μSR Study of Magnetic Order in LTO and LTT Phase of
La$_{2-x}$M$_x$Cu$_{1-y}$Zn$_y$O$_4$ ($M = \text{Sr, Ba}$)


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In order to investigate the origin of so-called 1/8 anomaly in La(Sr,Ba)-214, we have performed μSR experiments for the low-temperature orthorhombic (LTO) and low-temperature tetragonal (LTT) structure phases in La$_{2-x}$Sr$_x$Cu$_{1-y}$Zn$_y$O$_4$ (LSCO) and La$_{2-x}$Ba$_x$Cu$_{1-y}$Zn$_y$O$_4$ (LBCO), and decided the magnetic order temperature $T_m$ where μ-spin coherent rotation starts. 1%Zn-substitution depresses magnetic order in the LTT phase of LBCO while it induces or enhances magnetic order in the LTO phase of LSCO. With doping $T_m$ rises first and keeps constant around $x = 1/8$ and decreases in both Zn-substituted LSCO and LBCO. This implies that doped holes are never uniformly distributed on the CuO$_2$ plane, suggesting the segregation of spin and hole around $x = 1/8$.

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1. Introduction

Superconductivity in La$_{2-x}$M$_x$CuO$_4$ ($M = \text{Ba or LBCO}$) is strongly suppressed at around hole density $x \sim 1/8$, which is called the “1/8” anomaly.\textsuperscript{1,2} Around this hole density, a structural transition from low temperature orthorhombic (LTO) phase with space group $Bmab$ to a low temperature tetragonal (LTT) phase with $P4_2/nmc$ takes place at low temperature. On the other hand, in the sample of LSCO ($M = \text{Sr}$) a slight suppression of superconductivity is observed but no structural transition occurs around $x = 1/8$. In La-214 compounds around $x \sim 1/8$ magnetic order has been observed by neutron elastic scattering experiments\textsuperscript{3} and μSR
measurements. Furthermore, dynamical magnetic correlation has been observed by neutron inelastic scattering experiments in LSCO over wide doping range. On the other hand, Tranquada et al. carried out neutron scattering experiment for Nd-substituted La$_{1.6-x}$Nd$_{0.4}$Sr$_x$CuO$_4$ which has LTT phase and suppressed $T_c$ around $x = 1/8$, and observed magnetic and charge superlattice peaks. They proposed a static stripe correlation model in the LTT phase to explain their neutron data. In our previous μSR studies, we have reported the possibility of charge and spin domains segregation in Zn-free and Zn-substituted LSCO around $x = 0.115$. The problem of the “1/8” anomaly contains an important relation among superconductivity, structure and magnetic correlation in high-$T_c$ superconductor. In order to clarify these relation we have carried out zero-field μSR experiments for Zn-free and Zn-substituted LSCO and LBCO over a wide hole doping range.

2. Experimental

The samples of La$_{2-x}$M$_x$Cu$_{1-y}$Zn$_y$O$_4$ ($M = $ Sr, Ba, $0.095 < x < 0.16$, $y = 0$ and 0.01) for μSR experiment were prepared by solid state reaction method using the starting materials La$_2$O$_3$, SrCO$_3$ and BaCO$_3$ with a purity of 99.99% and CuO and ZnO with 99.999% purity. The stoichiometric amount of them were ground and the mixture was calcined at 970 °C for 15 hours. After being pressed into a pellet with a diameter of 32 mm and a thickness of 3 mm, it was sintered at 1100 °C for 40 hours and annealing at 500 °C. The calcination, sintering and annealing were carried out in flowing oxygen gas. Zero-field μSR experiment was carried out in a temperature range between 1.6 K and 300 K. The obtained μSR time spectra were analyzed by the following equation:

$$P_\mu(t) = A_\perp \exp \left( -\frac{1}{2} \sigma^2 t^2 \right) J_0(2\pi \nu t) + A_\parallel \exp(\lambda_2 t) + A_{nm} \exp(-\lambda_3 t),$$  \hspace{1cm} (1)

$A_\perp$, $A_\parallel$ and $A_{nm}$ and are amplitudes reflecting the magnetic and non-magnetic fractions of the muons contributing to the depolarization of the muon spin, $\nu$ is the Larmor frequency of the coherent precession and $\sigma$, $\lambda_2$ and $\lambda_3$ are relaxation rate associated with the three components, $J_0$ is Bessel function to describe the oscillation. According to the detailed investigation, a muon stays within a distance of about 1 Å from an apical oxygen. Therefore muons can detect the magnetic information on CuO$_2$ plane.

3. Results and Discussion

Fig. 1(a) and (b) show hole concentration dependence of superconducting transition temperature $T_c$ which is decided from the magnetic susceptibility measurements using SQUID magnetometer for Zn-free ($y = 0$) and Zn-substituted