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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

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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 etal. [2]. Moreover, biomedical applications, including bone tissue regeneration and Covid-19 diagnosis reported by Pen etal. [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

$Ni_{0.3Cu0.3}Zn_{0.4}Fe_{1.8}Cr_{0.2}O_4$ 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.…

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