MLF Experimental Report	提出日 Date of Report 2013. 2. 11
課題番号 Project No. 2012A0149 実験課題名 Title of experiment μSR study of the magnetism and superconductivity in the multi-layer Bi-2223 high-T_c superconductor 実験責任者名 Name of principal investigator Tadashi Adachi 所属 Affiliation Department of Applied Physics, Graduate School of Engineering, Tohoku University	装置責任者 Name of responsible person Yasuhiro Miyake 装置名 Name of Instrument/（BL No.） D1 実施日 Date of Experiment 2012. 10. 26-29

試料、実験方法、利用の結果得られた主なデータ、考察、結論等を、記述して下さい。（適宜、図表添付のこと）
Please report your samples, experimental method and results, discussion and conclusions. Please add figures and tables for better explanation.

1. 試料 Name of sample(s) and chemical formula, or compositions including physical form.

Bi-based high-T_c superconducting cuprates
$Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$
Single crystals

2. 実験方法及び結果（実験がうまくいかなかった場合、その理由を記述してください。）
Experimental method and results. If you failed to conduct experiment as planned, please describe reasons.

Zero-field (ZF) μSR measurements have been performed at temperatures between ~ 7 K and 300 K in the underedoped (T_c = 86.5 K) and optimally doped (T_c = 108.5 K) $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ crystals. Measurements around the base temperature have been performed in the single-pulsed mode, while others have been performed in the double-pulse mode.

Because of thin crystals of $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ with the thickness of ~ 0.1 mm, at first we performed ZF measurements using Ho by changing the thickness of Ag foils as the degrader at the room temperature. Through monitoring the strong depolarization of Ho, we finally decided the appropriate thickness of Ag foils to be 150 μm.

Figure 1 shows ZF-μSR time spectra of the underdoped and optimally doped crystals. The statistics of the data is a little low due to small surface of the crystal. It is found that in the underdoped crystal, the spectrum

show Gaussian-like slow depolarization at 211 K due to the randomly oriented nuclear spins. Below 211 K, the depolarization of muon spins becomes fast down to 123 K. However, the spectrum does not change between 123 K and 32 K. The depolarization of muon spins becomes fast again below 32 K. These results suggest that the development of the Cu-spin correlation is not monotonic and two kinds of development of the Cu-spin correlation exist.

For the optimally doped crystal, the spectra show Gaussian-like depolarization above 40 K, indicating the Cu-spin fluctuations faster than the μSR time window. Below 40 K, a fast depolarization of muon spins is observed. It is found that the development of the Cu-spin correlation is monotonic, which is different from that in the underdoped crystals.

These contrasting results between the underdoped and optimally doped crystals suggest the followings. In the underdoped crystals, the Cu-spin correlation in the inner CuO_2 plane starts to develop below 211 K due to the low hole concentration, while the Cu-spin correlation in the outer CuO_2 plane starts to develop below 32 K due to the high hole concentration. On the other hand, in the optimally doped crystals, the Cu-spin correlation in the inner plane starts to develop below 40 K due to high hole concentration and no development of the Cu-spin correlation is observed in the outer plane due to over doping of holes. To our knowledge, this is a first observation of the two kinds of the developed Cu-spin correlation in the multi-layer cuprates from μSR. To be conclusive, μSR measurements at lower temperatures are important.

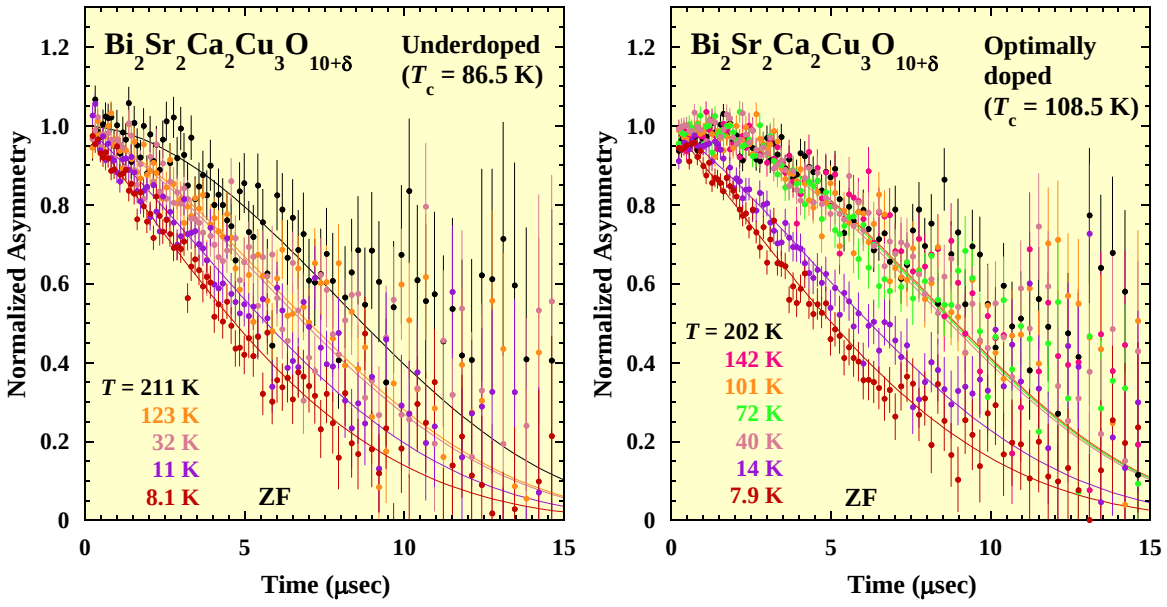

Fig. 1. Zero-field μSR time spectra of the underdoped and optimally doped $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$.