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Report:

We investigated the spin excitations in electron doped cuprate $La_{2-x}Ce_xCuO_4$ (LCCO), a superconductor in the T′ structural phase by resonant inelastic x-ray scattering (RIXS) measurement at the Cu L_3 edge. We have performed a doping dependence level from x=0.07 to x=0.185 by using doping-concentration-gradient (combi) films.

The primary goal of our experiment is to probe the putative spin polaron quasiparticle, and the second is to measure the evolution of paramagnon upon doping. Thus polarization and geometry condition were carefully chosen during the experiment to select charge and spin channels. In our experiment, as shown in Fig.1(a), the RIXS data was collected with the out-going angle β fixed at 5° and the incident angle $\alpha = 125°, 93°,\ 62\ °$ corresponding to $(0.9\pi, 0)$, $(0.6\pi, 0)$, $(0.3\pi, 0)$ in both parallel (π) and perpendicular (σ) polarization. Thus, the major different between our measurement and previous studies is that we fix the outgoing angle rather than keep the scattering angle 2θ, by which we can separate the spin-flip component and spin-non-flip component better.

As shown in Fig.1(d), our geometry and polarization selection worked well so that the profiles of spectra are dramatically different between LH and LV, where the paramagnon and multimagnon dominates, respectively. Total RIXS data is shown in Fig. 1(b)-(c),€-(h). Evolution of paramagnon (multimagnon) is obvious and systematic in LH (LV) channel for all Q points. For RIXS spectrum at $(0.3\pi, 0)$ taken in LV, the plasmon emerges. The expected spin-polaron excitation is hard to identify, and we will focus on paramagnon which dominates in the LH channel in the following analysis.

From the data, we extract the pure paramagnon component more reliably than previous studies. The paramagnon component is fitted by anti-Lorenz function and the parameters ω_q (the propagating frequency), $\omega_{\max}$ (the maximum of the peak) and Γ_q (damping rate) are shown in Fig. 2 (b)-(d), (f)-(h). It is noted that $\omega_{\max}$ is different from ω_q and the latter represents the energy of the excitation.

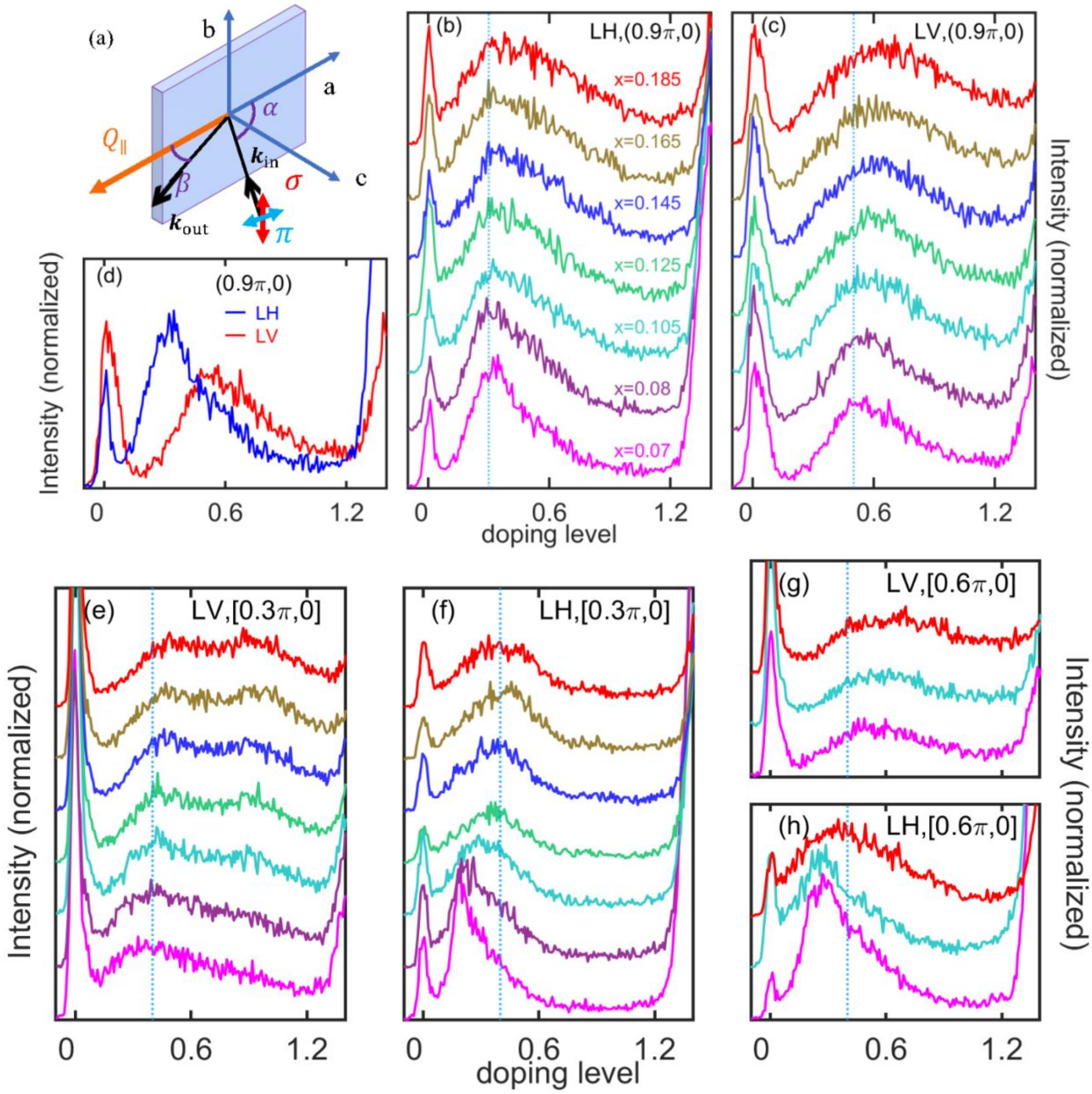

Fig1.: Experimental geometry is shown in (a) and total RIXS spectra taken at different momentum points and polarizations are shown in (b)-(h).

The damping rate Γ_q shown in Fig. 2(a) and (b) relates to the lifetime of the spin excitation, which increases almost linearly across the total doping range, in agreement with the earlier study. Surprisingly, Fig.2 (c) and (g) shows that the energy of paramagnon hardly shifts upon doping from x=0.07 to x=0.147, in contrast to the previous report where dramatic hardening is observed [1-3]. And Fig.2 (b) and (f) shows that the maximum of the peak which couples to Γ_q shift about 40 meV. This is our key observation in our experiment, suggesting that the hardening measured previously is mainly due to the mix of paramagnon and multimagnon. It is the fact that paramagnon merges into multimagnon upon doping makes the observation of hardening, rather than the real energy shift of the original magnon mode in this electron doped cuprate.

For comparison, we also did a simple fitting without LH vs. LV channel cross-checking, the same as what was done in previous studies. Results from such treatment are shown in Fig. 2(a),(e). The center shifts about 100 meV, qualitatively consistent with the earlier report [1-3]. This contrast indicate that the mix of the paramagnon and multimagnon could be really misleading.

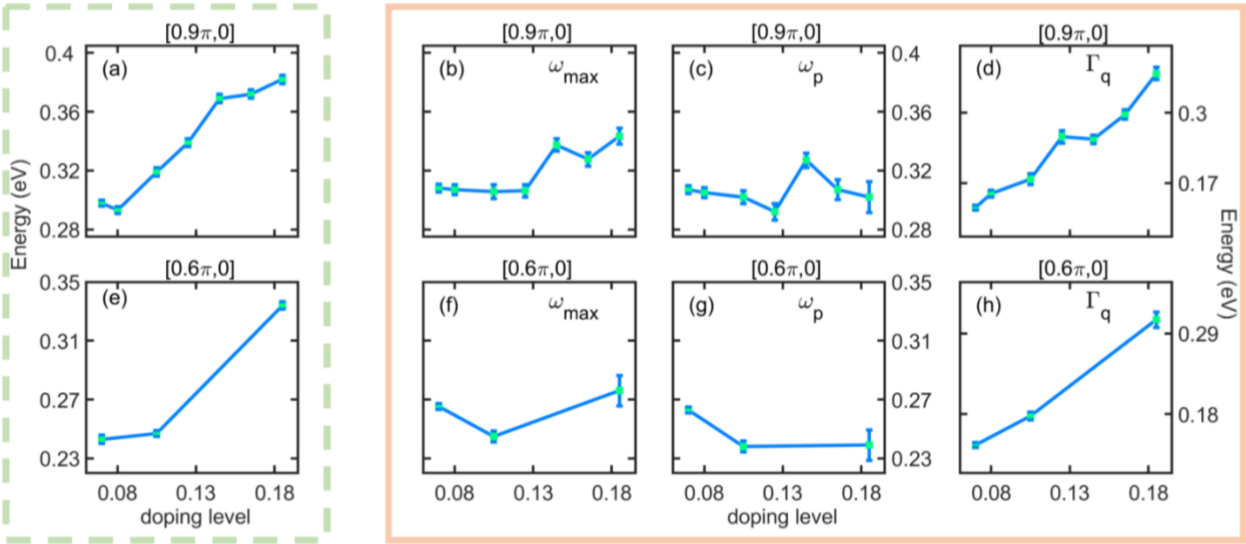

FIG.2: Fitting parameter. The fitting peak center without data treatment are shown in (a) and (e). ω_q(the propagating frequency), ω_{max}(the maximum of the peak) and Γ_{q} (damping rate) obtained from fitting after data treatment are shown in (b)-(d), (f)-(h).

In summary, we investigated the doping evolution of low-energy spin excitation by Cu L_3 edge RIXS measurements on the electron-doped cuprate LCCO. Special geometry and polarization conditions are selected to get two sets of data corresponding to paramagnon-dominating and multimagnon-dominating channels. Further fitting process is adopted to separate the paramagnon and multimagnon completely. After the process, we find that the hardening of paramagnon component is insignificant when doping changes from x=0.07 to x=0.18, in contrast to the previous report.

[1] W.S. Lee *et al*., Asymmetry of collective excitations in electron- and hole-doped cuprate superconductor, Nature Physics 10, 883 (2014).
[2] K. Ishii *et al*., high-energy spin and charge excitations in electron-doped copper oxide superconductors, Nature Communications 5, 3714 (2014).
[3] G. Dellea *et al*. , Spin and charge excitations in artificial hole- and electron-doped infinite layer cuprate superconductors, Phys. Rev. B 96, 115117 (2017).