The effect of particle size on magnetic properties regarding La_2CuO_4 nanoparticles

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The nano size effect is an interesting physical phenomenon because it shows unique properties compared to those observed in a bulk condition. One example is the gold (Au). When the particle size of Au was reduced to be in the nano-scale size, ferromagnetic behavior was observed, whose origin is still unknown.[1)] Changes in magnetic properties due to particle size reductions were also observed in the La-based high-T_c superconducting oxide, $La_{2-x}Sr_xCuO_4$ (LSCO).[2)] Synthesizing LSCO nanoparticles experiences numerous difficulties regarding the control of defects and impurities.[3)] Thus, an investigation to optimize sample preparation is a prerequisite.

The La_2CuO_4 (LCO), a parental compound of LSCO exhibiting antiferromagnetic Mott insulator behavior at $T_N \approx 300$ K,[4)] will be investigated considering a nano-size particle. LCO nanoparticle were synthesized using sol-gel method with lanthanum oxide, La_2O_3 (99.99%), and cooper oxide, CuO (99.99%), as a raw material similar to a previous research.[5)] Particles size of LCO can be controlled by varying the sintering temperature at 650°C, 700°C, 750°C, 800°C, and 1100°C over 6 hours which produce 43 nm, 54 nm, 70 nm, 90 nm, and 161 nm particle size, respectively. Rietveld refinement method is used to analyze the X-ray diffractometer (XRD) pattern, which exhibit an orthorhombic crystal structure with Bmab-space group. Small impurities were detected at the lowest sintering temperature of 650°C, which correspond to approximately 1.3% of La_2O_3 coming from the raw material. Because La_2O_3 has no magnetic component, the magnetic properties of this sample should not be affected. The LCO particle size (D) estimated using the Debye Scherrer method is express using the following equation:

$$D = \kappa\lambda/\beta \cos\theta \qquad (1)$$

where κ is the Scherrer constant (0.9), λ is the wavelength of Cu-K_α (1.5406 Å) obtained from XRD measurements, β denotes the full width of half maximum intensity observed from XRD pattern and θ is the Braggs angle.

The La_2CuO_4 is composed of a basic unit of CuO_6 octahedron crystal structure, which has been thoroughly investigated in the past. Changing the particle size of LCO affects the antiferromagnetic transition temperature (T_N), as shown in Fig 1. Reducing the particle size of LCO up to 43 nm can decrease the T_N down to 65 K. This nano-size effect was also investigated on magnetic materials, such as CuO. Accordingly, it was reported that the Néel temperature, T_N, of CuO could be reduced from 290 K down to 40 K when CuO particle size was reduced to approximately 5 nm.[6)] Those studies indicated that the magnetic exchange interaction would be affected by the reduction of particle size.

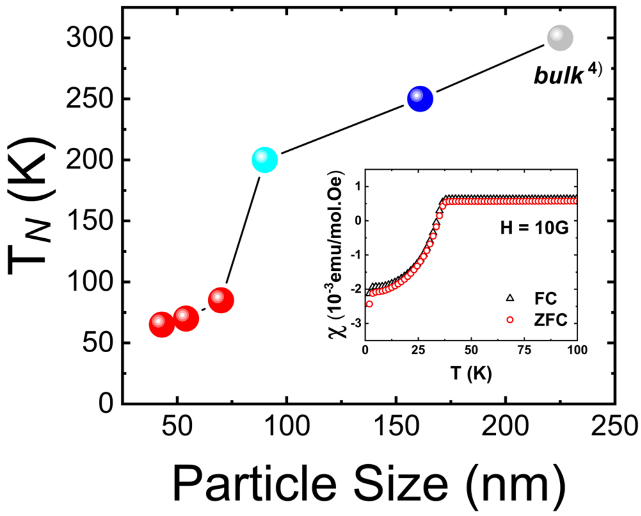

Fig. 1. Particle size dependance of the antiferromagnetic transition temperature, determined from the χ measurement at 0.0001 T with zero field cooled method using Superconducting Quantum Interference Device (SQUID) magnetometer MPMS. The insert figure demonstrates the temperature dependance of magnetic susceptibility for sample A.

The largest particle size exhibits a superconducting state below 40 K, which corresponds to the transition temperature of LSCO doped with 15% strontium.[2)] The antiferromagnetic long-range order was suppressed and superconductivity occurred owing to the excess oxygen inside the LCO sample,[7)] which led to the phase separation of partial superconductivity. Interestingly, reducing the particle size of LCO down to nano-size suppressed the superconductivity behavior below 40 K, which occurred owing to the excess oxygen. Otherwise, magnetic susceptibility of LCO nanoparticle below 50 K can be fit using Curie-Weiss equation, showing that the magnetic free spins increase by decreasing the particle size.

References

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