Magnetic excitations in the spin-glass phase of $La_{2-x}Sr_xCuO_4$

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Abstract

Magnetic excitations of $La_{1.95}Sr_{0.05}CuO_4$ were investigated using pulsed neutron inelastic scattering over a wide range of energy up to 300 meV. In contrast to the optimally doped superconductor the dynamical magnetic susceptibility $\chi"(\omega)$ around (π,π) in the spin-glass phase monotonically decreases with increasing ω and nearly saturates beyond $\sim$ 50meV. We found that the energy dependence of the q-position in the latter energy region is ascribed to a two-dimensional spin-wave dispersion relation with the nearest neighbor interaction J of 108±6 meV, which is smaller by $\sim$ 20% than that of La_2CuO_4.

Key words: $La_{2-x}Sr_xCuO_4$; spin excitation; neutron scattering

1. Introduction

It is widely believed that magnetism is relevant for the superconductivity in the high-T_c cuprate. In the hole-doped $La_{2-x}Sr_xCuO_4$ (LSCO), systematic studies on the low energy spin excitation have been performed by neutron scattering in a wide hole concentration range, and the results of these studies clearly demonstrate a close relation of the low-energy spin excitations with the superconducting transition [1].

On the other hand, the high-energy neutron scattering studies have been reported only for the non-doped and optimally doped LSCO, and these studies revealed distinct feature in the energy spectrum between the nondoped and optimally doped LSCO [2]-[5]. Therefore, particularly, information on the spin excitations for the lightly doped or underdoped LSCO is very important.

Then we started a high-energy neutron scattering study on the spin excitations of $La_{1.95}Sr_{0.05}CuO_4$ which is in the spin-glass phase near the superconducting phase boundary.

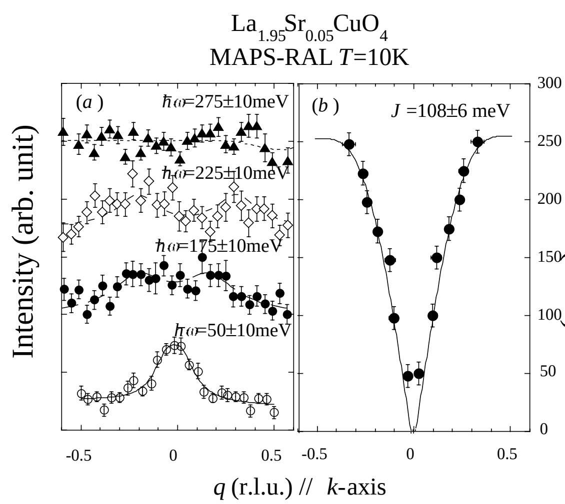

Fig. 1. (a):Peak profiles around (π,π) at various energies. (b):The dispersion relation of $La_{1.95}Sr_{0.05}CuO_4$ in the energy region larger than 50 meV.

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2. Experimental

Single crystals of $La_{1.95}Sr_{0.05}CuO_4$ were grown by a Traveling-Solvent-Floating-Zone (TSFZ) method. Total volume of the assembled crystals is about 10 cc. Pulsed neutron scattering experiments were performed on the chopper spectrometer MAPS newly installed in ISIS Facility at Rutherford Appleton Laboratory. The crystals were aligned with the c-axis parallel to the incident beam. Measurements were performed using incident neutron energies E_i= 21.5, 30, 50, 100, 200, and 400 meV. Most of the measurements were performed at T=10 K and for the measurement with E_i= 50 meV we studied temperature dependence up to T= 200 K.

3. Results

Fig. 1(a) shows peak profiles taken by a scan through the position (π,π) at various energies between 50 and 275 meV. The peak height is arbitral. It is shown that the peak split enlarges as the energy increases. The relation between the width of the peak split and the energy-transfer is shown in Fig. 1(b). This relation is well ascribed to the 2D antiferromagnetic dispersion relation. From the least-squares fitting of the data to the relation we evaluated a nearest neighbor magnetic interaction J=108±6 meV which is smaller by ∼ 20% than that reported for non-doped LSCO [2]. However, for the results in the lower energy region below around 50 meV, it is very difficult to apply the abovementioned dispersion relation

In the middle panel of Fig. 2 (a) we show the energy spectrum of dynamical magnetic susceptibility $\chi"(\omega)$ of $La_{1.95}Sr_{0.05}CuO_4$ integrated in q around (π,π). The $\chi"(\omega)$ in the spin-glass phase decreases monotonically up to around 50 meV and gradually saturates at higher energy region. Such energy dependence of $\chi"(\omega)$ is clearly distinct from both data of nondoped and optimally doped samples as shown in the top and bottom panels of Fig. 2 (a), respectively. The upper panel of Fig. 2 (b) shows the in-plane peak-width κ of $La_{1.95}Sr_{0.05}CuO_4$ as a function of $\sqrt{T^2 + (\hbar\omega/k_B)^2}$. We refer the result of κ of $La_{1.86}Sr_{0.14}CuO_4$ in the lower panel [6].

4. Discussion

The present high-energy pulsed neutron experiment newly revealed two features in the magnetic excitations of $La_{1.95}Sr_{0.05}CuO_4$. One is that the inelastic response at high energy region beyond around 50 meV is similar to that of the nondoped antiferromagnetic insulator and the magnetic interaction evaluated by using a 2D spin-wave dispersion relation is reduced by about 20% upon hole doping with x=0.05. Second is that the $\chi"(\omega)$ below around 50 meV increases with decreasing the energy. Also the $\chi"(\omega)$ in this energy region show substantial temperature dependence. At present we have no clear explanation on the enhancement of $\chi"(\omega)$ in the low energy region. However, charge stripe model is one of possible scenarios where two distinct types of magnetic excitations naturally coexist, one originates from the nondoped antiferromagnetic region with the large energy-scale and the other from the hole doped region with the small energy-scale.

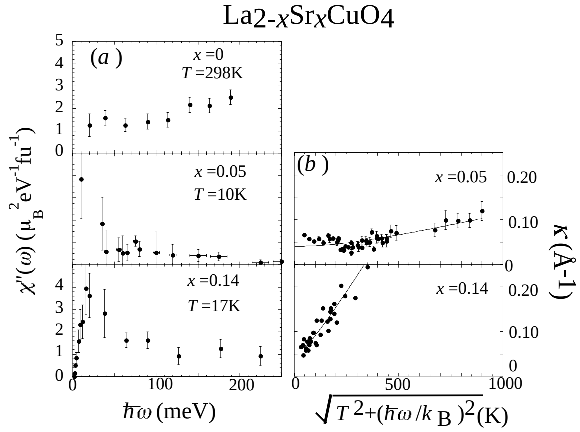

Fig. 2. (a): Energy spectra of $\chi"(\omega)$ of $La_{2-x}Sr_xCuO_4$ nondoped LSCO (top), $La_{1.95}Sr_{0.05}CuO_4$ (middle), and $La_{1.86}Sr_{0.14}CuO_4$ (bottom). Note that $\chi"(\omega)$ of $La_{1.95}Sr_{0.05}CuO_4$ is arbitral, and we cannot compare the absolute value of $\chi"(\omega)$.(b): Relation between the Lorentzian peak-width κ and $\sqrt{T^2 + (\hbar\omega/k_B)^2}$ for $La_{1.86}Sr_{0.14}CuO_4$(lower) [6], and $La_{1.95}Sr_{0.05}CuO_4$(upper).

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