ScienceDirect

Inorganic Chemistry Communications
Volume 156, October 2023, 111204

Short communication

Structural, surface, magnetic, and dielectric properties of $Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.4}Cr_{0.6}O_4$ spinel ferrite nanocrystals prepared by sol-gel auto combustion route

Shrikant M. Suryawanshi [a], Kamlesh V. Chandekar [b], Dilip S. Badwaik [a], Vijay V. Warhate [c], Nomdeo M. Gahane [d], Sarang R. Daf [a]

Show more

Share Cite

https://doi.org/10.1016/j.inoche.2023.111204
Get rights and content

Highlights

- Synthesis of $Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.8}Cr_{0.6}O_4$ nanoparticles by sol-get auto combustion route.

- Evaluation of microstructural parameters and different inter-atomic bonding lengths between ions of the crystal structure on the basis of lattice parameter.

- Correlation between the inter-atomic bonding lengths and bonds.

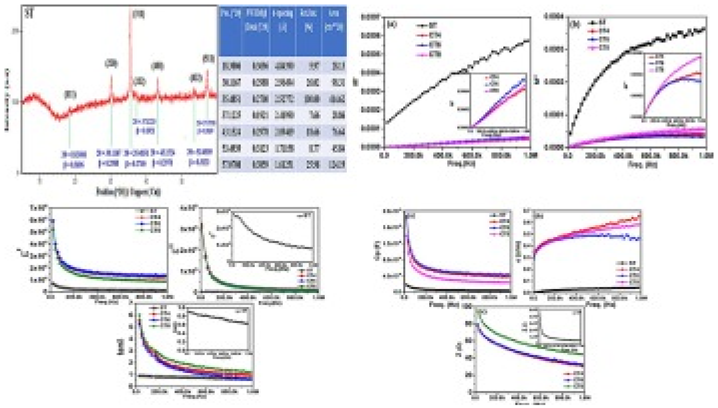
- Variation between the magnetic properties due to particle size effect.

- Examination of dielectric properties by impedance spectroscopy.

Abstract

Multi-metal spinel ferrite nanocrystals of $Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.4}Cr_{0.6}O_4$ was synthesized by sol–gel auto-combustion route. Structural, magnetic, and dielectric properties of the prepared nanocrystals were affected by different calcination temperatures. The values of crystallite size 30.9–51.1 nm, lattice strain 3.68×10^{-3}–2.21×10^{-3}, and dislocation density 1.046×10^{-3}–0.382×10^{-3} $1/nm^2$ were estimated for the prepared NPs. The magnitudes of saturation magnetization 20.83–33.37 emu/g, retentivity 1.18–1.98 emu/g, coercivity 30.56–35.29 Oe, and magnetic anisotropy 3.531×10^3–6.133×10^3 emu/cm^3 of the prepared NPs were evaluated under the applied magnetic field of (17kOe). The dielectric constant magnitudes 6810.41, 5.85×10^4, 5.91×10^4, and 5.21×10^4 were reported for non-calcinated NPs (ST), calcinated CT4 NPs at 400 °C, CT6 NPs at 600 °C, and CT8 NPs at 800 °C, respectively at low-frequency range. The dielectric loss magnitudes 2210.84, 3.23×10^5, 3.10×10^5, and 3.13×10^5 were reported for ST, CT4, CT6, and CT8 NPs at the low-frequency range, respectively. The conductivity values 2.46×10^{-3}, 361.79×10^{-3}, 372.49×10^{-3}, and 342.63×10^{-3} S/m for ST, CT4, CT6 and CT8 at low frequency range, respectively. Impedance values 4250, 95, 81, and 80 (Ohm) were recorded ST, CT4, CT6, and CT8 NPs at low-frequency range, respectively. The prepared NPs of $Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.4}Cr_{0.6}O_4$ can be used for the fabrication of good-quality capacitors, recording systems, high-frequency devices and multilayer chip inductor applications.

Graphical abstract



Introduction

Spinel ferrite nanocrystalline materials are being effectively used in electronics [1], [2], antibacterial activity [3], [4], plant and water treatment [5], [6], etc. The spinel ferrite with one metallic ion in the formula of M (II)Fe_2O_4 such as $CoFe_2O_4$, $NiFe_2O_4$, $CuFe_2O_4$, and $ZnFe_2O_4$ etc, shows outstanding electromagnetic and biomedical properties. In the recent era, multi-metal spinel magnetic nanocrystals have received tremendous attraction due to their application in multilayer chip inductors (MLFCI) [7], [8], electromagnetic interference (EMI) [9], [10], super-capacitors [11], [12], and medical applications [12] with the introduction of suitable multi-metal atoms into the M(II)Fe_2O_4 structure, that tunes the physical and chemical properties of the material. According to Malaie *et al.* [11] and Abdel *et al.* [12], spinel ferrite can also be used in energy storage devices such as super-capacitors and batteries.

These spinel ferrites exhibited excellent physical and chemical properties at the nanoscale which can be utilized in the fabrication of super-capacitor and batteries as compared to other compounds like Tin nitride (SnNx) [13], Manganese-based oxides (Mn_xO_y) [14], Sn-based materials [15], and Phosphorus@graphene (rP@rGO) [16]. Katoch *et al.* [17] reported the tuning of superparamagnetic properties with the incorporation of transition metals like Cr^{3+}, Cu^{2+}, and Zn^{2+} into host lattice structures that control the chemical and physical properties which are imperative for biological applications. NiCuZn spinel ferrites belong to the family of soft magnetic materials at the nanoscale that can be used in various applications [18], [19]. Due to the low eddy current losses, high resistivity, high permeability, and low manufacturing cost makes these materials preferable for reducing radar signatures, multilayer cheap inductor, EMI in cellular phones, computer and video cameras, and other electronic devices [20], [21].

These applications, however, may have different requirements that can be achieved by producing nano-crystallites utilizing a wet chemical technique with precisely calibrated parameters including such as fuel type, stoichiometry, and heating treatment on synthesized nano-crystalline material [22]. Wet chemical methods are being extensively utilized in the synthesis of magnetic nano-crystalline material because of cost-effective, easy to prepare, have less synthesis time, and produce particles of nanoscale dimensions. Chemical methods such as co-precipitation, sol–gel auto-combustion, hydrothermal, solvothermal, thermal decomposition, and microwave combustion routes have been employed for the preparation of spinel ferrite nanocrystals [23], [24], [25]. The sol–gel auto-combustion technique, which uses a low reaction temperature up to 100°Cwith short response time for the preparation of powder samples, which is one of the most convenient parameter for wet chemical procedures.

The less research work on the prepared NPs as-compared other magnetic materials for the same application. In the present study, $Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.4}Cr_{0.6}O_4$ NPs have been synthesized using a sol–gel auto-combustion route followed by some amount of the prepared NPs calcinated at the temperature of 400°C, 600°C and 800°C, respectively to examine the effect of calcination temperature on the microstructural and magnetic parameters due to the crystallization. Moreover, the structural, magnetic, and dielectric properties of the $Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.4}Cr_{0.6}O_4$ NPs have been examined to get more information that can be utilized in application.

Section snippets

Materials and synthesis route

The nanocrystals of $Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.4}Cr_{0.6}O_4$ NPs were prepared by utilizing the sol–gel auto-combustion method under urea as the fuel. To preserve the stoichiometry of synthesized nanocrystalline material, ACS grade Nickel nitrate, Copper nitrate, Zinc nitrate, Iron Nitrate, and Chromium nitrate of 99.9% purity in stoichiometric amount and dissolved in 30 ml of double distilled water. After vigorous stirring for 30 min, a homogenous solution is formed, which is followed by the formation of…

XRD analysis

Fig. 1(A) shows XRD patterns of as-synthesized $Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.4}Cr_{0.6}O_4$ NPs such as ST, CT4, CT6, and CT8, respectively. The indexed peak of (111), (220), (311), (222), (400), (422), and (511) corresponds to single-phase spinel ferrite having space group Fd-3 m consistent with JCPDS (#34–0140). The data profiles of the prepared NPs have been fitted using the Lorentz function, as exhibited in Fig. 1(B). The obtained values of diffraction angle (2θ), peak broadening β_{hkl}, area under the curve, …

Conclusions

The multimetal spinel nanocrystals of $Ni_{0.3}Cu_{0.3}Zn_{0.4}Fe_{1.4}Cr_{0.6}O_4$ were synthesized by the sol–gel auto-combustion route. The obtained nanocrystals undergo calcination treatment at 400, 600, and 800 °C to investigate the effect of calcination treatment on the structural, magnetic, and dielectric properties of the prepared NPs. The crystallite size, lattice strain, and dislocation density of the prepared NPs have been increased due to complete crystallization as a function of the calcination…

CRediT authorship contribution statement

Shrikant M. Suryawanshi: Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Kamlesh V. Chandekar:** Conceptualization, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Dilip S. Badwaik:** Project administration, Resources, Software, Supervision, Validation, Visualization. **Vijay V. Warhate:** Project administration, Resources, Software, Supervision, Validation, Visualization. **Nomdeo M. Gahane:** Project…

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 and CIL facility Chandigarh for XRD, and FTIR characterizations, respectively. Moreover, Authors are also thankful to Central Instrumentation facility (CIF) Pondicherry University for X-ray Photoelectron Spectroscopy (XPS) and CIF at IIT Guwahati for magnetic characterizations, respectively. The authors are also thankful to the Department of Physics, Dr. Ambedkar College, Nagpur for Dielectric facility and Department of Physics Kamla Nehru Mahavidyalaya Nagpur for…

Recommended articles

References (89)

A. Nigam *et al.*
Structural, magnetic, and antimicrobial properties of zinc doped magnesium ferrite for drug delivery applications
Ceram. Int. (2020)

R. Suresh *et al.*
Recent advancements of spinel ferrite based binary nanocomposite photocatalysts in wastewater treatment
Chemosphere (2021)

S.M. Kabbur *et al.*
Magnetic interactions and electrical properties of Tb3+ substituted NiCuZn ferrites
J. Magn. Magn. Mater. (2019)

D. Kumar *et al.*
Current trends in spinel based modified polymer composite materials for electromagnetic shielding
Mater. Today Chem. (2020)

K. Malaie *et al.*
Spinel nano-ferrites for aqueous supercapacitors; linking abundant resources and low-cost processes for sustainable energy storage
J. Energy Storage (2021)

M.Z. Ansari *et al.*
Fundamentals and recent progress of Sn-based electrode materials for supercapacitors: A comprehensive review
J Energy Storage (2022)

M.A. Almessiere *et al.*
Effect of Nd-Y co-substitution on structural, magnetic, optical and microwave properties of NiCuZn nanospinel ferrites
J. Mater. Res. Technol. (2020)

N. Yasmin *et al.*
Structural and magnetic properties of Cr doped strontium spinel ferrite SrFe2O4 by sol-gel auto-combustion method
Physica B Condens. (2018)

M. Gharagozlou
Synthesis, characterization and influence of calcination temperature on magnetic properties of nanocrystalline spinel Co-ferrite prepared by polymeric precursor method
J. Alloy. Compd. (2009)

K.V. Chandekar *et al.*
Comprehensive study of MFe2O4 (M=Co, Ni, Zn) nanostructures prepared by co-precipitation route
J. Alloy. Compd. (2023)

View more references

Cited by (6)

Study on multifunctional magnesium copper zinc spinel ferrite nanoparticles prepared by hydrothermal route; Physical, electrical, and anti-microbial investigation

2024, Nano-Structures and Nano-Objects

Show abstract

Synthesis, microstructure, and electromagnetic behavior of graphene nanoplatelets/CZCF ferrite nanocomposites

2024, Synthetic Metals

Show abstract

Facile combustion-synthesis, structural, morphological, vibrational, photoluminescence, dielectric, and electrical properties of ZnFe<inf>2</inf>O<inf>4</inf> nanostructures: an effect of citric acid concentrations

2024, Journal of Alloys and Compounds

Show abstract

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

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

Simple co-precipitation synthesis of activated carbon-cobalt ferrite (AC-CoFe<inf>2</inf>O<inf>4</inf>) nanocomposites: enhanced photocatalytic dye degradation and antimicrobial activity ↗

2024, Zeitschrift fur Physikalische Chemie

View full text