Size-dependent magnetic behavior of La_2CuO_4 nanoparticles

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The study of high-T_c copper-oxide-based superconductors has been pursued for more than thirty years. The magnetic ordering of the parent compound is strongly influenced by element doping.[1)] The superconductivity (SC) appeared on increasing the hole-doping concentration.[1)] It was reported that weak magnetism appeared in the heavily doped regime for ($x \geq 0.30$).[2)] Those results could provide valuable clarifications of the magnetic phase diagram of the high-T_c copper-oxide-based superconductors, but the correlation between spin dynamics and SC remains unclear.

In the case of nanoparticles, Nèel predicted theoretically that ferromagnetic spins appear at the surface of nanoparticles.[3)] This kind of magnetism was observed in nanogold systems and antiferromagnets such as CuO and CoO.[4,5)] The nano-size effect also caused a reduction in magnetic transition temperature, T_N, of CuO.[5)] In $La_{2-x}Sr_xCuO_4$, Yin et al. reported possible weak magnetism when the particle size was 113 nm with $0.1 \leq x \leq 0.30$.[6)] With these results, the remaining problems on the magnetism and superconductivity of high-T_c superconductors become more complicated.

We aim to investigate the nano-size effect in $La_{2-x}Sr_xCuO_4$. We present the results of the parent compound, La_2CuO_4 (LCO). This report is an update to our last year's report.[7)] The sol-gel method was used to produce the samples by controlling sintering temperatures and times to vary the particle size. We prepared 4 samples with different particle sizes: 24 nm, 32 nm, 52 nm, and 71 nm. The detailed sample synthesis procedure was reported in our previous paper.[8)] Zero-field (ZF) muon spin relaxation (μSR) measurements of these samples were performed at the RIKEN-RAL Muon Facility, Rutherford-Appleton Laboratory, UK, by using a pulsed positive surface muon beam.

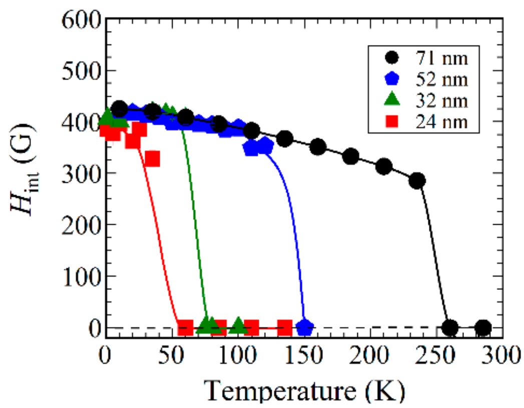

Fig. 1. Temperature dependence of the internal field at the muon site, d H_{int}, in La_2CuO_4 nanoparticles.

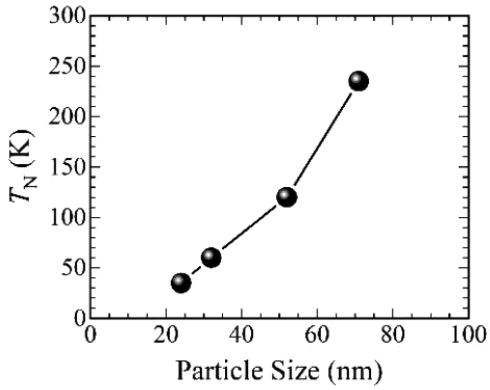

Fig. 2. Temperature dependence of the magnetic transition, T_N, of La_2CuO_4 nanoparticles.

ZF-μSR time spectra of each sample were analyzed using Eq. (1). Muon spin precession, which shows the appearance of a long-range magnetically ordered state, is expressed in the first component. Slow relaxation of muon-spin polarization is expressed in the second component. From the fitting results of the time spectra, we could obtain the internal magnetic field at the muon site, H_{int}, which is shown in Fig. 1. The saturated H_{int} did not change significantly in all samples, showing a value of about 420 G. This value is identical to that observed in bulk LCO.[9)]

$$A(t) = A_1 e^{-\lambda_1 t}\cos(\omega t + \phi) + A_2 e^{-\lambda_2 t} \tag{1}$$

Figure 2 depicts the temperature dependence of T_N which is defined from Fig. 1. as the temperature where H_{int} suddenly drops to zero with increasing temperature. The figure shows that T_N decreases with reducing particle size. These results indicate that the particle size affects T_N without changing the saturated H_{int}. The result that the saturated d H_{int} value is the same between nanoparticles of different sizes and the bulk sample implies that the magnetic moments of Cu sensed by injected muons were almost the same. The reduction in T_N might be due to the destruction of the three-dimensional exchange interaction between the spins of Cu ions, which existed in bulk LCO,[10)] as a result of reducing the particle size. We are now summarizing these results for submission to an international journal.

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