ScienceDirect

Journal of Molecular Structure

Volume 1272, 15 January 2023, 134173

A comprehensive study on structural, magnetic and dielectric properties of $Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.8}Cr_{0.2}O_4$ nanoparticles synthesized by sol-gel auto combustion route

Shrikant M. Suryawanshi [a], Dilip S. Badwaik [a], Bipin S. Shinde [b], Kunal D. Gaikwad [c], Mohd. Shkir [d e], Kamlesh V. Chandekar [f], Shweta Gundale [g]

Show more

Share Cite

https://doi.org/10.1016/j.molstruc.2022.134173

Get rights and content

Highlights

- Reporting the new auto combustion synthesized $Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.8}Cr_{0.2}O_4$ compound.
- Evaluation of microstructural parameters in details is performed and discussed.
- Variation between the magnetic properties due to particle size effect is discussed.
- High values of M_S(50.01 (emu/g),H_C(44.06 Oe), andM_r(1.92 emu/g) are reported.

- Outstanding properties of NCZF NPs suggest their use in multi-layer chip inductors.

Abstract

$Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.8}Cr_{0.2}O_4$ (NCZF) ferrite nanoparticles (NPs) were prepared by sol-gel auto-combustion route. As obtained NCZF powder NPs from sol-get auto combustion route were divided into four parts equally. A non-calcinated part of NCZF NPs was considered as SS1 sample, whereas the three separated parts of NCZF NPs were calcinated at 400°C, 600°C and 800°C, accordingly and were considered as SS2, SS3 and SS4 samples, respectively. X-ray diffraction (XRD) patterns of as-prepared samples were used to evaluate the microstructure parameters. The obtained crystallite sizes were found to be 25, 26.5, 23.4 and 28.1 nm for SS1, SS2, SS3, and SS4 samples, respectively. Transmission electron microscopy images of samples exhibit the spherical shape particles. Average particle size was found to be 6.18, 8.24, 12.7, and 17.14 nm from particles size distributions of SS1, SS2, SS3 and SS4 samples, respectively. The saturation magnetization M_S(45.96, 49.84, 48.84 and 50.01 (emu/g), coercivityH_C(41.40, 43.00, 44.06, and 43.69 Oe), and remanant magnetization M_r(2.00, 1.85, 1.88 and 1.92 emu/g) were determined from M-H analysis of as-prepared samples. Surface analysis of SS2, SS3 and SS4 samples were examined by X-ray photoemission spectroscopy. Dielectric properties and real value of electric modulus of SS4 sample were reduced drastically as-compared to SS2 sample. Frequency dependent conductivity and impedance of SS4 sample was enhanced as-compared to SS2. Outstanding structural, dielectric and electric, and magnetic properties of NCZF NPs can be used for the multi-layer chip inductor applications.

Introduction

The synthesized spinel nanoparticles (NPs) are an eminent magnetic material because of their strong physical and chemical properties compared to their bulk material [1].The magnetic material, especially spinel ferrites, has been at the forefront of contemporary nanotechnology for use in various applications reported by Ansari et al. [2]. Moreover, biomedical applications, including bone tissue regeneration and Covid-19 diagnosis reported by Pen et al. [3]. The spinel ferrite is also known as soft magnetic material represented with the general formula MFe_2O_4; divalent metal ions are suitable in place of M, such as copper, nickel, zinc, cobalt etc. The spinel ferrites are classified into three types namely, normal, inverse and mixed spinel ferrite. When divalent ions occupy the tetrahedral site, the resulting spinel is called normal spinel. Distribution of cations on both tetrahedral

(A) and octahedral (B) sites results in an inverse spinel structure, similarly mixed spinel is a result of cation distribution on both sites. The site preference of cations can be determined by comparing the relative size of ions and the size of sublattice sites. Recently, development in NCZF spinel ferrite shows exceptional physical and chemical properties with technological as well as medical applications. The NCZF ferrite is the dominant material for the miniaturization of electronic devices due to its high electrical resistivity, low sintering temperature and tunable magnetic properties at high frequency range. The physical and chemical properties depend on several factors such as synthesis condition, cation distribution on A-site and B-sites, calcination temperature etc.[4]. From the previous reports we observed that, spinel phase was occured during the calcination process. The calcination temperature plays major a role in distribution of the cations as well as enhancement in the particle size which greatly affect structural, optical and electromagnetic properties [[5], [6]]. However, these properties may be enhanced due to introduction of trivalent metal ions into NCZF spinel ferrite due to the distribution of ions onto tetrahedral (A) and octahedral (B) or both sites within the structure. The calcination at higher temperatures results in regularizing the cationic distribution which improves the grain growth process resulting more ordered spinel structure [7]. It is observed that electrical and magnetic properties are size-dependent. However, particle size is a function of calcination temperature i.e. the calcination temperature is responsible for adjusting the size of particles [8]. This is due to the temperature greatly affecting the grain growth process and hence the particle size. In present work, we discussed various physical properties of the prepared NCZF magnetic nanoparticles for multi-layer chip inductor applications..

Section snippets

Synthesis route

Iron (III) nitrate nonahydrate Fe $(NO_3)_3.9H_2O$, Nickel (II) nitrate hexahydrate Ni $(NO_3)_2.6H_2O$, Copper (II) nitrate hexahydrate Cu $(NO_3)_2.6H_2O$, Chromium (III) nitrate nonahydrate $Cr(NO_3)_3$ $.9H_2O$ and urea were used for preparation of $Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.8}Cr_{0.2}O_4$ (NCZF). The precursors of Fe, Cu, Zn and Ni were employed in stoichiometric proportion as indicated in the chemical formula $Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.8}Cr_{0.2}O_4$ and dissolved in 50 ml double distilled water under continuous stirring at 80°C for 30…

XRD analysis

X-ray diffraction (XRD) patterns of SS1, SS2, SS3, and SS4 samples are exhibited in Fig. 1. XRD patterns of SS1, SS2, SS3, and SS4 NPs were indexed with (220), (311), (222), (400), (422), (511), and (440) planes that correspond to mixed spinel structure of NCZF samples according to JCPDS card (#34-0140). The observed XRD patterns of samples confirmed the formation of NCZF NPs with space group Fd_3m [9]. In observed XRD patterns of the prepared NPs, the diffraction peak (311) becomes sharper and…

Conclusions

$Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.8}Cr_{0.2}O_4$ NPs were prepared by the sol-gel auto-combustion route. The synthesized NPs were calcinated in the range of temperature 400-800°C to investigate the effect of calcination temperature on the microstructural and magnetic properties of the prepared NCZF samples. The other structural parameters such as ionic radii, bond length, hopping length, tetrahedral and octahedral edge, and shared and unshared octahedral edge were calculated and show the variations because of their …

CRediT authorship contribution statement

Shrikant M. Suryawanshi, Dilip S. Badwaik, Bipin S. Shinde, Kunal D Gaikwad, Mohd. Shkir, Kamlesh V. Chandekar, Shweta Gundale: Conceptualization, Data curation, Formal analysis, Writing – original draft, **Mohd. Shkir, Kamlesh V. Chandekar, Shweta Gundale**: Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing…

Data availability statement

The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.…

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

Authors are thankful to SAIF facility NEHU Shillong for TEM characterization and CIF facility IIT Guwahati for magnetic characterizations. The authors are also thankful to the college administration for support and providing the necessary facilities for the research.…

Recommended articles

References (58)

K.V. Chandekar *et al.*

Strain induced magnetic anisotropy and $3d^7$ ions effect in $CoFe_2O_4$ nanoplatelets

Superlattice Microst. (2017)

M. Ansari *et al.*

Super-paramagnetic nanostructured CuZnMg mixed spinel ferrite for bone tissue regeneration

Mater. Sci. Eng. C. (2019)

S.V. Bhandare *et al.*

Mechanistic insights into the sol-gel synthesis of complex (quaternary) Co–Mn–Zn-spinel ferrites: An annealing dependent study

Ceram. Int. (2020)

J Li *et al.*

Cation distribution dependence of magnetic properties of sol–gel prepared MnFe2O4 spinel ferrite nanoparticles

J. Magn. Magn. Mater. (2010)

X Liang *et al.*

The variation of cationic microstructure in Mn-doped spinel ferrite during calcination and its effect on formaldehyde catalytic oxidation

J. Hazard. Mater. (2016)

A.M. Shahare *et al.*

Influence of Cr^{3+} on structural and dielectric properties of Ni0. $25Cu_{0.2}Zn0$. $55Fe_2O_4$ nanoparticles

Mater. Today: Proc. (2020)

Yu-jia Sun *et al.*

Synthesis, structure and magnetic properties of spinel ferrite (Ni, Cu, Co) Fe_2O_4 from low nickel matte

Ceram. Int. (2017)

S.B. Somvanshi *et al.*

Hyperthermic evaluation of oleic acid coated nano-spinel magnesium ferrite: Enhancement via hydrophobic-to-hydrophilic surface transformation

J. Alloy. Compd. (2020)

S.B. Somvanshi *et al.*

Influential diamagnetic magnesium (Mg^{2+}) ion substitution in nano-spinel zinc ferrite ($ZnFe_2O_4$): Thermal, structural, spectral, optical and physisorption analysis

Ceram. Int. (2020)

K.V. Chandekar *et al.*

Size-strain analysis and elastic properties of $CoFe_2O_4$ nanoplatelets by hydrothermal method

J. Mol. Struct. (2018)

View more references

Cited by (20)

Synthesis of Cu<inf>0.5</inf>Zn<inf>0.5-x</inf>Ni<inf>x</inf>Fe<inf>2</inf>O<inf>4</inf> nanoparticles as heating agents for possible cancer treatment

2024, Arabian Journal of Chemistry

Show abstract

Single phase metamaterial behavior in Ag⁺ and Ti⁴⁺ doped cobalt ferrites

2024, Materials Chemistry and Physics

Show abstract

Calcination temperature dependence of tri-magnetic nanoferrite Ni<inf>0.33</inf>Cu<inf>0.33</inf>Zn<inf>0.33</inf>Fe<inf>2</inf>O<inf>4</inf> : Structural, morphological, and magnetic properties

2024, Ceramics International

Show abstract

Exploring the multiferroic and water sensing behavior of Cu/Er co-substituted ferrites as key enablers for next-gen hydroelectric cells

2024, Materials Chemistry and Physics

Show abstract

Structural, surface, magnetic, and dielectric properties of Ni<inf>0.3</inf>Cu<inf>0.3</inf>Zn<inf>0.4</inf>Fe<inf>1.4</inf>Cr<inf>0.6</inf> O<inf>4</inf> spinel ferrite nanocrystals prepared by sol-gel auto combustion route

2023, Inorganic Chemistry Communications

Show abstract

Ni–Ag ferrites synthesized by sol gel route using aloe vera extract as a solvent: Enhancement in structural, dielectric, magnetic and optical properties

2023, Physica B: Condensed Matter

Show abstract

View all citing articles on Scopus ↗

View full text

ELSEVIER