μSR study of Fe-substitution effects on ferromagnetic fluctuations in nonsuperconducting heavily overdoped Bi-2201 cuprates

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Hole-doped high-T_c cuprate superconductivity arises by hole doping into a parent antiferromagnetic (AF) Mott insulator, suggesting that superconductivity is mediated by AF spin fluctuations in the underdoped and optimally doped regimes. For the overdoped regime, where superconductivity weakens and eventually disappears with hole doping, it has been theoretically suggested that a ferromagnetic (FM) phase exists in the nonsuperconducting heavily overdoped regime and competes with superconductivity.[1] In fact, zero-field (ZF) μSR and transport measurements have revealed an FM order/FM fluctuations in nonsuperconducting heavily overdoped $La_{2-x}Sr_xCuO_4$[2] and Bi-2201.[3] To understand the details of the FM fluctuations, we previously performed ZF-μSR at RIKEN-RAL in 5% Fe-substituted Bi-2201 single crystals of $Bi_{1.74}Pb_{0.38}Sr_{1.88}Cu_{1-y}Fe_yO_{6+\delta}$. It was found that the relaxation rate of the muon spins was significantly enhanced at low temperatures and a peak was observed at approximately 6 K, which coincided with the onset temperature of the hysteresis between the ZF-cooled and field-cooled magnetic susceptibility, T_{SG}.[4] These results suggest the occurrence of an FM cluster spin-glass state in which FM spin clusters are formed around Fe and the random orientation of the spins between the clusters results in the formation of a spin-glass state.[4] However, the details have not yet been clarified.

To further understand the Fe-substitution effects on FM fluctuations, we performed ZF and longitudinal-field μSR of 9.6% Fe-substituted single crystals of $Bi_{1.74}Pb_{0.38}Sr_{1.88}Cu_{1-y}Fe_yO_{6+\delta}$ with $y = 0.096$ using the HELIOX and VARIOX cryostats at the RIKEN-RAL.

Figure 1 shows ZF-μSR time spectra of the 9.6% Fe-substituted single crystals of $Bi_{1.74}Pb_{0.38}Sr_{1.86}Cu_{1-y}Fe_yO_{6+\delta}$ with $y = 0.096$. At high temperatures above 57 K, the spectra show Gaussian-like relaxations due to nuclear dipole fields randomly oriented at the muon site. Below 57 K, the muon spin relaxation becomes fast and an exponential-like behavior is caused by the development of spin correlation. At 4.1 K, a muon spin precession in a short-time region and slow relaxation in a long-time region are observed, suggesting the coexistence of a long-range magnetic order and slowly fluctuating spins in a sample.

The spectra were analyzed using the following function: $A(t) = A_0 \exp(-\lambda_0 t) G_Z(\Delta, t) + A_1 \exp(-\lambda_1 t) \cos(\omega_t + \phi) + A_{BG}$. The first, second, and third terms represent slowly fluctuating component, muon spin precession component, and background asymmetry, respectively. λ_0 was found to exhibit a peak at approximately 12 K, which almost coincides with T_{SG} determined from magnetic susceptibility.[4] The internal field at the muon site, B_{int}, was estimated from ω as ~92 G, which is comparable to Bint ~100 G obtained for overdoped Bi-2201, in which an incommensurate AF order is formed.[5] The magnetic volume fraction was estimated from the A_0 at the base temperature as ~33%, suggesting the coexistence of long-range ordered and slowly fluctuating regions.

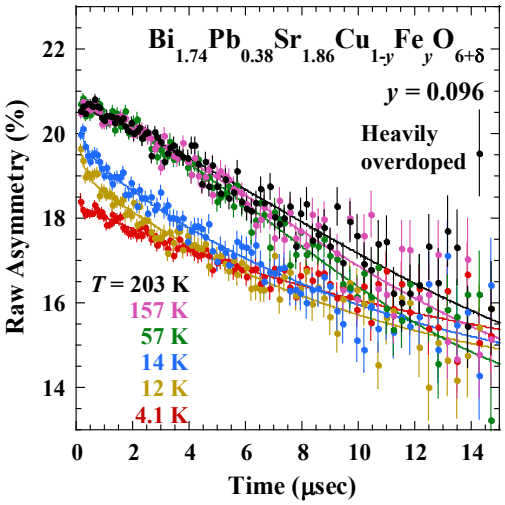

Fig. 1. ZF μSR time spectra of 9.6% Fe-substituted single crystals of $Bi_{1.74}Pb_{0.38}Sr_{1.86}Cu_{1-y}Fe_yO_{6+\delta}$ with $y = 0.096$.

The present results suggest that 9.6% Fe substitution forms a long-rage magnetic order, which is not observed in a 5% Fe-substituted sample. Accordingly, the FM fluctuations are probably stabilized by the Fe substitution. Concurrently, considering the similar values of B_{int} of the heavily overdoped and overdoped[5] samples, an incommensurate AF order might also occur in the heavily overdoped Bi-2201. How the AF and FM order/fluctuations coexist in the heavily overdoped Bi-2201 is to be clarified in future.

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