A study on anisotropic changes of $\text{MFe}_2\text{O}_4$ (M=Mn, Gd) for bio-applications.

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Introduction
The ferrite nanoparticles have long been studied due to its scientific and technological interests
with the novel magnetic properties caused by its small sizes, hyperthermia, target drug delivery,
and the magnetic resonance imaging (MRI) [1-2]. Q. Song et al. were reported to have enhanced
properties of MnFe$_2$O$_4$ for MRI reagents, when their sizes reach in nanometer scale [3].
In this study, we have characterized with the magnetic properties, hyperfine structure and indirectly
measurements for hyperthermia of MnFe$_2$O$_4$ (M=Mn, Gd).

Experiment
MFe$_2$O$_4$ (M=Mn, Gd) was synthesized by a thermal decomposition method. Manganese (II) acetyl-
lactonate (acac), gadolinium acetylacetionate and Iron(III) acetylacetionate were used as starting
materials to prepare MFe$_2$O$_4$ (M=Mn, Gd) nanoparticles. Manganese acac, gadolinium acac and
Iron(III) acac were mixed and stirred with phenyl ether with 1, 2-hexadecanediol for mono dis-
persed nanoparticles. The mixture was heated up to 200 °C to dissolve and uniformly disperse the
particles, and maintained for 30 min under Ar atmosphere. It was reheated up to 256 °C and main-
tained for 30 min to form the MnFe$_2$O$_4$. Then, it was cooled down to room temperature (RT) and
the black MnFe$_2$O$_4$ powder was obtained. The reaction with surfactants at high temperature suc-
cessfully leads to form the ferrite nanoparticles, because the reaction allows ferrite nanoparticles
to be easily isolated during the chemical reaction between byproducts and the ether solvent.

Results and Discussion
The crystal structure of MFe$_2$O$_4$ (M=Mn, Gd) was cubic spinel with space group of Fd3m by x-ray
diffraction (XRD). The high resolution transmission electron microscopy (HRTEM) was measured
to confirm the XRD measurement on the average particle sizes. The magnetization measurement
was performed with vibrating sample magnetometer (VSM). The hyperfine interaction between the
Fe and its environment in the crystal lattice was characterized by Mössbauer spectroscopy. Möss-
bauer spectrometer of the electromechanical type with a 50 mCi $^{57}$Co source in Rh matrix was used
in the constant-acceleration mode. Mössbauer spectra were taken at various temperatures ranging
from 4.2 K to RT. The drastic line broadening for the temperature dependence was observed in the
temperature dependent Mössbauer spectra. The temperature versus time of synthesized nanopar-
ticles was measured in the agar solution.
Here, we have investigated MFe$_2$O$_4$ (M=Mn, Gd) nanoparticles prepared in order to characterize
the magnetic properties and hyperthermia applications. We have observed the superparamagnetic
behaviour at room temperature and rapidly increasing relaxation frequencies with increasing tem-
perature. Also, the temperature versus time measurements in agar solution under 112 kHz and 25
mT showed that the temperature increases up to 45 °C for GdFe$_2$O$_4$ while temperature increases up
to 38 °C for MnFe$_2$O$_4$. It suggests that the gadolinium ferrite was preferable for hyperthermia bet-
ter than manganese ferrite. Also, the relaxation frequencies at RT rapidly increased with increasing
temperature due to its small sizes and thermal energy, which leads to increasing of the magnetic
anisotropy energy.