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MOLAR SPIN-SUSCEPTIBILITY MEASUREMENT OF MAGNESIUM FERRITE NANOPARTICLES USING ELECTRON SPIN RESONANCE STUDY

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ABSTRACT

The Electron Spin Resonance of Magnesium ferrite nanoparticles was studied. Depending on the temperature, Electron Spin Resonance spectrum was deconvoluted into two different signals. The temperature independent Electron Spin Resonance signal intensity and its magnitude lead to the Pauli spin-susceptibility whereas temperature dependent Electron Spin Resonance signal intensity and its magnitude lead the Curie spin-susceptibility. Electron Spin Resonance linewidth of Pauli was weakly increases with increasing temperature but for Curie it was decreased. From Pauli and Curie spin-susceptibilities density of states of Magnesium ferrite nanoparticles were calculated. This density of states of Magnesium ferrite increased with increasing temperature. This raise in density of states was more reliable property which could be used in spintronics applications.

Keywords: Nanoparticles, Electron Spin Resonance, Curie spin-susceptibility, Pauli spin-susceptibility

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1. Introduction

Identification of an Electron Spin Resonance (ESR) signal originating from free electrons in a metal surface depends on the following factors (i) the value of the measured spin-susceptibility should match the Pauli spin-susceptibility, which is related to the density of state. (ii) The temperature dependence of the signal intensity should be characteristically different from the Curie, i.e. 1/T dependence. (iii) For a metal with inversion symmetry, the line width should increase with increasing temperature [1]. In this study, the electron spin resonance (ESR) of Magnesium ferrite nanoparticles was studied under different temperatures from 103 – 423 K. In this temperature range four ESR signals observed with a temperature dependence which is characteristic for localized paramagnetic centers. In addition, an ESR signal, which is assigned to conduction electrons, is observed. The identification is made by examining the signal intensity and its temperature dependence, which cannot be explained by localized spins. The calibrated signal intensity yields the Pauli spin-susceptibility whose experimental value leads to calculate the density of states of Magnesium ferrite nanoparticles.

2. Experimental

In the co-precipitation method, an aqueous solution of Magnesium chloride and aqueous solution of ferric chloride was prepared with Fe-to-Mn mole ratio of 2:1. An aqueous solution of sodium hydroxide was used as the precipitant agent. The desired amount of aqueous solution of Magnesium chloride and ferric chloride were taken and subjected to stirring using a magnetic stirrer for half an hour. Under stirring, the aqueous solution of sodium hydroxide was added drop wise to the mixed solution until a pH = 11.5 was reached. The liquid precipitate was then brought to reaction temperature of 80°C and stirred for 1 h. The product was then cooled to room temperature. The precipitates were filtered and washed several times

with deionised water. Finally, the precipitated powders were dried overnight using an oven at 80°C in order to remove excess water. The resulting material was annealed 800°C for 5 h [2]. ESR experiments were carried out on finely powder samples using a JES FA200 ESR spectrometer.

3. ESR Intensity Calibration

ESR spectroscopy measures the net amount of magnetic moments, which is proportional to the sample amount. In order to gain information on the corresponding sample spin-susceptibility **(χ_s),** the ESR intensity of an unknown material must be calibrated against a Curie spin system with known amount of spins [1].

The molar Curie spin-susceptibility

$$\chi_s(\text{Curie}) = \frac{g^2 S(S+1)\mu_B^2}{3k_B T}.\ N_A \qquad (1)$$

Where S denotes the spin state of the non-interacting spins, μ_B is the Bohr moment, k_B is the Boltzmann constant, and N_A is the Avogadro number. The Pauli spin-susceptibility for itinerant electrons in a metal is

$$\chi_s(Pauli) = \frac{g^2 \mu_B^2}{4} D(E_F).\mathrm{N}_A \qquad (2)$$

Where $D(E_F)$ denotes Density of States at the Fermi energy. The spin-susceptibilities are related to the ESR intensity as

$$I_{ESR} \propto \Sigma\, m = B_{res}\ \chi_s\ .\ n \qquad (3)$$

Where n is the amount of the sample and B_{res} is the magnetic field of the resonance. Therefore, the comparison of the ESR intensity of an unknown material with electrons to a known amount of Curie spins yields

$$\frac{I_{ESR}(Pauli)}{I_{ESR}(Curie)} = k_B T D(E_F) \frac{n\,Pauli)}{n(\text{Curie})} \qquad (4)$$

Equ (4) can be used to determine the Density of States at the Fermi energy [3].

4. Result and Discussion

The X-band ESR spectrum of Magnesium Ferrite nanoparticles at different temperatures from 103 - 423 K range were shown in Fig.1. These spectrums reveal the high spin-spin relaxation nature due to its high line width. These derivative ESR spectrums integrated and deconvoluted into two different signals. This was shown in Fig.2 for the ESR spectrum of 103 K. In this *A* signal dominates the integrated spectrum due to its large linewidth. The broader lines are suppressed compared to the narrower ones in the ESR. Thus the integration visually enhances the broader components [4]. The signal *A* is a strongly asymmetric Lorentzian, with an equal mixture of dispersion and absorption components. This ESR line-shape is usually encountered in metals when the itinerant electrons relax their spin state [5]. The linewidth of the *A* signal weakly increases with temperature whereas *B* signal line width decreased with temperature and exhibit a Curie temperature dependence which is characteristic for localized, paramagnetic centers. This was illustrated in Fig.3. The linewidth of *A* increases by a factor that this signal would originate from the itinerant conduction electrons of Magnesium ferrite not from localized spins. This is due to that on increasing temperature the microwave penetration depth increases due to the increasing resistivity thus resulting in an increasing signal A [6,7]. So signal A associate with temperature independent Pauli spin-susceptibility of itinerant electrons. In Fig.4 spin-susceptibilities of A and B signals were plotted against temperature. This would confirm that A definitely not from local spins also B strongly exhibit a curie spin-susceptibility against temperature. Magnitude of Pauli spin-susceptibility used to find the density of states in Magnesium ferrite nanoparticles by using the above equations. In Fig.5 density of states plotted against temperature. With rise in temperature density of states also increased. This was purely due to Pauli spin-

susceptibility nature of conduction electrons in Magnesium ferrite nanoparticles.

5. Conclusion

Magnesium ferrite nanoparticles were synthesized by co-precipitation process and characterized by powder XRD. ESR experiments were carried out for 103-423 K temperature range with four particular temperatures. From the ESR spectrum, identification of conduction electrons signals could be analysed which leads to the Pauli spin-susceptibility nature. This temperature independent character from conduction electrons differ from conventional temperature dependent Curie spin-susceptibility. From the values of Pauli spin-susceptibility, density of states of Magnesium ferrite nanoparticles could be calculated which increased with increasing temperature. This increasing density of states property could be expected for some useful applications in spintronics.

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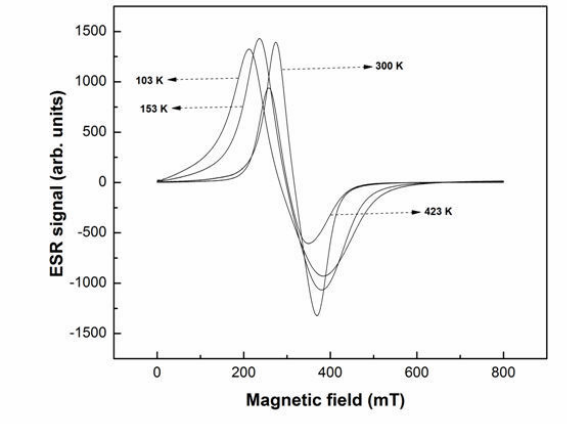

Fig. 1 Electron Spin Resonance spectrum of Magnesium ferrite nanoparticles at different temperatures.

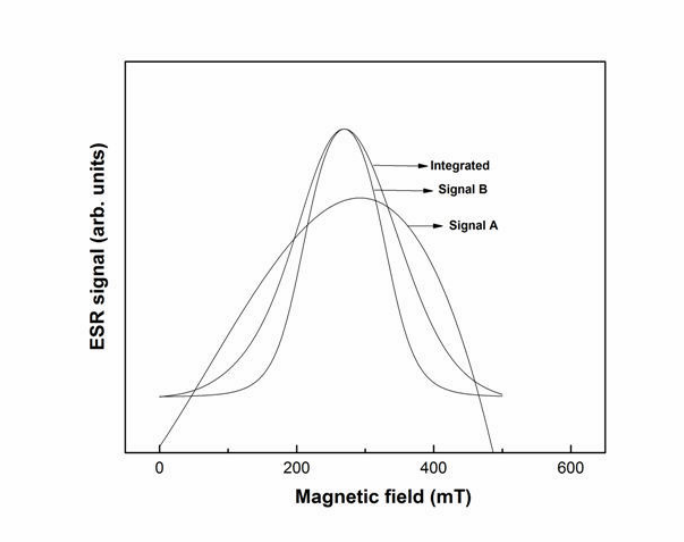

Fig. 2 Integrated fit spectrum at 103 K

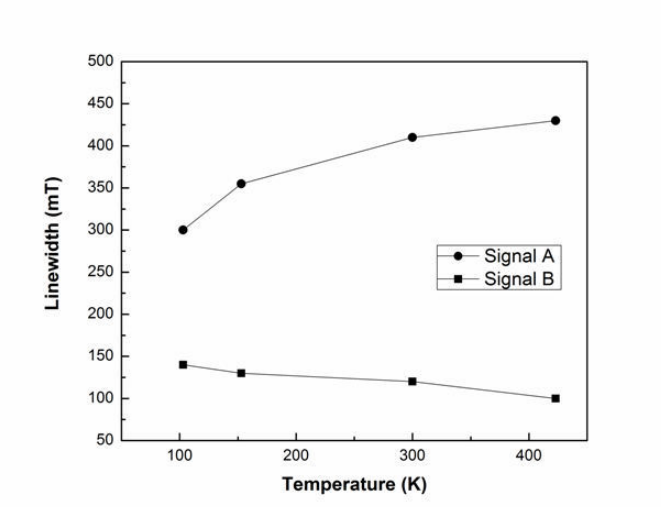

Fig. 3 Electron Spin Resonance linewidth of signal A and signal B

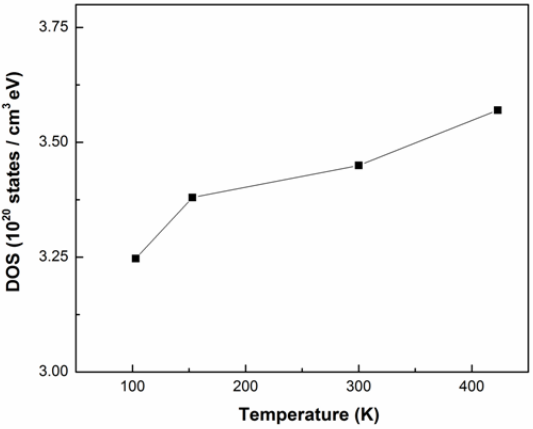

Fig. 4 Curie and Pauli spin-susceptibility obtained from Electron Spin Resonance signal intensity.

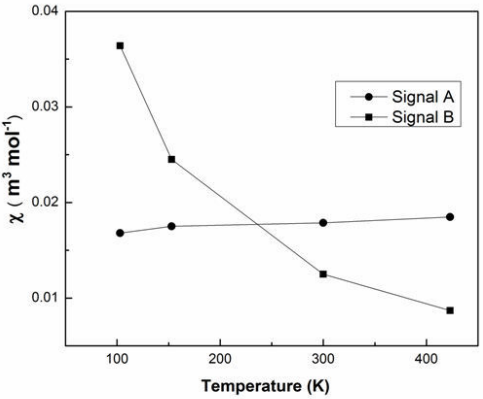

Fig. 5 Density of states in Magnesium ferrite nanoparticles.