Low Energy Muon Spin Relaxation of T' cuprate superconductors

K.M. Kojima[1,2], M. Hiraishi[2], M. Miyazaki[2], A. Koda[1,2], R. Kadono[1,2], A. Suter[3], H. Luetkens[3], Z. Salman[3], T. Prokscha[3], E. Morenzoni[3], Y. Krockenberger[4], H. Yamamoto[4], A. Ikeda[5] and M. Naito[5]

[1] *Muon Science Laboratory, Institute of Materials Structure Science, KEK and Material and Life Science Experimental Facility, J-PARC, Tokai, 319-1195, Japan*

[2] *SOKENDAI, Tsukuba, 305-0801, Japan*

[3] *Laboratory for Muon-Spin Spectroscopy, Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland*

[4] *NTT Basic Research Laboratories, Atsugi, 243-0198, Japan*

[5] *Department of Applied Physics, Tokyo University of Agliculture and Technology, Koganei, 184-8588, Japan*

Low energy muon beam, which has an energy of a few to mid-twenty keV makes it possible to stop muons into thin-film samples with the thickness of ∼100 nm. Utilizing the muon spin relaxation (μSR) technique, low energy muon beam provides a unique magnetic probe of thin-film samples [1], including the molecular beam epitaxy (MBE)-grown or metal organic decomposition (MOD)-grown superconductor thin-films. At the moment, low energy muon beam is available only at Paul Sherrer Institute (PSI), Switzerland, utilizing a cryogenic gas moderation to energetic (∼4MeV) muons generated via nuclear reactions [1]. The low-energy muons at PSI may be stopped at 100nm depth with the spread of the depth+20/−30nm at the half maximum of the stopping profile. Eventhough the depth resolution is not very sharp, it provides a unique opportunity to scan the magnetic volume fractions and the Meissner shielding of the applied magnetic field as a function of the depth within the thin-film.

We have performed low-energy muon spin relaxation (LE-μSR) measurement of MOD-grown Eu_2CuO_4 (80nm thickness) and MBE-grown $(La,Y)_2CuO_4$ (300nm thickness), both of which takes the T'-structure. After careful annealing to remove excess oxygens, the thin-film samples exhibit superconducting transitions at T_c = 21K (LYCO) and T_c = 26K (ECO) *without* cation substitution for doping [2,3]. Our LE-μSR has detected magnetic muon spin relaxation with a partial ($\sim 1/5 - 1/3$) magnetic volume fraction in the superconducting samples. The magnetic volume fraction of as-grown ECO (non-SC) is significantly larger and the magnetic ordering temperature is significantly higher than those for the annealed ECO (T_c=26K), exhibiting the anti-correlation between the static magnetism and the superconductivity, as has been reported previously in many (bulk) cuprate superconductors coexisting with magnetism (Fig.1).

In MBE-grown LYCO, the magnetic volume fraction is larger near the surface than in the deep region. In the same sample, we were able to measure the Meissner shielding profile of the applied magnetic field. This indicates a bulk superconductivity of non-doped T' cuprate. Our preliminary analysis suggests an elongated magnetic penetration depth of superconductivity (λ) near the surface than in the center of the thin-film. This also suggests the competing feature of static magnetism and the superconductivity within the thin-film sample.

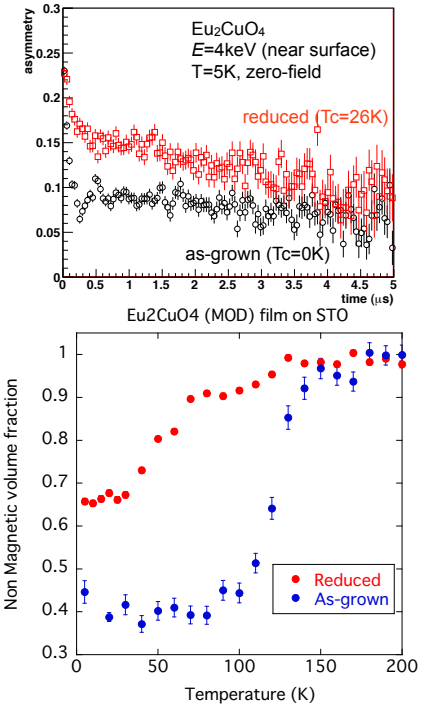

Fig. 1: Zero-field muon spin relaxation spectra at 5K with the inplantation energy of E = 4keV (upper) and the non-magnetic volume fraction as a function of temperature (lower) for T'-Eu_2CuO_4 MOD film: reduced (T_c = 26K) and as-grown (non-SC) samples.

[1]E. Morenzoni, Physica B **404**, 577, (2009) and references therein.

[2] O. Matsumoto *et al.*, Phys. Rev. B **79**, Art. No. 100508(R), (2009).

[3] A. Tsukada *et al.*, Physica C **426-431**, 459, (2005); Solid State Commun. **133**, 427, (2005).