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On identical nature of the superconductivity mechanisms in 30 K and 90 K superconductors

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Abstract. A systematic study of Zn substitution in both lanthanum and yttrium-based oxide superconductors with T_c of 30 K and 90 K has been carried out simultaneously under identical conditions. Contrary to the general belief, the results indicate that the mechanism responsible for superconductivity in 30 K compounds is unlikely to be radically different from that of the 90 K compounds.

Keywords. High temperature superconductivity; Zn substitution; lanthanum; yttrium.

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Although the origin of high T_c in ceramic superconductors is still being debated, there have been suggestions (Weber 1987; Verma *et al* 1987; Morris *et al* 1988; Hirsch *et al* 1988; Batlogg *et al* 1987a, b; Leary *et al* 1987) that the mechanism leading to a T_c of about 30 K in lanthanum-based superconductors might be different from that of 90 K in yttrium-based compound. Some of the reasons advanced to justify this are as follows: (i) while a T_c of about 30 K seems conceivable, the T_c of 90 K is believed to be beyond the limits of the conventional phononic mechanism. (ii) The detection of a small isotope effect in La-compounds (Batlogg *et al* 1987a) and its absence or near absence in Y-compounds (Batlogg *et al* 1987b; Leary *et al* 1987; Morris *et al* 1988) is suggestive of a possible involvement of phonons in the former and its likely absence in the latter. (iii) finally, while mere planar CuO_2 networks are present in the former, both the planar as well as CuO-chainer networks exist in the latter. It is suggested that the Cu-O chains are responsible for 90 K superconductivity of yttrium compounds through an excitonic mechanism (Callaway *et al* 1987). On the other hand, Salamon and Bardeen (1987) have reasoned that, even as compared to the conventional superconductors, except for the high T_c there is nothing particularly unusual about the mechanism of superconductivity in ceramic oxides.

To gain an insight into the above problem we have studied both lanthanum and yttrium-based systems simultaneously under identical conditions of substitution. We have preferred Zn as the substitutional element in $La_{1\cdot8}Sr_{0\cdot2}CuO_{4-y}$ and $YBa_2Cu_3O_{7-y}$ for the following reasons applicable to both the systems: (i) preliminary studies (Borges *et al* 1987; Tarascon *et al* 1987) indicated that a small substitution of Zn for Cu had a pronounced effect in depressing T_c; (ii) for small substitutions of Zn there was no structural change from orthorhombic to tetragonal (O–T) and the lattice parameter remained invariant (Xiao *et al* 1988; Strobel *et al* 1988) and (iii) there was no change in the oxygen stoichiometry reported (Strobel *et al* 1988). All these factors are unique for Zn substitution which make the interpretation of the results far less ambiguous by considerably reducing the complexities affecting T_c. A preliminary report describing some aspects of Zn substitution in the yttrium compound has already been communicated (Jayaram *et al* 1988).

The samples of $La_{1{\cdot}8}Sr_{0{\cdot}2}Cu_{1-x}Zn_xO_{4-y}$, where $0 < x < 0{\cdot}04$ and $YBa_2(Cu_{1-x}Zn_x)_3O_{7-y}$, where $0 < x < 0{\cdot}1$ were prepared by solid state reaction under identical conditions. The X-ray diffraction results confirmed that there was no change in the orthorhombic structure and the lattice parameters. The T_c depression as a function of Zn concentration observed for both the systems is depicted in figure 1. A remarkable similarity in the two cases is apparent. Over the concentration range studied both the T_c-onset and T_c ($R = 0$) decrease monotonically in a linear fashion. The rate of T_c decrease with Zn substitution for both the system is nearly of the same magnitude; 11 K/at.% for the La-system while 15 K/at.% for the Y-system. It is worth noting that in the former 2·3 at.% of Zn is found to quench superconductivity while 5·8 at.% Zn is needed for the same in the latter. This can be readily related to the difference of their coherence length of about 24 Å and 14 Å respectively in the Cu-O planes which can be intercepted and thereby break the coherence of the superconducting state by Zn substitutions of about 2·2% and 5·9% respectively, in close agreement with the experimental values.

In addition to T_c depression, the transition width, as evident from figure 1, increases continuously with increasing Zn concentration. In order to estimate the transition width $\Delta T_c(x)$ resulting from Zn substitution we have subtracted from the measured values the width corresponding to zero Zn substitution by drawing a broken line parallel to T_c ($R = 0$) and by measuring its separation from the T_c-onset value. The values of $\Delta T_c(x)$ thus obtained for both the oxides are plotted as a function of concentration X, which is shown in the inset of figure 1. Astonishingly, the transition widths due to Zn substitution for the two oxides fall on one and the same line, giving a slope $m = 2{\cdot}4$ K/at.%. Although there can be several factors which would broaden the superconducting transition in a multicomponent oxide superconductor, the observed increase in the width in the present case may be mainly attributed to disorder and local composition variations caused by incorporation of Zn. Thus, in the two different systems Zn substitution and resulting disorder in the planar and/or chainer

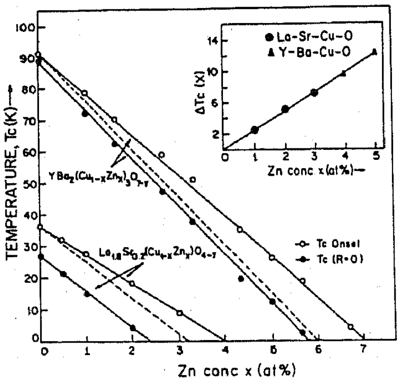

Figure 1. Concentration dependence of T_c ($R = 0$) and T_c-onset for Zn-substituted lanthanum and yttrium oxides. Inset shows the variation of transition width $\Delta T_c(x)$ with Zn concentration.

networks give rise to almost identical effects. This clearly would not have happened if the microscopic factors responsible for superconductivity in the two systems had been radically different. In other words, the mechanism that operates in the 30 K material possibly also holds in the 90 K material. This contention seems partly substantiated by the measurements of energy gap coefficient in the two systems. Although the gap coefficient, as determined from a host of different methods (Gupta *et al* 1987) like point contact tunnelling, scanning tunnelling microscopy, infrared studies and a.c. susceptibility, in both the oxides is found to vary from 2 to 10, interestingly a majority of data in both cases seem to centre around 3·5 to 5. Although these values correspond to electron phonon coupling and give some credence to the suggestion of Salamon and Bardeen (1987), the actual mechanism whether excitonic, RVB or anything else, however, remains an open question.

Detailed discussions of site occupancy, unusually large T_c depressions and other related effects observed on Zn substitutions in the two systems form the subject matter of a separate paper to be published elsewhere.

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