Magnetic nanoparticles and superparamagnetic resonance (3)
" Parallel pumped spectrum of magnetic nanoparticles "

Product used : Electron Spin Resonance spectrometer (ESR)
Dual mode cavity (ES-14040DMC)

Harmonic resonant lines of magnetic nanoparticles

Magnetic nanoparticles (MNPs) like magnetite (Fe_3O_4) and maghemite (γ-Fe_2O_3) show "superparamagnetism". Especially, unique superparamagnetic resonance (SPR) can be observed below 10 nm diameter[1][2]. Characteristics on SPR spectra of these MNPs is that multi-harmonic resonant lines at the position of $B_0 = {}^{B_0}/_{k}$ (k = 2,3,4 …) are observed, where B_0 is the magnetic field at g = 2. These positions correspond to g = 4,6,8,...n (n is an even number). Noginova *et al*. proposed these multi-lines as a multiple quantum transition modeled by the total magnetic moment in a particle and the dipole-dipole interaction between particles[2]. In paramagnetic resonance, we can sometimes observe the forbidden transition of Δm_s=±2 and the allowed transition of Δm_s=±1 simultaneously, in the case of S > 1. This transition of Δm_s=±2 is called as "multiple quantum transition". Noginova *et al.* regarded the multi-lines of MNPs similarly as the multiple quantum transitions[2]. As is well known, the measurements of parallel pumped spectra are one of the selective detection methods for the forbidden transitions. The parallel mode uses a high frequency magnetic field parallel to the static magnetic field. Using dual mode cavity (ES-14040DMC) can measure two types of spectra by switching the perpendicular and parallel modes. Figures 1 (b) and (d) show perpendicular and parallel pumped spectra of a paramagnetic sample (ultramarine blue powder) as an example for the mode check. Because the spectrum of the Lorentzian shape shown in Fig.1 (b) is the allowed transition, it can hardly be observed in parallel mode as shown in Fig.1 (d). However, a tiny leak signal is observed at the degree of 1/1200 due to a misalignment of B_1 direction. A spectrum shown in Fig. 1 (c) is a parallel pumped spectrum of MNPs with diameter of 5 nm. Small peak level observed at g = 2 decreased to 1/1500 compared to the perpendicular mode. Therefore, this signal can be interpreted as an allowed transition. However, multi-absorption lines at g=4,6,8,10 can be regarded as multiple quantum transitions responded to parallel irradiation, because a signal ratio of these lines to the line at g = 2 is completely different compared to the perpendicular mode. Consequently, parallel pumping measurements can be expected to be very useful for exploring electron states affected by the unknown size effect.

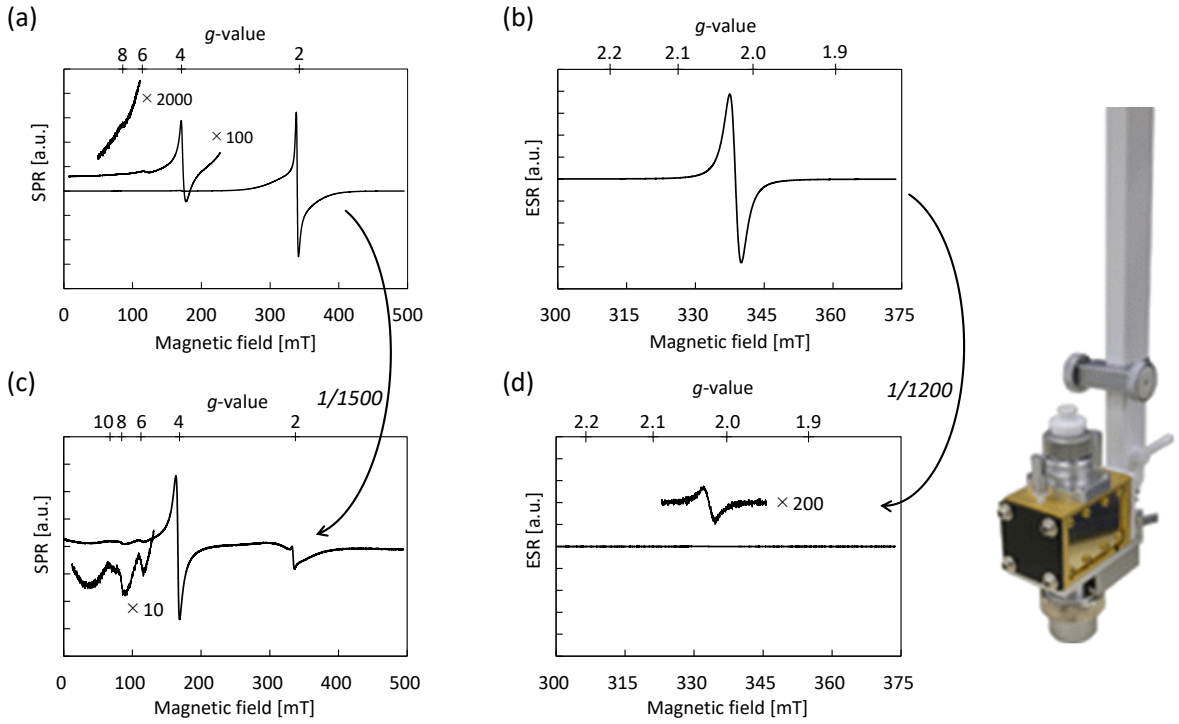

Fig. 1 SPR dual mode spectra of Fe_3O_4 magnetic nanoparticles dispersion in toluene (5 nm diameter, 1.25 mg / mL) and ESR dual mode spectra of ultramarine blue powder. (a) Perpendicular excitation mode of Fe_3O_4 – MNP, (b) Perpendicular excitation mode of ultramarine blue, (c) Parallel excitation mode of Fe_3O_4 – MNP, and (d) Parallel excitation mode of ultramarine blue. All spectra were obtained using dual mode cavity (ES-14040DMC) shown in photo.

Reference: [1] M. M. Noginov *et al.*, Journal of Magnetism and Magnetic Materials, **320**, 2228-2232 (2008).
[2] N . Noginova *et al.*, Phys. Rev. B **77**, 014403 (2008).

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