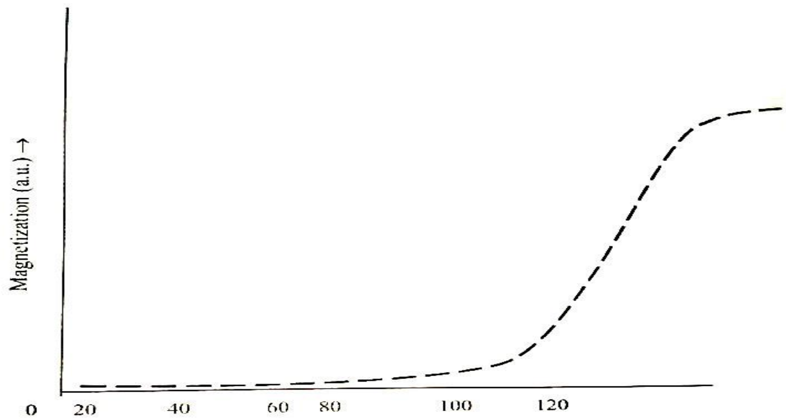
and the superfluid density, obtained from the real part of the dielectric function $\in_1$ (ω). In conventional superconductor, the FGT sum rule is fulfilled for $\omega_c = 4\Delta$ where Δ is the superconducting gap. Recent works by different authors have shown that for both in-plane and interlayer optical measurements, the FGT sum rule is partially violated in high temperatures superconductors (HTSC) as done by Homes et.al.[40] in the year 2004 and Boris et. al.[41] in 2002. The inplane SW is recovered only at energy larger than 0.6eV and leV in under doped Y Ba_2 Cu_2 $O_{6.6}$ as done by home et. al. in 2004 and Bi_2 Sr_2 Ca Cu_2 O_8 films by Lobo, Bontemps et. al.[42] in the year 2003. Moreover, Basov et. al.[43] pointed out that the interlayer FGT sume rule is violated up to to at least 1200cm^{-1}. These values are larger than conventional energy scale (-800cm^{-1}). These results suggest that energy scale involved in the pairing mechanisms are larger than bosonic excitations. The violation of the FGT sum rule upto a conventional energy scale, can be interpreted as a change in charge carrier kinetic energy in the framework of the tight binding model given by Abraham's et.al. (in the year 1999. Such a change can be explain within various scenarios by P.W. Anderson[45] in 1998. Both in-plane (in underdoped $Bi_2Sr_2CaCu_2Og$) and interlayer (in Tl_2 Ba_2 $CuO_{6.6}$) sum rule violation have been proposed as an evidence of a decrease of kinetic energy by Basov et. al. in 1999. The situation is also unusual in multiplayer cuprates. Indeed the SW change ΔW takes negative value as shown by the Munzar et. al.[46] in 2001. This behaviour is due to an increase of the SW related to the appearance of a broad band around 450cm^{-1} as temperature is decreased as calculated by Bernhard et. al.[27] in 2000. Concomitantly with the growth of the 450cm^{-1} absorption band, anomalous temperature dependence of some phonon modes is observed. To describe the result, Van der marel and Tsevetko[48] in 1996 considered the system as stacked superconducting layer with non-equivalent intralayer and interlayer Jopsephson Plasma Frequencies and int respectively. In this so called Josephson Super Model(JSM), the dielectric function $\in$ (ω) results in the contribution of the different conduction channels added in parallel. An extension of this model was proposed by Munzar et. al.[49] in the year 1999, to describe both 450cm^{-1} mode and phonon anomalies by taking into account local electric fields acting of different ions involved in a vibration mode. This approach was successful used to optical response of several bilayer cuprates in the year 2001 by Zeleny et. al.[50]. In the JSM, the internal electric field is not homogenous in the whole multilayer superconductor. Therefore, the usual tight binding sum rule cannot be applied. Recently, in the year 2003, an approximate tight binding sum rule has been developed to quantity the change of kinetic energy multilayer compounds by Munzar and Holden[31]. Using this sum rule boris et. al.[32] found a possible decrease of the kinetic energy on $Bi_2Sr_2Ca_2Cu_3O_{10}$. However, this value cannot be compared with other quantities such as condensation energy because of the lack of specific data. Our main aim is to analze quantitatively the optical conductivity of trilayer $Bi_2Sr_2Ca_2Cu_3O_{10}$ in the framework of the Josephson superlattice mode.

II. MATERIALS AND METHOD

From this investigation we extract the temperature dependence of relevant parameteres and as the plasma frequency of the Condensate, or equivalently the Josephson Coupling energy. Moreover, we found a possible decrease of kinetic energy deduces from the multilayer tight tight- binding sum rule, which confirm the results of Boris et. al. Finally, the decrease of kinetic energy is compared with Josephson Coupling energy obtained independently from the JSM. Using the nominal composition Bi_2 Pb Sr_2 Ca_2 Cu_2 Cu_3 suggested by Maeda et. al.[53] and adopted by Hong et. al.[54], the powder precursor was obtained by the polymer matrix method. The sample microstructure exhibits good $Bi_2Sr_2Ca_2Cu_{30}O_{10}$ grain alignment. Magnetization measurement exhibit a quite broad transition with a T_c, onset at 104^0K as a shown in the graph- Thermoelectric power measurement have been performed as a function of temperature. At higher temperature, TEP value is nearly $11mvk^{-1}$. According to Obertelli and cooper[55], this value indicates that the compound is slightly underdroped,



Temperature (K)

Magnetization measurements shows an T_c onset at 104-105 K.

Magnetizatioin measurements shows an T_c onset at 104-105 K with T_c/T_{max} = 0.95, which yields Tc = 104^0K. This value of T_c is in agreement with the value deduced from the magnetization measurements. To quantify the error of the spectrum due to the leakage of the plans response, we filled both the spectra with the dielectric model given by petit et.al.[56].

$$\in=\in_\alpha \ [\pi_j \left\{\frac{\omega_{jL0}^2 - \omega^2 + iT_{jLo\omega}}{\omega_{jTo}^2 - \omega^2 + iT_{jTo\omega}}\right\} - \{(\omega_\rho^2 - i(T_\rho - T_o)\omega) - (\omega(\omega - iT_0)\}]$$

Where ω_{jLo}, T_{jLo} and ω_{jTo}, T_{jTo} are the frequencies and damping of longitudinal optic and transverse optic phonon modes respectively and the index refers to the plasma. the dielectric response $\in(\theta)$ to the incident energy with an angle of the sample is given by

$$\frac{1}{\in(\theta)} = \left\{\frac{\cos^2(\theta)}{\in_1}\right\} + \left\{\frac{\sin^2(\theta)}{\in_2}\right\}$$

So, we can calculate the reflectivity and the angle dependent dielectric function $\in(\theta)$ based on $\in_1$ and $\in_2$ respectively. The experimentally observed phonon modes agree remarkably well with recent assignment based on shell model calculation as a done by kovaleva et. al.[57]. The existence of two oxygen bond bending mode is a typical property of $Bi_2Sr_2Ca_2Cu_3O_{10}$. Actually, only one oxygen bond bending mode is predicted by Prase et. al.[58] and observed by zelenzy[59] in $Bi_2Sr_2CaCu_2O_8$. This assigned to apical oxygen vibration. The lattice dynamics calculations have been performed with the approximate tetragonal space group, so that the phonons experimentally one non-predicted and probably due to incommensurate structure or disorder. The spectra show no substantial change down to T_c. In a superconducting state, a broad peak rapidly grows. This is in agreement with result of Boris and on $Bi_2Sr_2CaCu_2O$ as observed by zelenzy. We plotted Δ6(W,T)=6(W,5K) - 6(W,T) to determine the frequency regions when changes occur. The SW of the apical oxygen vibration strongly decreases below Te. Such a feature is explained in the framework of the JSM by large change in interlayer local electric field as explained by Munzar et. al.[29] in 1999. We analyze the data as a function of temperature in the framework of the JSM, because we are mainly interested in tunneling current only and in order to reduce the number of the parameters, the model was simplified as given by Phuoe et. al.[60] that the interlayer region is assumed to be insulting so that its susceptibility read $\chi_{int} = 0$. Such an approximation was also made to fit optical conductivity of $Bi_2Sr_2CaCu_2O$ as shown by Zelenzy et. al.[50]

The itratrilayer susceptibility Zint includes a London term to describe the superconducting condensate, and a Drude term which represent the electronic background $\chi_{int} = [-\{\omega_{tl}^2/\omega^2\} - \{\Omega_{tl}^2/(\omega^2 + iy_{tl})\}]$. In this equation, it was supposed that the conductivity is the same for the two potential barriers of the Josephson junction within the trilayer block. Also, the local electric field renormalization due to displacement of the ion is neglected.

It is considered that the electric field acting on the ions involved in phonon modes is assumed to be in the interlayer local field E_{int}. For the sake of simplicity, we fit the bond bending mode regardless of local field effects. The anoma lies are than taken into account by changing the oscillator strength and damping. Thus, the dielectric function $\in(\omega)$ reads

$$\in = \in_\alpha + \left\{\frac{d_{int}}{(d_{int} + d_{tl})}\right\}\chi_{int}\left(\frac{E_{int}}{E}\right) + \left\{\frac{d_{tl}}{(d_{int} + d_{tl})}\right\}\chi_{tl}\left(\frac{E_{tl}}{E}\right) + \chi_{phonon}\left(\frac{E_{int}}{E}\right) + \chi_{bb_1} + \chi_{bb_2} + \chi_{mir}$$

Where, $\chi_{phonon} = \sum_i\{S_i\omega_i^2/(\omega_i^2 - \omega^2 - ir_i\omega^2)\}$
and $\chi_{mir} = \{S_{mir}\omega_{mir}^2/(\omega_{mir}^2 - \omega^2 - ir_{mir}\omega^2)\}$

The interlayer and intratrilayer local electric fields Eint and Etl are determined by the set of equations
$E_{tl} = E_{int} + \{(\chi_{int}E_{int} - \chi_{tl}E_{tl})/\in_\alpha\}$ and

$$E(d_{tl} - d_{int}) = E_{tl}d_{tl} + E_{int}d_{int}$$

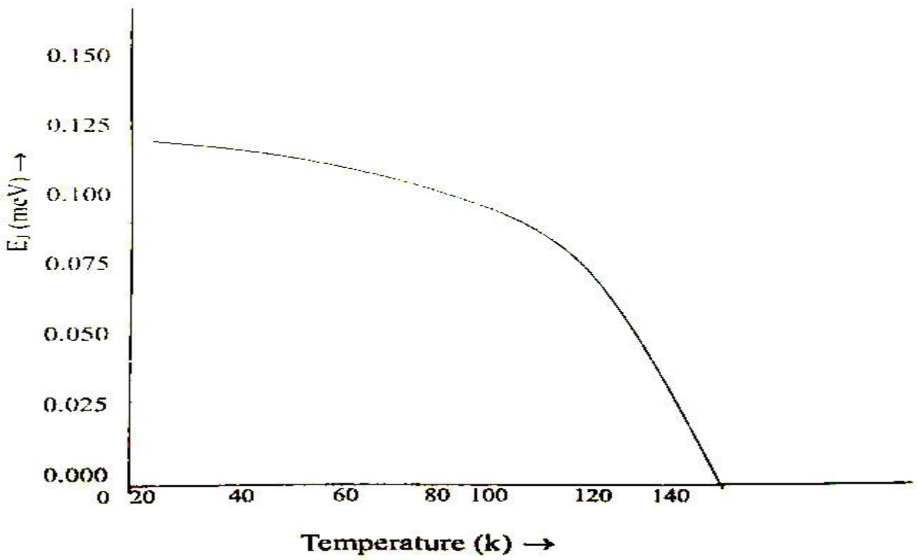
Where E is the applied electric field. Although this model captures the main physics of the electronic properties of the system, it fails to reproduce the anomalies of bond-bending modes. An extension of the JSM has been recently proposed by Dubroka dn Munzar (61) to take this phonons anomalies into account.

The intratrialyer Josephson Frequency obtain ω_{tl} obtained from the fit is useful to estimate the intralayer Josephson coupling by the equation $E_J = (h^2 \in_0 a^2/4e^2 d_{bl})\omega_{tl}^2$. The uncertainty on ω_{bl} is probably larger than the error bars obtained.

In the framework of the interlayer tunneling theory, the Josephson's coupling energy E_J represents the decrease of the kinetic energy due to pair tunneling which is expected to be responsible for higher values of Tc. The decrease of kinetic energy is predicated to be equal to the condensation energy $U_o=E_J$. Unfortunately, the value of U_o for $Bi_2Sr_2Ca_2Cu_3O_{10}$ is not known. However the value of E, calculated from the JSM for optically doped $Bi_2Sr_2Ca_2Cu_2O_8$. The possible change in Kinetic energy can be estimated independently by using the so called tight binding and sum rule. Recently an approximate tight binding sum rule has been developed to applied to multilayer compound

$$\Delta(H_c) = (2h^2 a^2/\pi e^2)\{((n-1)d_{bl} + d_{in})/d_{bl}^2\}\,\Delta\omega(\omega_c)$$

The value of Δ(H) thus obtained is sligtly larger than that calculated by Boris et. al.[21]. As displayed in the graph it is worthwile to compare the Josephson Coupling energy E, extracted from the JSM fit and te charge from Kinetic energy $\Delta(H_c)$. Both quantity show a wuite similar temrature difference. Considering large uncertainity in the determinationof E_j, both values are in quite responsible agreement. Then thsi result can account for ITL theory as a relevant ingredient of pairing mechanism in HTSC. However, as a point out by Timuskand Homes[62] in the year 2003 even JSm provides a good fit of experimental data above Te. is hard to recognise with simple Josephson tunneling current.



Temperature dependence of the interlayer Josephson energy

$$E_J = (h^2 \in_0 a^2/4e^2 d_{bl})\omega_{tl}^2$$

III.TUNNELING CURRENT DENSITY IN SINGLE CRYSTAL

Recently the intrinsic quasi-particle conductivity along the BSCCO single crystal mesa structures in the superconductive and normal states were studied by different workers. Direct measurement of the mesa temperature enable corrections to be made for self heating and permits the acquisition of reliable I-V charateristics over a wide range of temperatures and voltages. Unlike a conventional superconductor, there is no evidence for any change in quasi particle conductivity at Tc, consistent with precursor pairing of electron in the normal state. At low temperature the initial low voltage linear conductivity exhibits a T^2 dependence, approaching a limiting value at zero temperature. The interlayer quasi particle conductivity has been measured in the normal and superconducting state using small mesas litho-graphically patterned on the surface of a number of single crystals of BSCCO with a range of doping, thus forming the different potential barriers. The behaviour of the interlayer conductivity at low temperature and its dependence on passing through Tc. Very similar multi branched IV characteristics were observed to those reported by Kliner et. al.[63] in 1992. The temperature corrected I-V curves as well described by a tunnelling current is given by $I = \Delta(V + EV^3)$.

IV. CONCLUSIONS

The intrinstic linear conductance, α is inconsistent with models involving coherent interlayer tunneling between layers as proposed by Suzuki and Tanabe[64] previously. The derived linear component of the conductivity, σ_c, is plotted as a function of temperature. At low temperature conductivity is given by $\sigma_c(T)$= constant $(1+yT^2)$, consistent with impurity assisted interlayer hopping as reported by Xiang and Wheathly. σ_c is continuous at T_c, for no evidence for the discontinuity in slope expected from any model involving the onset of pairing at T_c. Because it is continuous on pairing through Tc, changes in conductivity above Tc are unlikely to be associated with superconducting fluctuations. For all samples, σ_c (T) decreases monotonically from temperatures well above, Tc, consistent with onset on a pseudo-gap, possibly due to precursor pairing in the normal state.

$$\left(\frac{1}{2\pi}\right)\int_{-\infty}^{\infty} F(\omega)\, e^{i\omega t} d\omega = \left(\frac{1}{2\pi}\right)\int_{-\infty}^{\infty} f(x)\,.\,dx \int_{-\infty}^{\infty} e^{j\omega(t-x)}\,.\,d\omega$$

$$\int_{-\infty}^{t} x(\lambda).\,d\lambda (j2\pi f)^{-1}.\,x(t) + \left(\frac{1}{2}\right) x(0).\,\delta(t)$$

$$x_p(K) = \sum_{n=0}^{N-1} x_p(n) e^{-j(\frac{2\pi}{N})nk}$$

$$x(Z)|_{z=e^{i\left(\frac{2\pi}{N}\right)k}} = x[e^{i\left(\frac{2\pi}{N}\right)k}]$$

$$x_p(K) = \sum_{n=0}^{N-1} x_p(n) e^{-j(\frac{2\pi}{N})nk}$$

$$\begin{cases} x(n) = \quad a^n, 0 \le K \le N-1 \\ \end{cases}$$

0, otherwise

$x\,(z) = \sum_{n=0}^{N-1} a^n z^{-n} = \sum_{n=0}^{N-1} (az^{-1})^n$

$$x(e^{i\omega}) = (1 - a^N e^{-i\omega N})/(1 - ae^{-i\omega})$$

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