The Effect of Oxygen Content On the Condensation Energy of Bi:2212 Superconductor

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Abstract

The effect of oxygen content $(0.07 \le \delta \le 0.64)$ on six samples of high temperature superconductor (HTS) $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi:2212) was studied . As the sample oxygen content increases the value of condensation energy $E_C(0)$ (which are calculated using the electronic specific heat C_{es} and the entropy S_s of the superconducting phase) increases at the overdoped region . $E_C(0)$ shows a maximum at the optimal doping (where $\delta = 0.35$ and the hole concentration in CuO_2 planes is $P_{opt.} \approx 0.167(hole/CuO_2)$), at underdoped region $E_C(0)$ decreases because of the effect of pseudo gap in the normal phase.

Key words: HTS, Specific heat, Entropy, Condensation Energy

Introduction :

The discovery of superconductivity in layered copper oxide compounds came as a great surprise, not only because of the recorded high transition temperature T_C , but also because these materials are relatively poor metals even at high doping levels [1] . the possible importance of inhomogeneity in the physics of high temperature superconducting (HTS) cuprates has been stressed since their first discovery. despite their highly variable disorder the cuprates display a universal phase behavior [2] . their physical properties vary systematically with doping in much the same way for each compound provided that the disorder lies outside of the active CuO2 planes [3].

We calculated the E_C, which is known as the difference in energy between the superconducting and normal states [4], for six Bi:2212 samples [3] at temperature from 0k to 265k with changing oxygen content $(0.07 \le \delta \le 0.64)$ from C_{es} and S_S of the superconducting phase . Where δ was changed in small increments by annealing at elevated temperatures in an appropriate oxygen partial pressure [5].

Results and Discussion:

Fig.(1) shows the calculated electronic specific heat C_e for a series of doping states for Bi:2212 $(0.07 \le \delta \le 0.64)$ versus temperature T, for the superconducting phase the following relations were used ;

$$C_{es} = 3\gamma T^3 T_C^{-2} \quad [6]. \qquad \text{------(1)}$$

And for the normal phase ;

$$C_{en} = \gamma T \quad [7]. \qquad \text{-------(2)}$$

It is clear that C_e reaches a maximum peak at T_C . The increase of oxygen content in these samples at overdoped region $(0.07 \le \delta \le 0.35)$ caused the increase of T_C and the specific heat coefficient values $\gamma(T) = \frac{C_e}{T}$ in this region . The dashed curve in fig.(1) denotes

the optimal doping $\delta = 0.35$ where $P_{opt.} \approx 0.167(hole/CuO_2)$. Values of P were determined from T_C values by using the approximate parabolic phase curve, $T_C(P)$, given by [8];

$$T_C(P) = T_{C,\max}[1 - 82.6(P - 0.16)^2] \qquad \text{-------(3)}$$

The values of T_C and γ of the sample which were used in this work, were published by Loram and et al. [3] . We noticed that the C_{es} in the Fig.(1) reaches a maximum at optimal doping, depending on the values of T_C and γ, which it reaches the maximum at the same doping too . Such behaviour, seen also in La:214 [1,9], Bi:2212 (20% pb) [10] and YBCO:123 (0 , 20% Ca) [11-13], are generic to the cuprates.

In the underdoped region $(0.35 \le \delta \le 0.64)$, we noticed that C_{es} values decrease, because of the normal state pseudogap opens abruptly [10,12,14].

Plot of the calculated entropy S(T) are shown in Fig. (2) for a series of doping states of Bi:2212 $(0.07 \le \delta \le 0.64)$ versus temperature T for superconducting phase, we used the following relation to calculate S(T) [15,16]:

$$S(T) = \int_0^T \frac{C_e}{T} dT \qquad \text{---------(4)}$$

For $P > P_{crit.}$ (where $P_{crit.}$ critical doped and $P_{crit.} \approx 0.19 holes/CuO_2$ at doped $\delta = 0.19$) the normal state (NS) entropy $S_n(T)$ extrapolates to zero or positive values at T=0, as for a conventional metal with a constant NS DOS . However blow $P_{crit.}$ and coincident with the collapse of the specific heat jump (Fig.(1)).

Fig.(3) shows that the condensation energy for zero temperature $E_C(0)$ values (which was calculate using the following equation $E_C(T) = \frac{1}{2}\int_0^{T_C}[C_{es}(T) - S_s(T)]dT$ [11]) increases at overdoped region, and they reach the peak at optimal doping, then they decrease at underdoped region.

We can conclude that the large effect of changing oxygen content on the values of $E_C(0)$ for Bi:2212 samples depends on its effect on the values of T_C and γ, where the $E_C(0)$ depends on the T_C and γ values, pursuant to the equation [11]:

$$E_C = \frac{1}{2}\gamma T_C - \int_0^{T_C} S_S(T)dT \qquad \text{-------(5)}$$

The condensation energy $E_C(0)$ shown in Fig.(3) peaks sharply at $P_{opt.}$ rather then $P_{crit.}$. For $P > P_{opt.}$ the decrease in $E_C(0)$ satisfies the relation $E_C(0)/\gamma_n T_C^2 \approx 0.48$ expected for a BCS SC with a flat DOC.

The maximum value of $E_C(0)$ at optimal doping ($\delta = 0.35$) is because of the vanishing of the energy gap E_g at this region Fig.(3) as $E_g(p)/k_B \approx 980(1 - P/P_{crit.})$ (K), where $P_{opt.} \approx 0.167(hole/CuO_2)$, and the transition temperature T_C reached to its maximum value ($T_{C,\max}$). Similar studies used such values of δ for both Bi:2212 (20%pb, 15%Y) [5] and YBCO:123 [17] and got the same results.

For the underdoped region, where $P < P_{opt.}$ ($\delta > 0.35$), the $E_C(0)$ values decreases because of the decrease of values of T_C and γ. This decrease for $E_C(0)$ values, indicates that there is loss in energy resulting from the existence of the energy gap in this region, this is in good agreement with [13,15-18]. The effect of the pseudo gap appears, when the values of

E_g begin to increase in this region and the values of δ increases in the sample which leads to decrease the hole concentration in CuO_2 planes (P), which effects directly and grievous the condensation energy (measure for condensate couples) [12,17].

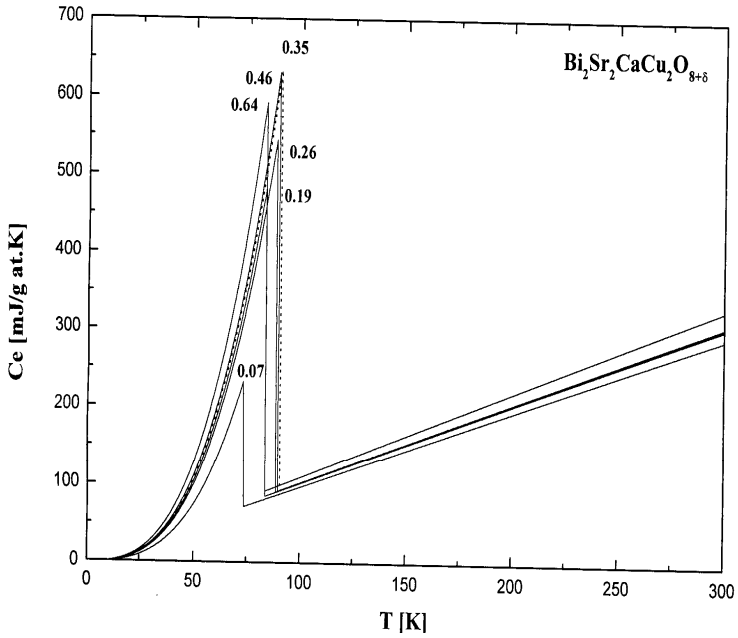

Fig.(1) : The electronic specific heat C_e for a series of doping states of Bi:2212 $(0.07 \le \delta \le 0.64)$ **vs temperature T ; dashed curve denotes optimal doping** $(\delta = 0.35)$**.**

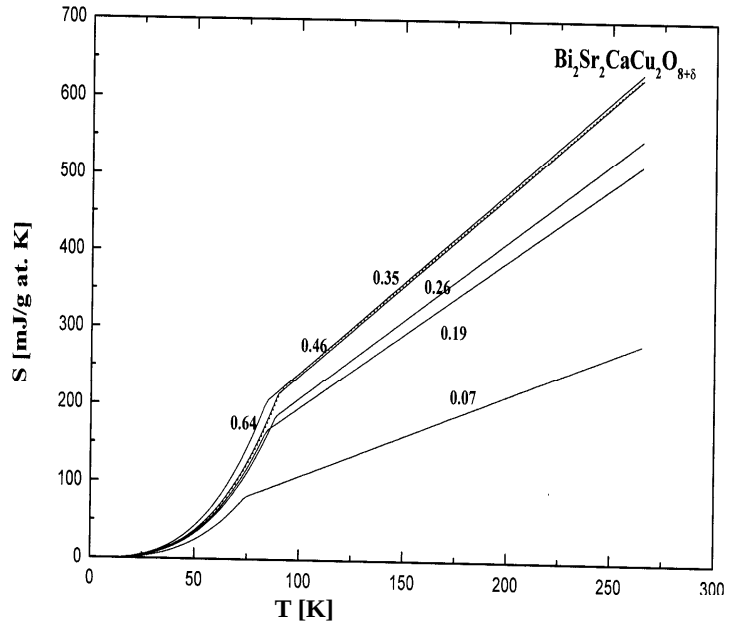

Fig.(2) : The entropy $S(T)$ for a series of doping states of Bi:2212 $(0.07 \le \delta \le 0.64)$ **vs temperature T ; dashed curve denotes optimal doping** $(\delta = 0.35)$ **.**

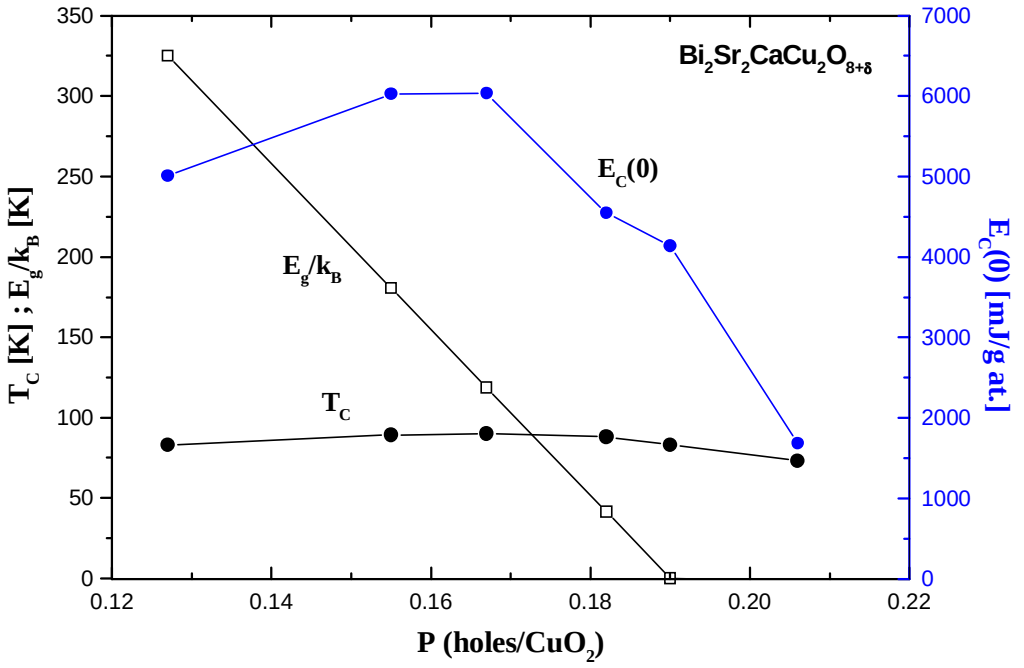

Fig.(3) : The T_C [3] , E_g / k_B and $E_C(0)$ values vs hole concentration $P(hole/CuO_2)$ **for Bi:2212 samples.**

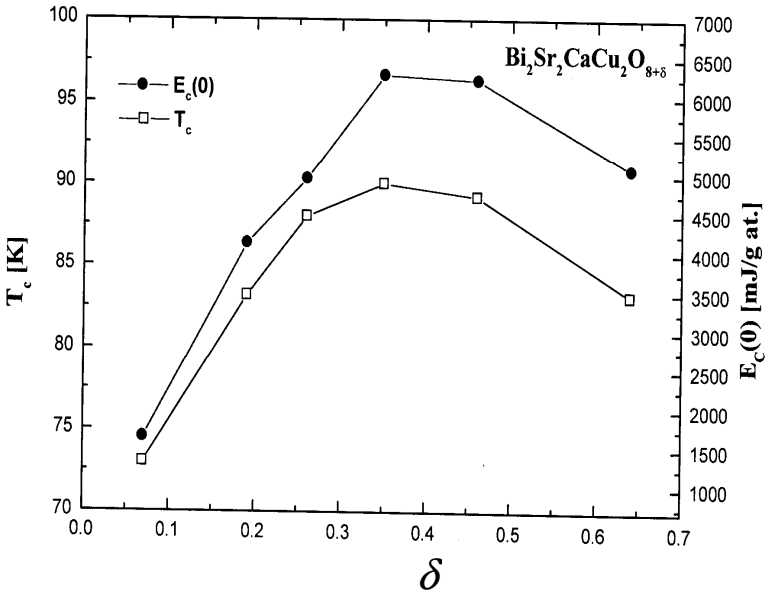

Fig.(4) : The effect of changing oxygen content δ on the transition temperature T_C [3] and condensation energy of zero temperature $E_C(0)$ values for Bi:2212 samples.

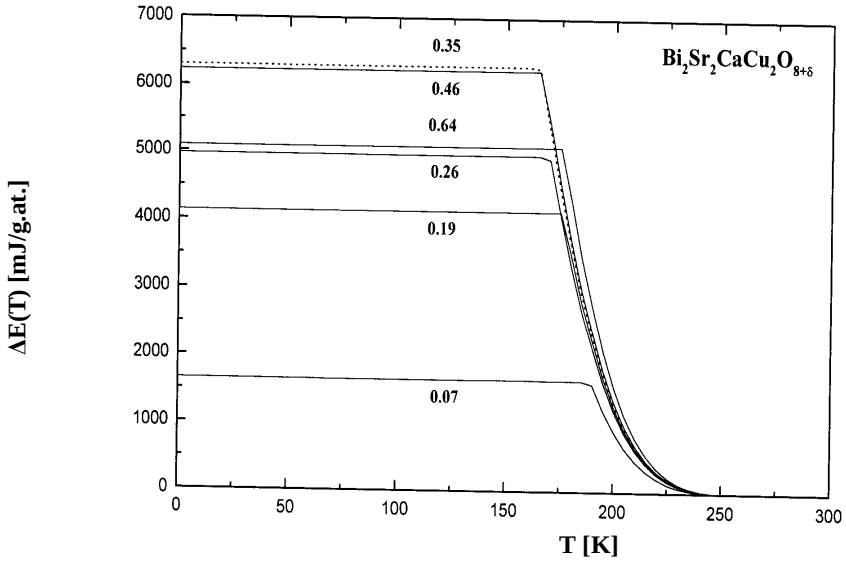

Fig.(5) : The changing of energy $\Delta E(T)$ equ.(5) for a series of doping states of Bi:2212 $(0.07 \le \delta \le 0.64)$ vs temperature T ; dashed curve denotes optimal doping $(\delta = 0.35)$ and the condensation energy of zero temperature $E_C(0)$ values .

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تأثير محتوى الأوكسجينِ على قِيَمِ طاقةِ التكثيفِ في عينات لنظام Bi:2212 الفائق التوصيل

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الملخص

مِنْ دِراسَة تأثير تغير محتوى الأوكسجين ($0.07 \le \delta \le 0.64$) في ستّة عيناتٍ من نظام $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi:2212) الفائق التَوصيل ذو درجة حرارة انتَقال عاليةِ (HTS) ، وَجدَ إن بزيادة محتوى الأوكسجينَ في هذه العينات تزداد قِيَم طاقةِ التكثيفِ عند درجة حرارة الصفر $E_C(0)$ (التي تم حسابها باستخدامْ السعة الحراريةِ الإلكترونيةِ C_{es} والقصور الحرارِي S_s في طور التوصيل المفرط) في منطقة فوق التشويب (overdoped) ، وتصل طاقة التكثيف إلى أعلى قيمةِ عند التشويبِ الأفضل (optimal doped) (والذي عنده يكون تركيز الفجوات في المستوي CuO_2 هو $P_{opt.} \approx 0.167(hole/CuO_2)$)، بعدها تبدأ قِيَم $E_C(0)$ في منطقة تحت التشويب (underdoped) بالانخفاض باستمرار زيادة محتوى الأوكسجينِ في العينة بتأثيرِ ظهور الفجوةِ الكاذبة (pseudogap) في الطور الاعتيادي في هذه المنطقةِ مِنْ محتوى الأوكسجينِ.