Magnetism and superconductivity in underdoped region of T*-type $La_{1-x/2}Eu_{1-x/2}Sr_xCuO_{4-y}F_y$

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In the study of high-transition-temperature cuprates, the doping evolution of magnetism and its relationship with superconductivity are important issues. It had been considered that the superconductivity is induced by carrier doping into Mott insulators.[1)] However, the appearance of superconductivity in RE_2CuO_4 (RE = rare earth) without effective carrier doping (undoped superconductivity) was clarified by improving material synthesis and annealing techniques.[2,3)] After the discovery of undoped superconductivity, the broad superconducting (SC) phase was reported.[4)]

Recently, we succeeded in synthesizing T*-type structured $La_{1-x/2}Eu_{1-x/2}Sr_xCuO_4$ (LESCO) in which the oxygen coordination around a copper ion is five and reported the magnetic and SC properties as functions of Sr concentration.[5,6)] Our muon spin rotation/relaxation (μSR) measurement of LESCO revealed the presence of a spin-glass state and the absence of static magnetism in the as-sintered non-SC and high-pressure oxidated SC samples, respectively. Therefore, the short-range magnetic order disappears with the emergence of superconductivity, suggesting competition between the two states. However, as it is challenging to synthesize a single-phase sample of LESCO with a smaller x, the electronic state of the underdoped (UD) region of T*-type cuprates has not been investigated. Thus, we newly synthesized $La_{1-x/2}Eu_{1-x/2}Sr_xCuO_{4-y}F_y$ (LESCOF), in which the hole concentration can be reduced by increasing y while keeping the single-phase T*-type structure. The evidence of low carrier density in both as-sintered and oxidation-annealed LESCO was reported by x-ray absorption spectroscopy measurement,[6)] and LESCO with $x \lesssim 0.23$ corresponds to UD $La_{2-x}Sr_xCuO_4$. Therefore, LESCOF with $x = 0.18$ is expected to be located in a more UD region. The magnetism in UD LESCOF was studied by μSR measurements at RIKEN-RAL.

Figure 1(a) shows the temperature dependence of the zero-field μSR time spectra of as-sintered LESCOF with $x = 0.18$ and $y = 0.14$. Exponential-type spectra are observed below ~80 K, and muon spin precession was observed at the lowest temperature of 5.1 K. The appearance of precession suggests the emergence of long-range magnetic order. Furthermore, the temperature at which the spectra change from Gaussian-type to exponential is higher than that in the pristine

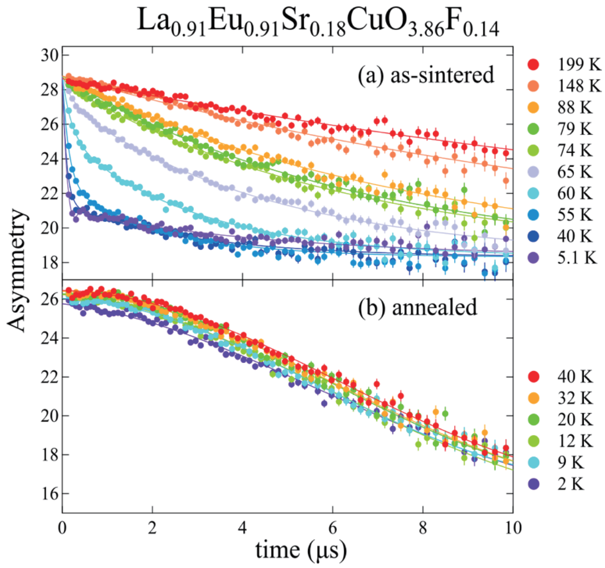

Fig. 1. Zero-field μSR time spectra of (a) as-sintered and (b) oxidation-annealed $La_{1-x/2}Eu_{1-x/2}Sr_xCuO_{4-y}F_y$ with $x = 0.18$ and $y = 0.14$.

LESCOF with $x = 0.18$,[4)] indicating the development of static magnetism upon underdoping. On the other hand, the oxidation-annealed SC sample shows no evidence of magnetic order down to 2 K (Fig. 1(b)).

Two characteristic features of magnetism were clarified in the present study. Firstly, a long-range magnetic ordered state exists in the lightly doped sample of as-sintered T*-type LESCOF. Combined with previously reported results,[4)] the short-range spin-glass state is replaced by the long-range state upon underdoping, as is the case with other cuprates. Secondly, such an ordered state disappears with annealing in connection with the emergence of superconductivity. Therefore, our results suggest that strong Cu-spin correlations cause the superconductivity in T*-type LESCO, and that the spin fluctuations play an essential role in the mechanism of superconductivity in the lightly hole-doped region.

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References

1) N. P. Armitage *et al.*, Rev. Mod. Phys. **82**, 2421 (2010).
2) A. Tsukada *et al.*, Solid State Commun. **133**, 427 (2005).
3) T. Takamatsu *et al.*, Appl. Phys. Express **5**, 073101 (2012).
4) O. Matsumoto *et al.*, Physica C **469**, 924 (2009).
5) S. Asano *et al.*, J. Phys. Soc. Jpn. **88**, 084709 (2019).
6) S. Asano *et al.*, J. Phys. Soc. Jpn. **89**, 075002 (2020).