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San Diego, California

May 8-12, 2006

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CB-10

Dependence of Frequency and Magnetic field on Self Heating Effect of $NiFe_2O_4$ Nanoparticles for Hyperthermia.

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Introduction

Hyperthermia therapy in the treatment of malignant cancer cells is currently paid a great deal of attention as it is expected to provide fewer restrictive side effects compared to chemotherapy and radiotherapy [1]. Although the application of magnetic nanoparticles for hyperthermia in tumor therapy has been investigated for a several decades, there are still many practical issues to be overcome before they can be used for practical medical applications.

M. Hanson [2] conducted experiments on the frequency dependence of magnetic susceptibility and interpreted heat dissipation as a relaxation process due to Néel rotation of the magnetization direction in the nanoparticles. However, the real physical mechanism behind the temperature rise in such systems has yet to be clarified. The aim of this investigation is to study the properties of superparamagnetic (SPM) ferrite nanoparticles with a specially designed RF-induced LC-circuit system for hyperthermia in both isolated solid state nanoparticle powders and cell culture media. The effect of nanoparticle quantity, as well as the magnetic field strength and operating frequency, on the maximum temperature rise for hyperthermia applications was studied. Besides the physical and magnetic properties of the nanoparticles, the physical origin of temperature rise and specific absorption rate will be considered to explore the possibility for real clinical treatments.

Experiment

$NiFe_2O_4$ nanoparticles with various sizes were prepared by sol-gel and high temperature thermal decomposition methods (HTTDM). Oleic acid and oleylamine were added in the solutions to obtain high quality nano-powder samples. A wave function generator, high frequency amplifier, and magnetic LC coils were used for the self-heating experiments. The frequency and magnetic field dependence of temperature rise were measured at various magnetic field frequencies and magnetic field strengths. The frequency dependence of temperature increase in self-heating experiments was measured under fixed magnetic field of 80 Oe, and the magnetic field dependence was measured with frequencies of 40 kHz and 110 kHz.

Results and Discussions

Figure 1 shows the dependence of applied magnetic field on the maximum temperature rise at fixed frequency. As can be seen in Fig. 1, the temperature was rapidly increased up to 72.6°C depending on the applied magnetic field within 100 sec. stressing time. According to the results in Fig. 1, it is suggested that increasing the magnetic field can increase the magnetic energy barrier of $NiFe_2O_4$ nanoparticles which resulted in the acceleration of the Néel relaxation[2]. Figure 2 shows the frequency dependence of maximum temperature rise. It is revealed that maximum temperature rise is linearly proportional to the applied frequency, which strongly proves that the initial stage of the temperature rise of $NiFe_2O_4$ nanoparticles is dominantly induced by Néel relaxation rather than Brownian relaxation. As can be confirmed in Fig. 1 and 2, the saturated temperature rise is plausibly thought to be due to Brownian relaxation and reduction of temperature caused by the surface magnetization relaxation of the nanoparticles. With regards to verifying the contribution of Brownian rotation and surface magnetization behavior on temperature rise, experiments are still in progress using systems with different viscosities.

In conclusion, $NiFe_2O_4$ shows promising temperature rise characteristics for hyperthermia. According to the test results, nanosize-controlled $NiFe_2O_4$ can provide effective temperature rise characteristics even at lower frequencies and magnetic fields, which are suitable for the treatment of human patients. [1] P. Moroz, S. K. Jones, and B. N. Gray, Int. J. Hyperthermia 18, 267 (2002)
[2] M. Hanson, J. Magn. Magn. Mater. 96, 105 (1991)

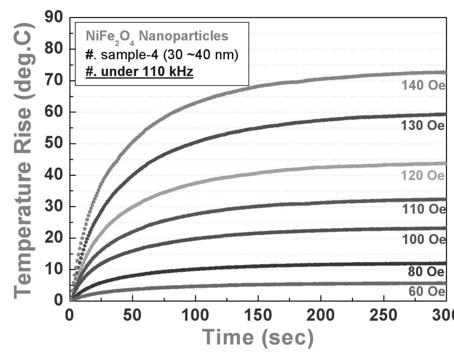

Figure 1. Temperature rise results of the magnetic field dependence of $NiFe_2O_4$ nanoparticles under a fixed frequency of 110 kHz

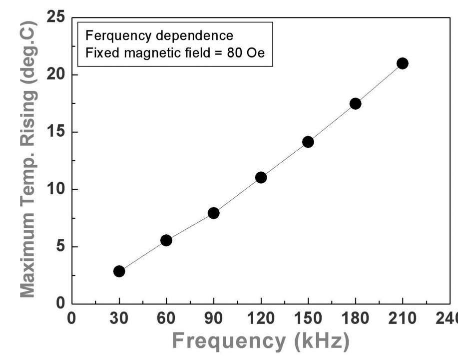

Figure 2. Maximum temperature rise vs. frequency of $NiFe_2O_4$ nanoparticles under a fixed magnetic field of 80 Oe