^{63}Cu-NMR study of single-layer high-T_c cuprate $Bi_{2.1}Sr_{1.9}CuO_6$

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Abstract

We have studied the ground state of the overdoped single-layered cuprate superconductor $Bi_{2.1}Sr_{1.9}CuO_{6+\delta}$ (T_c=8 K) by applying a strong magnetic field of 15.3 T to suppress superconductivity. In the normal state down to T=1.6 K induced by the field, ^{63}Cu nuclear spin-lattice relaxation rate ($1/T_1$) is found to obey a T_1T=const. relation, indicating that the ground state in the overdoped regime is a Fermi liquid state. Our result is at variance with a recent study by scanning tunneling microscopy (STM) that finds a pseudogap in a similar sample. The implication is discussed

Key words: pseudogap; high-T_c cuprate; $Bi_2Sr_2CuO_6$; NMR

1. Introduction

It has been realized that in some high transition-temperature (T_c) cuprate superconductors, the normal state above T_c deviates strongly from that described by the Landau's Fermi liquid theory. One of the experimental facts taken as evidence for such deviations is the opening of a pseudogap above T_c, a phenomenon of loss of density of states [1]. The pseudogap is pronounced at low doping level, in the so-called underdoped regime; its temperature, T^*, generally decreases as the carrier doping rate increases. However, its origin remains unresolved, neigher is it clear whether T^* finally merges into the T_c curve in the overdoped regime, or it has a distinct doping dependence from T_c. Since the topology of the phase diagram has great impact on the mechanism of the high-T_c superconductivity, it is important to clarify the doping dependence of the pseudogap. Unfortunately, the onset of superconductivity, typically at ∼100 K and the large upper critical field H_{c2} (∼ 100 T) prevents investigation of how the pseudogap evolves. The highest static field availabe to date (∼ 30 T) was only able to reduce T_c to its half value at most. [2,3] Even the pulsed magnetic field is not enough to suppress superconductivity completely [4]. The previous study found that the seeming pseudogap observed in the overdoped regime is due to Cooper-pair density fluctuations which suggests that a "real" pseudogap, *i.e.*, a spin gap, is absent in the overdoped regime [3], but it is desirable to directly access the ground state of the cuprates.

Here we address this issue by using single layered cuprate compounds $Bi_{2.1}Sr_{2-x}La_xCuO_{6+\delta}$ which have comparatively lower T_c and H_{c2}. We study the property of the ground state induced by the application of magnetic field of 15.3 T, by using nuclear magnetic resonance (NMR) technique. This system is suitable for such study for it can be tuned from the overdoped regime to the underdoped regime by replacing La for Sr [5,6]. In the field-induced normal state of $Bi_{2.1}Sr_{1.9}CuO_{6+\delta}$ (T_c=8 K) down to T=1.7 K, ^{63}Cu nuclear spin-lattice relaxation rate ($1/T_1$) is found to obey a T_1T=const. relation, indicating that the ground state in the overdoped regime is a Fermi liquid state.

2. Experimental Results and Discussion

Single crystals of $Bi_{2.1}Sr_{1.9-x}La_xCuO_{6+\delta}$ were grown by the travelling solvent floating zone (TSFZ)

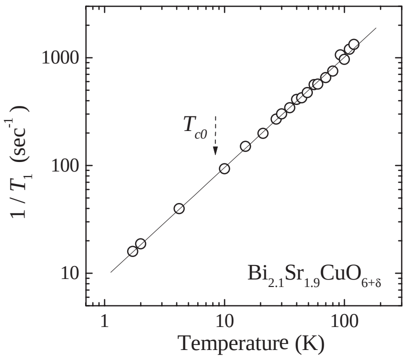

Fig. 1. Temperature dependence of the ^{63}Cu nuclear spin-lattice relaxation rate $1/T_1$

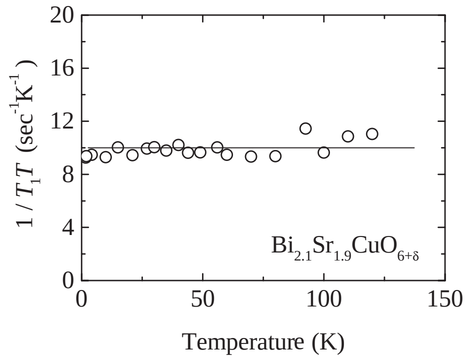

Fig. 2. Temperature dependence of $1/T_1T$

method with starting materials of Bi_2O_3, $SrCO_3$, La_2O_3 and CuO (Ref. [7]). Compositional measurement was performed by chemical analysis of Auger electron spectroscopy within an error of ±2 wt.%. The excess oxygen δ resides on the Bi_2O_2 block and is believed to be responsible for the carrier doping in the CuO_2 plane. The amount of δ of the present samples was estimated to be 0.36. The T_c of the overdoped $Bi_{2.1}Sr_{1.9}CuO_{6.36}$ without La-doping is found to be 8 K from measurements of the ac susceptibility and the resistivity. The maximal T_c=32 K was obtained for La concentration of x=0.4, which is in good agreement with that reported in Ref. [8]. H_{c2} for $Bi_{2.1}Sr_{1.9-x}La_xCuO_{6+\delta}$ was obtained by measuring the ac-susceptibility at 174.75 MHz using the same coil and the same set-up for the NMR measurements. Superconductivity is destroyed completely by a field of 15.25 T under which the NMR measurements were carried out. For NMR measurements, two or three platelets of single crystals with the dimensions of 15×5×1 mm^3 were aligned along a- and c-axes. For all measurements, the external field is applied along the c-axis.

Figure 1 shows the temperature dependence of $1/T_1$. Most remarkable is that $1/T_1$ is in proportion to T down to T=1.6 K where superconductivity is destroyed. In Fig. 2, $1/T_1T$ is plotted as a function of temperature.

In many high-T_c cuprates, in particular in the underdoped regime, $1/T_1T$ increases upon decreasing temperature but starts to decrease below a temperature T^* (above T_c), which is ascribed to be due to a pseudogap. This also happens in the optimally-doped sample with La concentration x=0.4 and T_c=32 K [9]. However, in the current overdoped sample with T_c=8 K, $1/T_1T$=constant relation holds, as expected for conventional metals. Namely, the pseudogap disappeared before the system enters a doping level corresponding to x=0. Our result is in disagreement with a recent STM report which found a pseudogap opening at T ~70 K in a sample free of La doping with a similar doping level and a similar T_c. [10]

Our result indicates that the ground state of the overdoped regime of the superconducting cuprates is the Landau Fermi liquid state. This is a remarkable result which indicates that there is a crossover in the electronic state of the cuprate superconductor as a function of doping. Since the pseudogap persists in the optimally doped sample, our results imply that the pseudogap terminates at some point slightly larger than the optmal doping. The present result will put a constraint on theoretical modeling of both the pseudogap and the mechanism of superconconductivity in high-T_c cuprates.

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