Distribution of Magnetic Nanoparticles Anisotropy Energy Estimated from AC Susceptibility and Magnetic Relaxation

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Magnetic nanoparticles (MNPs) have been extensively studied for applications in biomedicine such as magnetic immunoassay, magnetic particle imaging and hyperthermia. For these applications, one of the key parameters of the MNPs is its anisotropy energy *E*. This is due to the strong dependence of the Néel relaxation time of MNPs on the value of *E*. Hence, the anisotropy energy *E* of MNPs should be appropriately selected in order to be suitable for the intended application. Therefore, estimation of the *E* distribution in MNP samples is significantly important to develop MNPs that are suited for specific applications. Distribution of *E* can be estimated by analyzing experimental measurement results of the magnetic properties for MNP samples, i.e., the AC susceptibility (ACS) and the magnetic relaxation (MRX) of immobilized MNP sample [1].

In this work, the distribution of anisotropy energy *E* was estimated from the frequency dependence of the ACS for immobilized MNP sample that was measured from 10 Hz to 1 MHz. The distribution of anisotropy energy *E* was estimated by analyzing experimental result using a method published previously [2]. Next, the AC susceptibility measurement in much lower frequency range was substituted by the MRX measurement. For relaxation measurement, immobilized MNP sample was first magnetized with an excitation field of 40 mT. After the excitation field was turned off, magnetic relaxation of MNP sample was measured from 2 to 10^4 s. This time range corresponds to the frequency range from 10^{-4} to 0.5 Hz in the AC susceptibility measurement. The relaxation curve was analyzed using a newly developed analytical method to estimate the *E* distribution of the MNPs in the range of large *E* values. The distribution of *E* estimated from the ACS and MRX was expressed by *E* vs. $n(E)E^2$ curve, where *n(E)* represents the number of MNPs with *E* value.

Figure 1 represents the estimated *E* vs. $n(E)E^2$ curve obtained in this manner for commercial MNP sample of (SHP25, Ocean Nanotech). The estimated *E* vs. $n(E)E^2$ curve from ACS is shown by circle markers, which we were able to estimate in the region of 3.7×10^{-20} J < *E* < 6.7×10^{-20} J. The obtained *E* vs. $n(E)E^2$ curve from MRX is shown by triangle markers, which we can estimate the distribution of *E* in the region 9.5×10^{-20} J < *E* < 1.3×10^{-19} J. The proposed method can be useful to estimate core size distribution of MNP samples.

References

1) F. Ludwig *et al*., *J. Magn. Magn. Mater*., 360, pp. 169-173, 2014
2) Enpuku *et al*., *J. Appl. Phys.* **119** 184902 (2016).

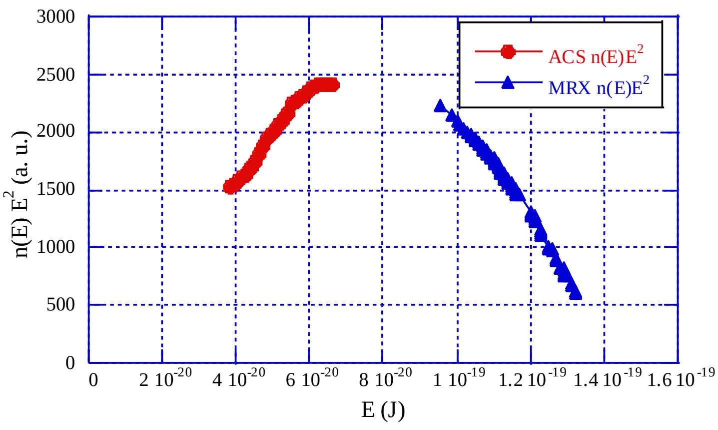

Fig. 1: Estimated *E* vs. $n(E)E^2$ curve. Circle markers were obtained from the ACS measurement, while triangle markers were obtained from the MRX measurement.