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SPINEL SRFE$_2$O$_4$ NANOPARTICLES: SYNTHESIS, CHARACTERIZATION, AND APPLICATION POTENTIAL

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ABSTRACT

Spinel SrFe$_2$O$_4$ nanoparticles were successfully synthesized using a simple and cost-effective microwave heating method. The prepared samples were characterized using X-ray diffraction (XRD), energy-dispersive X-ray spectroscopy (EDX), Fourier-transform infrared spectroscopy (FT-IR), high-resolution scanning electron microscopy (HR-SEM), and vibrating sample magnetometry (VSM). The XRD, EDX, and FT-IR analyses confirmed the formation of a pure single-phase spinel structure with no secondary phase impurities. SEM images revealed that the nanoparticles exhibit a predominantly spherical morphology. Magnetic measurements performed using VSM indicated superparamagnetic behavior, with a saturation magnetization (Ms) value of 0.153 emu/g for the SrFe$_2$O$_4$ nanoparticles.

INTRODUCTION

Spinel ferrite nanoparticles have attracted significant attention in recent years due to their remarkable magnetic, electrical, optical, and catalytic properties, making them highly versatile for applications in data storage, sensors, biomedical devices, and photocatalysis. Among these, strontium ferrite (SrFe$_2$O$_4$), a member of the orthorhombic spinel ferrite family, has emerged as a promising material owing to its multiferroic behavior, thermal stability, and magnetic tunability at the nanoscale.

The synthesis method plays a crucial role in determining the structural and functional properties of SrFe$_2$O$_4$ nanoparticles. Conventional methods such as sol-gel, hydrothermal, and microemulsion routes have been widely employed to prepare ferrite nanoparticles; however, they often involve lengthy processing times and multiple steps. In contrast, microwave-assisted synthesis offers a rapid, energy-efficient, and uniform heating mechanism that facilitates the formation of homogeneous, phase-pure nanoparticles with controlled morphology and reduced particle size. Recent studies have demonstrated that SrFe$_2$O$_4$ nanoparticles exhibit superparamagnetic behavior when synthesized at the nanoscale, which is highly desirable for magnetic drug delivery, targeted therapy, and hyperthermia applications. Moreover, the intrinsic magnetic properties of SrFe$_2$O$_4$ can be tailored by modifying synthesis conditions, particle size, and crystallinity.

In this study, we report the successful synthesis of spinel SrFe$_2$O$_4$ nanoparticles using a simple and cost-effective microwave heating technique. The prepared nanoparticles were characterized using X-ray diffraction (XRD), energy-dispersive X-ray spectroscopy (EDX), Fourier-transform infrared spectroscopy (FT-IR), high-resolution scanning electron microscopy (HR-SEM), and vibrating sample magnetometry (VSM). The results confirmed the formation of a pure spinel phase with spherical morphology and superparamagnetic behavior, highlighting the potential of SrFe$_2$O$_4$ nanoparticles for advanced magnetic and functional applications.

2. LITERATURE REVIEW

Liu et al.,[1] investigated annealing effects on Zn$_{0.2}$Mn$_{0.8}$Fe$_2$O$_4$ nanoparticles, showing enhanced magnetothermal behavior, useful for hyperthermia. The study used XRD, TEM, and magnetic measurements, emphasizing particle size and cation distribution influence on heating efficiency.

[2] Kumar et al., focused on MgFe$_2$O$_4$ nanoparticles for microwave applications. The work demonstrated good magnetic behavior and dielectric properties, highlighting their potential in microwave absorbing materials. [3] Ghahfarokhi et al., studied sintering temperature impacts on structural and magnetic properties, finding that increased temperature improved crystallinity and magnetic performance. [4] Maaz et al., synthesized NiFe$_2$O$_4$ via co-precipitation and studied its magnetic behavior, showing superparamagnetic nature at room temperature. This study investigates the magnetic properties of cobalt ferrite (CoFe$_2$O$_4$) nanocrystals synthesized via the hydrothermal method, with a focus on understanding how size and crystallinity affect magnetic behavior by Zhou et al[5].

2. LITERATURE REVIEW

Several studies have explored the magnetic and structural properties of spinel ferrites. Liu et al. [1] investigated the effect of annealing on $Zn_{0.2}Mn_{0.8}Fe_2O_4$ nanoparticles, finding that heat treatment significantly improved magnetothermal behavior, which is crucial for biomedical applications. Kumar et al. [2] examined Mg ferrites and confirmed their suitability for microwave applications due to favorable dielectric and magnetic behavior. The synthesis temperature and dopant levels play a crucial role in determining ferrite properties. Ghahfarokhi et al. [3] reported that increasing the sintering temperature improved the crystallinity and magnetic properties of Sr-ferrites. Maaz et al. [4] synthesized $NiFe_2O_4$ nanoparticles via co-precipitation and reported superparamagnetism with size-dependent magnetic features. Zhou [5] utilized the hydrothermal method for $CoFe_2O_4$ and highlighted its high coercivity. Chen and Chen [6] prepared ultrafine $SrFe_2O_4$ using microemulsion processing, emphasizing enhanced homogeneity and phase purity. Valhal et al. [7] showed that Ni substitution in Co ferrites influenced structural distortion and enhanced magnetic performance. Zhou et al. [8] analyzed Ni^{2+}-doped ZnS and highlighted the role of vacuum annealing in controlling optical properties.

Andersen et al. [9] provided a detailed study on the nucleation and growth kinetics of spinel ferrite nanoparticles, bridging experimental data with thermodynamic modeling. Their insights are valuable for controlling size and morphology during synthesis. Fkhar et al. [11] introduced Nd and Sn into spinel ferrites and found that the dopants significantly altered magnetic anisotropy. Sen et al. [12] examined gamma-irradiated $NiFe_2O_4$, which showed radiation-induced structural defects affecting magnetic ordering. Sarkar et al. [13] explored geometry-mediated spin relaxation in $ZnFe_2O_4$, revealing quantum size effects. Abu El-Fadl et al. [14] synthesized Cr-substituted Ni-Zn ferrites using microwave combustion, noting improved saturation magnetization. Goya and Leite [15] highlighted spin canting effects in $ZnFe_2O_4$-ZnO composites. Fkhar et al. [11] introduced Nd and Sn into spinel ferrites and found that the dopants significantly altered magnetic anisotropy.

Sen et al. [12] examined gamma-irradiated $NiFe_2O_4$, which showed radiation-induced structural defects affecting magnetic ordering. Sarkar et al. [13] explored geometry-mediated spin relaxation in $ZnFe_2O_4$, revealing quantum size effects. Abu El-Fadl et al. [14] synthesized Cr-substituted Ni-Zn ferrites using microwave combustion, noting improved saturation magnetization. Goya and Leite [15] highlighted spin canting effects in $ZnFe_2O_4$-ZnO composites. Zhang et al. [21] and Seehra et al. [18] characterized the magnetic properties and revealed that nanoscale $SrFe_2O_4$ exhibits ferrimagnetism with moderate coercivity and saturation magnetization. Kumar et al. [25] focused on magnetic behavior for storage applications.

3. EXPERIMENTAL

3.1. MATERIALS AND METHODS

Analytical-grade strontium nitrate ($Sr(NO_3)_2$) and ferric nitrate ($Fe(NO_3)_3 \cdot 9H_2O$) were used as starting materials. Millipore water served as the solvent throughout the synthesis. Stoichiometric amounts of strontium nitrate and ferric nitrate were dissolved in Millipore water under constant magnetic stirring for 1 hour to obtain a homogeneous solution. The resulting solution was then subjected to microwave heating in a domestic microwave oven for 15 minutes. This process yielded solid precipitates, which were subsequently collected, washed thoroughly with distilled water and ethanol to remove impurities, and dried at 70 °C for 1 hour to obtain the final $SrFe_2O_4$ nanoparticle powders

3.2. CHARACTERIZATION

The structural formation of spinel $SrFe_2O_4$ nanocrystals was investigated using X-ray diffraction (XRD) with a Rigaku Ultima diffractometer employing Cu-Kα radiation (λ = 1.5418 Å). The presence of metal-oxide functional groups was confirmed through Fourier-transform infrared (FT-IR) spectroscopy using a PerkinElmer spectrometer. The surface morphology and particle shape of the synthesized nanoparticles were examined using high-resolution scanning electron microscopy (HR-SEM) with a JEOL JSM-6360 system at appropriate magnifications.

4. RESULTS AND DISCUSSION

4.1. POWDER XRD ANALYSIS

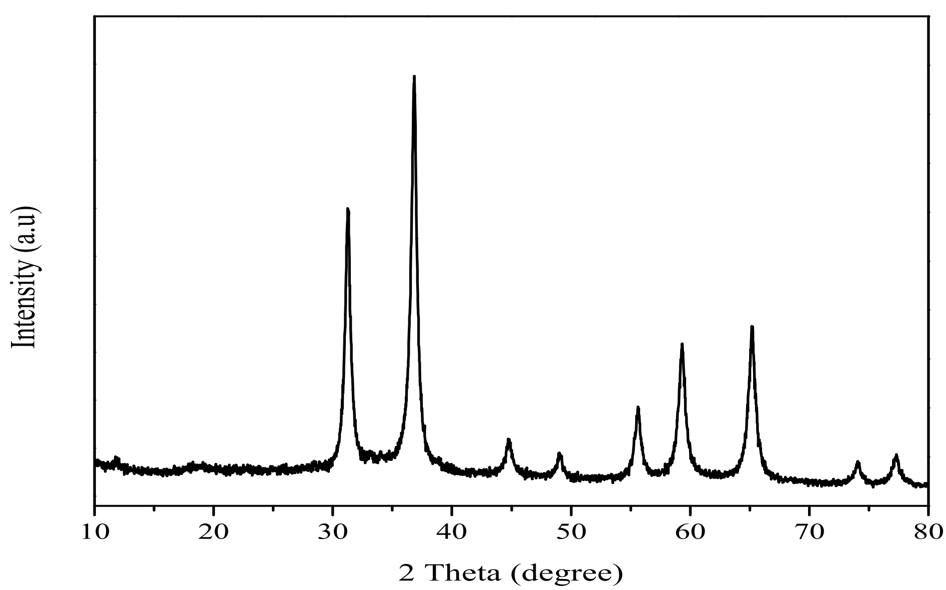

Figure 1. Powder XRD pattern of spinel $SrFe_2O_4$ sample.

The crystallinity, phase formation, crystallite size, and purity of the sample were confirmed through powder X-ray diffraction (XRD) analysis. Fig. 1 displays the XRD pattern of the $SrFe_2O_4$ sample. The observed diffraction peaks correspond well to a single-phase cubic spinel structure of $SrFe_2O_4$, with no evidence of secondary phases.

The lattice parameter was calculated using the following formula (Eq. 1):

$$\sin^2\theta = \frac{\lambda^2}{4}\left[\frac{4}{3}\left(\frac{h^2+hk+k^2}{a^2}\right)+\frac{l^2}{c^2}\right] \quad \text{---- (1)}$$

where '*θ*' is the diffraction angle, *h*, *k*, and *l* are Miller's indices and '*λ*' is the incident wavelength (λ = 0.1540 nm). The lattice parameter of $SrFe_2O_4$ sample is 8.055 Å .

The crystallite size of was designed by Scherrer formula given in Eq. (2):

$$L = \frac{0.89\lambda}{\beta \cos\theta}$$

------ (2)

Where L is the crystallite size, θ is the Bragg diffraction angle, λ is the X-ray wavelength (1.5406 Å), and β is the full width at half maximum (FWHM) of the diffraction peak. The calculated average crystallite size of the spinel $SrFe_2O_4$ sample is 35.28 nm. During the microwave irradiation process, the domestic microwave oven operated at a power of 850 W, converting microwave energy into thermal energy. This rapid and uniform heating facilitated the formation of functional nano-sized $SrFe_2O_4$ particles.

4.2. FT-IR SPECTROSCOPY

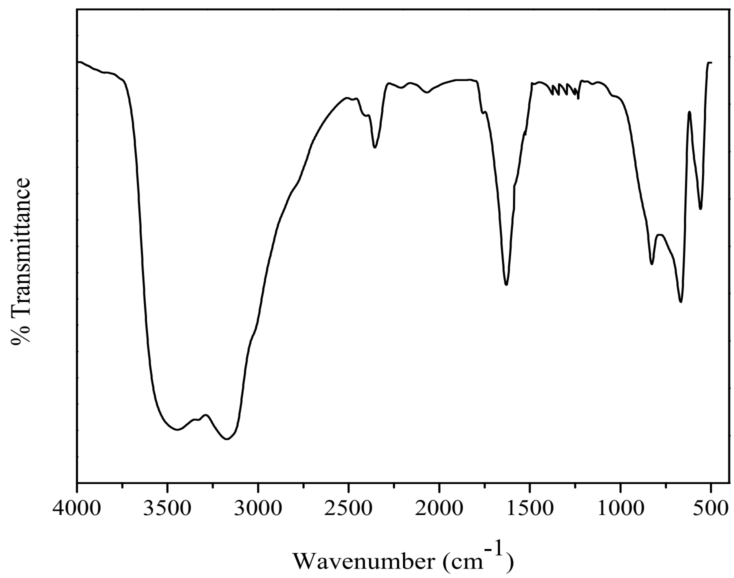

Figure 2. FT-IR spectra of spinel $SrFe_2O_4$ sample.

The FT-IR spectrum of the spinel $SrFe_2O_4$ sample is presented in Fig. 2. A broad absorption band observed between approximately 3425 cm⁻¹ and 3255 cm⁻¹ corresponds to the O–H stretching vibrations of adsorbed water molecules, indicating the presence of surface hydroxyl groups. Additionally, two characteristic wide bands in the range of 420–900 cm⁻¹ are attributed to metal-oxygen (M–O) vibrations, confirming the formation of the spinel $SrFe_2O_4$ structure.

4.3. HR-SEM ANALYSIS

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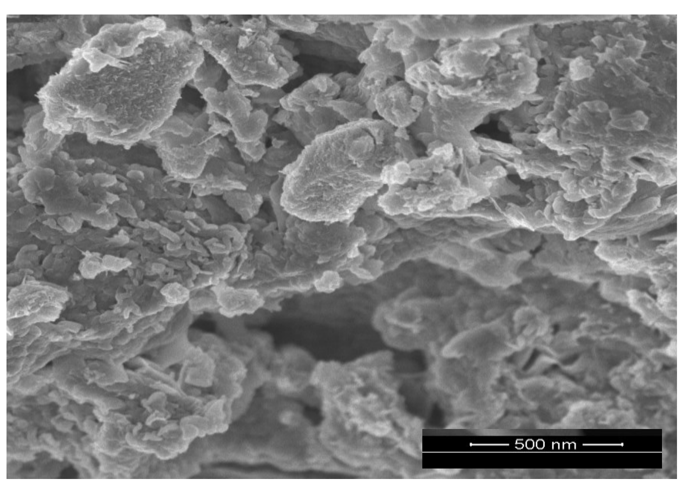

Figure 3. HR-SEM image of spinel $SrFe_2O_4$ sample.

The surface morphology of the spinel $SrFe_2O_4$ sample was examined using high-resolution scanning electron microscopy (HR-SEM), as shown in Fig. 3. The HR-SEM image reveals that the sample consists of homogeneously distributed, sphere-like nanoparticles. The presence of slight agglomeration is attributed to the effect of microwave irradiation during synthesis, which promotes uniform nucleation and particle growth. Additionally, magnetic interactions among the nanoparticles may also contribute to the observed agglomeration

4.4 EDX ANALYSIS

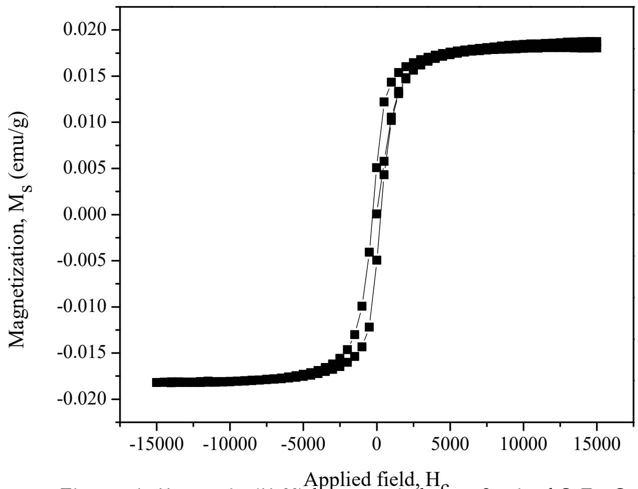

Figure 4. Magnetic (M-H) hysteresis loop of spinel $SrFe_2O_4$ sample

The elemental composition and purity of the $SrFe_2O_4$ sample were confirmed using energy-dispersive X-ray (EDX) spectroscopy. As shown in Fig. 4, the EDX spectrum displays distinct peaks corresponding to strontium (Sr), iron (Fe), and oxygen (O), indicating the presence of the desired elements. The absence of any additional or unexpected elemental peaks confirms the high purity of the synthesized product.

4.5. VSM MEASUREMENTS

The magnetic properties of the spinel $SrFe_2O_4$ sample were analyzed using a vibrating sample magnetometer (VSM) under an applied magnetic field ranging up to ±10 kOe. The VSM hysteresis (M–H) loop confirmed the super

CONCLUSION

The spinel $SrFe_2O_4$ sample was successfully synthesized using a facile microwave heating route. XRD, EDX, and FT-IR analyses confirmed that the synthesized $SrFe_2O_4$ possesses a well-defined spinel structure with high crystallinity and is free from secondary phase impurities. HR-SEM analysis revealed that the sample exhibits a nanoparticle-like morphology. Magnetic measurements showed that the saturation magnetization (Ms) value for the spinel $SrFe_2O_4$ sample is 0.125 emu/g.

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