Hole-doping effect on the magnetic correlation in the undoped (Ce-free) superconductor T'-$La_{1.8}Eu_{0.2}CuO_4$ studied by μSR

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The electronic state of the high-T_c cuprate Ln_2CuO_4 (Ln: lanthanide elements) with the Nd_2CuO_4-type (so-called T'-type) structure has attracted great interest, because adequately oxygen-reduced samples of T'-Ln_2CuO_4 have been reported to show superconductivity without electron-carrier doping.[1,2] Regarding the electron-doped (Ce-doped) high-T_c superconductors T'-$Ln_{2-x}Ce_xCuO_4$, it has been believed since their discovery that superconductivity appears at $x > 0.14$, while an antiferromagnetic (AF) long-range order is developed in oxygen-reduced samples with $x < 0.14$.[3] Hence, the reason why superconductivity emerges without carrier doping in the undoped (Ce-free) superconductor T'-Ln_2CuO_4 has yet to be clarified.

Two reasons have been suggested for the electronic state of the undoped superconductivity in T'-Ln_2CuO_4. One is a strongly correlated metallic state without a charge-transfer (CT) gap between the upper Hubbard band (UHB) of Cu3$d_{x^2-y^2}$ and the O2p band.[4] In this case, the half-filled Fermi surface with a good nesting condition is formed from UHB of Cu3$d_{x^2-y^2}$ and the O2p band, indicating a strong AF correlation. Therefore, the AF correlation is expected to be weakened by electron- and hole-carrier doping, leading to a bad nesting condition. The other is a strongly correlated metallic state with a finite CT gap and the UHB of Cu3$d_{x^2-y^2}$ having been doped with electron carriers due to oxygen defects induced by reduction annealing.[5] That is, superconductivity appears due to electron-carrier doping of the Mott insulator. In this case, the AF correlation is expected to arise due to hole doping corresponding to a decrease in the electron-carrier concentration. Accordingly, an investigation of changes in the AF correlation caused by hole doping of the undoped superconductor T'-Ln_2CuO_4 is expected to reveal why superconductivity emerges without carrier doping.

We performed muon spin relaxation (μSR) experiments on the polycrystalline samples of T'-$La_{1.8-x}Eu_{0.2}Sr_xCuO_4$ ($x = 0.01, 0.02, 0.03$), whereby the undoped (Ce-free) superconductor T'-$La_{1.8}Eu_{0.2}CuO_4$ was doped with hole carriers.

It is found that the μSR spectra at high temperatures above 100 K show a Gaussian-type slow depolarization of the muon spins and that the μSR spectra change to Lorentzian-type fast depolarization gradually with decreasing temperature for all x. The depolarization at low temperatures is the slowest for $x = 0.03$ in all samples, indicating that the AF correlation becomes weak at $x = 0.03$. The AF transition temperature, T_N, is estimated from the analysis of the μSR spectra and is plotted together with T_N of the electron-doped and undoped superconductors T'-$La_{1.8}Eu_{0.2}CuO_{4-y}F_y$[6] in Fig. 1. It is found that T_N has a maximum for $x = 0.01$ and it decreases by both hole and electron doping. These results are incompatible with a finite CT-gap model in which T_N increases with Sr substitution of the AF Mott insulator. Therefore, the present results suggest that the electronic state of the undoped superconductor T'-$La_{1.8}Eu_{0.2}CuO_4$ is a strongly correlated metallic state without a CT gap.[4]

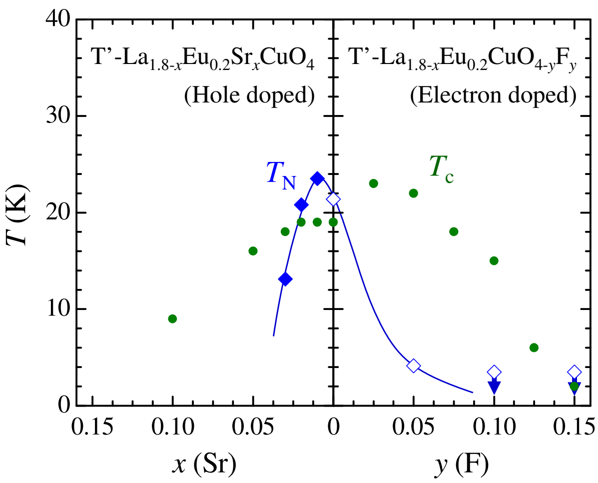

Fig. 1. Doped-carrier concentration dependence of the magnetic transition temperature, T_N, of T'-$La_{1.8-x}Eu_{0.2}Sr_xCuO_4$ and T'-$La_{1.8}Eu_{0.2}CuO_{4-y}F_y$.[6] Green solid circles indicate the critical temperature, T_c, of T'-$La_{1.8-x}Eu_{0.2}Sr_xCuO_4$[2] and T'-$La_{1.8}Eu_{0.2}CuO_{4-y}F_y$.[7] Solid line is guide for the eyes. Arrows indicate that samples are not antiferromagnetic above ~3.8 K.

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References

1) O. Matsumoto *et al.*, Physica C **469**, 924 (2009).
2) T. Takamatsu *et al.*, Phys. Procedia **58**, 46 (2014).
3) Y. Tokura *et al.*, Nature **337**, 345 (1989).
4) T. Adachi *et al.*, J. Phys. Soc. Jpn. **82**, 063713 (2013).
5) M. Horio *et al.*, Nat. Commun. **7**, 10567 (2016).
6) T. Kawamata *et al.* (unpublished).
7) T. Sunohara *et al.*, J. Phys. Soc. Jpn. **89**, 014701 (2020).