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Carrier concentration induced transformations and existence of pseudogap in $NdBa_2Cu_3O_{7-\delta}$

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ABSTRACT

We have studied transport properties of several $NdBa_2Cu_3O_{7-\delta}$ superconductors using wide range of excess oxygen content δ. The buckling angle is found to be very sensitive with δ. Disordered copper oxide planes are origins of the superconducting properties controlling of which is possible by changing the buckling angle in superconducting planes in addition to the carrier concentration. A phase diagram consisting of the characteristic temperature T^* related to the formation of pseudogap and critical temperature with δ has been obtained. The effect of the changed buckling angle on the pseudogap formation with δ has been also studied.

1. Introduction

The normal state and phase transition region is affected strongly by excess oxygen in $NdBa_2Cu_3O_{7-\delta}$ (NBCO). Keeping all other factors in the same order of magnitude the variation of the critical temperature and normal state conduction mechanism depends on the carrier concentration which can be controlled by changing excess oxygen. However, it is not very easy to solely study the impact of the excess oxygen. There are several other changes which take place because of the variation of the excess oxygen [1,2]. Among these changes few are directly affecting the pair formation scenario in the origin of the superconducting properties over a wide range of temperature as well as the nature of the phase transition in cuprates.

A variation of the excess oxygen content (δ) is an effective method which can alter the pseudogap in cuprate superconductors [3,4]. In addition to the carrier concentration few other structural parameters influence the pairing mechanism which in turn can modulate the pseudogap formation. The buckling in copper oxide plane and critical temperature scales with the excess oxygen content in $YBa_2Cu_3O_{7-\delta}$ (YBCO). Both buckling angle and critical temperature is found to be maximum at same oxygen content [2]. Structural changes caused by the variation of δ may be very influential to affect the critical temperature as well as formation of pseudogap in NBCO.

Lattice constants, bond angles and bond valance sums (BVS) are known to be very sensitive to the doping and excess oxygen in high temperature superconductors (HTS) [5,6]. Our objective of the present work is to understand how the variation in oxygen content changes the disorder level in CuO_2 planes that affects both the normal state and superconducting properties in addition to the change in the hole concentration. We have synthesized several samples of $NdBa_2Cu_3O_{7-\delta}$ ($\delta = 0$ through 1). These samples are studied using the Reitveld refinement of the X-ray diffraction (XRD) data for calculating structural parameters. The variation of structural parameters and their impact on the conducting properties of the samples have been studied. Buckling angles associated with the CuO_2 layers varies with excess oxygen randomly reflecting the disorder level varies in different samples. From the temperature dependence of resistivity we have studied that the variation of the critical temperature and possibility of the pseudogap formation [7]. A phase diagram consisting of both the critical temperature and a characteristic temperature related to the onset of pseudogap formation as a function of δ has been suggested.

2. Experimental

Synthesis of the samples $NdBa_2Cu_3O_{7-\delta}$ ($\delta = 0$ through 1) has been carried out using the standard solid state reaction. Finely ground mixture of highly pure Nd_2O_3, $BaCO_3$ and CuO_2 powder is pressed into pellets. Sintering is done at 940 °C in air with intermediate grindings followed by a cooling at the rate of 2 °C/min to room temperature. Then these samples were annealed at 450 °C in flowing oxygen for 24 hours. Phase detection and structural analysis are done by using X-ray diffraction (XRD) method (Bruker D8

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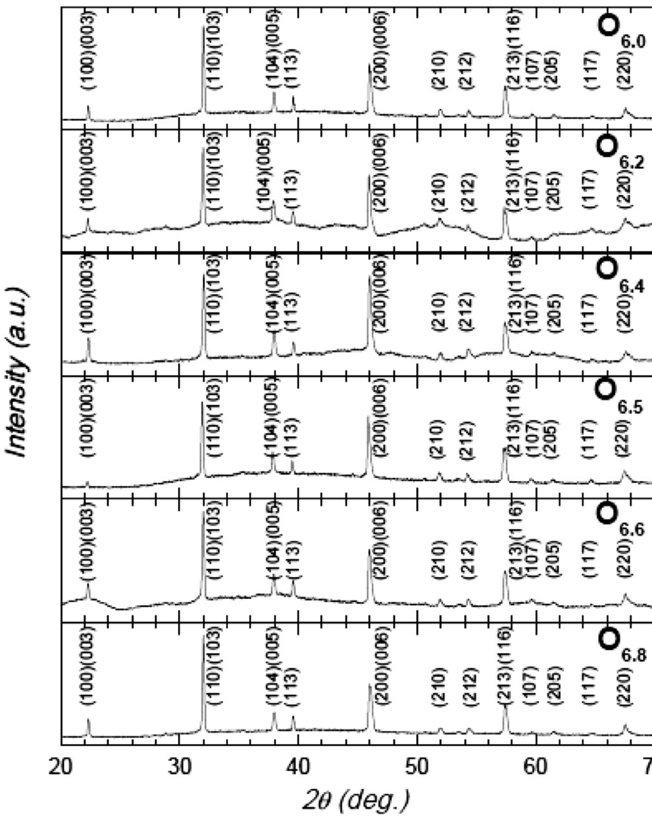

Fig. 1. X-ray diffraction patterns of several $NdBa_2Cu_3O_{7-\delta}$. Inside each panel we have mentioned stoichiometry of total oxygen content.

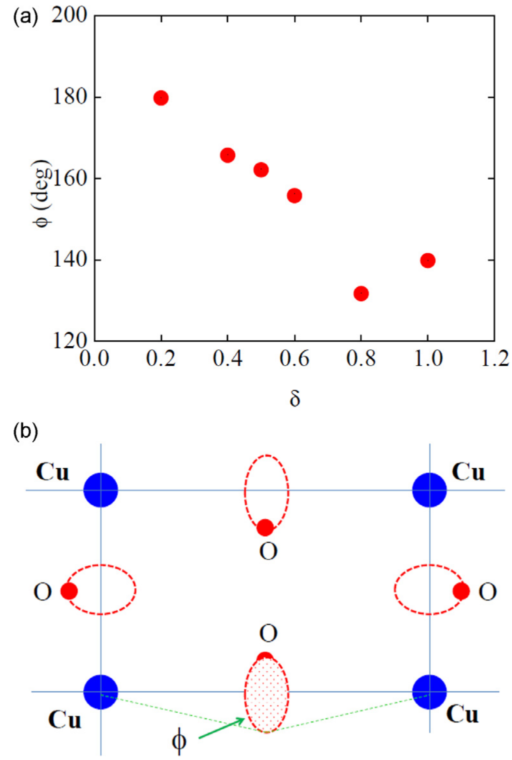

Fig. 2. (a) Representative bond angle Cu(2)–O(2)–Cu(2), ϕ in typical CuO_2 planes obtained by using *FullProf* program as a function of δ. (b) We have shown the possible change in the angle with respect to the position of the oxygen atom O(2) schematically. Dashed lines (in green) represents angle [Cu(2)–O(2)–Cu(2)], ϕ.

Advance). Rietveld refinement for the structural analysis is done by using *FullProf*. The materials have been characterized by using Scanning electron microscope (SEM). Bar shaped samples are used for the transport measurements down to 10.0 K. Resistivity as a function of temperature has been measured by using the standard four probe method with the help of a cryogenerator (Janis, USA) [8].

3. Results and discussions

In Fig. 1 we have plotted intensity as a function of 2θ using all identified (*hkl*) peaks. Lattice parameters and cell volumes are extracted using *FullProf* refinement program [9]. With the increase in δ, we have observed no systematic change in lattice constants and cell volume. A typical *c*-axis lattice constant $c \sim 11.71$ Å for $\delta = 0.2$. The typical unit cell volume is of the order of 177.9 Å^3. An unaltered peak position of (110) indicates that no systematic deformation in copper oxide plane is detectable with the change in δ. The microscopic changes in these planes are found to be more complicated. Most interesting example is the change in the bond angle of Cu(2)–O(2)–Cu(2). A deviation from the collinear position making is observed in all samples. It manifests that with the variation of δ the intrinsic level of disorder in copper oxide plane changes.

Among several changes in bond lengths we found that, the angle ϕ [Cu(2)–O(2)–Cu(2)] changes strongly with the reduction in oxygen content. We have plotted a representative variation of this angle with δ in Fig. 2(a). Clearly, the linear arrangements of Cu–O–Cu in the superconducting planes are strongly affected with the increase in δ which is associated with the buckling angle in the superconducting plane. Earlier it is shown that buckling angle $\sim$ (180° - ϕ)/2, varies with Pr doping in Nd-123 system [10]. By using a suitable rare earth doping a critical buckling is said to be found which can completely destroy the superconducting properties [11]. In Fig. 2(b) we have shown a schematic diagram to clarify a possible change in the angle ϕ. A cone with respect to the Cu(2) position is formed by the possible positions of the displaced O(2) as shown in Fig. 2(a). All four O(2)s of any copper oxide plane are following bases of such cones. Any pairing formation is therefore affected by the uncertainty in relative positions induced by the variation of δ. A shifting in the Cu(2) position with respect to

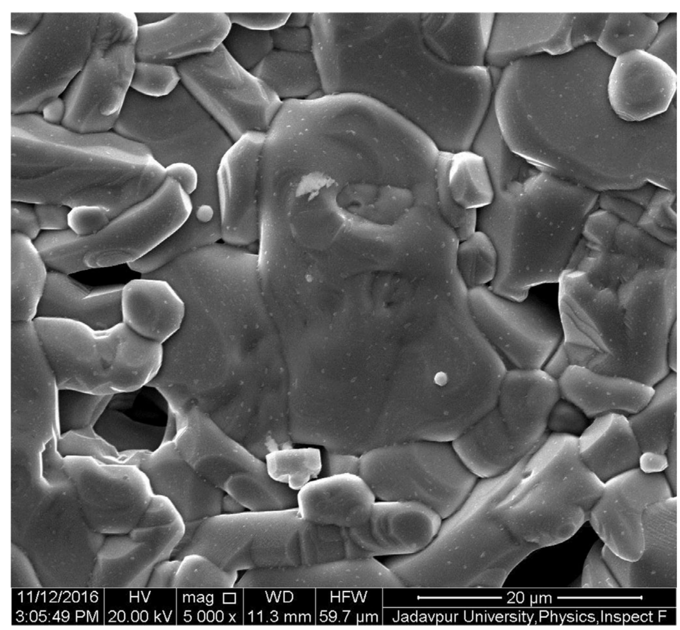

Fig. 3. A representative Scanning electron micrograph (SEM) of $NdBa_2Cu_3O_{6.4}$ ($\delta = 0.6$).