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Particle size dependence of magnetostriction effects on NiO nanoparticles

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1 Introduction

Because of the high proportion of surface atoms and the finite size effects, nanoparticles possess unusual magnetic properties and crystal structures that differ from those of the bulk crystal. Surface states of nanoparticles are changed by the development of the lattice strain owing to the existence of edges and defects at the surface of a particle as well as the crystallographic structure different from that of the bulk crystal. NiO bulk crystals are antiferromagnetic materials with Néel temperature T_N = 523 K, and its crystal structure changes from lock-salt structure with cubic symmetry to rhombohedral symmetry below T_N. The NiO nanoparticles have been investigated by both experimental and theoretical methods, which show unique magnetic properties such as the magnetic moment enhancement, large coercive field, exchange bias, and unusual hysteresis behavior [1-4]. The magnetic properties of the NiO nanoparticles were explained by the core−shell model and exhibited large shell moment at surface of a nanoparticle. The size dependence of magnetic properties and crystal structures on NiO nanoparticles indicated an existence of strong correlation between spin configuration and crystallographic structure [1]. Kodama *et al*. calculated the equilibrium spin configurations in NiO nanoparticles, which resulted in 8-, 6-, or 4-sublattice spin ordering with decreasing particle size [2]. It is expected that the change in spin configuration by applying external magnetic field results in the change in the crystallographic structure, and the effect of magnetic field on crystallographic structure varies with particle size owing to change in sublattice spin order. In this study, we investigated magnetostriction effects and magneto-structural correlation through X-ray diffraction measurements in magnetic fields.

2 Experiment

The NiO nanoparticles with particle size d = 2.6–22 nm were synthesized in the pores of mesoporous silica SBA-15 [1]. Powder XRD measurements were carried out using the a Debye-Scherrer camera at room temperature in external magnetic field H up to 0.34 T. The incident X-ray energy was 16 keV and its wavelength was calibrated using the XRD pattern of the CeO_2 powder. Two facing NdFeB magnets were used to produce the external magnetic field. The magnetic field were changed by controlling the distances between the sample and NdFeB magnets [5]. The XRD patterns were analyzed to estimate the lattice constants by Rietveld analysis.

3 Results and Discussion

We observed the powder XRD patterns for the NiO nanoparticles with d = 3–20 nm in magnetic fields up 0.34 T at 300 K. The XRD patterns of all NiO nanoparticles exhibited some broad Bragg peaks, which could be attributed to the rhombohedral distorted rock-salt structure in magnetic field up to 0.34 T. Figure 1 (a–c) shows magnetic field dependence of lattice constants normalized by those for H = 0 Oe. The NiO nanoparticles exhibited prominent magnetostriction behavior, and the effect was enhanced with decreasing particle size. The amount of change in the lattice constants for all NiO nanoparticles increased with increasing external magnetic field, and the amplitude of magnetic field at which the maximum of magnetostriction occurred depended on the particle size. In addition, the rhombohedral distortion, c/a, changed under magnetic field. The rhombohedral distortion is known to consist of a contraction along the [111] direction. The rhombohedral phase of the NiO was characterized by the antiferromagnetic ordering with Ni^{2+} ions in the alternating (111) layers having their spins in mutually opposite directions and coupling of the d electrons through p electrons of the O^{2-} ions [6]. There the variation in c/a led to the change in magnetic exchange interactions in NiO nanoparticles.

The tendency of changes in lattice constants depended on particle size in magnetic field. At H > 2000 Oe, for d < 6 nm, lattice constant a and c contracted and expanded, respectively, whereas, for d > 6 nm, both the a and c stretched. As shown Fig. 1 (d), the relative changes in lattice constants increased with decreasing particle size, especially below 6 nm, the relative change increased rapidly. These results indicated that the magnetostriction effects for the NiO nanoparticles were enhanced with decreasing particle size. Now, the theoretical calculation results indicated that the equilibrium spin configurations for NiO nanoparticles were increased with decreasing particle size below 6 nm [2]. It is considered that the enhancement of magnetostriction below 6 nm is attributed to the change in the sublattice spin ordering and increase in the net magnetic moment.

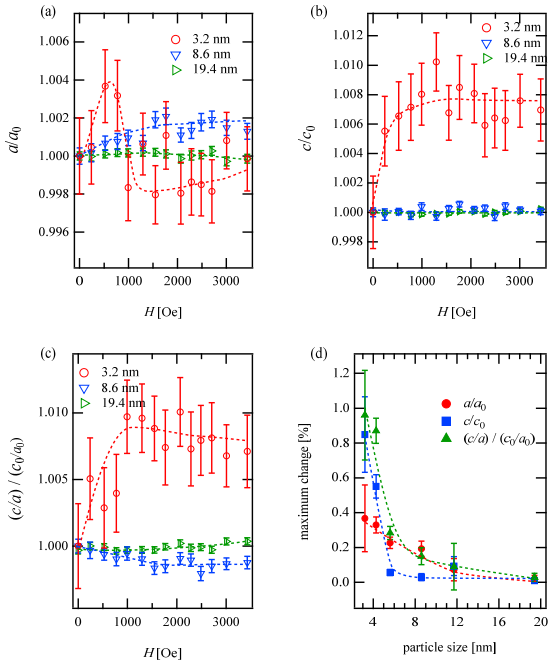

Fig. 1: (a–c) Magnetic field dependence of lattice constants normalized by that for H = 0 Oe at room temperature. (d) Particle size dependence of maximum change of lattice constants in magnetic field at room temperature.

References

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