Zn-induced wipeout effect on Cu NQR spectra in $La_{2-x}Sr_xCu_{1-y}Zn_yO_4$

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Abstract

We report a systematic study of Zn-substitution effect on Cu NQR spectrum for high T_c superconductors $La_{2-x}Sr_xCu_{1-y}Zn_yO_4$ from carrier-underdoped to -overdoped regimes (polycrystalline samples, x =0.10, 0.15, and 0.20). We observed no appreciable wipeout effect for the overdoped samples, a gradual and partial wipeout effect below about 80 K for the optimally doped ones, and very abrupt and full wipeout effect below about 40 K for the underdoped ones. The wipeout effect indicates a highly enhanced spectral weight of Cu spin fluctuations at a low frequency. We associate the wipeout effect with a Zn-induced local magnetism far above 40 K and with a localization effect below 40 K.

Key words: nonmagnetic impurity Zn effect; nuclear quadrupole resonance; $La_{2-x}Sr_xCu_{1-y}Zn_yO_4$; wipeout effect

1. Introduction

Ultra slow spin fluctuation causes pair breaking effect and suppresses the superconducting transition temperature T_c of high-T_c cuprate superconductors [1,2]. The wipeout effect on Cu nuclear quadrupole resonance (NQR) spectrum, which suggests the existence of such a slow fluctuation, is observed in the deeply underdoped $La_{2-x}Sr_xCuO_4$ [3,4] and in the nonmagnetic impurity Zn-doped $YBa_2Cu_3O_7$ [5]. Thus, the wipeout effect on Cu NQR spectrum may play a key role in understanding the mechanism of suppression of T_c.

Here, we report Zn-substitution effect on Cu NQR spectrum in $La_{2-x}Sr_xCu_{1-y}Zn_yO_4$ from carrier-underdoped to -overdoped regimes. For Sr x=0.1, T_c is ∼30, 13, <4.2 K for Zn y=0, 0.01, 0.02,respectively. For Sr x=0.15, T_c is ∼38, 13 K for Zn x=0, 0.02,respectively. For Sr x=0.2, T_c is ∼30, 13, <4.2 K for y=0, 0.03, 0.06,respectively. We observed no appreciable wipeout effect for Sr-overdoped samples, a partial wipeout effect below about 80 K for the optimally doped ones, and full wipeout effect below about 40 K for Sr-underdoped ones.

Zero field Cu NQR measurements with a pulsed spin-echo technique have been carried out for powder samples, which were synthesized by a solid state reaction method. The transverse relaxation curve of the spin-echo was measured as a function of time τ between the first and the refocusing pulses and was analyzed by a function of $E(\tau) = E(0)\exp[-2\tau/T_{2L} - 0.5(2\tau/T_{2G})^2]$ with fitting parameters $E(0)$, T_{2L} and T_{2G}. The frequency integrated $E(0)$ is the observed intensity of NQR spectrum $I(x, y)$ (after T_2 correction). The details will be published elsewhere [6]

2. Experimental results and discussion

Figure 1 shows the T dependence of Cu NQR spectrum of Zn-free and of Zn-doped samples with

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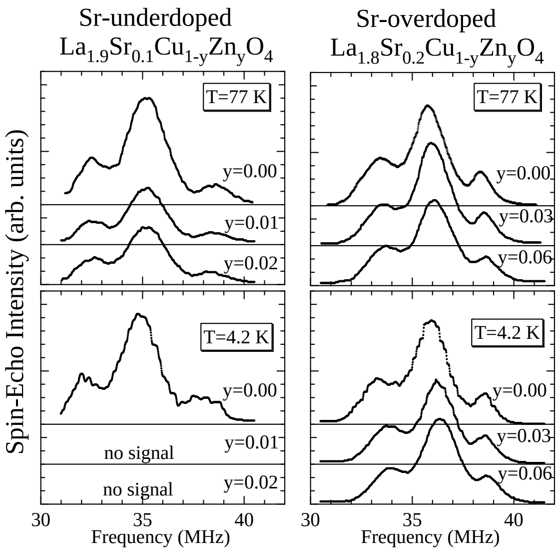

Fig. 1. T dependence of Cu NQR spectra in Zn-doped LSCO (x=0.1; T_c ∼30, 13, <4.2 K for y=0, 0.01, 0.02) (left) and (x=0.2; T_c ∼30, 13, <4.2 K for y=0, 0.03, 0.06) (right).

Sr-underdoped x=0.10 (left) and -overdoped x=0.20 (right). Obviously, the NQR signal diminishes at 4.2 K for Sr-underdoped samples with Zn doping, whereas it is still observable for Sr-overdoped ones with Zn doping.

Figure 2(a) shows the T dependence of the relaxation rate $1/T_{2L}(\gg 1/T_{2G}$ below about 100 K). No precursory effect, e.g. divergence of $1/T_{2L}$, is observed near the onset temperature of the wipeout effect in the Zn-doped, Sr-underdoped sample (x, y)=(0.1, 0.02). Thus, the observed signal does not indicate any slowing down effect of the observed spin fluctuation. A toy model of dynamical spin susceptibility is shown in Fig. 2(b) to account for such a sudden wipeout effect [6].

Figure 3 shows Zn-doping effect on the in-plane resistivity (upper panel) [7] and the relative intensity of the integrated Cu NQR spectrum $I(x,y)/I(x,y=0)$ (lower panel). Since the resistivity is metallic at 300 K, the high-T wipeout effect, i.e. $I(x,y)/I(x,y=0) < (1-y)$ at 300 K is associated with pure magnetic effect due to the local field fluctuation of Zn-induced local moments [8,9]. At lower temperatures the resistivity of Sr-underdoped sample is semiconducting, so that the low-T wipeout effect is associated with electron localization effect. Thus, we associate the wipeout effect with Zn-induced local magnetism far above 40 K and with localization effect below 40 K.

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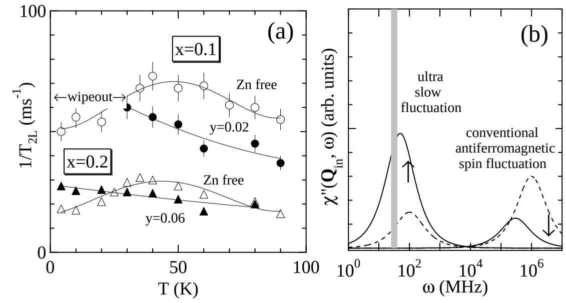

Fig. 2. (a) T dependence of the transverse relaxation rate $1/T_{2L}$ for Zn-free (open symbols) and Zn-doped samples (closed symbols). The solid curves are guides for the eye. (b) A schematic toy model of dynamical spin susceptibility to account for the wipeout effect without any precursory divergence in $1/T_{2L}$ nor in the Cu NQR linewidth. Ultra slow spin fluctuation must appear to diminish suddenly the Cu NQR signal. The arrows indicate the direction of change when cooling down below the onset temperature of the wipeouteffect. The shaded area indicates an NQR frequency window around 35MHz.

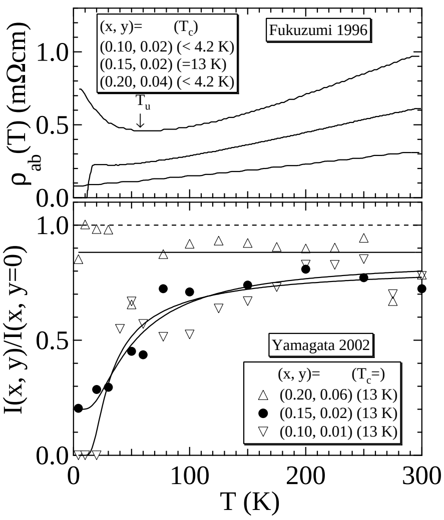

Fig. 3. Zn-doping effect on the in-plane resistivity for single crystals, reproduced from Ref. [7] (upper). The T dependence of the ratio of the integrated intensity $I(x,y)$ of Cu NQR spectrum of Zn-doped sample to Zn-free one (lower). Th solid curves are guides for the eye.

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