Study of Magnetic Properties of Magnesium Doped Zinc Ferrite Nanomaterials

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Abstract: *This study describes the synthesis of magnesium-doped zinc ferrite nanomaterial by sol-gel auto combustion process. Using a vibrating sample magnetometer, the magnetic characteristics of the produced nanomaterial were measured, and various magnetic properties were determined and discussed in the light of crystal structure and cation distribution.*

Keywords: Connective tissue disorders, cutaneous manifestations, systemic manifestations, ANA

1. Introduction

The fields of nanoscience and nanotechnology have made significant advancements in the current scenareo. Nanomaterials are defined as substances containing particles, grains, fibres, or other constituents with at least one dimension in the realm of the nanoscale (1 nm to 100 nm). Nanoscale materials have distinct characteristics that are not apparent in their bulk phase [1]. A reduction in size is the cause of the modifications that have been seen. There are two main elements that emerge and play significant roles when the size of the material decreases. The surface-to-volume ratio is one, while quantum effects are the other. When a material's size is reduced to the nanoscale, its surface area, surface roughness, and surface area to volume ratios all suddenly increase, giving it better physiochemical properties like mechanical, electrical, optical, catalytic, magnetic, and so on. As a result, a variety of applications for nanomaterials with such exceptional features have been thoroughly investigated.

Nanomaterials are generally made of metals, ceramics, polymers, organic materials, and composites. Therefore, just like conventional or micron-structured materials, nanomaterials include nanofilms, nanorods nanowires, nanofibers, nanoclusters, nanoparticles, nanocrystals, nanotubes, etc. [2]. Among these nanomaterials, magnetic nanomaterials have a unique position because of their application in the diverse fields of science and technology. On the basis of their interaction with the applied magnetic field, diamagnetic, paramagnetic, ferromagnetic, antiferromagnetic, and ferrites are magnetic materials. In these magnetic materials, ferrites possess excellent magnetic, electrical, and dielectric properties that cannot be found simultaneously and in such a fashion in other magnetic materials described above. Ferrites are ceramic materials composed of iron oxide and metal oxides. Iron oxide is the main constituent of the ferrites. Ferrites are thermally and chemically stable. Ferrites with these properties have many applications, such as in magnetic cores, magnetic recording heads, transformer cores, microwave, ferrofluids, magnetic resonance imaging (MRI), drug delivery, photocatalysis, drug delivery, phase shifters, gas and humidity sensors, etc.[3-5]. Generally, ferrites nanomaterials are found in three structures: spinel, hexa, and garnet. We'll concentrate on the spinel ferrite structure in this section.

The typical formula for spinel ferrite nanoparticles is MFe_2O_4, where M is a divalent ion such as Zn^{2+}, Co^{2+}, Ni^{2+}, Cd^{2+}, Mg^{2+}, etc. [6]. Metal ions occupy the tetrahedral (A) and octahedral (B) sites created by the oxygen atoms in the spinel ferrite structure, which is an FCC lattice. At the tetrahedral site, a metal cation is bonded to four atoms, but at the octahedral site, it is bonded to six atoms. Metal cations appear in different ways depending on which locations they are present. Spinel is referred to as normal when the divalent metal cations occupy a tetrahedral location (A). On the other hand, spinel is referred to as inverse when divalent metal cations occupy an octahedral position (B). Between the two extremes of normal and inverse, there is a third form known as mixed spinel, in which the distribution of divalent and trivalent metal cations is random. [7]

Spinel ferrite's magnetic characteristics are influenced by a number of factors, including type, cation concentration, synthesis technique, annealing temperature, and atomic composition. As is well known, zinc ferrite ($ZnFe_2O_4$) is a normal spinel ferrite while magnesium ferrite ($MgFe_2O_4$) is an inverted spinel ferrite [8]. The magnetic characteristics of the synthesized nanomaterial magnesium doped zinc ferrite are significantly influenced by the distribution of the divalent metal cations Mg^{2+} and Zn^{2+} on distinct lattice sites, specifically tetrahedral (A) and octahedral(B). There is consequently a widespread interest in how the magnetic characteristics of produced nanomaterials vary with various magnesium doping amounts.

In the current study, magnesium-doped zinc ferrite nanomaterial was created utilizing the sol-gel auto combustion method, and a vibrating sample magnetometer (VSM) was used to assess its magnetic properties

2. Experimental Methods

For the synthesis process, the sol-gel auto-combustion approach was used. Citric acid with a purity of 99.8%, ferric nitrate ($Fe(NO_3)_3.9H_2O$) with a purity of 98%, zinc nitrate ($Zn(NO_3)_2.6H_2O$) with a purity of 99%, magnesium nitrate ($Mg(NO_3)_2.6H_2O$) with a purity of 98.5%, and Alfa Aesar's (Merk India) and Fizmerk India's

(Merk India These substances were added in the proper stoichiometric ratio to 100 mL of DI water and then dissolved. The prepared solution had a metal nitrate to citric acid ratio of 1:3. To keep the pH level at 7, ammonia was added dropwise while the mixture was continually agitated at 80 °C for one hour. The final mixture underwent three hours of continuous stirring heating at 235 °C on a hot plate. Currently, the solution is beginning to change into a gel form, which after a period of time spontaneously burns and turns into ash. This ash was cooled down to room temperature, ground by mortar and pestle, and converted into the form of powder. This powder was kept in the furnace at 600 °C for 5 hours for calcination. This calcined powder was used for further analysis [9]. The vibrating sample magnetometer (VSM) was applied for the investigation of magnetic properties.

3. Result and Discussion

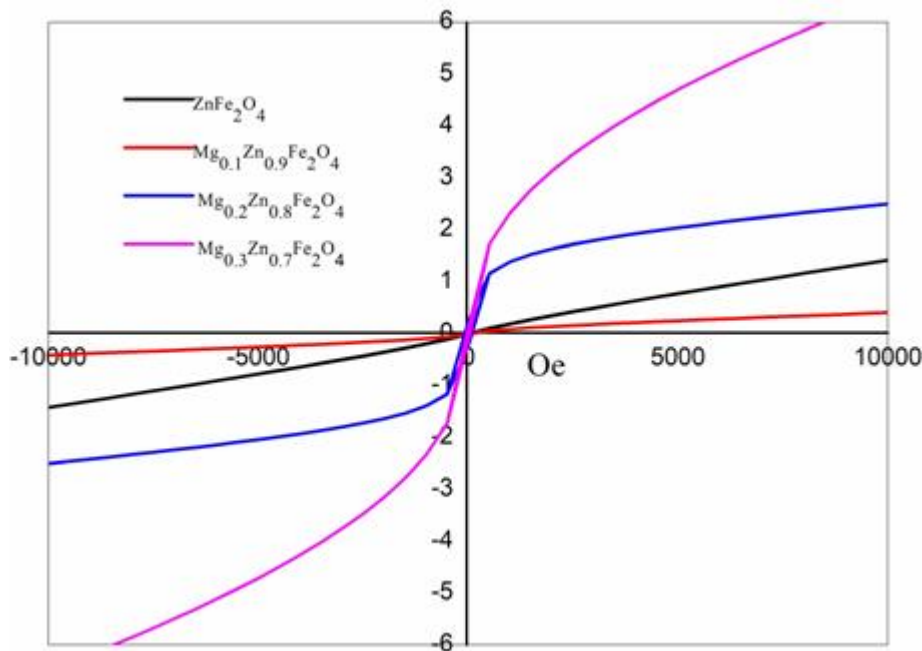The magnetic properties of the produced nanomaterial were measured using a vibrating sample

Figure 1: Hysteresis plots of $Mg_x Zn_{1-x} Fe_2 O_4$ (x = 0.0, 0.1, 0.2, and 0.3)

magnetometer (VSM) at room temperature with an applied field range of -10 to +10 kOe. The hysteresis plots for nanocrystalline $Mg_x Zn_{1-x} Fe_2 O_4$ (x = 0.0, 0.1, 0.2, and 0.3) are shown in Fig.

These graphs show how magnetization (Ms, emu/g) varies in relation to the applied magnetic field (H, Oe). The produced nanomaterial has a soft magnetic character, as evidenced by the low coercivity (Hc) value, and its magnetic properties, such as saturation magnetization (Ms), remanent magnetization (Mr), and coercivity (Hc), dramatically alter when Zn^{2+} ions are replaced by Mg^{2+} ions [10]. It is evident from the hysteresis plot that the value of Ms rises as the concentration of magnesium ions does (expect x=0.1). The levels of saturation magnetization (Ms) rely on how the Fe^{3+} ions are distributed between the tetrahedral and octahedral sites because Zn^{2+} and Mg^{2+} are not magnetic by nature. The figure clearly demonstrates that the samples of $ZnFe_2 O_4$ and $Zn_{0.9} Mg_{0.1} Fe_2 O_4$ with lower Mg concentrations (x = 0.0 and 0.1) exhibited superparamagnetic behaviour. According to this, Zn^{2+} ions occupied the tetrahedral sites and Fe^{3+} ions the octahedral sites whereas the dopant Mg^{2+} ions occupied either the octahedral or tetrahedral sites [11], exhibiting superparamagnetic behaviour.

Table 1: Magnetic parameters of MgxZn (1-x) Fe2O4 (where, x =0.0 0.1, 0.2 and 0.3)

Magnesium concentration (x)	Saturation magnetization (Ms) in emu/g	Remanence (Mr) in emu/g	Coercivity (Hc) (Oe)	Reduced Remanence S=Mr/MS
0.0	1.4208	0.01062	22.64	0.000469
0.1	0.4108	0.01485	89.46	0.000166
0.2	2.5097	0.29074	91.23	0.003187
0.3	6.4952	0.20038	39.54	0.005068

Ms values are 2.5 and 6.4 emu/g, respectively, for samples of $Zn_{0.8} Mg_{0.2} Fe_2 O_4$ and $Zn_{0.7} Mg_{0.3} Fe_2 O_4$. Because of the higher magnesium concentration, there is a rise in the ferromagnetic behaviour. The highest value of Ms recorded was 6.4 emu/gm. Due to super exchange interactions, the non-collinear nature of moments in the B-site, the imbalance of Fe^{3+} ions in the octahedral (B) and tetrahedral (A) sites, and the increase of the net magnetization (Ms) with increasing Mg concentration [12,13], the net magnetization increases with increasing Mg concentration. The graph

demonstrates that the curve at x = 0.3 exhibits unsaturation. It might be because the atoms at the surface have shortened bonds and poor coordination among themselves. The mutual exchange interaction is lessened by such surface disarray. This surface disorder is caused by bond frustration of exchange contact between ferrimagnetically linked spins of various sublattices close to the surface [20]. Due to the high surface-to-volume ratio, such disorder and agitation at the nanoparticle's surface become increasingly prominent as the particle size decreases. Table 1 shows that the value of remanence (Mr) and coercivity (Hc) increases with the concentration of magnesium (except x=0.3).

4. Conclusion

Ferromagnetic behaviour increases with Mg cation doping, changing the form of MH- loops. The change in the cationic distribution at tetrahedral and octahedral sites is responsible for the progressive rise in magnetization at maximum field with increasing Mg content. Smaller coercivity values reveal the soft magnetic properties of these ferrite nanoparticles. The rearrangements of divalent metal cations at various lattices are inferred to cause various variations in the characteristics of Mg-doped Zn-ferrite nanoparticles.

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