Tl, Cu-NMR study on high T_c cuprate $TlBa_2Y_{1-x}Ca_xCu_2O_7$

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Abstract

Tl,Cu-NMR study has been performed on the high-T_c cuprate, $TlBa_2Y_{1-x}Ca_xCu_2O_7$ with wide range hole concentration from the antiferromagnetic (Ca = 0) to the slightly overdoped (Ca = 1.0). For superconducting samples (Ca = 0.6 $\sim$ 1.0) the local spin susceptibility (K_S) at Cu-site stayed constant around room temperature, and starts slight a decrease from 160K, which is higher than T_c. This T-dependence is what has been reported in other high-T_c cuprates in overdoped region. $(T_1T)^{-1}$ at Tl-site for every superconducting sample, which obeys Curie-Weiss law at high temperature, showed a significant reduction from T_{SG} ($> T_c$), suggesting the existence of spin-gap even in slightly-overdoped region.

Key words: high-T_c cuprate; NMR ; spin-gap ;

1. Introduction

Recently electronic phase diagram of theoretical models, based on the spinon and the holon for the family of high-T_c cuprates, have attracted much interest [1][2]. In underdoped region, for spinon condensates at T_{SG} higher than holon, there emerges a temperature region where the low-energy part of spin fluctuation is strongly suppressed. This is so-called spin-gap. The models predict a disappearance of the spin-gap in overdoped region, where T_{SG} coincides with T_c. We believe that the test of this model on many cuprates leads the full understanding of the phase diagram of cuprates. $TlBa_2Y_{1-x}Ca_xCu_2O_7$ (Tl1212) system is one of the high-T_c superconducting oxide with bilayer-type CuO plane, the structure of which is similar to YBCO and Bi2212. The electronic phase diagram of this system is unusual compared with other cuprates. The insulator of Ca = 0 is doped hole by substitution of Ca^{2+} for Y^{3+}. With increasing hole-concentration, the superconducting phase appears suddenly at Ca = 0.6 with $T_c \simeq$ 100K, and with still further doping T_c decreases only slightly to $\simeq$ 80 K for Ca = 1.0. So far, we have shown by Tl-NMR, where Tl nuclei is located at the block layer and can probe the electronic state of CuO plane through a large hyperfine coupling to Cu-3d spins [3], that the spin-gap exists even in slightly overdoped region [4]. We report in this paper the electronic state of CuO plane of Tl1212 probed by Cu-NMR.

2. Experiment

Polycrystalline samples of $TlBa_2Y_{1-x}Ca_xCu_2O_7$ (x = 0 $\sim$ 1.0 step 0.1) were prepared by the conventional solid-state reaction method. The detailed process is published in elsewhere [5][6]. The powder samples mixed with epoxy resin were magnetically aligned along the crystalline c-axis for NMR measurements. Cu-NMR spectra were obtained by integrating spin echo amplitude by boxcar integrator with sweeping magnetic field around 10T. The ^{63}Cu Knight shift, a measure for the uniform spin susceptibility, were obtained by measuring spectrum of the central transition ($-1/2 \sim +1/2$) for several different resonance frequencies between 105 to 130 MHz. Tl nuclear spin-lattice relaxation rate, T_1^{-1}, is measured by the saturation-

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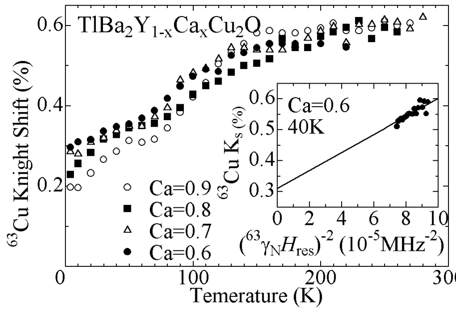

Fig. 1. Temperature-dependence of Cu-Knight shift. The inset indicates Knight shift vs $\gamma_N H_{res}^{-2}$ plot for Ca = 0.6 at 40K. The ν_Q of Cu which may reflects the small distortion in CuO plane is estimated $\simeq$ 13 MHz at 40K. This value is much smaller than other cuprates (Bi,La-system 20 $\sim$ 40 MHz).

recovery method with pulse train.

3. Results and Discussion

Figure 1 shows the T-dependence of the Knight shift at Cu-site from 4.2 to 280 K. The Knight shift is T-independent above 200 K, and shows a slight decrease from 160 K, which is much higher than T_c. This T-dependence is seen in overdoped region of other cuprates [7]. Note the difference from the typical spin-gap behavior reported in Knight shift of underdoped region where the significant reduction starts from room temperature. Tl-Knight shift for every superconducting sample is T-independent in the normal state [4], which is explained by relatively weak hyperfine coupling of Tl-site compared with on-site Cu ($A_{Tl} \simeq 1/4 A_{Cu}$). These results indicate that underdoped region does not exist or is confined in a very narrow region (Ca = 0.5 $\sim$ 0.6) in this system.

The averaged value of Cu-Knight shift in high temperature region is nearly constant for Ca = 0.6 $\sim$ 0.9. On the other hand Tl-Knight shift increases with hole-doping as seen in Fig2. This difference means that in the overdoped region some carrier is bound in the Tl-O layer and does not contribute to the density of states of CuO plane.

Figure 3 shows Tl nuclear spin-lattice relaxation rate. $(T_1T)^{-1}$ for all samples follows the Curie-Weiss law in the normal state, indicating that the two-dimensional antiferromagnetic spin fluctuation remains even in the slightly overdoped region. With decreasing temperature, $(T_1T)^{-1}$ deviates from the Curie-Weiss law at T_{SG} higher than T_c. T_{SG} decreases with hole doping, and is still higher than T_c even in the overdoped region. The existence of spin-gap in overdoped region, which has also been reported in other cuprates of La,Bi-system [8][7], indicates either that another mechanism, different from the one in underdoped region, causes the spin-gap, or that T_c is anomalously suppressed in the region Ca = 0.8 $\sim$ 1.0.

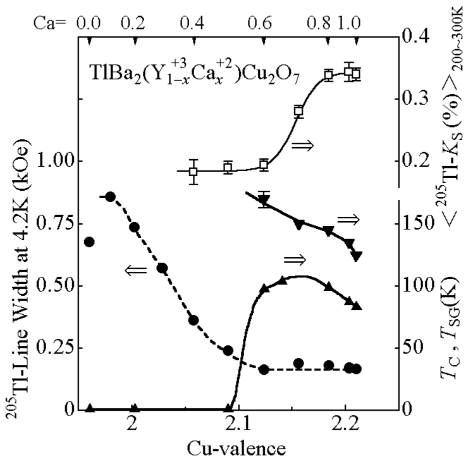

Fig. 2. Nominal Cu-valence vs T_c, T_{SG}, the average value of ^{205}Tl-Knight shift at 200 $\sim$ 300K, and the width of Tl-NMR resonance peak [4]. Nominal Cu-valence is obtained as to be $2+(x/2)-\delta$, where δ is the oxygen defect [9].

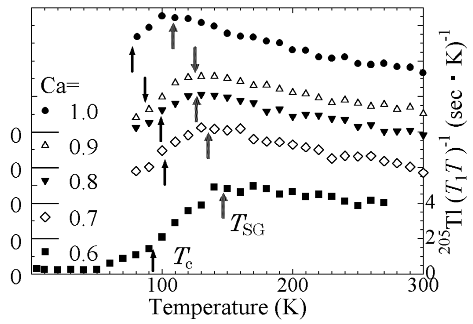

Fig. 3. Temperature-dependence of $(T_1T)^{-1}$ at Tl-site for Ca = 0.6 $\sim$ 1.0. The arrows indicate T_c and T_{SG}, where $(T_1T)^{-1}$ deviates from Curie-Weiss law.

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