ScienceDirect

Materials Science and Engineering: B

Volume 298, December 2023, 116879

Effect of hydrothermal processing duration on physical and antimicrobial properties of $Mg_{0.2}Zn_{0.5}Mn_{0.3}$ Fe_2O_4 ferrite nanoparticles

Sarang R. Daf [a], Dilip S. Badwaik [a], Shrikant M. Suryawanshi [a], Gaurav D. Kale [b], Yograj D. Choudhari [c]

Show more

https://doi.org/10.1016/j.mseb.2023.116879 ↗

Get rights and content ↗

Highlights

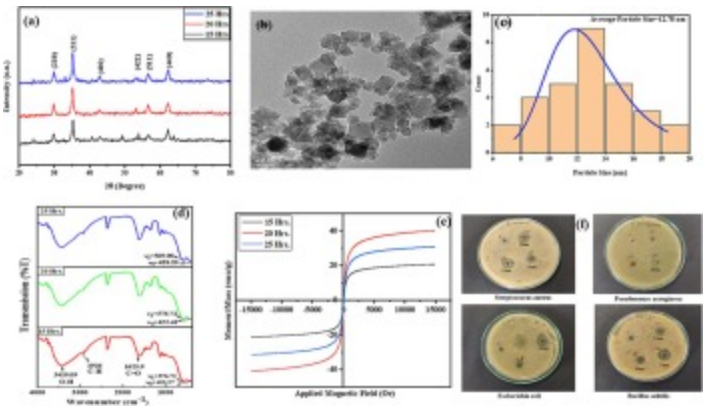
- Polycrystalline magnetic nanoparticles of $Mg_{0.2}Zn_{0.5}Mn_{0.3}Fe_2O_4$ Spinel ferrite were synthesized using a hydrothermal technique.
- The detailed investigation of synthesized spinel ferrite was committed by XRD, TEM, EDS and FTIR.
- Magnetic Study using VSM indicates superparamagnetic nature of synthesized SFNPs.
- Gouy's Balance method used to determine Curie Temperature of synthesized SFNPs.
- Antimicrobial Activity of synthesized SFNPs have been studied on different pathogens.

Abstract

Spinel ferrite nanoparticles (SFNPs) have high demand in the field of electronics and medical engineering. The properties of these spinel ferrites are greatly influenced by the synthesis techniques and their parameters. The spinel ferrite nanoparticles (SFNPs) of $Mg_{0.2}Zn_{0.5}Mn_{0.3}Fe_2O_4$ were successfully prepared using hydrothermal route at 180°C for 15, 20 and 25 hrs duration. The effect of processing duration on structural, magnetic and antibacterial behaviour were recorded by XRD, FTIR, TEM, EDS, VSM and Gouy's balance. The cubic structural morphology with space group Fd-3m confirms spinel nature of prepared nanoparticles recorded by TEM and XRD. The multidomain superparamagnetic nature of synthesized nanoparticles were observed by magnetic parameters from smooth S shaped M-H curve of VSM. Antibacterial efficacy of SFNPs against different pathogenic bacteria were demonstrated using Zone of influence (ZOI).

Graphical abstract

Structural (Fig a), morphological study (Fig b & c), vibrational study (Fig d), Magnetic (Fig e) and antibacterial (Fig f) of synthesized FNPs at different processing duration.



Download: Download high-res image (204KB)

Download: Download full-size image

Introduction

Owing to its unique and flexible magnetic characteristics as well as their superior activity toward microbes and fungi, and biocompatibility, Spinel ferrite magnetic nanoparticles have received a lot of attention [1]. Spinel ferrite (MFe_2O_4) is a class of magnetic material showing a face center cubic (FCC) structure, whereas oxygen represents anions and 'M' metal cations, e.g., Mg^{2+}, Cd^{2+}, Co^{2+}, Mn^{2+}, Zn^{2+}, Ni^{2+}. A spinel ferrite unit cell contains eight formula units whereas each unit cell comprises 64 and 32 tetrahedral (A) sites and octahedral (B) sites, respectively [2]. They have distinct physicochemical characteristics, such as a high Curie temperature, a large magnetic crystalline anisotropy, superior thermal stability, and a simple chemical composition. They also have superior elastic properties, customizable size and shape, a high specific surface area, surface active sites, high chemical stability, and ease of modification or functionalization [3]. These features are influenced by the nature of divalent cations in the spinel structure and their placement at tetrahedral and octahedral sites, as well as the synthesis mechanism, grain size, morphology, temperature, pH, and other variables, which should all be considered. [4], [5].

Nanocrystalline Spinel Ferrites can be synthesized with Top-Down approaches like mechanical milling [6] and Bottom-Up Approaches [7] like the Co-precipitation method, Sol-gel Auto-combustion Method, the Solvo Hydrothermal.

In the perspective of biological applications, Mg-Zn-Mn Spinel Ferrites are widely used for wastewater treatment [8], photocatalysis [9], Drug delivery application [9], Anticancer Potentialities [10], and many more.

M.I.A. Abdel Maksoud et al. [11] a synthesised series of $Mn_{0.5}Zn_{0.5-x}Mg_xFe_2O_4$ NPs samples with the Sol-gel method. It has been observed that they exhibit an antibacterial effect for pathogenic bacteria and a photocatalyst for functional applications. Maksoud, MIA Abdel, et al. [12] synthesized various samples of MnZnMg spinel ferrite with different composition of Mg with Solgel method. Among the series of different concentrations $Mn_{0.5}Zn_{0.25}Mg_{0.25}Fe_2O_4$ shows highest antibacterial efficacy towards different pathogens like S. aureus, P. aeruginosa, and C. tropicalis. Synthesized series of samples also shows Photocatalytic activity potential. Oznur Karaagac et al. [13] produced manganese ferrite nanoparticles hydrothermally. Different synthesis factors, such as reaction temperature and duration, were tested to maximize manganese ferrite nanoparticle characteristics. Particle size rises with reaction temperature and duration, from 16.1±6.1 nm to 25.8±7.4 nm and 19.4±8.4 nm to 25.8±8.2 nm, respectively. The saturation magnetization, Ms, increased with reaction temperature and duration. XRD patterns reveal secondary phase (hematite) in samples produced at high temperature (220°C). The Ms values for samples synthesized at high temperature (220°C for 4 h) and long reaction time (16 h at 130°C) are similar, but the optimal conditions for obtaining manganese ferrite nanoparticles without other phases are 130°C and 16 h, resulting in a high Ms value of 65 emu/g. F. Ozel, H. Kockar et al. [14] conducted a study where they synthesized magnetic nanoparticles with tunable size using the hydrothermal method at various reaction times and temperatures. The sizes of nanoparticles observed in the TEM images exhibited an increase from 14.74 nm to 74.79 nm as the reaction time was prolonged. The saturation magnetization of the samples exhibited an increase from 74.9 to 93.5 emu/g, while the saturation field experienced a decrease from 8698 to 2773 Oe.

In present case, $Mg_{0.2}Zn_{0.5}Mn_{0.3}Fe_2O_4$ Spinel ferrite nanoparticles (SFNPs) were synthesized by bottom-up hydrothermal approach at 180°C, with the aim of studying the influence of the hydrothermal processing duration and find out the best possible processing duration for the synthesis process of SFNPs. The various structural, morphological, elemental composition, spectroscopic-elastic, magnetic parameters are obtained from X-ray diffraction, Transmission electron microscopes, Energy-dispersive X-ray spectroscopy, Fourier Transforms Infrared Analysis, Vibrating Sample Magnetometer respectively are discussed which is seen to be influenced by synthesis process and duration. Furthermore, antibacterial efficacy of prepared SFNPs against P. aeruginosa, S. aureus, and B. subtilis, E. coli bacteria were demonstrated and discussed.

Section snippets

Synthesis process for SFNPs

Stock solutions of 0.4M $FeCl_3$ (Oxford Lab, Purity 99%) and 0.2M $MnCl_2{\cdot}4H_2O$, $MgCl_2{\cdot}6H_2O$ and $ZnCl_2$ (LOBA CHEMIE, Purity 98%) were prepared. The stoichiometrically required amounts of metal chloride solutions were used to obtain the desired composition of $Mg_{0.2}Zn_{0.5}Mn_{0.3}Fe_2O_4$. The neutralization was done using 4M sodium hydroxide solutions, which caused the precursors to precipitate. During precipitation, the ph was changed to 12 to ensure that the precipitation process was completed.…

X-ray diffraction analysis

XRD patterns of $Mg_{0.2}Zn_{0.5}Mn_{0.3}Fe_2O_4$ SFNPs synthesized with different processing duration are shown in Fig. 2. The samples are found to be crystallised, with a cubic spinel structure that corresponds to the Fd3m space group, as evidenced by the clear, substantial Braggs reflections that have been seen. All the Bragg's reflections (220), (311), (400), (422), (511), and (440) lined up perfectly with JCPDS cards 00-008-0234 and 74-2082 [16]. The additional peak that was seen at around 24°Celsius…

Conclusion

The influence of processing duration of the hydrothermal synthesis on $Mg_{0.2}Zn_{0.5}Mn_{0.3}Fe_2O_4$ SFNPs was examined. According to XRD examination, the crystallite size was in the range of 11–14nm for a processing duration of 15–25h. Packing factor rises with processing duration, indicating that crystal imperfections decrease, and packing efficiency improved. TEM investigation indicated the average crystallite size to be around 12.78nm, confirming the development of Nanoparticles. The FTIR spectrum …

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

Acknowledgment

SAIF and CIL Chandigarh for XRD and FTIR facilities, SAIF North-Eastern Hill University, Shillong for TEM and EDS, CIF facility IIT Guwahati for VSM, and Dr. Ambedkar College, Nagpur for impedance spectroscopy studies, Vishakha Clinical Microbiology Laboratory, Nagpur, are gratefully acknowledged by the authors.…

Recommended articles

References (37)

A.B. Naik
Structural, magnetic and electrical properties along with antifungal activity & adsorption ability of cobalt doped manganese ferrite nanoparticles synthesized using combustion route
Ceram. Int. (2020)

M.A. Almessiere
Magneto-optical properties of rare earth metals substituted Co-Zn spinel nanoferrites
Ceram. Int. (2019)

Amal Soufi
Spinel ferrites nanoparticles: Synthesis methods and application in heterogeneous Fenton oxidation of organic pollutants–A review
Appl. Surf. Sci. Adv. (2021)

V. Mahdikhah
Control of structural and magnetic characteristics of cobalt ferrite by post-calcination mechanical milling
J. Phys. Chem. Solid (2019)

S.F. Shaikh
Types, synthesis methods and applications of ferrites
Spinel Ferrite Nanostructures for Energy Storage Devices. Elsevier (2020)

A. Nigam *et al.*

Structural, magnetic, and antimicrobial properties of zinc doped magnesium ferrite for drug delivery applications

Ceram. Int. (2020)

F. Ozel *et al.*

Growth and characterizations of magnetic nanoparticles under hydrothermal conditions: Reaction time and temperature

J. Magn. Magn. Mater. (2015)

U.R. Ghodake

Effect of Mn2+ substitution on structural, magnetic, electric and dielectric properties of Mg–Zn ferrites

J. Magn. Magn. Mater. (2016)

C. Hasirci *et al.*

Superparamagnetic zinc ferrite: a correlation between high magnetizations and nanoparticle sizes as a function of reaction time via hydrothermal process

J. Magn. Magn. Mater. (2019)

K.V. Chandekar *et al.*

Size-strain analysis and elastic properties of CoFe2O4 nanoplatelets by hydrothermal method

J. Mol. Struct. (2018)

View more references

Cited by (2)

Structural and magnetic behaviour of temperature influenced Mn<inf>0.5</inf>Zn<inf>0.25</inf>Cu<inf>0.25</inf>Fe<inf>2</inf>O<inf>4</inf> spinel nanoparticles by co-precipitation route ↗

2024, Journal of Materials Science: Materials in Electronics

Nanohydrometallurgy with superparamagnetic nanoparticles for selective separation of lanthanum from a real spent catalyst ↗

2024, Journal of Material Cycles and Waste Management

View full text