

Superconductors

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Local structure and T_c suppression in $\text{Bi}_2\text{Sr}_2\text{Ca}_{1-x}\text{Y}_x(\text{Cu}_{1-y}\text{Zn}_y)_2\text{O}_{8+\delta}$ superconductor at 1/8 doping

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Local structural studies on the $\text{Bi}_2\text{Sr}_2\text{Ca}_{1-x}\text{Y}_x(\text{Cu}_{1-y}\text{Zn}_y)_2\text{O}_{8+\delta}$ superconductor have been carried out by Cu K-edge X-ray absorption spectroscopy. The Cu K-edge XANES spectra show a systematic evolution with the hole doping for $y=0.0$ while there is anomalous relaxation of the CuO_2 plane in the underdoped regime for $y=0.025$. Our results suggest that the 1/8 doping is a special doping below which the local structure of the CuO_2 plane shows strong sensitivity to extrinsic effects. The XANES features, associated with local structural distortions of the CuO_2 plane are discussed.

Key words: local CuO_2 lattice, stripes, 1/8 suppression,

1. Introduction

High T_c compounds show a complex phase diagram with doping and temperature. In the optimum doping regime the system shows stripes or incommensurate anharmonic charge density wave. The stripe phase segregation appears to be a common feature of all the high T_c compounds around the optimum doping (Bianconi et al, 1996a, Bianconi et al, 1996b; Lanzara et al, 1997, Saini et al, 1997, Tranquada, et al, 1997).

The T_c suppression at critical hole doping, 1/8, was considered to be a characteristic feature only of hole doped $\text{La}_{2-x}(\text{Sr},\text{Ba})_x\text{CuO}_4$ (La214) systems (Maeno et al, 1991). Sr doped La214 shows a small anomaly in T_c around the 1/8 hole doping while in the Ba doped samples there is drastic suppression of T_c . Recently the 60K plateau in the hole doped $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) system has been assigned to the 1/8 T_c suppression (Akoshima & Koike, 1998). It has been shown that the 1/8 anomaly exists in the hole doped $\text{Bi}_2\text{Sr}_2\text{Ca}_{1-x}\text{Y}_x\text{Cu}_2\text{O}_8$ (Bi2212) superconducting system (Akoshima et al, 1998) supporting the idea that this feature is common to all high T_c superconductors. It has been proposed that this anomaly is related with a formation of a Wigner crystal of polarons at a critical charge density (Bianconi, 1994). The 1/8 anomaly is found to be related with the local structural stress in the CuO_2

plane as evidenced by the fact that, in the La214 system, the suppression amplitude is related with the ionic radii of the dopant, e.g. the suppression is small with Sr doping while large when the dopant is Ba (Maeno et al, 1991). Similarly, without Zn impurity it was not possible to put in evidence the 1/8 anomaly in the Bi2212 system (Akoshima et al, 1998). Also, the 1/8 suppression in the La214 system was found to be strongly dependent on external impurities at the Cu site (Koike et al, 1992). Thus it appears that the local lattice distortions play vital role in controlling the T_c suppression at the 1/8 hole density in the cuprates.

X-ray near edge spectrum (XANES) is very sensitive to any small change in the local atomic distribution being a probe of higher order pair distribution function. Thus Cu K-edge XANES could be smartly exploited to investigate any local structural changes in the CuO_2 plane due to doping and any elemental substitutions. We have made a systematic study of local structural changes in the CuO_2 plane of $\text{Bi}_2\text{Sr}_2\text{Ca}_{1-x}\text{Y}_x(\text{Cu}_{1-y}\text{Zn}_y)_2\text{O}_{8+\delta}$ superconductor by Cu K-edge x-ray absorption. In this system the hole doping in the CuO_2 plane is controlled by substitution of Y in place of Ca. We have made the measurements on samples ranging from underdoping to overdoping, across the critical 1/8 hole doping and the optimum doping. In this communication we report XANES results on $\text{Bi}_2\text{Sr}_2\text{Ca}_{1-x}\text{Y}_x(\text{Cu}_{1-y}\text{Zn}_y)_2\text{O}_{8+\delta}$ at low temperature. The results suggest that small amount of Zn introduces large change in the local atomic distribution around the Cu-site below the 1/8 hole doping.

2. Experimental

The high resolution Cu K-edge X-ray absorption measurements were made on powder samples (Akoshima et al, 1998). We have used two series of samples with $x=0.0, 0.15, 0.20, 0.30, 0.3125, 0.4, 0.5$ and 0.6 and $y=0.0$ and 0.025 . The temperature dependent absorption measurements were performed on the beam-line BM29 at the ESRF. A Si(311) double crystal monochromator was used. Well-pressed pellets of the samples were placed in a closed-cycle two stage cryostat and the temperature was controlled with an accuracy of $\pm 1\text{K}$. The spectra were recorded by detecting the $\text{Cu K}\alpha$ fluorescence yield using a 13 Ge element solid state detector. Using this approach we could select the absorption spectra due only to the partial cross section for transitions from the Cu 1s initial states. Several absorption scans were collected to obtain high signal-to-noise ratio.

3. Results and Discussion

Figure 1(a) shows normalized Cu K-edge XANES spectra measured on the Bi2212 at several dopings of Y. Fig. 1(b) contains spectra on the $\text{Bi}_2\text{Sr}_2\text{Ca}_{1-x}\text{Y}_x(\text{Cu}_{0.975}\text{Zn}_{0.025})_2\text{O}_{8+\delta}$ (Bi2212Zn) series at the same temperature (30K). All spectra were given similar treatment in which the pre-edge background was subtracted and the atomic absorption jump is normalized to one. The spectra are similar to the one that is created by averaging over the in-plane and out of plane polarized spectra measured on single crystal of the Bi2212 system (Saini et al, 1998) and LSCO system (Saini et al, 1997) and show the characteristic features observed in Cu K-edge XANES of the cuprates.

We have identified different features using polarized spectrum and used standard notations. Pre-peak P in the powder spectra is due to $1s \rightarrow 3d_{x^2-y^2}$ quadrupole transition and a residual from dipole contribution that exists due to static and dynamic local lattice distortions of the CuO_2 plane (Saini et al, 1998). A_1 and A_2 are characteristic features of the spectrum measured in the out of plane geometry while B_1 and B_2 are observed in the in-plane polarized spectrum. Physical origin of the XANES features has already been discussed (Bianconi et al, 1991).

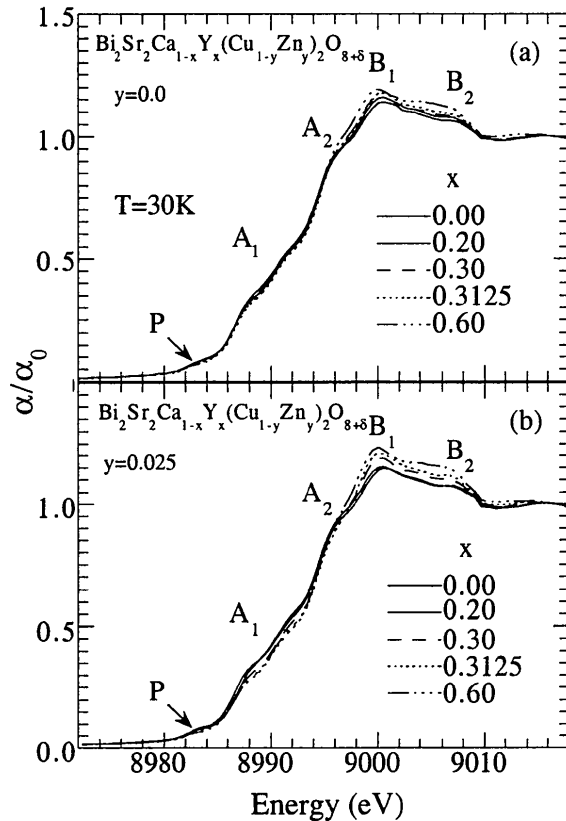


Figure 1
Normalized XANES spectra of $\text{Bi}_2\text{Sr}_2\text{Ca}_{1-x}\text{Y}_x(\text{Cu}_{1-y}\text{Zn}_y)_2\text{O}_{8+\delta}$ at several Y dopings (x), with $y=0.0$ (panel a) and $y=0.025$ (panel b) measured at 30K.

The main absorption features in the powder spectrum are due to complex multiple scattering of the photoelectron excited from the Cu $1s$ core levels. For example A_1 and A_2 are mainly determined by the multiple scattering of the ejected photoelectron with apical oxygen O(apical) and Sr/Ca/Y atoms, on the other hand, the peak B_1 is due to the multiple scattering of the photoelectron with oxygen and Cu atoms within the CuO_2 plane. The peak B_2 is a shake-up peak due to high electronic correlation in the system. Thus any change in the multiple scattering peaks directly reflects local atomic distribution in a cluster of radius of $\sim 5 \text{ \AA}$ from the central Cu.

The differences in the XANES spectra with Y concentration are evident in the Fig. 1 indicating a systematic change in the local atomic distribution

around the Cu atom. The doping dependent changes are comparatively stronger in presence of small amount of Zn impurity in the superconducting CuO_2 plane. Here we will focus our attention on the evolution of the main absorption peak B_1 that could be considered a characteristic parameter to study the average local lattice distortions in the CuO_2 plane.

Fig. 2 shows the intensity of the main absorption peak B_1 at 30 K as a function of Y concentration for the two series studied in this work. As Y concentration is increasing, the hole density is decreasing in the CuO_2 plane. We have adopted two methods to obtain the peak intensity. In the first case we have taken maximum of the peak intensity while in the second case, a constant atomic absorption background, given by an arctan function is subtracted from the XANES spectra and the difference was fitted with Gaussian functions. The two approaches provided similar behavior of intensity of the peak B_1 .

The results show that the peak intensity evolves gradual increase with Y doping in the Bi2212 system. The general increase of the B_1 peak intensity, representing mainly the Cu-O-Cu multiple scattering, is not expected from the nearly constant in-plane lattice parameters (Onozuka et al, 1991). On the other hand, peak A_2 , probing the Cu-O(apical) bonds does not change while the out-of-plane lattice parameter (c -axis) shows a large decrease. The evolution of the B_1 peak intensity in the Bi2212Zn system shows a general increase with an anomalous upturn of its intensity above $x \sim 0.3$. This indicates that a small amount of Zn impurity in the superconducting plane introduces large change in the local structure around the Cu site. At lower Y doping the Zn does not appear to make any substantial change while at the higher Y concentration the local structure is substantially different. This implies that, Zn introduces significant local structural changes when the CuO_2 plane is underdoped by holes (increase of Y doping reduces the hole density).

The observed behaviour is quite similar to the external pressure dependence of the superconducting transition temperature showing large dependence in the underdoped regime while small effect in the optimum and overdoping regime (Schilling, 1998). Without going into details it could be stated that the CuO_2 plane has a particular stress, suitable for giving highest T_c , that seems to be less sensitive to external effects for hole doping higher than the $1/8$. Thus the lattice stress on the CuO_2 plane is an important parameter for superconducting and normal state characteristics of the perovskite superconductors.

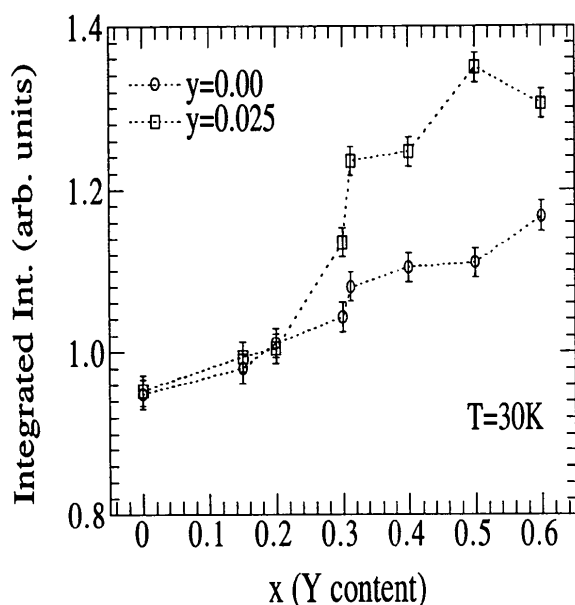


Figure 2
Doping dependence of the integrated intensity of the main XANES peak B_1 at 30K for $y=0.0$ (circles) and $y=0.025$ (squares).

Looking at the XANES and EXAFS data (not shown here) on the two series we have learned that the Y doping makes the CuO_2 plane relaxed gradually indicating that tilting of square pyramids in the distorted stripes decreases (Bianconi et al, 1996a, 1996b). Once the Zn is introduced, the CuO_2 plane shows further relaxation for higher Y (Y content higher than ~ 0.3 , i.e., hole doping less than $1/8$ holes per Cu site). This shows that at low hole doping a small Zn content induces a further reduction of in-plane CuO_2 lattice distortions. However, a question about the evolution of local atomic displacements around the Zn sites with hole doping remains unanswered and is an object of future X-ray absorption studies to be performed at the Zn K-edge.

The change in the local CuO_2 lattice seems to be associated with a concomitant change in the transition temperature T_c suggesting that a particular lattice stress in the CuO_2 plane is a necessary ingredient for high T_c in the perovskite superconductors. A related effect has been further uncovered by recent experiments where an amplification of the superconducting transition temperature was realized by manipulating the lattice strain in the underdoped regime (Locquet et al, 1998; Attfield et al, 1998). It is clear from the experimental data that the Zn substitution affects the local structure around the Cu site below the $1/8$ hole doping. Therefore the $1/8$ hole doping seems to be a crossover doping below which the lattice stress could be easily manipulated either by external pressure or by substitution in the CuO_2 plane.

It is getting known that the CuO_2 plane in Bi2212 system shows lattice-charge stripes in the diagonal direction where the distorted and undistorted CuO_2 planes are ordered in stripes (Bianconi et al, 1996b).

The Zn substitution in the CuO_2 plane appears to be reducing the local tilting of the CuO_2 plane in the distorted stripes as shown by the present experimental results. This decrease in tilting leads to a reduction of the potential barrier for electrons at the interface between the two types of stripes. Therefore the decrease of the superconducting transition temperature by Zn substitution may be a consequence of shape resonance effect (Bianconi et al 1998).

In summary, we have made a systematic study of local structure of the CuO_2 plane as a function of hole density in a superconducting Bi2212 system by XANES, with and without a small Zn impurity content in the CuO_2 plane. The study shows that local lattice inhomogeneities in the CuO_2 plane induced by the charge carriers and dopants play vital role to control the superconducting transition temperature in the perovskite cuprates.

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References

- Akoshima, M., Noji, T., Ono, Y., & Koike, Y. (1998). *Phys. Rev. B* **57** 7491.
 Akoshima, M. & Koike, Y. (1998). *J. Phys. Soc. Jpn.* **67** (1998) in press.
 Attfield, J.P., Kharlanov, A.L., & McAllister, J.A. (1998). *Nature* **394**, 157.
 Bianconi, A., Li, C., Campanella, F., Della Longa, S., Pettiti, I., Pompa, M., Turtu, S., & Udron, D. (1991). *Phys. Rev. B* **44** 4560.
 Bianconi, A., (1994) *Solid State Comm.* **91**, 1; *Solid State Comm.* **91**, 287.
 Bianconi, A., Saini, N. L., Lanzara, A., Missori, M., Rossetti, T., Oyanagi, H., Yamaguchi, H., Oka, K., & Ito, T. (1996a). *Phys. Rev. Lett.* **76**, 3412.
 Bianconi, A., Lusignoli, M., Saini, N. L., Bordet, P., Kvik, Å., Radaelli, P.G., (1996b) *Phys. Rev. B* **54**, 4310; Bianconi, A., Saini, N. L., Rossetti, T., Lanzara, A., Perali, A., Missori, M., Oyanagi, H., Yamaguchi, H., Nishihara, Y., & Ha, D.H. (1996b). *Phys. Rev. B* **54**, 12018.
 Bianconi, A., Valletta, A., Perali, A., & Saini, N.L. (1998) *Physica C* **296**, 269.
 Koike, Y., Kobayashi, A., Kawaguchi, T., Kato, M., Noji, T., Ono, Y., Hikita, T., & Saito, Y. (1992). *Sol. State. Comm.* **82**, 889.
 Lanzara, A., Saini, N.L., Bianconi, A., Hazemann, J.L., Soldo, Y., Chou, F.C., & Johnston, D.C., (1997). *Phys. Rev. B* **55**, 9120.
 Locquet, J.P., Perret, J., Fompeyrine, J., Mächler, E., Seo, J. W., & Van Tendeloo, G. (1998). *Nature* **394**, 453.
 Maeno, Y., Odagawa, A., Kakehi, N., Suzuki, T. & Fujita, T. (1991) *Physica C* **73**, 322; *Phys. Rev. B* **44** 7753. and references therein.
 Onozuka, T., Iwabuchi, Y., Fukase, T., Sato, H., & Mitchell, T.E. (1991). *Phys. Rev. B* **43** 13066.
 Saini, N.L., Lanzara, A., Oyanagi, H., Yamaguchi, H., Oka, K., Ito, T., & Bianconi, A. (1997). *Phys. Rev. B* **55** 12759.
 Saini, N.L., Lanzara, A., Bianconi, A., & Oyanagi, H. (1998) *Phys. Rev. B* **58** 11768.
 Schilling, J.S. (1998). *J. Phys. Chem. Solids* **59**, 553.
 Tranquada, J.M., et al, (1997) *Phys. Rev. Lett.* **78**, 338 and references therein.

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