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Observation of inverted hysteresis loops in cobalt nanoparticles fabrication by laser irradiation

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1. Introduction

Recently, magnetic materials with nanometer scaled have attracted much attention due to a rich variety of interesting magnetic, transport, and mechanical properties, depending on the size of the magnetic particles and its distribution. In almost magnetic materials, hysteresis loops is one of the most important phenomena observed and reflects the material properties. Generally, the behavior of the loop is governed not only by intrinsic properties of the materials, but also the extrinsic factor, such as the temperature, shape, interaction etc. In addition, the hysteresis loop has common character: when the field decreases from the positive saturation field to zero, the magnetization does not decrease to zero but remains positive. However, a negative remanence or inverse hysteresis loop in which the hysteresis loops progress clockwise direction displays a negative remanence and coercivity has recently been reported in other group. [1] For example, O'Shea et al. persisted a two-phase theory for inhomogeneous systems (FM-AFM systems), in which the two phase, a high anisotropy phase with small magnetic moment and a low anisotropy phase with large magnetic moment, are antiferromagnetically coupled. J. Geshev et al. proposed that competing anisotropy theory was later extended to the systems involving competing cubic and uniaxial anisotropies, and two competing uni-axial anisotropies. Some authors argued that the magneto-static interaction, between different parts of the inhomogeneous system is responsible for inverted hysteresis. In this report, we observed negative remanence in Co nanoparticles (NP) system. We explained this behavior that the coupling effect of antiferromagnetic type between ferromagnetic Co NP and superparamagnetic Co NP is considered.

2. Experiments and Results

The Co NP are simply prepared on SiO_2/Si substrates by applying an external laser irradiation on ultra thin Co films at room temperature. An ultrahigh vacuum sputtering instrument is used to prepare Co thin film at a base pressure of 10^{-8} Torr. The light source used in our experimental is a Nd: YAG laser of 355 nm wavelength at a laser power of 2 W. More details of laser irradiation are reported elsewhere. [2] Structural properties of Co NP are investigated by scanning electron microscope, atomic force microscope, and transmission electron microscope (TEM). Magnetic measurements were performed, at temperatures between 5 K and 300K, with a superconducting quantum interference magnetometer.

Figure 1 shows surface image of Co NP imaged by the TEM. The optimum laser power and scan times are determined at 0.01 W and two times, respectively. As shown in this figure, the average diameter and center-to-center distance of neighboring NP are observed to be about 35 nm and 70 nm, respectively. The averagedensity, defined as the number of dots per unit area, is determined to be about $3\times10^{10}/cm^2$. The formation of NPis explained as follows. At first, ultra-thin film is locally melted at an extremely short time when the laser is irradiated onto the Co thin film. Then the melted material is caused to become NP by the strain. This TEM results suggest that no coupling among the Co NPs.

Figure 2 shows the remanent magnetization (Mr) as a function of temperature with 35 nm Co NP in average diameter. At each temperature, the Mr was measured in an applied field of 0.3 T;

then, 120 s after the 0.3 T field was removed, the magnetization was measured. The 0.3 T data are essentially temperature independent, indicating that the magnetization is saturated in this field. When the sample was cooled to 5 K where the rotation of the isolated particles was frozen, the measured Mr was positive, similar to the behavior in a conventional ferromagnetic. Note that increasing temperature, Mr changes sign, through 0 at 92 K, to a negative value. The zero Mr value clearly indicates that there are isolated particles whose magnetization can follow the external magnetic field like superparamagnetic materials. Generally, the Mr of superparamagnetic NP is zero, because thermal fluctuations prevent the existence of a stable magnetization. In our system, the zero Mr value at 92K demonstrates that the moments are at least partially blocked below 92 K, however, the dispersion of NP is superparamagnetic above 92 K. In addition, negative remanence is observed in the temperature range of above 92 K. This indicates that the negative remanence is associated with the presence of the superparamagnetism of the system. At the temperatures where negative remanence appears, most of the Co NPs become superparamagnetic. However, some Co NPs still maintain ferromagnetic phase because of the broad size distribution, as mentioned TEM result. The moment of ferromagnetic Co NP have an effect on the moments of the superparamagnetic Co NP due to the dipolar interaction. The total magnetic moment of the superparamagnetic Co NPs may be larger than that of the ferromagnetic Co NP due to the number difference of the two particles collections. Therefore, we explained the negative magnetization that coupled of two phases, antiferromagnetic like coupling, between ferromagnetic Co NP and superparamagnetic Co NP is considered. More experiment is currently under research in order to its mechanism clearly.

3. Summary

We have investigated negative remanence in Co NP system. TheCo NPs were uniquely fabricated by using a laser irradiation technique. Magnetization measurements performed on Co NP system show negative remanence taken at temperatures higher than 92 K. The observed negative remanence correlates to the blocking temperature of superparamagnetism. Although we have no clear explanation for negative remanence, this behavior is associated to the magnetic coupling characteristic between the ferromagnetic Co NP and superparamagnetic Co NP.

4. Reference

[1] M. J. O'Shea, A.-L. Al-Sharif, J. Appl. Phys. 75, 6673 (1994), X. Yan and Y. Xu, J. Appl. Phys. 79, 6013 (1996).

[2] J. Y. Yang, K. S. Yoon, Y. H. Do, C. O. Kim, J. P. Hong, J. Appl. Phys. 93, 8766 (2003).

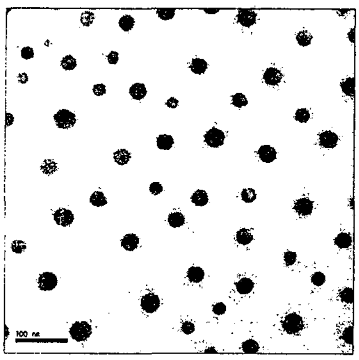

Fig. 1. TEM image of Co NP fabricated by Laser irradiation method.

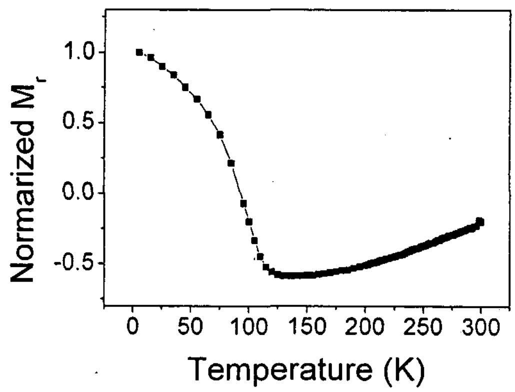

Fig. 2. Remanence magnetization (M_r) as a function of temperature curves.