PHYSICA C

HIGH PRESSURE CHANGES THE CHARGE CARRIER CONCENTRATION IN HIGH-T_c SUPERCONDUCTORS: EXPERIMENTS TO 50 GPa

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For the first time the T_c of high temperature superconductors was measured up to 50 GPa, corresponding to a volume compression of ~ 25 %. The T_c of $YBa_2Cu_4O_8$ was found to increase from 78 K to a maximum of 106 K at ~ 10 GPa before decreasing again, while the T_c of $CaLaBaCu_3O_7$ only changed from 80 K to 86 K at ~ 35 GPa. The charge carrier concentration $\delta(p)$ is calculated from our simultaneous measurement of the upper critical field $H_{c2}(p)$ and $T_c(p)$. An excellent description of the pressure dependence of T_c is given by a simple model. Also the enigmatic pressure dependence of the $La_{2-x}Sr_xCuO_4$ compounds, as measured by Tanahashi et al. can be understood within the same framework.

1. INTRODUCTION

High pressure has played an important role in the identification of new materials and mechanisms in high temperature superconductivity[1]. Recently, we have shown[2] that pressure modifies one of the key parameters in these compounds, i.e. the charge carrier density. Here we show that a simple empirical model is capable of explaining i) the full curve $T_c(p)$ in these compounds and ii) the somewhat enigmatic Sr-concentration dependence of $(\partial T_c/\partial p)_{p=0}$ in $La_{2-x}Sr_xCuO_4$.

2. FULL CURVE OF $T_c(p)$ TO 50 GPa

In figure 1 we show some of our measurements of $T_c(p)$ in high-T_c superconductors. Pressure was generated by a diamond anvil cell, while T_c was determined by four-point resistometry[3]. To try and understand the qualitatively different behaviour, we determined[4,5] the charge carrier concentration δ under pressure by measuring the upper critical field $H_{c2}(p)$ and $T_c(p)$. The expression[2]

$$\frac{\partial \ell n\delta}{\partial p} = \frac{-1}{3B} - \frac{1}{3}\frac{\partial \ell nc}{\partial p} - \frac{1}{3}\frac{\partial \ell nH_{c2}(T=0)}{\partial p} + \frac{2}{3}\frac{\partial \ell nT_c}{\partial p} \quad (1)$$

can be integrated to obtain $\delta(p)$. B is the bulkmodulus and c is the length of the crystal lattice vector $\vec{c}$. The resulting $\delta(p)$ for $YBa_2Cu_4O_8$ and $CaLaBaCu_3O_7$ is shown in the inset

of figure 1. The full $T_c(p)$ curve can be understood from i) the linear function $\delta(p)$ observed in the inset of figure 1 and ii) the parabolic $T_c(\delta) \sim 1-\alpha\delta^2$ dependence as observed by Shafer and Penney[6], which give together a parabolic $T_c(p) = T_c(\delta(p))$.

The difference in $\partial T_c/\partial p$ between $YBa_2Cu_4O_8$ and $CaLaBaCu_3O_7$ is mainly determined by the much larger $\partial\delta/\partial p$ in the former, $\delta(p=0)$ being roughly equal. The difference in $\partial\delta/\partial p$ is caused by the structure: $YBa_2Cu_4O_8$ is orthorhombic and hence has "chains", while $CaLaBaCu_3O_7$ is tetragonal and without "chains". Since charge transfer to the CuO_2-layers is
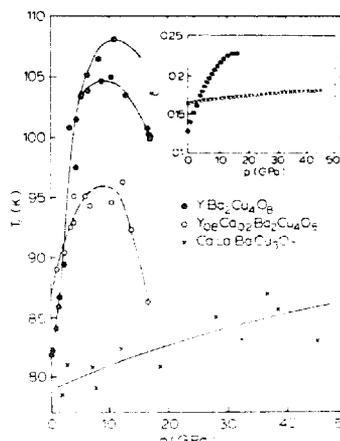

Figure 1. Pressure dependence of the onset critical temperature T_c for the compounds indicated. Inset: pressure dependence of the charge carrier concentration δ, calculated by means of eq.1 from $H_{c2}(p)$ and $T_c(p)$ data.

facilitated[7] by the presence of long "chains", one indeed expects a larger $\partial\delta/\partial p$ for $YBa_2Cu_4O_8$.

3. PRESSURE DEPENDENCE OF T_c IN $La_{2-x}Sr_xCuO_4$

In figure 3 we show $T_c(x)$ of $La_{2-x}Sr_xCuO_4$ as determined by Tanahashi et al.[8] (circles and the curve connecting them). We calculate $\delta(p=0)$ from the stoichiometry (i.e. $\delta(p=0) = x$). This assumption may not be completed correct, in which case the δ-axis should be slightly modified; for our present argument this is irrelevant.

To understand how $\partial T_c/\partial p$ can be always positive for various x in this compound, it is necessary to realize that the above assumption $T_c(p) = T_c(\delta(p))$ is only approximately true. Of course, other parameters apart from δ may change T_c. To make this explicit we introduced a third axis, labeled A, in figure 3 which symbolizes all other parameters affecting T_c. The pressure axis clearly must have projections on the δ-axis and the A-axis, and is in the Aδ-plane. The projection on the δ-axis can be found from the $H_{c2}(p,x)$ measurements by Tanahashi et al. by means of eq.1, which gives $\partial\delta/\partial p = 0.016$ hole GPa^{-1}, roughly independent upon x. Using this value we have plotted his $T_c(p)$ curves for p between 0 and 1 GPa for various x (the lines connecting 0 and × in
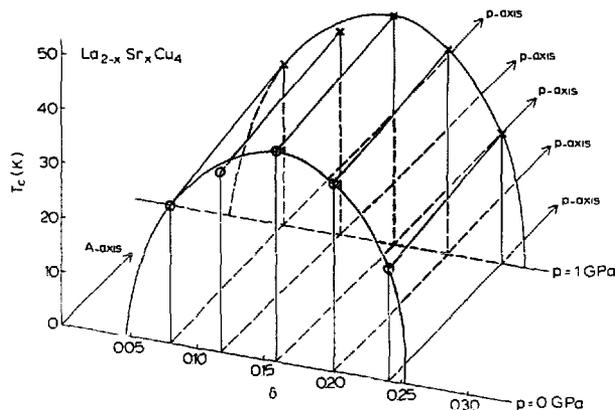
figure 3). The locus of $T_c(p = 1)$ GPa points (marked ×) is connected by a curve, which is $T_c(\delta)$ at 1 GPa. This curve is very similar to the curve $T_c(\delta)$ at $p = 0$, as expected. The differences are i) a slight increase in the maximum T_c-value and ii) a small shift of the maximum of the curve to higher δ-values. The first of these observations is in agreement with the fact that the maximum T_c under pressure is often higher than that obtained as a function of chemical doping. We have thus demonstrated that this measurement can be interpreted by a slightly extended version of our model of Ref 2.

REFERENCES

1. R.J. Wijngaarden and R. Griessen "High Pressure Studies" in "Studies of high temperature superconductors", A.V. Narlikar ed., Vol 2, Nova Science Publ., Commack, 1989, p29

2. R.J. Wijngaarden, J.J. Scholtz, E.N. van Eenige and R. Griessen, submitted for publication

3. E.N. van Eenige, R. Griessen, R.J. Wijngaarden, J. Karpinski, E. Kaldis, S. Rusiecki and E. Jilek, Physica C 168 (1990) 482

4. J.J. Scholtz, E.N. van Eenige, R.J. Wijngaarden, R. Griessen, to be published

5. J.J. Scholtz, E.N. van Eenige, R.J. Wijngaarden, R. Griessen and D.M. de Leeuw, to be published

6. M.W. Shafer and T. Penney, Eur. J. Solid State Inorg. Chem. 27 (1990) 191

7. M. Gupta and R.P. Gupta, Physica C 173 (1991) 381

8. N. Tanahashi, Y. Iye, T. Tamegai, C. Murayama, N. Mori, S. Yomo, N. Okazaki and K. Kitazawa, Jap. J. Appl. Phys. 28 (1989) L 762

Figure 2. Charge carrier concentration dependence of T_c at zero pressure (O) and at 1 GPa (×), calculated from the $T_c(p)$ data (lines connecting O and ×) by Tanahashi et al. (Ref 8).