Int. J. Nanosci. Nanotechnol., Vol. 18, No. 4, Dec. 2022, pp. 275-284

Short Communication

Optical, Thermal and Magnetic Properties of Strontium Ferrite Nanoparticles

Sigamani Saravanan[1, *], Tamilarasan Sivanandan[2] and Gopal Ramalingam[3]

[1]Department of Nanotechnology, Swarnandhra College of Engineering & Technology,
Narsapur-534 280, West Godavari, Andhra Pradesh, India
[2]Department of Physics, Indian Arts & Science College, Tiruvannamalai (TN), India
[3]Department of Nanoscience and Technology, Alagappa University, Karaikudi (TN), India

(*) Corresponding author: shasa86@gmail.com

(Received: 29 March 2022 and Accepted: 14 September 2022)

Abstract

This study endeavors to investigate the influence of calcination temperatures (650, 750 & 850°C) on the strontium ferrite ($SrFe_2O_4$) nanoparticles synthesized by the co-precipitation method. The prepared powder samples were characterized by various measurement techniques such as X-ray diffractometer (XRD), scanning electron microscopy (SEM), thermo gravimetric analysis (TGA), and vibrating sample magnetometer (VSM). Initially, the XRD patterns were confirmed the presence of spinel $SrFe_2O_4$ phases. Overall, the number of diffraction peaks increased due to the enhancement of calcination temperature. The SEM morphological features are shown the spherical-shaped nanoparticles with less agglomeration. Considerably, the agglomeration between the nanoparticles increased due to the higher calcination temperatures. However, the structural and morphological investigation was helpful and carried out for the TGA and VSM investigation. At 850°C calcination temperature, TGA revealed 5.8% of weight loss and VSM endorsed the magnetic properties such as high saturation magnetization (Ms), remanent magnetization (Mr) and coercivity (Hc) come out to be 37.26 emu/g, 19.788 emu/g and 6188.4 Oe, respectively.

Keywords: *$SrFe_2O_4$, Nanoparticles, Calcination, Thermal, Coercivity.*

1. INTRODUCTION

The strontium ferrite ($SrFe_2O_4$) materials have great fundamentals, an abundance of raw material, low manufacturing cost, and stable properties that are technologically applied in permanent material applications such as photocatalyst (biodiesel), optical, electronic and magnetic (regarding media) properties [1-4]. Also, the ferrites are classified into two different types like soft and hard magnets. The magnetic property of nanoscale materials has been depending on the pH, particle size, precursor, solvents, and the amount of interactions, calcination (or preparation) temperatures and preparation of methods. The various synthesis and deposition techniques including the co-precipitation, salt-melt, sonochemistry, micro emulation, hydrothermal, sol-gel, sol-gel auto-combustion, glass crystallization, the mechanical alloying methods and ultrasound-assisted synthesis methods have been successfully used to develop the efficient strontium ferrite nanostructures [5-14]. Compared to the above methods, the co-precipitation method is simple, promising and easy to synthesis ferrite nanoparticles. The solvent plays a pivotal role and is studied by various solvents in the preparation of ferrite nanostructures like acetonitrile, formamide, N, N-dimethyl formamide, water, ethylene glycol and glycerol, dimethylacetamide, aqueous NH_3, $(NH_4)_2CO_3$, NH_4Ac, NH_4HCO_3 and N-methyl acetamide [15]. The co-precipitation method is wellestablished and used to synthesis important oxide materials due to its simple and good control of grain size. Ghahfarokhi et al. (2020) prepared 10-25 nm size of $SrFe_2O_4$ nanoparticles using sol-gel method using ethylene glycol as a surfactant. X-ray diffraction (XRD) pattern revealed the cubic spinel- $SrFe_2O_4$ structures and field emission scanning electron microscopy (FESEM) morphological image confirmed the reduced particle size by the addition of ethylene glycol surfactant. The ultraviolet-visible spectroscopy and vibrating sample magnetometer (VSM) results depict a wider energy gap and improved magnetic properties due to the increment of surfactant addition [16]. Zafar et al. (2018) synthesized $SrFe_2O_4$nanoferrites and $SrFe_2O_4$/ground eggshell nanocomposites using micro emulation and solvothermal methods. The prepared samples were utilized as an efficient adsorbent for anionic dye, eriochrome black T, and cationic dye methylene blue. The $SrFe_2O_4$nanoferrite and $SrFe_2O_4$/ground eggshell nano-composites powders were tuned and proved as efficient adsorbents [17]. Yasmin et al. (2018) investigated the structural and magnetic properties of Cr-doped $SrFe_2O_4$ clusters using the sol-gel auto-combustion method. XRD pattern reveals that crystallite size and lattice parameters were improved with the effect of Cr-substitution increment. SEM micrographs showed inhomogeneous grains with agglomeration and VSM studies confirmed the soft magnetic properties [18]. Zhang et al. (2016) investigated the $SrFe_2O_4$/reduced graphene oxide (RGO) composite prepared using an ultrasonic-assisted sol-gel process and studied the photocatalytic performance. The experimental studies showed great applied potential in environmental purification due to its improved photocatalysis, easy separation and good reusability [19]. Ali Ghasemi (2012) prepared the $SrFe_2O_4$ nanoparticles and thin films (on a silicon wafer) using sol-gel and thermal oxidation methods. The narrow size particle distribution with an average particle size of 50 nm was confirmed by transmission electron microscopy (TEM). Pardeshi and Pawar (2011) synthesized spinel-type $SrFe_2O_4$ catalyst using citrate gel method. They have investigated the optimization and effects of different environmental conditions on styrene conversion and product distributions. After the 18 hrs chemical reaction, the maximum benzaldehyde yield was received at 70°C using water solvent over 0.1 g of catalyst [20].

In this study, $SrFe_2O_4$ nanoparticles were synthesized via the chemical co-precipitation method. The influences of different calcination temperatures (650, 750, and 850°C) were investigated on the $SrFe_2O_4$ nanoparticles by their structural (XRD), morphological (SEM), and magnetic (VSM) properties. The required synthesis materials and preparation methods are discussed in section 2 and the results are discussed in section 3. Finally, summarize the work in section 4.

2. EXPERIMENTAL APPROACH

2.1. Materials

The analytical grade raw materials were accurately weighted for the preparation of $SrFe_2O_4$ nanoparticles. Initially, strontium nitrate ($Sr(NO_3)_2$) and ferric nitrate ($Fe(NO_3).9H_2O$) are the primary sources of the materials. Next, ethylene glycol, distilled water, and ethanol procured to carry out the experimental work.

2.2 Synthesis & Characterizations

The $SrFe_2O_4$ nanoparticles were synthesized by using the co-precipitation method as depicted in Figure 1. Strontium nitrate and ferric nitrate are used as the primary source materials. Strontium nitrate is used for strontium species and ferric nitrate is used for iron species. Additionally, ethylene glycol was used chemicals for the synthesis as a surfactant and solvent. Among various solvents (methanol, formamide, ethylene glycol, dimethyl acetamide, glycerol etc.), mostly ethylene glycol ($C_3H_6O_2$) is one of the best due to their formation of inter- and intramolecular hydrogen bonds and self-assembly of surfactants [15]. The co-precipitation method is simple to synthesize $SrFe_2O_4$ nanoparticles. All starting precursors were high purity compounds. First, 0.846 g $Sr(NO_3)_2$ and 1.6 g of $Fe(NO_3).9H_2O$ with Sr:Fe, atomic ratio of 1:2 were dissolved in ethylene glycol by maintaining gentle heat and stirring. Using a magnetic stirrer, the solution stirred for 2 hrs at room temperature. Finally, observed gelatinous precipitates were washed by several times using distilled water and ethanol. Further, the obtained precipitates were dried at room temperature. Thereafter, the dried powders were calcinated (muffle furnace) at 650, 750 and 850°C for 2 hrs. Ultimately, the prepared $SrFe_2O_4$ nanopowder was collected when the temperature cooled down to the room temperature. The following chemical reaction occurred during the synthesis process is given below,

$$Sr(NO_3)_2 + 2Fe(NO_3)_2.9H_2O + C_2H_6O_2 \rightarrow SrFe_2O_4 + 6HNO_3 + 7H_2O + C_2H_{10}$$

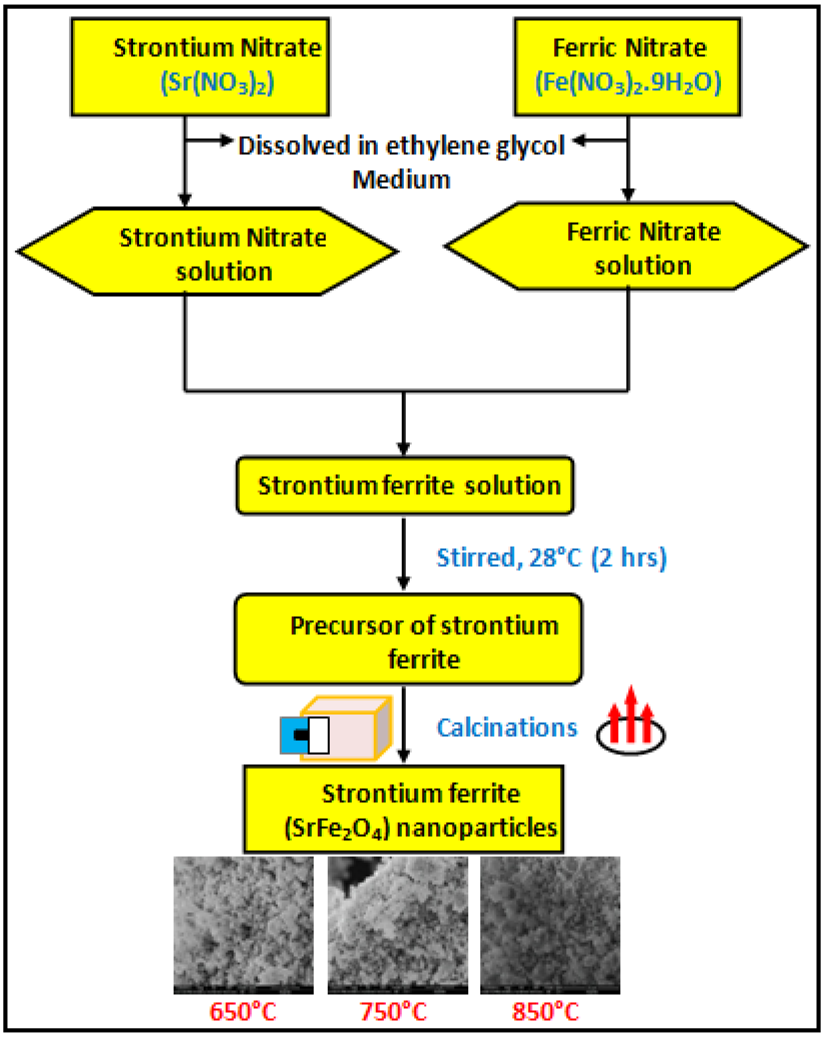

Figure 1. *The procedural steps of* $SrFe_2O_4$ *nanoparticles with different calcination temperatures.*

After the preparation of the samples, tested for their structural, functional, magnetic, and morphological properties of the $SrFe_2O_4$ nanoparticles by using an X-ray diffractometer (Rigaku Ultima III, Japan), Fourier transform infrared (Perkin Elmer-LS 45, USA) spectroscopy, vibrating sample magnetometer (Lakeshore, USA; Model 7404) and scanning electron microscopy (FBI Quanta).

3. RESULTS AND DISCUSSION

3.1. Results of X-ray Diffraction (XRD)

Figure 2 (a)-(c) shows the XRD patterns of prepared samples were calcinated at 650, 750, and 850°C. The sharp and relative intensities of all diffraction peaks of $SrFe_2O_4$ nanoparticles are well aligned with the (002), (311), (331), (420), (520), and (440) planes matching with the standard JCPDS card no. 00-01-1027. It is indicated that the diffraction peaks are indexed by the formation of spinel $SrFe_2O_4$ structure [21-23]. With the influence of enhanced calcination temperatures, the intensity of diffraction peaks increased obviously and no other impurity peaks were presented. The average crystallite size can be calculated using the Scherrer's equation as follows,

$$D = \frac{K\lambda}{\beta \, \mathrm{Cos}\theta}$$

Where 'D' is the crystalline size of the particles, 'K' is a constant (k=0.89), 'λ' is the wavelength of Cu Kα radiation, 'β' is the full-width half-maximum (FWHM) of the peak, and 'θ' is Bragg's angle. Further, the lattice constant 'a', 'b' & 'c' is calculated such as 8.03, 18.02 and 5.45 A° were similar to the M-type strontium ferrite phase and evidenced the presence of materials [24]. Kahlenberg (2001) and Berthet (1992) reported the same crystallographic data of $SrFe_2O_4$ phases and compared them [25-26].

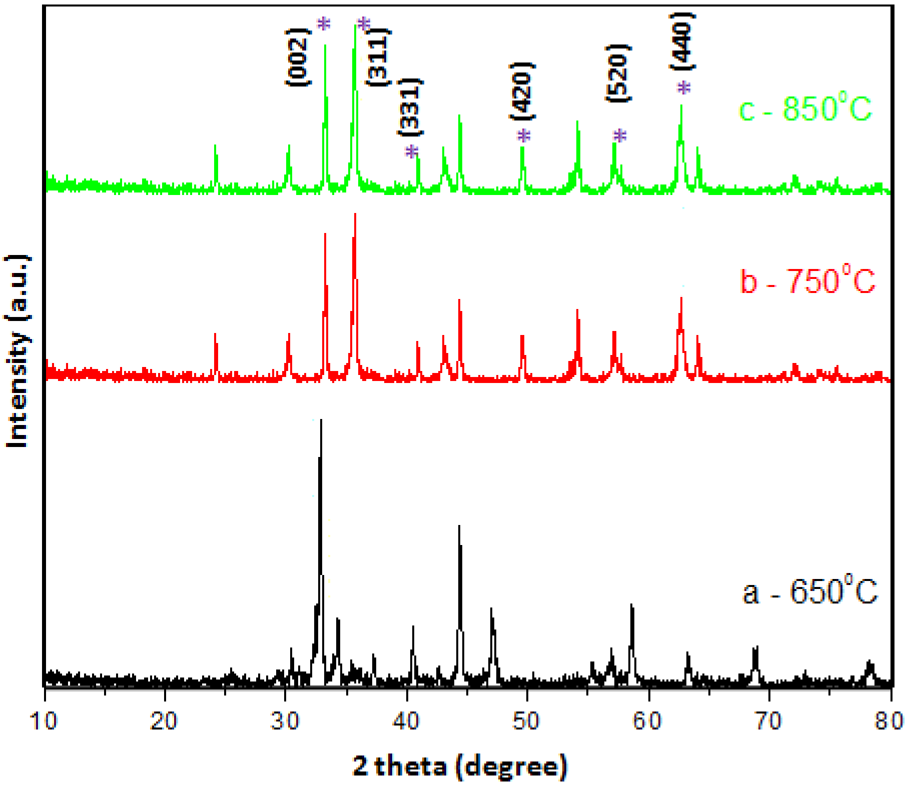

Figure 2. *XRD spectrum of $SrFe_2O_4$ nanoparticles a) 650°C, b) 750°C and c) 850°C.*

3.2. Results of Scanning Electron Microscopy (SEM)

Figure 3(a)-(c) shows the surface morphology of the various calcined

$SrFe_2O_4$ nanoparticles were explored by SEM. Figure 3(a)-(c) shows the spherical nanoparticles with the agglomareted nanoparticles due to magentic properties among the particles. With the effect of calcination temperature, observed the same nature (size) of the particles with some agglomeration. Usually, the magnetic nanoparticles are agglomerated with the effect of dipole-dipole interaction between the nanoparticles. This interaction generates a negative effect on the various applications. The different morphological investigations employed by Zhang et al. (2016) [19]. The agglomerates could be reduced by covering the particle surface with surfactants (non-magnetic/non-metallic compounds). Surfactant materials include hydrophilic head and hydrophobic tails [27-31]. Larger particles, as well as large pores, were located at the agglomeration junctions. Here, ethylene glycol acts as a solvent as well as a surfactant due to the size of the nanoparticles decreased. However, the nanoparticles size enhanced with water solvent based strontium ferrite nanoparticles as reported [32].

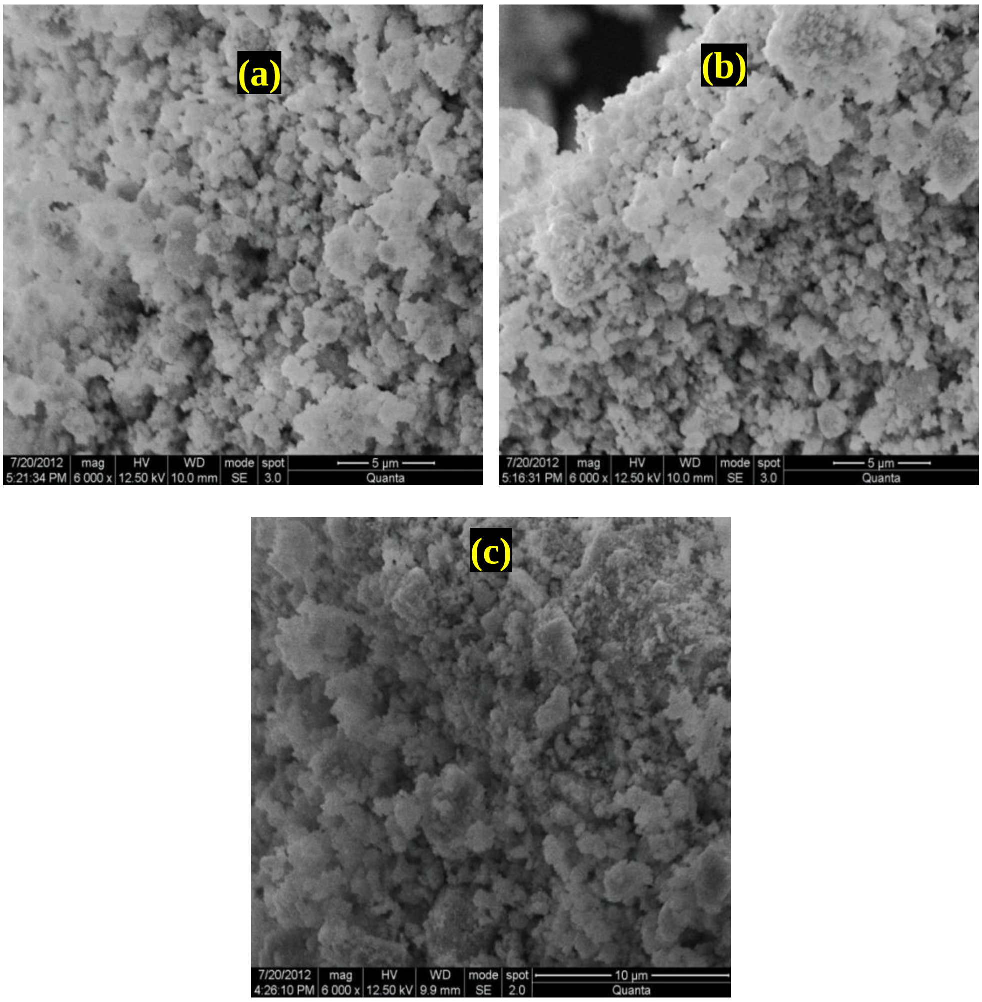

Figure 3. *SEM images of $SrFe_2O_4$ nanoparticles 650°C (a), 750°C (b) and 850°C (c).*

Natarajan and Wang (2000) reported that the aggregation (cluster) performance is due to the selection of surfactant, solvent dielectric constant, and less magnitude of the hydrocarbon mixed solvent interfacial tension [15]. Sivanadhan (2021) reported highly agglomerated $SrFe_2O_4$ nanoparticles (size, 112-130 nm) with the effect of water medium [32]. Among various solvents, ethylene glycol is a suitable choice for the preparation of ferrite nanoparticles.

3.3. Results of Thermogravimetric Analysis (TGA)

The weight loss (%) as a function of temperature using thermogravimetric analysis (TGA) is shown in Figure 4. It is the TGA analysis curve of the $SrFe_2O_4$ nanoparticles which is calcinated at 850°C. This curve shows four distinct steps of weight loss.

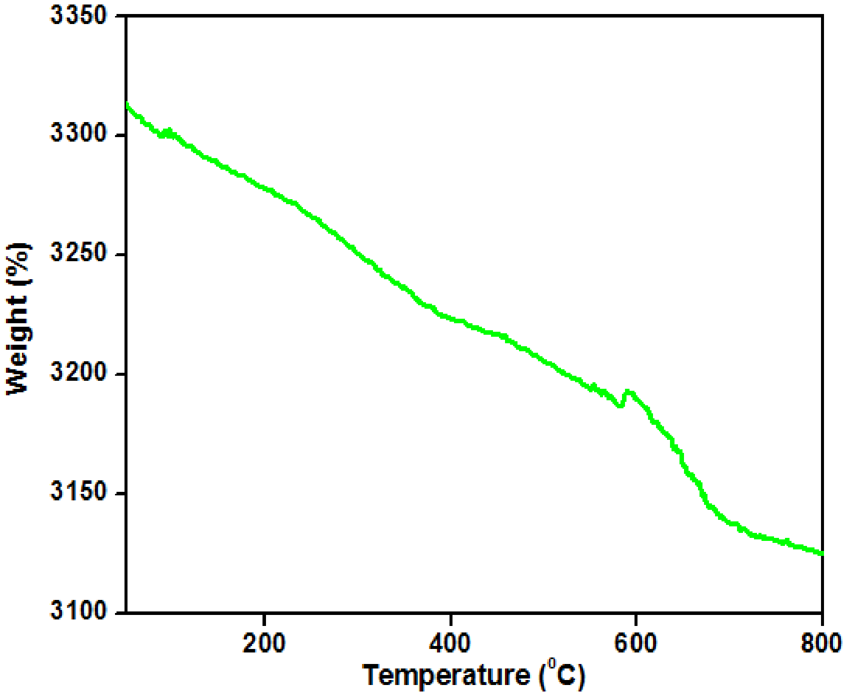

Figure 4. *TGA curve of as-prepared $SrFe_2O_4$ nanoparticles (850°C).*

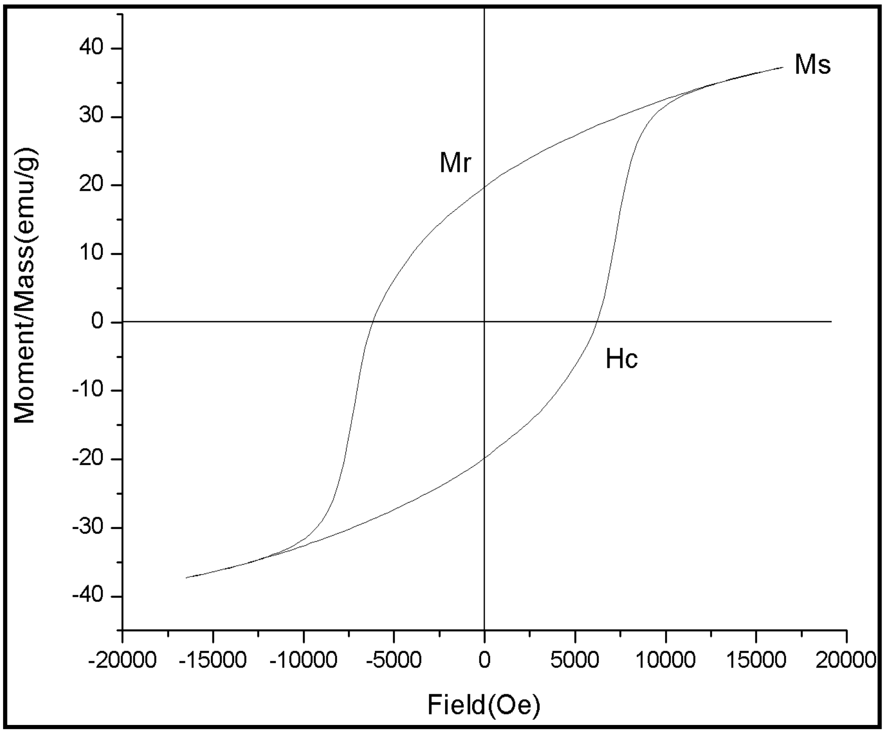

Figure 5. *Hysteresis loop of $SrFe_2O_4$ nanoparticles at 850°C calcination temperature.*

The first step weight loss is between 50 to 100°C due to adsorptions of water molecules and the second step the weight loss between 350 to 400°C which is due to hydroxyl ions (O-H) [33]. The weight loss of 550 to 580°C and 640 to 710°C due to the decomposition of nitrates and metal nitrate. Saleh et al. reported the formation of strontium oxide phases depending on the reaction temperature and the molar ratio among the reactants. The monoferrite ($SrFe_2O_4$) formation obtained from 592 to 765°C [34-35].

3.4. Results of Vibrating Sample Magnetometer (VSM)

The magnetic properties are saturation magnetization (M_s), remanent magnetization (Mr), and coercivity ($H_{c,}$) increasing with the effect of calcination temperatures.

Table 1. *The list of coercivity of strontium ferrite nanoparticles.*

Temp. (°C)	Nanoparticles	Coercivity (Oe)	Solvent	Ref.
850	$SrFe_2O_4$	5662	Water	[32]
1000	$SrFe_{12}O_{19}$	4900	Water	[5]
800		5000		
700	$SrFe_2O_4$	299	Water	[19]
950	$SrFe_{12}O_{19}$	3500	Tween-80, DI Water	[33]
1100		2375		
700	$SrFe_2O_4$	709	DI water	[21]
		453		
		440		
		15		
		137		

These magnetic properties are depending on the size of the nanoparticles, magneto-crystalline anisotropy, preparation/ calcination temperatures, the effects of tilting, the distribution of cations, and the degree crystallinity as reported by Ghahfarokhi and Shobegar (2020) [21]. Consequently, the magnetocrystalline value is increasing with the effect of the highest calcination temperature [5]. Here, VSM studies revealed the hysteresis curve of $SrFe_2O_4$ nanoparticles prepared under the conditions of Fe^{3+}/ Sr^{2+} mole ratio and calcination temperature which was calcinated at 850°C as shown in Figure 5. The improved coercivity (6188.4 Oe), remanent magnetization (19.788 emu/g), and the saturation magnetization (37.26 emu/g) reached a maximum as compared to water solvent [32]. Vogel and Evans (1979) investigated the $SrFe_2O_4$ composition and improved the complex chemical and physical interactions that could lead the superior magnetic properties [36]. The coercivity of different strontium ferrite, and calcination temperatures as compared (Table-1). Accordingly, coercivity, remanent magnetization and saturation magnetization of $SrFe_2O_4$ nanoparticles can be useful in various applications. The spinel strontium ferrites were found as highly active in catalytic, permanent magnetic, hard magnetic devices, and microwave applications [19, 37-39]. The magnetic properties of nanoparticles are varied by size which could play significant role in physics [40-44]. By comparing other methods [40], this co-precipitation method is a good candidate for the preparation of nano material structures because it is a relatively easy, low-cost and reproducibility.

4. CONCLUSION

In summary, the strontium ferrite ($SrFe_2O_4$) nanoparticles were synthesized by the co-precipitation method. The primary source materials are strontium nitrate and ferric nitrate. The prepared samples were calcinated at three different temperatures. The spinel $SrFe_2O_4$ phase was confirmed with the XRD diffraction spectra. SEM morphological investigation revealed small spherical-shaped nanoparticles, and some agglomeration. The average particle size of 117, 24, and 19 nm corresponds to the calcination temperature of 650, 750, and 850°C. The reduced thermal properties were noticed with the effect of the highest calcination temperature by the TGA. The VSM magnetic study indicated magnetic properties such as the H_C (6188.4 Oe), H_S (37.26), and M_r (19.78). Accordingly, we studied spinel $SrFe_2O_4$ nanoparticles that can be tested for various applications such as a photocatalyst.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

1. Chaves de Abreu, W., Moraes, A. F., Nascimento Reis, R. Y., Pinto, B. F., Rodarte de Moura, C. V., Nicolodr, S., Miranda de Moura, E., “Magnetic materials enriched with strontium: a study of the use as catalysts in the transesterification reaction of babassu oil”, *Mater. Res.,* 22 (2019) 1-8.
2. Ghasemi, E., Ghahari, M., "Synthesis of silica coated magnetic nanoparticles", *Int. J. Nanosci. Nanotechnol.,* 12 (2015) 133-137.
3. Peiravi, M. M., Ashabi, A., “Magneto effects on Fe_3O_4 nanoparticles through the triangular and rectangular baffles on thread stretching surface for rotary seals in computer hardware”, *Int. J. Nanosci. Nanotechnol.,* 18 (2022) 93-98.
4. Saravanan, S., Dubey, R. S., “Synthesis of SiO_2 nanoparticles by sol-gel method and their optical and structural properties”, *Solid State Sci.,* 4 (2002) 175-182.
5. Ganjali, M., Ganjali, M., Eskandari, A., Aminzare, M., “Effect of heat treatment on structural and magnetic properties of nanocrystalline $SrFe_{12}O_{19}$ hexaferrite synthesized by co-precipitation method”, *J. Adv. Mater. Process.,* 1 (2013) 41–48.
6. Guo, Z. B., Ding, W. P., Zhong, W., Zhang, J. R., Du, Y. W., “Preparation and magnetic properties of $SrFe_{12}O_{19}$ particles prepared by the salt-melt method”, *J. Magn. Magn. Mater.,* 175 (1997) 333–336.
7. Fang, J., Wang, J., Gan, L. M., Ng S. C., Ding, J., Liu X., “Fine strontium ferrite powders from an ethanol-based microemulsion”, *J. Am. Ceram. Soc.,* 83 (2000) 1049–1055.
8. Dang, T. M. H., Trinh, V. D., Bui, D. H., Phan, M. H., Huynh, D. C., “Sol–gel hydrothermal synthesis of strontium hexaferrite nanoparticles and the relation between their crystal structure and high coercivity properties”, *Adv. Nat. Sci. (Nanosci Nanotech),* 3 (2012) 25015-1-7.
9. Kanagesan, S., Hashim, M., Jesurani, S., Kalaivani, T., Ismail, I., Ahmod, C. S., “Effect of microwave sintering on microstructural and magnetic properties of strontium hexaferrite using sol-gel technique”, *J. Mater. Sci. Mater. Electron.,* 24 (2013) 3881–3884.
10. Azis, R. S., Sulaiman, S., Ibrahim, I. R., Zakaria, A., Hassan J., Che Muda, N. N., Nazlan, R., Saiden, N. M., Fen, Y. W., Mustaffa, M. S., Matori, K. A., “Influence of pH adjustment parameters for sol-gel modification on structural, microstructure and magnetic properties of nanocrystalline strontium ferrite”, *Nanoscale Res. Lett.,*13 (2018)1-13.
11. Godara, S. K., Kaur, V., Narang, S. B., Singh, G., Singh, M., Bhadu, G. R., Chaudhari, J. C., Babu, P. D., Sood, A. K., “Tailoring the magnetic properties of M-type strontium ferrite with synergistic effect of co-substitution and calcinations temperature”, *J. Asian Ceram. Soc.,* 9 (2021) 686-698.
12. Sato, H., Umeda, T., “Grain growth of strontium ferrite crystallized from amorphous phases”, *J. Jpn. I. Met. Mater.,* 34 (1993) 76–81.
13. Ding, J., Miao, W. F., Mccormick, P. G. et al., “High-coercivity ferrite magnets prepared by mechanical alloying”, *J. Alloys Compd.,* 281 (1998) 32–36.
14. Perelshtein, I., Perkas, N., Magdassi, S., et al., “Ultrasound-assisted dispersion of $SrFe_{12}O_{19}$ nanoparticles in organic solvents and the use of the dispersion as magnetic cosmetics”, *J. Nanopart. Res.,* 10 (2008) 191–195.

15. Nagarajan, R., Chien-Chung, W., “Theory of surfactant aggregation in water/ethylene glycol mixed solvents”, *Langmuir,* 16 (2000) 5242-5251.
16. Ghahfarokhi, S. E. M., Shobegar, E. M., “An investigationvof the ethylene glycol surfactant on the structural, microstructure, magnetic and optical properties of $SrFe_2O_4$ nanoparticles”, *J. Magn. Magn. Mater.,* 495 (2020) 165866-1-7.
17. Zafer, M. N., Amjad, M., Tabassum, M., Ahmad, I., Zubair, M., “$SrFe_2O_4$ nanoferrites and $SrFe_2O_4$/ground eggshell nanocomposites: Fast and efficient adsorbents for dyes removal”, *J. Clean Prod.,* 199 (2018) 983-994.
18. Yasmin, N., Inam, I., Malik, I. A., Zahid, M., Ashiq, M. N., Abdulsatar, S., Safdar, M., Mirza, M., “Structural and magnetic properties of Cr-doped strontium spinel ferrite $SrFe_2O_4$ by sol-gel auto-combustion method”, *Physica B Condens. Matter.,* 550 (2018) 90-95.
19. Zhang, D., Zhang, L., “Ultrasonic-assisted sol-gel synthesis of rugby-shaped $SrFe_2O_4$/reduced graphene oxide hybrid as versatile visible light photocatalyst”, *J. Taiwan Inst. Chem. E.,* 69 (2016) 156-162.
20. Pardeshi, S. K., Pawar, R. Y., “$SrFe_2O_4$ complex oxide an effective and environmentally benign catalyst for selective oxidation of styrene”, *J. Mol. Catal A-Chem.,* 334 (2011) 35-43.
21. Ghahfarokhi, S.E.M., Shobegar, E.M., “Influence of pH on the structural, magnetic and optical properties of $SrFe_2O_4$ nanoparticles”, *J. Mater. Res. Technol.,* 9 (2020) 12177-12186.
22. Chen, Y., Wu, Q., Bu, N., Chen, M., J. Wang, Song, Y., “Immobilization of black $TiO_{2-X}/SrFe_2O_4$ heterojunction on diatomaceous earth as magnetic visible-light-driven photocatalyst for efficient ibuprofen mitigation”, *J. Alloy Compd.,* 858 (2021)157728-1-15.
23. Karahroudi, Z. H., Hedayati, K., Goodarzi, M., “Green synthesis and characterization of hexaferrite strontium-perovskite strontium photocatalyst nanocomposites”, *Main Group Met. Chem.,* 43 (2020) 26-42.
24. Ze Wu, Zhang, R., Yu, Z., Shan, L., Dong, L., Zhang, X., “The magnetic properties of permanent strontium ferrite doped with rare-earth by chemical co-precipitation method”, *Ferroelectrics,* 529 (2018) 120-127.
25. Kahlenberg, V., Fischer, R. X., “Structural characterization of strontium monoferrite, a new stuffed framework compound”, *Solid State Sci.,* 3 (2001) 433-439.
26. Berthet, P., Berthon, J., Heger, G., Revcolevschi, A., “Structure of metastable strontium ferrite”, *Mater. Res. Bull.,* 27 (1992) 919-924.
27. Ghahfarokhi, S. E. M., Shobegar, E. M., “An investigation of the ethylene glycol surfactant on the structural, microstructure, magnetic and optical properties of $SrFe_2O_4$ nanoparticles”, *J. Magn. Magn. Mater.,* 495 (2020) 165866-1-7.
28. Wu, K. H., Chang, Y. C., Chang, T. C., Chiu, Y. S., Wu, T. R., “Effect of SiO_2 content and solution pH in raw materials on Ni-Zn ferrite magnetic properties”, *J. Magn. Magn. Mater.,* 283 (2004) 380–384.
29. Wu, W., Jiang, Ch. Z. H., Roy, V. A. L., “Designed synthesis and surface engineering strategies of magnetic iron oxide nanoparticles for biomedical applications”, *Nanoscale,* 8 (2016) 19421–19474.
30. Bayoumy, W. A. A., “Synthesis and characterization of nano-crystalline Zn-substituted Mg–Ni–Fe–Cr ferrites via surfactant-assisted route”, *J. Mol. Struct.,* 1056–1057 (2014) 285–291.
31. Kurtan, U., Topkaya, R., Baykal, A., Toprak, M. S., “Temperature dependent magnetic properties of $CoFe_2O_4$/CTAB nanocomposite synthesized by sol–gel auto-combustion technique”, *Ceram. Int.,* 39 (2013) 6551–6558.
32. Sivanadhan, T., Saravanan, S., “Temperature influence on strontium ferrite nanoparticles prepared by chemical co-precipitation method”, *Wulfenia,* 28 (2021)39-45.
33. Panchal, N. R., Jotania, R. B., “Effect of heat treatment on microstructure and magnetic properties of strontium hexaferrite nanoparticles prepared in presence of non-ionic surfactant”, *Solid State Phenom.,* 202 (2013) 193-205.
34. Jimenez-Miramontes, J. A., Dominquez-Arvizu, J. L., Salinas-Gutierrez, J. M., Melendez-Zaragoza, M. J., Lopez-Ortiz, A., Collins-Martinez, V., “Synthesis, characterization and photocatalytic evaluation of strontium ferrites towards H_2 production by water splitting under visible light irradiation”, *Int. J. Hydrogen Energ.,* 42 (2017) 30257-30266.

35. Saleh, H. I., “Reaction mechanisms of strontium ferrites synthesis”, *J. Chin. Chem. Soc.,* 49 (2002) 341-348.
36. Vogel, R. H., Evens, B. J., “Solid state- and magneto-chemistry of the SrO-Fe_2O_3 System”, *J. Magn. Magn. Mater.,* 13 (1979) 294-300.
37. Mishra, S., Kumari, S., Kumar, P., Samanta, S. K., “Microwave synthesized strontium hexaferrite 2D sheets as versatile and efficient microwave catalysts for degradation of organic dyes and antibiotics”, *Sci. Total Environ.,* 790 (2021) 147853.
38. Chakradhary, V. K., Akhtar, M. J., “Highly coercive strontium hexaferrite nanodisks for microwave absorption and other industrial applications”, *Compos. B: Eng,* 183 (2020) 107667.
39. Pardeshi, S. K., Pawar, R. Y., “$SrFe_2O_4$ complex oxide an effective and environmentally benign catalyst for selective oxidation of styrene”, *J. Mol. Catal. A: Chem.,* 334 (2011) 35–43.
40. Javidan, A., Ramezani, M., Sobhani-Nasab, A., Hosseinpour-Mashkani, S. M., “Synthesis, characterization, and magnetic property of monoferrite $BaFe_2O_4$ nanoparticles with aid of a novel precursor”, *J. Mater. Sci: Mater. Electron.,* 26 (2015) 3813-3818.
41. Maddahfar, M., Ramezani, M., Hosseinpour-Mashkani, S. M., “Barium hexaferrite/graphene oxide: controlled synthesis and characterization and investigation of its magnetic properties”, *Appl. Phys. A.,* 122 (2016) 752.
42. Javidan, A., Rafizadeh, S., Hosseinpour-Mashkani, S. M., “Strontium ferrite nanoparticles study: Thermal decomposition synthesis, characterization, and optical and magnetic properties”, *Mat. Sci. Semicon. Proc.,* 27 (2014) 468-473.
43. Sobhani-Nasab, A., Mahnaz, M., Hosseinpour-Mashkani, S. M., “$Ce(MoO_4)_2$ nanostructures: Synthesis, characterization, and its photocatalyst application through the ultrasonic method”, *J. Mol. Liq.,* 216 (2016) 1-5.
44. Hosseinpour-Mashkani, S. M., Mahnaz, M., Sobhani-Nasab, A., “Precipitation synthesis, characterization, morphological control, and photocatalyst application of ZnWO4 nanoparticles”, *Journal of Electronic Materials, 4*5 (2016) 3612-3620.