Ni impurity spin fluctuations in $YBa_2(Cu_{1-x}Ni_x)_4O_8$ and $YBa_2(Cu_{1-x}Ni_x)_3O_{6.92}$ via Cu NQR

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Abstract

We report a Cu NQR study of Ni impurity spin fluctuations in high T_c cuprate superconductors, $YBa_2(Cu_{1-x}Ni_x)_4O_8$ and $YBa_2(Cu_{1-x}Ni_x)_3O_{6.92}$, from measurement of Ni-induced Cu nuclear spin-lattice relaxation times. We found that the temperature dependence of the Ni spin correlation time is different from that of Kondo impurity in a conventional metal, e.g. Mn or Fe in Cu.

Key words: magnetic impurity Ni effect; nuclear quadrupole resonance; $YBa_2Cu_4O_8$; $YBa_2Cu_3O_7$

1. Introduction

Magnetic impurity Ni can be a probe to detect strong correlation effect on high-T_c cuprate superconductors, because the superconducting transition temperature T_c is suppressed but the host Cu electron spin dynamics on the CuO_2 plane is robust to Ni doping [1,2]. Here, we discuss the temperature (T) dependence of Ni spin fluctuations in carrier-underdoped $YBa_2(Cu_{1-x}Ni_x)_4O_8$ [1] and in optimally doped $YBa_2(Cu_{1-x}Ni_x)_3O_{6.92}$ [3] through Ni-induced Cu nuclear spin-lattice relaxation time τ_1. The Ni impurity density x is estimated by inductively coupled plasma atomic emission spectroscopy.

The Ni-induced nuclear spin relaxation rate $1/\tau_1$ is expressed by

$$1/\tau_1 \propto c^2 T \frac{\partial B_S(x)}{\partial x} \frac{\Gamma(T)}{\omega_n^2 + \Gamma(T)^2}, \qquad (1)$$

where the number density of impurity c, $x = g\mu_B SH/k_B T$, the Brillouin function $B_S(x)$, an NQR frequency ω_n, and the Ni spin fluctuation frequency $\Gamma(T)$ (the notations of g, μ_B, S, H, and k_B conform to [4]). At moderately high temperatures ($\omega_n \ll \Gamma(T)$) and in the zero-field limit, one obtains $\Gamma(T) \propto \tau_1 c^2$. Thus, the Ni impurity relaxation rate $\Gamma(T)$ is proportional to the Ni-induced Cu nuclear relaxation time τ_1.

2. Ni(1)

Figure 1(a) shows Ni-doping effect on the ^{63}Cu(1) nuclear spin-lattice relaxation curve in $YBa_2(Cu_{1-x}Ni_x)_4O_8$ at T=90 K. Obviously, the ^{63}Cu(1) nuclear magnetization $M(t)$ relaxes more quickly with Ni doping.The recovery curve of ^{63}Cu(1) is changed from a single exponential curve in pure $YBa_2Cu_4O_8$ to nonexponential ones with Ni doping.

Figure 1(b) shows T dependence of the Ni-induced ^{63}Cu(1) nuclear spin-lattice relaxation rate $1/\tau_1$ estimated in the same way as in Ref. [1]. The magnitude of $1/\tau_1$ increases with Ni. Thus, a part of Ni impurities

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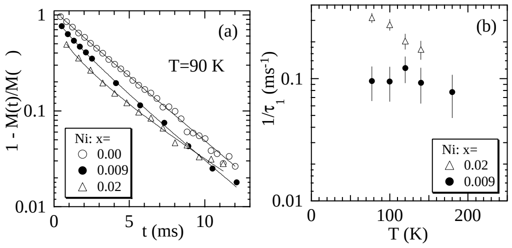

Fig. 1. (a) Ni-doping effect on the recovery curve of the chain-site ^{63}Cu(1) nuclear spin-echo intensity $M(t)$ (t is a time after an inversion pulse) in $YBa_2(Cu_{1-x}Ni_x)_4O_8$ at T=90 K. The solid curves are the least-squares fitting results using a stretched exponential function in [1]. (b) T dependence of the estimated Ni(1)-induced ^{63}Cu(1) nuclear relaxation rate $1/\tau_1$.

is substituted for the chain site Cu(1).

3. Ni(2)

Figure 2(a) shows T dependence of $\tau_1 c^2$ of Ni(2)-induced ^{63}Cu(2) nuclear spin-lattice relaxation time in $YBa_2(Cu_{1-x}Ni_x)_4O_8$ with x=0.03 (T_c=15 K) and 0.042 (<4.2 K) [1]. Here, we assume equal occupation of Ni at Cu(1) and Cu(2) sites, i.e. c=x. The T dependent $\tau_1 c^2$ lies on nearly the same curve. A higher power law of T more than Korringa law is observed. Figure 2(b) shows $\tau_1 c^2$ of ^{63}Cu(2) as a function of T in $YBa_2(Cu_{1-x}Ni_x)_3O_{6.92}$ with x=0.033, which also rapidly increases with T.

In Fig. 2(c), for comparison, the T dependence of magnetic relaxation rate of Kondo impurity in *Cu*Mn and *Cu*Fe is reproduced from Ref. [5]. At high temperatures, Korringa relaxation is predominant, whereas at low temperatures Kondo screening effect causes $\sqrt{T}$ and a constant behavior. Thus, the T dependence of Ni relaxation rate Γ in the high-T_c cuprate superconductors is different from that of magnetic impurity in a conventional metal. The T dependence of Ni impurity relaxation rate Γ is novel. For a paramagnetic impurity in a conventional metal, the T dependence of the impurity relaxation results from an impurity spin-lattice relaxation. Non-Korringa T dependence of the nuclear spin-lattice relaxation due to antiferromagnetic correlation [6,7] and underscreening Kondo effect [8] may account for such a novel T dependence of Γ.

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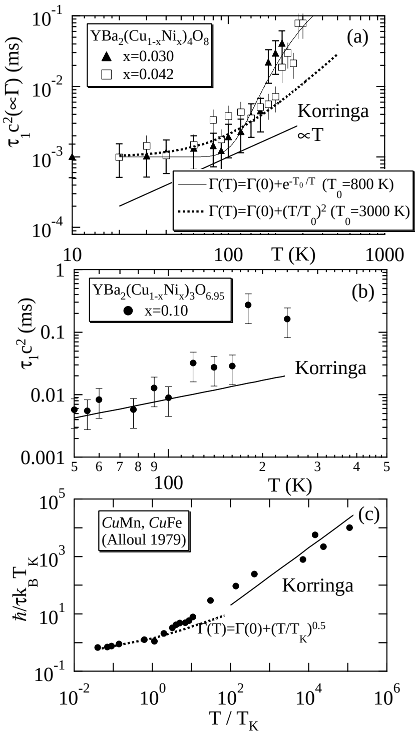

Fig. 2. (a) T dependence of $\tau_1 c^2$ of Ni-induced Cu(2) nuclear spin-lattice relaxation time in $YBa_2(Cu_{1-x}Ni_x)_4O_8$ [1]. Non Korringa (solid line) nor $\sqrt{T}$ behavior is seen. Rather, a higher power law of T is seen, e.g. T^2 (dashed curve). The solid curve is an activation type function. (b) T dependence of $\tau_1 c^2$ of Ni-induced Cu(2) nuclear spin-lattice relaxation time in $YBa_2(Cu_{1-x}Ni_x)_3O_{6.92}$ (T_c∼70 K) with c=x=0.033 [3]. (c) T dependence of the magnetic relaxation rate of Kondo impurity in *Cu*Mn and *Cu*Fe, reproduced from Ref. [5]. T_K is the Kondo temperature. One should note $1/\tau \equiv 2\pi\Gamma$.

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