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Cation effects in new superconductors $Sr_{2-x}Ba_xCuO_{3+\delta}$

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ABSTRACT

A series of new superconductors $Sr_{2-x}Ba_xCuO_{3+\delta}$ ($x \leqslant 0.6$) were prepared under high pressure high temperature. The superconductors crystallize into K_2NiF_4-type structure of $I4/mmm$ space group similar to the classical La_2CuO_4 but with partially occupied apical oxygen. It is found that T_c of this barium doped $Sr_2CuO_{3+\delta}$ superconductor is associated with the ratio of A-site cation substitution while keeping at optimal carrier doping level. The superconducting transition temperature with $T_c^{max} = 98$ K which represents the record high T_c in the single-layer copper oxide superconductors was achieved in this material.

1. Introduction

The improvement on superconducting transition temperature (T_c) is one of key concerns of studies on high temperature superconductors (HTS) [1–8]. HTS is realized in copper oxide materials upon doping charge carriers into the CuO_2 planes. Therefore, the doping level is a main factor in tuning T_c. Since superconductivity takes place in CuO_2 plane, the in plane Cu–O bond length as a measure of hybrid $Cu3d_{x2-y2}$ vs. O2p orbital will be related to the superconducting order parameters. From the stacking view, the in plane Cu–O bond length is confined by charger reservoir layer, in particular by apical oxygen layer since they are neighbor. Therefore, it is expected the T_c will also be pertinent to the average size of "A" site ion. In the present study, we study the effect of average "A" site ion size on T_c for the $A_2CuO_{3+\delta}$ (A = Sr, Ba) superconductors. Aiming to the A-site effect, we have successfully synthesized a series of $Sr_{2-x}Ba_xCuO_{3+\delta}$ ($x \leqslant 0.6$) superconductors under high pressure high temperature. We found that the superconducting transition temperature can be significantly enhanced from 75 K for $Sr_2CuO_{3+\delta}$ to 98 K for Ba-doped $Sr_2CuO_{3+\delta}$ through A-site ion size change. Fig. 1 shows the crystal structure of $(Sr,Ba)_2CuO_{3+\delta}$ that is isostructural with La_2CuO_4.

2. Experimental

The samples were synthesized using high pressure high temperature. The $Sr_{2-x}Ba_xCuO_3$ precursors were mixed with SrO_2 and CuO to form the nominal composition of $Sr_{2-x}Ba_xCuO_{3+\delta}$ in a dry glove box that was used to prevent the degradation of hygroscopic reagents. The materials were then subjected to high pressure synthesis under 6 GPa pressure and at 1000 °C for 30 min using a cubic-anvil-type high pressure facility, and then quenched to room temperature before releasing the pressure.

3. Results and discussion

Since a maximum T_c was obtained in the parent $SrCuO_{3+\delta}$ at a doping level $\delta = 0.4$, we keep all the $Sr_{2-x}Ba_xCuO_{3+\delta}$ samples with the same oxygen content in order to check the A-site effects without changing carrier density. The X-ray diffraction patterns show apparently tetragonal single phase for $Sr_{2-x}Ba_xCuO_{3+\delta}$ with space group $I4/mmm$ in the range of $x \leqslant 0.6$ (Fig. 1). Fig. 2 shows the temperature dependence of magnetic susceptibility for the samples with the nominal composition $Sr_{2-x}Ba_xCuO_{3+\delta}$ measured in field cooling mode that corresponds to Meissner effect at an external field of 20 Oe. Superconducting transition temperature increased with Ba substitution. A maximum $T_c = 98$ K was reached at $x = 0.6$. The Meissner volume fraction of $Sr_{2-x}Ba_xCuO_{3+\delta}$ sample is above 10% at 5 K, suggesting the nature of bulk superconductivity.

The experimental results indicated that the superconducting transition temperature is related to the A-site effects. Here the isovalence substitution for Ba-doped $Sr_{2-x}Ba_xCuO_{3+\delta}$ shows very small disorder effect comparing with other system with heterovalence substitution. The inter plan Cu–O bonding length seems closely correlates with the T_c. Fig. 3 shows the relationship between T_c and the copper oxygen bonding length for several high T_c cuprate with mono CuO_2 plane. The superconducting transition temperature with $T_c^{max} = 98$ K in $Sr_{2-x}Ba_xCuO_{3+\delta}$ represents the record high T_c in the single-layer copper oxide superconductors. The results suggested the even higher T_c can be achievable based on jointly

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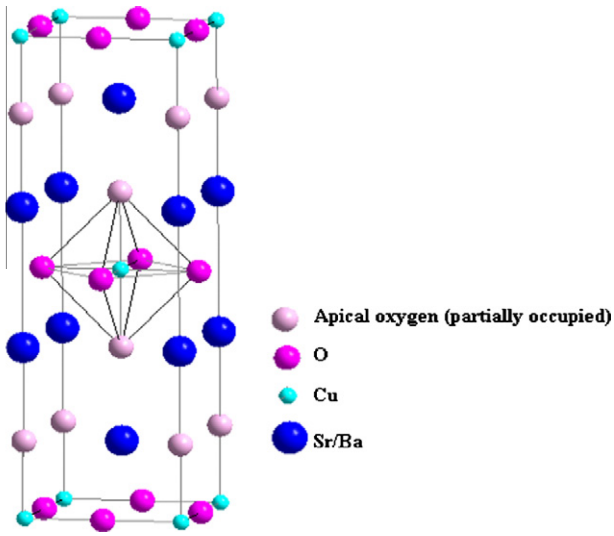

Fig. 1. The schematic view of the crystal structure of 214 type $Sr_{2-x}Ba_xCuO_{3+\delta}$.

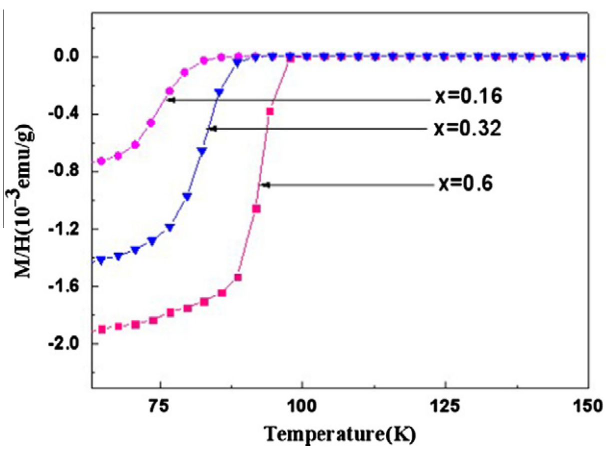

Fig. 2. Temperature dependence of magnetic susceptibility for $Sr_{2-x}Ba_xCuO_{3.4}$ with various x values.

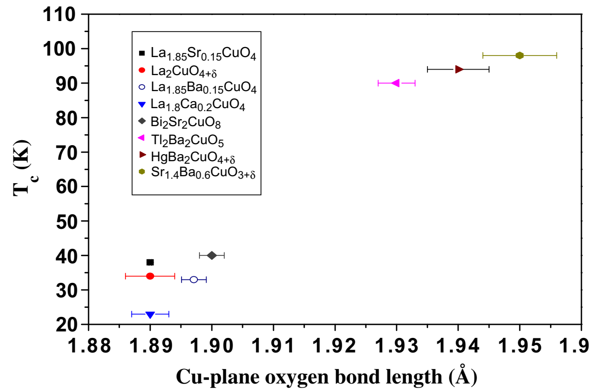

Fig. 3. The T_c dependence on the in plane Cu–O bond length for various single-layered HTS at an optimal doping level.

optimizing carrier density, order at the charge reservoir together with the planar copper oxygen distance.

Acknowledgments

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