Nano-size effect on Néel temperature and magnetic ordering of La_2CuO_4

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Finite-size effects of antiferromagnetic materials, which refer to the reduction in particle size of antiferromagnetic materials until they become nanoscale sized, have received much attention in recent years.[1,2] As predicted by Néel, there will be uncompensated spin from the surface due to the reduction in particle size of antiferromagnetic materials until they become nanoscale sized. Because of this, antiferromagnetic nanoparticles exhibit superparamagnetic properties, and the physical properties of antiferromagnetic nanoparticles will change.[3]

La_2CuO_4 (LCO) is chosen because it is one of the typical Mott insulating systems and is the parental compound of the superconducting high-T_c cuprate; therefore, this work can provide the basic knowledge for studying the size effect on Mott insulating systems.[4] Prof. Tanaka's group as our collaborator the grain size can be controlled to be in the nanoscale range. As far as we know, there has been no similar research on high-T_c cuprates so far.

A previous measurement, which investigated other nanoparticle systems, proved that dc magnetic susceptibility cannot measure the T_N value of an antiferromagnetic material.[5] The transition temperature obtained by this measurement is the blocking temperature or freezing temperature of the antiferromagnetic material, and not T_N.[5] In this case, muon spin relaxation (μSR) was used to investigate the magnetic ordering of this material. Prof. Tanaka's group has already performed the dc susceptibility measurement of LCO 96 nm.[6] Therefore, we can compare and analyze the results from susceptibility measurement and μSR measurement.

Zero-Field (ZF) μSR measurement at RAL, UK, using single pulsed muon beam, was carried out in order to detect the muon spin precession of the material. The ZF-μSR time spectrum at various temperatures is shown in Fig. 1. The muon spin precession can be clearly seen to start from 35 K, indicating that antiferromagnetic (AF) ordering starts at this temperature; however, the precession disappears at 100 K. This suggests that the Néel temperature T_N of this material is between 35 K and 100 K. The value of T_N is significantly reduced compared to bulk LCO, which has $T_N = 240 \pm 10$ K.[4]

Figure 2(a) depicts the temperature dependence of the internal field, H_{int}. H_{int} is zero at 100 K, since no muon precession is observed at this temperature; it increases with a decrease in temperature and reaches a saturated internal field of 400 G. The same tendency of H_{int} dependence on temperature and the same saturated internal field value is observed for LCO bulk material. However, in the bulk material, H_{int} is zero at 250 K. It means that although T_N decreases with reduction in particle size, the average magnetic moment and magnetic interaction are still the same.

The damping rate of muon spin precession, which is caused by the static and dynamic field dependence of this material on temperature, is demonstrated in Fig. 2. The damping rate seems to increase for temperatures below 100 K, achieve a maximum value at 35 K, and then decrease for temperatures below 35 K. The muon spin depolarization dependence of this material on temperature, which is shown in Fig. 2(c), also has the same tendency. It is indicated that below 35 K, the spin fluctuation slows down and there is an alignment of the magnetic moments of Cu^{2+}; this means that long range ordering starts at temperatures below 35 K.

We plan to complete ZF data between 35 K and 100 K in order to evaluate the T_N, and we are going to analyze the internal field of this material to find out whether it is coming from the static or dynamic spin fluctuation by measuring the Longitudinal Field (LF)-μSR. Besides, we plan to measure the other LCO nanoparticle whose particle size is different from that of this material. Hence, the analysis on the nano-size effect on Néel temperature and magnetic properties can be confirmed.

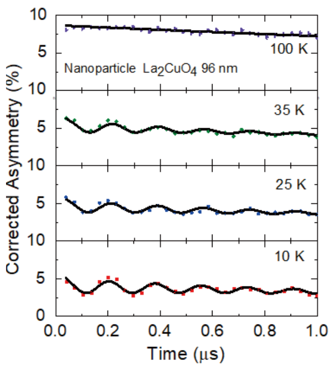

Fig. 1. ZF-μSR time spectrum of La_2CuO_4 with particle size of 96 nm.

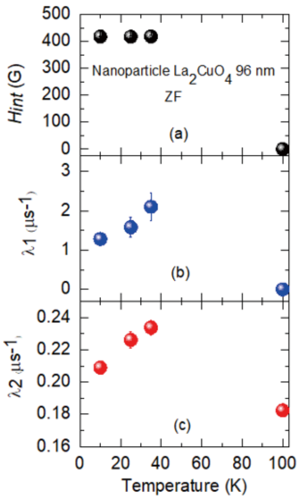

Fig. 2. Temperature dependence of (a) the internal field at the muon site; (b) the damping rate of muon spin precession; and (c) muon spin depolarization rate of La_2CuO_4 96 nm.

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References

1) M. M. Ibrahim *et al.*, Phys. Rev. B **51**, 2955 (1995).
2) S. Gider *et al.*, Science **268**, 77 (1955).
3) L. Néel, in *Low Temperature Physics*, (New York, 1962).
4) Budnick *et al.*, Phys. Lett. A **124**, 1, 2 (1987).
5) Tang *et al.*, Phys. Rev. B **67**, 054408 (2003).
6) H. Tanaka *et al.*, (in preparation).