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# 레이저 조사 방법으로 제조된 Co 나노닷의 초상자성 현상 관측
# (Observation of superparamagnetic behaviors in Co nano dots fabricated by laser irradiation method)

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## ABSTRACT

Superparamagnetic regions and magnetic anisotropic properties in randomly orientated Co nano dots (NDs) were investigated as a function of dot diameter, spacing, and density. The Co NDs were fabricated by intentionally exposing a laser source on ultra thin film. Various dot sizes are ultimately realized by changing laser power, scan condition, and initial film thickness. Magnetic hysteresis loops, angle-dependent magnetization, and temperature dependence magnetization of the Co NDs were measured with a superconducting quantum interference device. The analysis of magnetization and hysteresis loops was effectively used to determine superparamagnetic regions of the Co NDs. Up to now, the experimentally observed results repeal that room temperature superparamagnetic limit of our Co NDs was about 30 nm in diameter, with the confirmation of high resolution transmission electron microscope.

## I. Introduction

Below some critical size a nano dots (NDs) of ferromagnetic materials consist of single domains which present unique magnetic properties. The particle contains no domain boundaries and is in a state of uniform magnetization at any field. The direction of collective magnetization of an assemblage of these particles can rotate thermally, and thus behave like a paramagnetic substance with a very large moment. This phenomenon has been commonly called superparamagnetism. For superparamagnetic materials at thermal equilibrium the magnetic remanence and coercivity force are both zero. The magnetization of the particles can be reversed by thermal activation over an energy barrier KV, where V is the volume of the particle and K is the magnetic anisotropy. In this report, we approach a phenomenon of superparamagnetism through prepared Co NDs using laser irradiation method.

## II. Experiments

The Co NDs are simply prepared on Si substrates by applying an external laser irradiation on ultrathin Co films at room temperature. The 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 which is focused on the sample through a focusing objective with a 0.5 mm round spot. More detailed laser treatment process is described elsewhere. [1] The laser irradiation on ferromagnetic thin films locally melt the film at an extremely short time so that the melted film gets together to form the NDs by the strain effect. This laser irradiation process is very reproducible as well as very controllable.

Structural of Co NDs are investigated by scanning electron microscope, atomic force microscope (AFM) and transmission electron microscope (TEM). The hysteresis measurements performed at 5 ~ 300K on Co NDs of different sizes. In addition, magnetization as a function temperature with differential size of Co NDs measured at field cooling (FC) and zero field cooling (ZFC) method.

## III. Results and discussion

Figure 1 shows typical surface images of as-deposited Co thin film and NDs imaged by AFM.

Figure 1(a) shows an as-deposited Co thin film of 1 nm thickness that exhibits a highly smooth surface morphology. The well aligned NDs after laser treatment are presented in Fig. 1(b) and 1 (c). The optimum laser power and scan times are determined at 0.08 W and two times, respectively. As shown in Fig. 1(b), the average diameter and center-to-center distance of neighboring NDs are observed to be about 10 and 22 nm, respectively. The average density, defined as the number of dots per unit area, is determined to be about $2.43*10^{11}/cm^2$. The height of the dots is about 2.9 nm. In a similar way, a Co thin film 2 nm thick is also post treated by the laser and two times scan. As shown in Fig. 1(c), the average diameter, center-to-center distance, density, and height of the Co NDs are observed to be about 32 nm, 83 nm, $0.353*10^{11}/cm^2$, and 5.5 nm, respectively. This knowledge from the experiment indicates that our process can easily control the formation of the NDs, depending upon the experimental conditions. Generally, the way of obtaining conventional quantum dots by other groups has relied on the strain effect that can be induced by lattice mismatch between the substrate and thin films. In our case, laser irradiation of the ferromagnetic thin film melts the film locally in an extremely short time. And then the melted film would be driven to get together with the strain. This process is found be very controllable and reproducible.

Fig. 2 shows a representative plot of remanence magnetization ($M_r$) vs. temperature curves with various size of Co NDs. At each temperature, $M_r$ was measured in a 0.3 T applied field; then, 120 s after the 0.3 T field was removed, the remanent magnetization was measured. The 0.3 T data are essentially temperature independent, indicating that in this field magnetization is saturated. As shown in Fig. 2, temperature increase magnetization curve the diameter of Co NDs is increased with an increase in temperature at zero remanence magnetization. Generally, the remanence magnetization and coercivity of superparamagnetic nano dots is zero ($M_r$=0, $H_c$=0), because thermal fluctuations prevent the existence of a stable magnetization. The zero remanent value at each temperature demonstrates that below this temperature the moments are at least partially blocked. At higher temperature, the NDs dispersion is superparamagnetic.

## IV. Conclusion

Uniform ferromagnetic nano dots are successfully fabricated on Si substrates only by irradiating a laser onto ultrathin magnetic films. The diameter, center-to-center distance, and density of NDs are artificially controlled in our simple process. The hysteresis and magnetization measurements reveal that the Co NDs exhibit a phase transition from ferromagnetic to superparamagnetism. This experimental knowledge suggests that our process can easily control physical parameters of the NDs, depending on experimental conditions.

## V. Reference

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

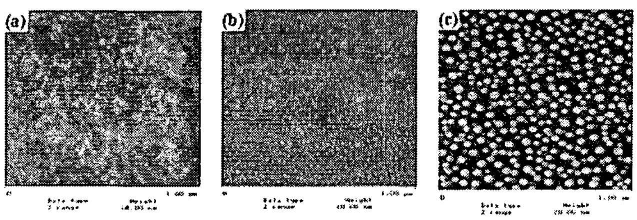


Fig. 1. (a) AFM image of Co thin film 1 nm thick and (b), (c) images after laser irradiation at laser power of 0.08- W and two scans for different thickness films; (a) is for 1 nm thickness and (b) is for 2 nm thickness.

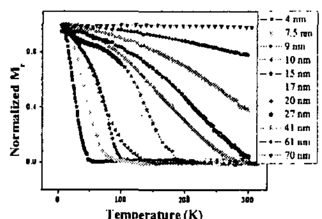


Fig. 2. remanence magnetization ($M_r$) as a fucntion of temperature curves with various size of Co NDs.