Lattice mismatching effect in composites systems

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Abstract. The superconductivity can be studied using composites systems. Recently studies are focused on the relation between magnetism and superconductivity by introducing manganese oxide, which exhibits room temperature ferromagnetism, into La$_{2-x}$Sr$_x$CuO$_4$ system. Results indicate that the magnetism can have effect on superconductivity properties. However, in this paper it is found that the influence of sintering temperature for superconductor is also very important. The composites systems are synthesized and the experimental results indicate that the local structural distortion can be caused by high sintering temperatures. The distortion leads to changes of energy band around Fermi level and it is commonly recognized that the energy band around Fermi Level is very important for superconducting. While in the low sintering temperatures the local structural distortion is not found so the sintering temperature should be carefully concerned when the composites systems are synthesized.

1. Introduction

High-T$_c$ superconductivity (SC) has been an extensive research topic since it was found in cuprates\textsuperscript{[1]}. Today many issues remain controversial and the basic mechanism has not been found. For example, the relation of pseudogap and SC gap is unclear and the “glue” of cooper pair in high-T$_c$ superconductivity hasn’t been found. Further studies are needed. Recently researches are focused on the relation of SC and magnetism which are mutually exclusive in general principles. However the opposite points are proposed. Julie A\textsuperscript{[2]} et al. imaged the coexistence of ferromagnetism (FM) and SC. Even amazingly magnetism can be a favorable factor for SC in CeCu$_2$Si$_2$\textsuperscript{[3]} and the magnetic induced stripe order in Y123 system, leading to further support that magnetism is an important factor in cuprates superconductors\textsuperscript{[4]}.

In order to clarify the relation between SC and antiferromagnetism (AFM), composites systems were proposed. In the composites systems of (La$_{1.85}$Sr$_{0.15}$CuO$_4$)$_x$(Lu$_2$Cu$_2$O$_5$)$_{1-x}$, it is believed that the enhancement of SC is driven by Lu$_2$Cu$_2$O$_5$\textsuperscript{[5]}. Other works still aim at how the FM can affect SC system using composites systems. In D. Hsu’ experiment, the composites of (La$_{1.85}$Sr$_{0.15}$CuO$_4$)$_{1-x}$(La$_{0.3}$Dy$_{0.4}$Sr$_{0.3}$MnO$_3$)$_x$, were synthesized, the low ferromagnetic coupling of La$_{0.3}$Dy$_{0.4}$Sr$_{0.3}$MnO$_3$ undergoes a spin glass transition below 70 K. The interaction induced structure distortion leads to the phase separation of LSCO into hole-rich and hole-poor regions\textsuperscript{[6]}. Just recently, in the composites of (La$_{1.85}$Sr$_{0.15}$CuO$_4$)$_{1-x}$(La$_{2/3}$Sr$_{1/3}$MnO$_3$)$_x$, the electronic phase separation is found which is attributed to the interaction between SC and FM at the grain surface\textsuperscript{[7]}. In the pervious research, magnetism and structural distortion are two important factors in the composites which can give great effect on SC.

In this paper we focus on the lattice mismatching effect and its effect on the electronic structure around Fermi level. The double layered system of LaSr$_2$Mn$_4$O$_{17}$ (LSMO) and La$_{1.85}$Sr$_{0.15}$CuO$_4$ (LSCO) are chosen. The two systems both have AFM properties and large lattice mismatch. After mixed the sintering temperatures are carefully chosen by which the interaction can be modulated. The interaction induces local structural distortion in the SC system of LSCO and the interaction effect can be carefully studied by changing sintering temperatures. A series of composite samples are synthesized. In order to
carefully investigate the relationship between sintering temperature and local structural distortion, and also to study how the local structural distortion affect the band structure, x-ray photoelectron spectra were measured in National Synchrotron Radiation Laboratory (NSRL) and Beijing Synchrotron Radiation Facility (BSRF). Extended X-ray absorption fine structure (EXAFS) and X-ray absorption near edge structure (XANES) were carried out in NSRL. The structures of the samples are characterized by x-ray diffraction. The two systems are immiscible at the chosen temperatures. The lattice parameters of the samples have almost no change.

2. Samples and experiments

The high quality samples of La$_{1.85}$Sr$_{0.15}$CuO$_4$ (LSCO) and LaSr$_2$Mn$_2$O$_7$ (LSMO) were synthesized. Polycrystalline samples of nominal composition LSCO are synthesized using high purity powders of La$_2$O$_3$, SrCO$_3$, CuO. The mixed powders are heated to 1250°C after grinding and repelletizing. The treatment was repeated three times. Using the same process, the LSMO system was synthesized with the sintering temperature of 1300°C. Then the two systems were mixed with the chemical formula: (La$_{1.85}$Sr$_{0.15}$CuO$_4$)$_{0.85}$(LaSr$_2$Mn$_2$O$_7$)$_{0.15}$ and sintered at 600°C, 800°C, and 1100°C, respectively. The structures of the samples are characterized by x-ray diffraction. The LSCO and LSMO are in a single phase and the two systems are immiscible after sintered at the above sintering temperatures.

3. Results and discussion

The O1s XPS spectra of the layered LSMO and LSCO are shown in Figure 1(a). The oxygen atoms have different sites which can be confirmed from the peak splitting. The binding energy of O1s is higher in LSCO than in LSMO. In Figure 1(b) the O1s spectra contain the information of two systems. Compared with Figure 1(a), it is believed that the peak A mainly comes from the contribution of LSCO. And the peak B mainly belongs to LSMO system. In the samples sintered at 600°C and 800°C, the binding energy of peak A is almost the same and no changes in shape are found. However, in the sample sintered at 1100°C, the peak A moves toward higher binding energy side and also broadens, which can be explained as the lattice mismatch effect [8, 9]. Our results indicate that in low sintering temperature (600°C, 800°C) the LSCO does not suffer strain from LSMO and no local structure distortion can be found, which will be discussed later. However in the sample sintered at 1100°C, large local lattice distortion happens at the grain boundary of LSCO and LSMO just as shown in Figure 2 (a). In order to clarify the relation between local lattice distortion and electron structure the extended X-ray absorption fine structure (EXAFS) and X-ray absorption near edge structure (XANES) experiments are performed which are shown in Figure 2.

Figure 1. (a): the XPS spectra of O1s in LSCO and LSMO. (b): the XPS spectra of O1s of the composite system with sintering temperatures of 600°C, 800°C, 1100°C.
Figure 2. (a) The Fourier transform (FT) curves of the Cu K-edge EXAFS for the samples sintered at 600°C, 800°C, 1100°C. (b) Cu K-edge XANES spectra of the pure LSCO, and samples sintered at 600°C, 800°C, 1100°C.

In Figure 2(a), the bond length $R_{\text{Cu-O}}$ does not change for samples sintered at 600°C, 800°C, but increases for sample sintered at 1100°C. The results indicate small strain happens in the samples sintered at 600°C, 800°C, but large strain exists for sample sintered at 1100°C. The interaction at the grain surface induces local structural distortions because of the high sintering temperature. In Figure 2(b), a transition of Cu 1s to 3d is generally dipole forbidden. The A feature is due to the Cu 1s to 3d state having a quadruple character $^{[10, 11, 12]}$, and the empty 3d band just above the Fermi level. While B feature arises from Cu 1s to 4p* $^{[13]}$. In the sample sintered at 1100°C, the features A and B shift to higher energy side comparing with samples sintered at 600°C and 800°C, which means that the electronic structure around Fermi level changes by local lattice distortion and the changes of the electronic structure can probably lead to great effect on SC in LSCO. This result is in agreement with the above mentioned results of O 1s spectra. The experimental results make it explicit the relation between sintering temperature, local structural distortion and the band structure. In the composites the high sintering temperature can affect the band structure around Fermi level by inducing local structural distortion.

4. Conclusion
In our experiments, a series of (LSCO)$_{0.85}$(LSMO)$_{0.15}$ samples are synthesized by solid state reaction method. The binding energy of O1s is investigated by XPS. EXAFS experiments are carried out in order to identify the local structure. In the samples sintered at 600°C and 800°C, no local distortions are found, but in the sample sintered at 1100°C, large local distortions exist which can be explained as the lattice mismatching effect. The LSMO can give large strain on LSCO and then affect the SC after sintered at high temperature. Suitable sintering temperature should be chosen in order to minimize the local lattice distortion. By XANES experiments the relationship between structural distortion and electronic band is found. The empty 3d band in LSCO can be affected at high sintering temperature when the structural distortion happens.

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