Spin fluctuation in $Sr_2Ca_{12}Cu_{24}O_{41}$ under high pressure up to 3.0GPa

Naoki FUJIWARA [a,1], Yoshiya UWATOKO [a], Nobuo MÔRI [b], Takehiko MATSUMOTO [c]
Naoki MOTOYAMA, and Sinichi UCHIDA [d]

[a] *Institute of Solid State Physics, University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba, Japan*
[b] *Dept. of Physics, Faculty of Science, Saitama Univ., Saitama, Japan*
[c] *National Research Institute for Metal, Tsukuba, Japan*
[d] *Department of Superconductivity, University of Tokyo, Hongo, Bunkyo-ku, Tokyo, Japan*

Abstract

Nuclear magnetic resonance (NMR) were performed under high pressure up to 3.0GPa on a spin ladder system, $Sr_2Ca_{12}Cu_{24}O_{41}$. The system is nowadays well established as a low dimensional cuprate where superconducting state is realized by applying pressure of 3GPa. In the present work, we measured relaxation rate $1/T_1$ on ^{63}Cu nuclei at the normal state. $1/T_1$ shows an activated behavior at high temperatures above 50K although the system is metallic. The fact implies breakdown of a scenario that pressure vanishes the spin gap and then superconductivity is induced.

Key words: spin ladder ; $Sr_2Ca_{12}Cu_{24}O_{41}$; NMR; low dimensional cuprate

1. Introduction

The hole-doped two-leg ladder $Sr_2Ca_{12}Cu_{24}O_{41}$ is nowadays well established as a low dimensional cuprate where superconducting state is realized at low temperatures by applying pressure up to 3.0 GPa [1]. The system has been extensively studied at ambient pressure for the past few years by various experimental methods. One of the remarkable features is the existence of an excitation gap although holes are doped into the ladder sites and the system becomes metallic for the leg direction, crystal c axis [2, 3]. Decreasing of the gap by applying pressure was observed from nuclear magnetic resonance (NMR) for the field (H) perpendicular to the ladder plane (b axis), and has been linked with the appearance of the superconducting state [4-6]. In fact the superconducting state is realized at low temperatures where thermal activation hardly occurs. Fluctuation at low temperatures is important as well as the problem whether the spin gap exists or not at the critical regime. In the present work, we measured nuclear spin-lattice relaxation rate ($1/T_1$) under pressure down to 1.4K and discussed the origin of fluctuation at low temperatures.

[1] Corresponding author. E-mail: naokif@issp.u-tokyo.ac.jp

2. Experimental Results and Discussion

A single crystal of $Sr_2Ca_{12}Cu_{24}O_{41}$ with a size of 4x3x1 mm^3 was used for the ^{63}Cu-NMR measurements. The field was applied along the c axis since the upper critical field is the largest among three crystal axes [7]. NMR spectrum at 3GPa is almost the same with that at ambient pressure as far as the splitting due to the E. Q. Q. effect is concerned. The spectra for central transition (I=-1/2, 1/2) at the ladder sites show no remarkable increase in the linewidth around 2K where an antiferromagnetic ordering is expected from neutron scattering [8]. The results of NMR implies that no

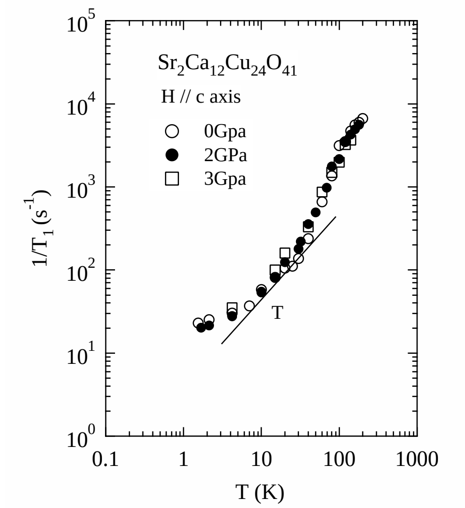

Fig. 1. $1/T_1$ of ^{63}Cu nuclei on ladder sites.

ordering occurs at the ladder sites. If the ordering is realized at the ladder sites, intensity of the NMR spectra drastically decreases at the critical regime as well as drastic broadening of the linewidth. In fact the T dependence of 2%-Zn doped $SrCu_2O_3$ which includes no chain sites shows drastic broadening of the linewidth at the ordering point[9].

The results of $1/T_1$ at the ladder sites are shown in Fig. 1. The values of pressure at room temperatures are shown in the figure. $1/T_1$ shows an activated behavior at high temperatures above 50K reflecting triplet-singlet spin excitation, however, deviates from the behavior with decreasing temperature. Then, $1/T_1$ is expressed as:

$$1/T_1 = Aexp(-\Delta/T) + BT^n \qquad (1)$$

where Δ represents the excitation gap. The value of the gap is about 173K, but depends on fitting range. The value of power, n is nearly 1 at temperature range between 50 and 5K. The value of n becomes about 0.5 at low temperatures below 5K.

The fact that the experimental results are well expressed by Eq. (1) implies the coexistence of a spin-gap excitation and a gapless excitation. The coexistence is a quite remakable feature since only one signal was observed from ^{63}Cu ladder sites. The activated behavior reflects singlet-triplet excitation which is seen in the insulator $SrCu_2O_3$. On the other hands, the power low behavior reflects Korringa relation with low density of states $n(E_F)$. The pre-factor B in Eq. (1) is proportional to $n(E_F)^2$ and the value of $n(E_F)$ is obtained as $1.77 \text{x} 10^{-3}$ $eV^{-1} atom^{-1}$.

The coexistence of two excitation modes is easily understood if spin fluctuations around holes and away from holes are different or independent, and low density of states originates from the fluctuation around holes. The ground state of a non-doped ladder system is overlap of spin dimmers on the rung. In a hole doped system, holes breaks spin dimmers, which causes the appearance of free spins on the same rung. In other wards, holon-spinon bound state is induced on the rung by hole doping. The activated and power low behaviors at high and low temperatures are caused from spin dimmers away from the bound state and free spins in the bound state, respectively. The experimental results are well explained by considering the bound state, however $1/T_1$ at low temperatures below 5K deviates from Korringa relation. The reason is not clear at present. A possibility may be that spins originating from the bound state is no longer free at low temperatures and some correrations between them causes a complex situation.

3. Conclusion

We have measured $1/T_1$ on ^{63}Cu nuclei for the H parallel to the c axis down to 1.4K under pressure up to 3GPa. The experimental results suggest the coexistence of the spin-gap excitation and the gapless excitation arising from the motion of the holon-spinon bound state on the rung.

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