Temperature dependence of FMR spectra of γ-Fe_2O_3 agglomerated nanoparticles in glue

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Abstract

Three samples of magnetic nanoparticles γ-Fe_2O_3 (with an average size of about 10 nm) forming three differently sized agglomerates in glue were prepared. Sample 1 contained agglomerates with diameter 1.5 mm, sample 2 contained smaller agglomerates, 0.5 mm in diameter, and sample 3 still smaller, below 0.2 mm. At room temperature the position of the FMR (ferromagnetic resonance) line is centered at about g_{eff}~2 what is essentially different from the position of FMR line found in small size agglomerates. The temperature dependence of the FMR spectra has been carried out. A very interesting behavior of the FMR spectral parameters was observed. The resonance field was strongly dependent on temperature in both investigated samples but the thermal dependence of other FMR parameters was strongly influenced by the size of agglomerates.

Introduction

Magnetic dipole interactions is one of the more expressive and from application using where from early ages on the macroscopic level is demonstrated in the schools. Now in the many order lower sizes (on the nano-sizes) this interaction is extensively investigated in the dispersed in different matrixes [1-13]. The ferromagnetic resonance (FMR) is unique method for studying the above interaction in different matrixes. The phenomena is quantum but the magnetic dipole-dipole interaction is the same without electronic structure of matrix. It is given possibility study the so called spin-glass state with superparamagnetism processes. Iron oxides nanoparticles, specially ferrimagnetic maghemite (-Fe_2O_3) in different matrixes attract the great interesting for studying magnetic interaction because the relatively narrow FMR lines at high temperatures could allow the better understudying dynamical processes between lattice and magnetic moments. The shifting resonance lines connected with internal magnetic field is given information about interagglomerates, between agglomerates and demagnetization processes. The internal magnetic field "seeing" by magnetic nanoparticles strongly dependent from concentration and the sizes of agglomerates where [12-16]. The low concentration magnetic nanoparticle or agglomerates in different matrixes have shown the different position of the resonance FMR lines at room temperatures where the higher sizes of the magnetic agglomerates is given lower values [17].

The aim of this report is temperature dependence of FMR spectra of glues TEC 4185H filled by nanoparticles in agglomerate states γ-Fe_2O_3 to order to estimate interagglometes magnetic interactions and demagnetization processes. The analytical calculation is impossible because the values of internal magnetic field "seeing" by magnetic nanoparticles is possessed very low values.

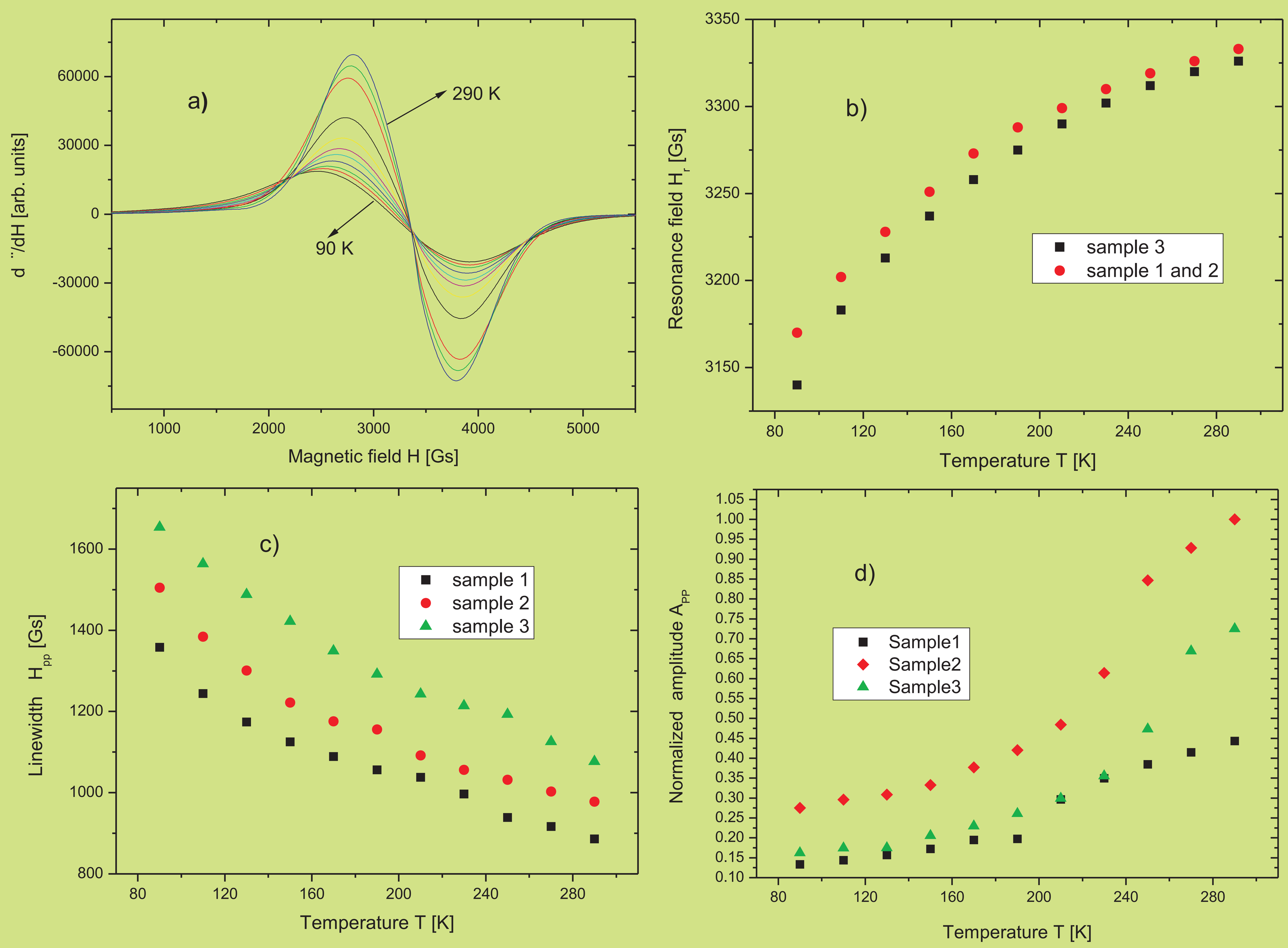

Figure 1. (a) The FMR spectra for sample 1 at different temperatures; (b) temperature dependence of the resonance field; (c) temperature dependence of the linewidth; (d) temperature dependence of amplitude.

Experimental

Three samples of magnetic nanoparticles (an average size 10 nm) of γ-Fe_2O_3 in agglomerated form (sizes 1.5 mm – sample 1, 0.5 mm – sample 2, and 0.2 mm – sample 3) mixed in glues as thing film TEC 4185H modified acrylic have been prepared. The process of preparation has been described previously [6, 7]. The glue TEC 4185H has been synthesized from modified acrylic PSA with the following constituents: 51.0 wt.% 2-EHA, 45.5 wt% BA, 3.5 wt% AA and added 30.0 wt% polyterphene phenolic resin to the polymer mass.

Ferromagnetic resonance measurements (FMR) were carried out on a conventional X-band (ν=9.43 GHz) Bruker E 500 spectrometer with 100 kHz magnetic field modulation. The measurements were performed in the temperature range of 90 to 300 K using an Oxford nitrogen flow cryostat. A square-shaped sample of 2.0 2.0 mm^2 cut out from a polymer sheet was attached to a sample holder made of a quartz rod 4 mm in diameter. The sample holder was accommodated in the center of the TE_{102} cavity, i.e., at the local maximum of the microwave magnetic component H_1 and in the nodal plane of the electric component E_1. Prior to the measurements, samples have been magnetized by a steady magnetic field of 1.6 T to saturate any domain structure.

Results and discussion

Figure 1a presents the temperature dependence of FMR spectra for sample 1. A slightly asymmetrical and a very intense FMR line is recorded for all three investigated samples. The registered FMR spectra have possessed similar temperature dependence and the same resonance field at room temperature as in [17]. The FMR line has been fitted by Lorentzian function for used temperatures. For description of FMR spectra of γ-Fe_2O_3 in glue the following parameters were introduced: H_L, H_R and $H_r=(H_L+H_R)/2$ where they are the left, the right peak positions of the line and the effective resonance field position, respectively [6]. Comparison of the resonance fields obtained for all samples has shown that they are almost the same and are centered near $g_{eff}=2$ at room temperature.

Figures 1b, 1c and 1d show the temperature dependence of the resonance field (H_r), linewidth (ΔH), and signal amplitude (A_{pp}). All parameters of the FMR spectra for three samples strongly depend on temperature. The resonance field shifts towards lower magnetic field with decreasing temperatures. This trend for samples 1 and 2 is similar while for sample 3 is essentially stronger **(Fig. 1b)**. The temperature dependence of the linewidth is similar (increases with temperature decrease) for all samples **(Fig. 1c)** but the linewidth differences have the following values; ΔH_2-ΔH_1=98 Gs (between samples 2 and 1), ΔH_3-ΔH_2=86 Gs (between samples 3 and 2) at room temperature, and ΔH_2-ΔH_1=146 Gs, ΔH_3-ΔH_2=157 Gs at 90 K. The amplitude decreases with decreasing temperature and the biggest change is observed for sample 2.

The values of resonance field and the linewidth for sample 3 are almost the same as for γ-Fe_2O_3 large agglomerates of nanoparticles embedded in polymer matrix [14]. At high temperatures the gradient $\Delta H_r/\Delta T$ is about 1.5 times greater than for small sized aggregates of γ-Fe_2O_3 [13,15,16]. The resonance condition could be written by the following relation: $h\nu = g_{eff}\,\mu_B\,H_r$, where h is the Planck constant, ν is the resonance frequency, μ_B is Bohr magneton. The resonance field could be created as a result of the following magnetic interactions: $H_r = H_o + H_{dip} + H_{Dem} + H`_{dip}$, where $H_o$ is the applied external magnetic field, $H_{dip}$ is an internal magnetic field of dipole-dipole interaction between agglomerates, $H_{dem}$ is an internal magnetic field from the demagnetization, $H`_{dip}$ is an internal magnetic field from dipole-dipole interaction between magnetic nanoparticles. The last three terms are very small at room temperature and only terms H_{dip} or H_{Dem} are important. Registered small increase of the internal magnetic field at low temperature **(Fig. 1b)** suggests that the term $H`_{dip}$ could play an important role for sample 3.

The obtained values of linewidth indicate that the increasing broadening is connected with the decreasing sizes of agglomerates. This could influence the magnetic dipole-dipole interaction which becomes intense at lower temperatures. A strong temperature dependence of the amplitude for smaller agglomerates could be connected with the reorientation processes. The FMR method is measured quantum phenomena and it is seeing the "mechanical strength" could be very important for reorientation/relaxation processes.

Conclusions

A strong temperature dependence of the FMR spectra of γ-Fe_2O_3 magnetic nanoparticles in large size agglomerates has been recorded. The inter-magnetic dipole interaction and the demagnetization effect are important for the above agglomerates. The orientation/relaxation processes are depended essentially on the type of host material.

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