Dimentional crossover/transition of magnetic correlation in T'-Eu_2CuO_4

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1. Introduction

The high-T_c superconductivity in cuprate oxides appears with either types of carrier (electron or hole) doping into an antiferromagnetic Mott insulator. The electron-hole asymmetry in physcial properties is a basis for a unified understanding of microscopic mechanism of the superconductivity. The parent compounds of prototypical electron-doped and hole-doped systems are T'-structured R_2CuO_4 (R = Pr, Nd, Sm, Eu) and T-structured La_2CuO_4, and have been recognized to have qualitatively the same electronic and magnetic properties [1,2]. However, it has been reported that superconductivity appears in R_2CuO_4 for thin film samples [3]. This result shed new light on understanding mechanisms of superconductivity in T'-structured electron-doped systems. Recently, we have performed μSR measurements for T'-structured Eu_2CuO_4, which is free from rare-earth magnetic moments and hence suitable for investigating easily the Cu spin correlation. We newly found an existence of a distinct magnetic phase in a wide temperature range between a static magnetic ordered state below T_{N2} = 110 K and a paramagnetic state above T_{N1} = 265 K. This phase is characterized by exponential decay of muon spin polarization with small oscillating component, indicating an inhomogeneous magnetic state of magnetically fluctuating regions and small ordered regions. Furthermore, it was found that the inhomogeneous magnetic phase below T_{N1} weakens with reduction annealing while the static ordered state below T_{N2} shows robustness against the annealing. It is possible that the magnetic features at T_{N1} and T_{N2} observed in μSR spectra come from the development in dimensinality of the magnetic correlation. Therefore, it is expected that peak profiles as well as intensity of the magnetic reflection obtained in neutron diffraction measurements would provide critical clue to elucidate the detailed magnetic nature of T'-structured copper oxides.

2. Experiment

A sylindrical-shaped single crystal of as-grown Nd_2CuO_4 were used for the measurement. The reason for using Nd_2CuO_4 instead of Eu_2CuO_4 is to avoid high abosorption cross section. We had confirmed Nd_2CuO_4 shows almost the same magnetic features as Eu_2CuO_4 in μSR spectra. The single-crystal diffraction measurements were carried out with the diffractometer installed at BL-18 using the second frame of neutron with the wave length = 4.6-8.8 Å. A closed-cycle cryostat was used to cool the sample down to 90 K. The obtained data were processed on StarGazer to obtain intensity mapping in the reciprocal lattice space.

3. Results

Neutron diffraction intensity distribution in the (HHL) reciprocal lattice plane at 90 K for the as-grown Nd_2CuO_4 is shown in Fig. (a). The intensities are normalized by the number of proton pulses. Two data taken with the sample angles rotated five degrees in a horizontal plane are merged to fill up the detector gaps. Three magnetic Bragg reflections are observed at (1/2, 1/2, L) with L = 1, 2 and 3. The weak spots at left lower position of the magnetic main spots are of impurity phases. We collected data with this condition at 90, 130, 190 and 290 K. Figures (b) and (c) are scans at (1/2, 1/2, 1) along H and L directions of (HHL), respectively. In Fig. (b), there is no appreciable change in peak width along the in-plane direction, while the intensity decreases with heating and the magnetic Bragg peak finally disappears above T_N ~ 280 K. In Fig. (c), the peak width along the inter-plane direction also shows no appreciable change. The peak position seems to be shifted slightly among the data probably because of inadequate sophistication of the UB matrix as manifested by the shifted peak position off from the right Bragg position. The same tendency is observed at the other Bragg peaks with $L = 2$ and 3. These results indicate doubtlessly that a three-dimensional long-range magnetic order is realized below T_{N1}.

Then, how is the sequencial magnetic development below T_{N1} observed in the μSR spectra explained? One may attribute the μSR results to muonic phenomena, such as disorder effects induced by implanted muons or uncertainty about muon stopping sites inside a unit cell. However, it is unlikely to induce such the complex sequencial development of the magnetic correlation by inducing muons, although weak ordered phases could be destroyed by muon disorder. Moreover, although a number of muon sites are often observed as multiple frequencies in oscillating spectra, it has never been reported a transition of muon sites wihtout structural transitions. Therefore, it is more plausible to consider the magnetic features as an intrinsic magnetic property to the Cu spin correlation in T'-R_2CuO_4.

The reason why neutron diffraction measurements failed to detect any magnetic anomalies below T_{N1} may be the high energy scale of incident neutron. While the present neutron diffraction used incident energies higher than ~1 meV, μSR measurements detects magnetic fluctuation slower than ~10^{-9} seconds, i.e. lower than ~4 μeV. Therefore, these results of neutron diffraction combined with μSR suggests very low energy scale physics of magnetic fluctuation.

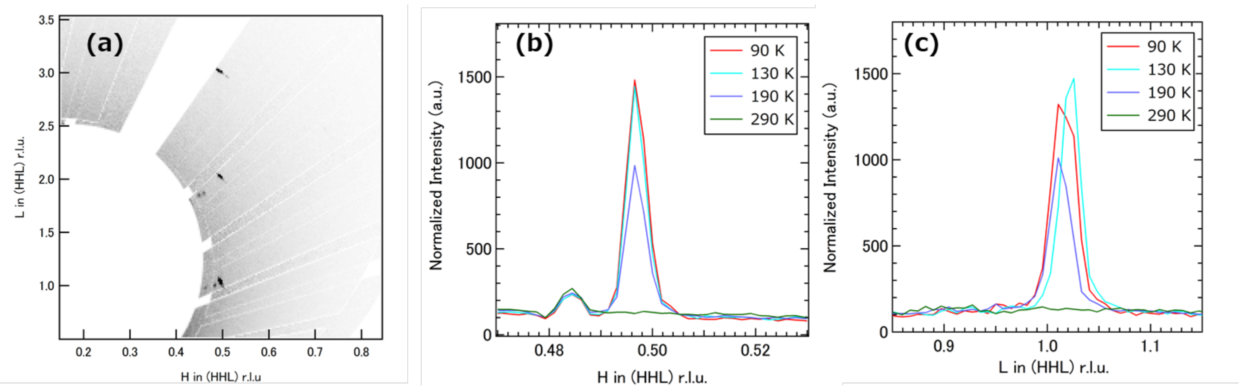

Fig.: (a) Neutron diffraction intensity distribution in the reciprocal lattice plane (HHL) at 90 K for as-grown Nd_2CuO_4. Two data with different sample angles are merged and averaged. (b)(c) Peak profiles of the (1/2, 1/2, 1) magnetic Bragg reflection along (b) *H* in (*HH*L) and (c) *L* in (HH*L*), respectively.

4. Conclusion

We have carried out single crystal neutron diffraction measurements for as-grown Nd_2CuO_4 to investigate details of the sequencial magnetic development below T_N observed from μSR spectra for T'-structured cuprate R_2CuO_4. Any anomalous magnetic features were observed neither in intensity or peak profiles, indicating three-dimensional long-range magnetic order well develops below T_N. The discrepancy between the results of neutron diffraction and μSR may be due to the difference of three orders in the energy scale between the probes. For understanding the magnetic property of R_2CuO_4, magnetic probes excelling at low-energy dynamics with high energy resolution such as back scattering neutron scattering measurements are necessary.

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