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Size Dependent Magnetic Properties of Zinc Ferrite Fine Particles

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Abstract. We investigate the particle size dependence of magnetic properties of ZnFe_2O_4 fine particles. The fine particles with different particle sizes were obtained by heating the coprecipitated powder. The magnetization slowly increases with decreasing the particle size, and drastically in the particles with diameter < 30 nm. The size dependent magnetization shows maximum around ~ 8 nm in diameter. The Curie temperature also increases with decreasing the particle size. Such changes in the magnetization and Curie temperature can be explained in terms of the distribution of Fe^{3+} ions dependent on the particle size.

1. INTRODUCTION

Zinc ferrite (ZnFe_2O_4) has an almost normal spinel structure with a tetrahedral A-site occupied by Zn^{2+} ions and an octahedral B-site by Fe^{3+} ions, and exhibits an anomalous antiferromagnetic behavior with a Néel temperature of about 9 K [1]. Lotgering [2] has suggested that a small number of Fe^{3+} ions occupy the tetrahedral A-site, and the clusters consisting of Fe^{3+} ions are formed at the octahedral B-site through a coupling by the A-B interaction. Ligenza [3] has found that 4% of the A-sites are occupied by Fe^{3+} ions.

Ultra-fine ZnFe_2O_4 particles prepared by the coprecipitation method have remarkably larger magnetization than the bulk materials by the ceramic method. [4] The enhanced magnetization would originate from the magnetic cluster formation caused by the deviation of cation distribution from the normal spinel structure. We expect that the magnetic clusters formation develop with decreasing the particle size. Thus, we investigate the size dependence of magnetic properties of ZnFe_2O_4 fine particles.

2. EXPERIMENTAL PROCEDURE

Ultra-fine ZnFe_2O_4 particles were prepared by the coprecipitation method. [4] The fine particles with different particle sizes were obtained by heating the coprecipitated powder. We evaluated the average particle size from the full width at half maximum of X-ray diffraction (XRD) pattern line (311) by using Scherrer's formula. The magnetic measurements were performed using a vibrating sample magnetometer (VSM) and a superconducting quantum interference device (SQUID) magnetometer. The size dependence of magnetization in a magnetic field of 15 kOe can be evaluated at 77 K and 300 K. The temperature dependent magnetization was measured in a magnetic field of 10 kOe at temperatures below 773 K.

3. RESULTS AND DISCUSSION

The XRD patterns of the coprecipitated powder of ZnFe_2O_4 and the specimens obtained by heating it indicate the increasing in average particle size with increasing the annealing temperature. Size dependent magnetizations of ZnFe_2O_4 fine particles at 300 K and 77 K are shown in Fig. 1. The magnetization slowly increases with decreasing the particle size, and drastically in the particles with diameter < 30 nm, and then, shows a maximum around ~ 8 nm in diameter.

Figure 1: Size dependent magnetization of ZnFe_2O_4 fine particles in a magnetic field of 15 kOe at 300 K and 77 K. The size dependence of the fine particles shows maximum around ~ 8 nm in diameter.

Figure 2: Temperature dependence of magnetization of ZnFe_2O_4 fine particles with different particle sizes in a magnetic field of 10 kOe. The Curie temperature T_c of ZnFe_2O_4 fine particles with the smaller particle size is larger than that with the larger particle size.

Temperature dependence of magnetization of ZnFe_2O_4 fine particles with different particle sizes measured in a magnetic field of 10 kOe are shown in Fig. 2. The magnetizations of ZnFe_2O_4 fine particles with 5.5 and 6.0 nm monotonically decrease with increasing temperature, while the magnetizations of ZnFe_2O_4 fine particles with 15.5 and 34.5 nm show maxima at 19 K and 20 K, respectively. The Curie temperatures, which are determined on the basis of the square magnetization[5], are 304 K, 303 K, and 197 K in ZnFe_2O_4 fine particles with 5.5, 6.0, and 15.5 nm, respectively. We could not determine the Curie temperature for the sample with 34.5 nm, because of non-linearity of the square magnetization. The Curie temperature of ZnFe_2O_4 fine particles tends to increase with decreasing the particle size.

The neutron diffraction study of ultra-fine ZnFe_2O_4 particles[6] indicated that occupancy of Fe^{3+} ions at the A-sites is 0.142 and 0.108 in the fine particles obtained by heating the coprecipitated powder of ZnFe_2O_4 at 500°C and 700°C, respectively. This suggests the increase in the number of the magnetic clusters consisting of the Fe^{3+} ions with decreasing of particle size. Such change in the distribution of Fe^{3+} ions may result in the increase in the number of the magnetic clusters consisting of the Fe^{3+} ions with decreasing the particle size. This picture is consistent with the size dependent magnetization of the ZnFe_2O_4 fine particles with diameter > 8 nm. The temperature dependent magnetization of such a larger particle retains some trace of antiferromagnetism in the bulk sample, i.e., the characteristic peak and the low Curie temperature, because of the small number of magnetic clusters. On the other hand, the magnetization of sample with diameter < 8 nm shows the size dependence opposite to that of the larger samples, although the temperature dependent magnetization of smaller particles is characterized by the ferromagnetic feature, i.e., the monotonical thermal evolution and the significantly high Curie temperature. Such behavior can be explained in terms of the increase in the magnetic clusters and the strengthened antiferromagnetic interaction between Fe^{3+} ions at the A and B sites accompanied by the increase in Fe^{3+} ions occupying the A sites with decreasing the particle size.

In conclusion, the magnetic behavior of ZnFe_2O_4 fine particles as a function of the particle size can be explained on the basis of the distribution of Fe^{3+} ions.

References

- [1] J. M. Hastings and L. M. Corliss, Phys. Rev. **102** (1956) 1460-1463.
- [2] F. K. Lotgering, J. Phys. Chem. Solids **27** (1966) 139-145.
- [3] S. Ligenza, Phys. Stat. Sol. (b) **75** (1976) 315-326.
- [4] T. Sato, K. Haneda, T. Iijima, and M. Seki, Proc. 6th Intern. Conf. Ferrites, (1992) 984-987.
- [5] J. S. Kouvel, and D. S. Rodbell, Phys. Rev. Letters **18** (1967) 215-218.
- [6] T. Kamiyama, K. Haneda, T. Sato, S. Ikeda, and H. Asano, Solid State Comm. **81** (1992) 563-566.