μSR study of the Cu-spin correlation in the electron-underdoped $Pr_{1.3-x}La_{0.7}Ce_xCuO_{4+\delta}$ ($x = 0.05$) single crystals

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It has widely been believed in electron-doped high-T_c cuprates with the so-called T'-structure that an antiferromagnetic (AF) order is formed in a parent compound and underdoped samples. Formerly, however, it has been reported that the superconductivity appears even in the parent compound and underdoped samples through the appropriate reduction of excess oxygen from as-grown thin films[1)] and polycrystals,[2)] resulting in a completely different phase diagram from that formerly obtained. These suggest that the superconductivity in the electron-doped cuprates cannot be understood in terms of carrier doping into Mott insulators as in the case of the hole-doped cuprates. Moreover, a raising question is whether or not the Cu-spin correlation is developed in superconducting (SC) samples.

Recently, through improved reduction annealing, we have prepared SC single crystals of the underdoped $Pr_{1.3-x}La_{0.7}Ce_xCuO_{4+\delta}$ (PLCCO) with $x = 0.05 - 0.10$ whose ground states had been believed to be AF.[3,4)] Our recent zero-field (ZF) μSR measurements of PLCCO with $x = 0.10$[4,5)] have revealed that, through the reduction annealing, a long-range AF order changes to a short-range one coexisting with the superconductivity. Moreover, it has been found that the further reduction brings about the destruction of the short-range AF order and the increase in the SC transition temperature T_c. However, in samples with high T_c values, the Cu-spin correlation has been found to be developed at low temperatures, suggesting the intimate relation between the developed Cu-spin correlation and superconductivity.

In order to investigate the doping dependence of the Cu-spin correlation, we have performed ZF-μSR measurements of lightly electron-doped PLCCO with $x = 0.05$ using a MiniCryo at RIKEN-RAL.

For the as-grown sample of $x = 0.05$, it has been found that a long-range AF order is formed below the Neel temperature $T_N \sim 250$ K and T_N decreases down to ~ 110 K for the moderately reduced sample. Figure 1 shows ZF-μSR time spectra of the further reduced sample of PLCCO ($x = 0.05$) with $T_c \sim 27$ K. It is found that the spectrum at 200 K shows slow depolarization of muon spins due to nuclear dipole fields at the muon site. With decreasing temperature, the depolarization of muon spins becomes fast gradually and the muon spin precession is observed below ~ 100 K,

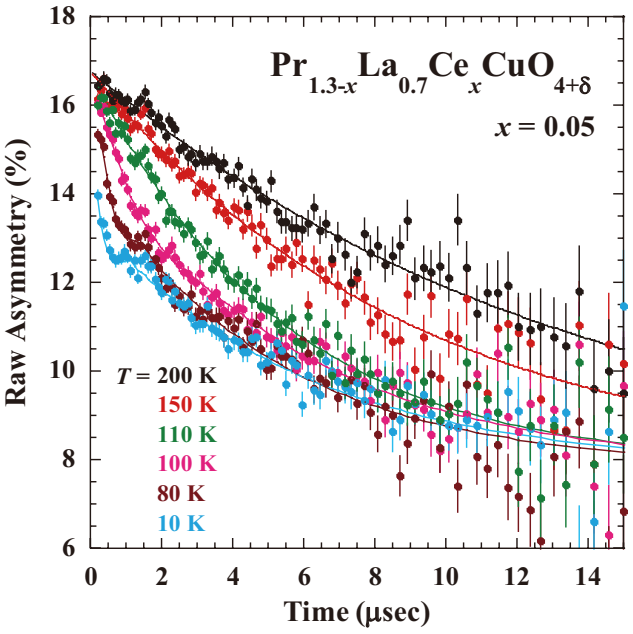

Fig. 1. Zero-field μSR time spectra of the further reduced $Pr_{1.3-x}La_{0.7}Ce_xCuO_{4+\delta}$ ($x = 0.05$) with $T_c \sim 27$ K.

indicating the formation of a long-range AF order. At the lowest temperature of 10 K, however, it is found that the slow depolarization is still observed in a long-time region and the amplitude of the muon-spin precession is small, suggesting that the long-range AF ordered region is not 100% in the further reduced sample but coexists with the slowly fluctuating region of Cu spins. From the analysis of the spectra, it has been estimated that the volume fraction of a magnetically ordered region is $\sim 25\%$ and the slowly fluctuating region exhibiting the superconductivity is $\sim 75\%$. These results suggest that the long-range AF order and superconductivity with a high T_c value coexist with each other in the further reduced sample of PLCCO with $x = 0.05$. In the ideally reduced sample of $x = 0.05$, the AF order would disappear and the superconductivity would appear homogeneously under the development of the Cu-spin correlation, which is probably the characteristic of the electron-doped high-T_c cuprates.

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