Role of Rare Earth (Gd^{3+}) on Structural and Dielectric Properties of Cobalt Ferrite

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Abstract: Nano ferrites are area of research focused due to their potential applications in various fields such as high-density magnetic recording, magnetic fluid and microwave devices etc. Usually substitution of metal ions in cobalt ferrite has led to enhancement in structural and electrical properties. These structural and electrical properties of the ferrites are influenced by their chemical composition, synthesis techniques, doping materials and environmental conditions. In the present investigation Gadolinium (Gd) substituted cobalt ferrites ($CoFe_{2-x}Gd_xO_4$) with variable Gd content (x = 0.0, 0.1, 0.3, 0.5) have been synthesized by sol-gel auto combustion method using glycine as a fuel and nitrates as oxidants. The crystal structure, electrical conduction and dielectric properties of the series of synthesised compound has been evaluated. X-ray diffraction spectra indicates that $CoFe_{2-x}Gd_xO_4$ crystallizes in the inverse spinel phase with a lattice constant of 8.373Å. It is evident from the FESEM (Field Emission Scanning Electron Microscope) and TEM (Transmission Electron Microscopy) study that substituiting Gd results in a smoother microstructure which may be attributed to the higher ionic radius of Gd^{3+} ions as compared to that of Fe, responsible for the increase in lattice constant. The EDS (Energy-Dispersive Spectroscopy) measurements show that the specimens are homogeneous with a uniform distribution. From the dielectric studies, it is observed that the specimens show Debye type of behaviour with a shift in dielectric maxima with increase in frequency at higher temperature. The temperature dependent dielectric constant, energy loss, ac electrical resistivity and conductivity studies indicates the existence of correlation and microstructural effect. Notably the effect of Gd-substitution in cobalt ferrite is significant on the resistivity which increases with increasing Gd content. The structural and dielectric studies can be tailored with the doping content of Gd in cobalt ferrite which can find applications in EMI shielding.

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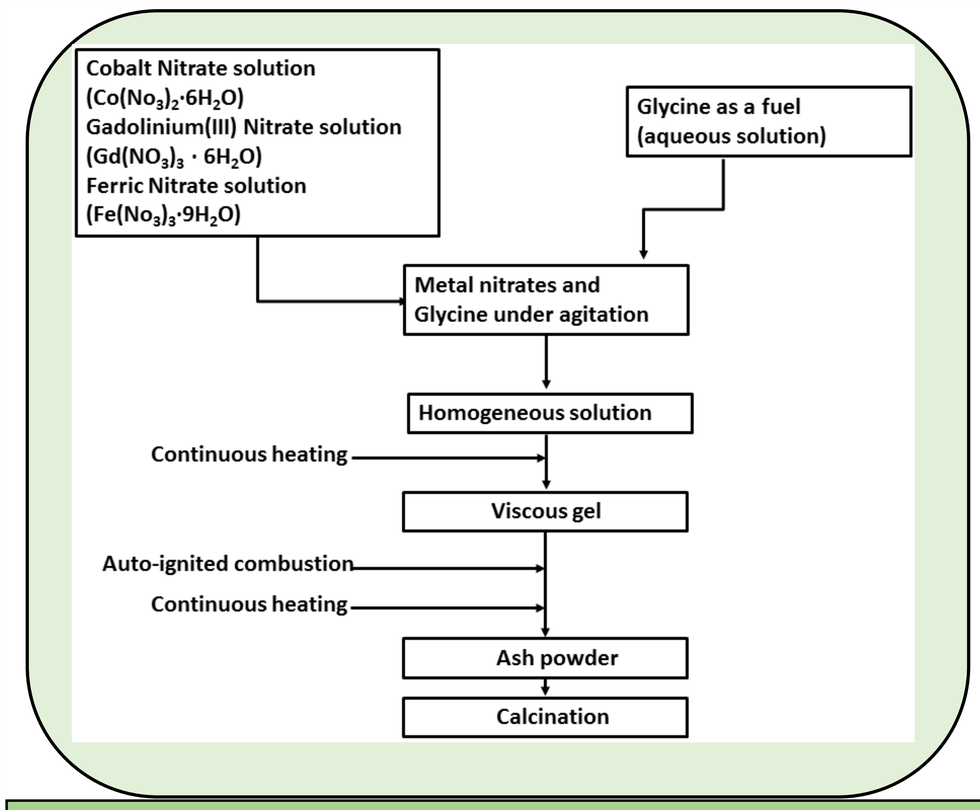
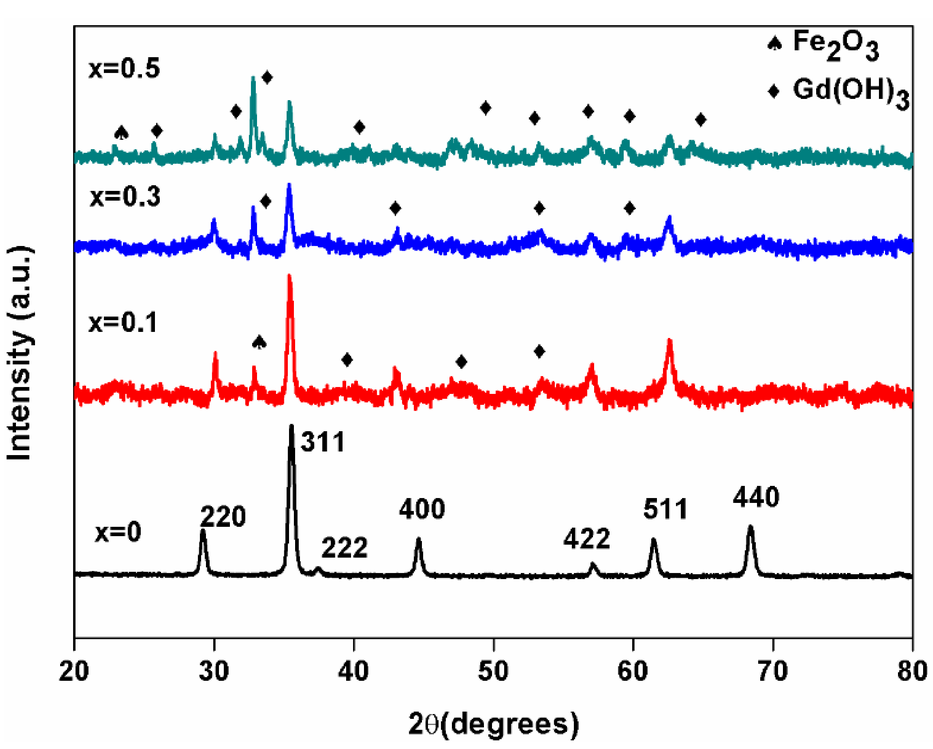
Motivation and Introduction

- Rare earth oxides are known to be good electrical insulators, their resistivities values are greater than 106 Ω cm. In case of ferrimagnetic spinels the suitable choice of rare earth cation can modify the structural, electrical and magnetic properties and have a large influence upon the magnetic anisotropy of the system resulting the spinel ferrite an excellent preference in place of hexa ferrites or garnets.
- It is reported[1] that doping ferrimagnetic spinels with rare earth cations (Y^{3+}, Gd^{3+}, Ho^{3+}, Sm^{3+}, Nd^{3+}) leads in structural disordering and lattice strain, thus increasing the electrical, dielectric and magnetic parameters because of partial substitution of Fe3+ by rare earth ion.
- The impetus for the present work is to study the role of Gadolinium (Gd^{3+}) incorporation on the structural and dielectric properties of cobalt ferrite (CFO). Herein, we emphasize the fabrication of gadolinium-doped $CoFe_2O_4$ nanoparticles by sol-gel auto combustion method and investigation of the effect of Gd^{3+} ion composition on the structural parameters and frequency dependence of the dielectric constant and dielectric loss tangent are carried out in the frequency range of 100 Hz to 1 MHz.

Synthesis technique

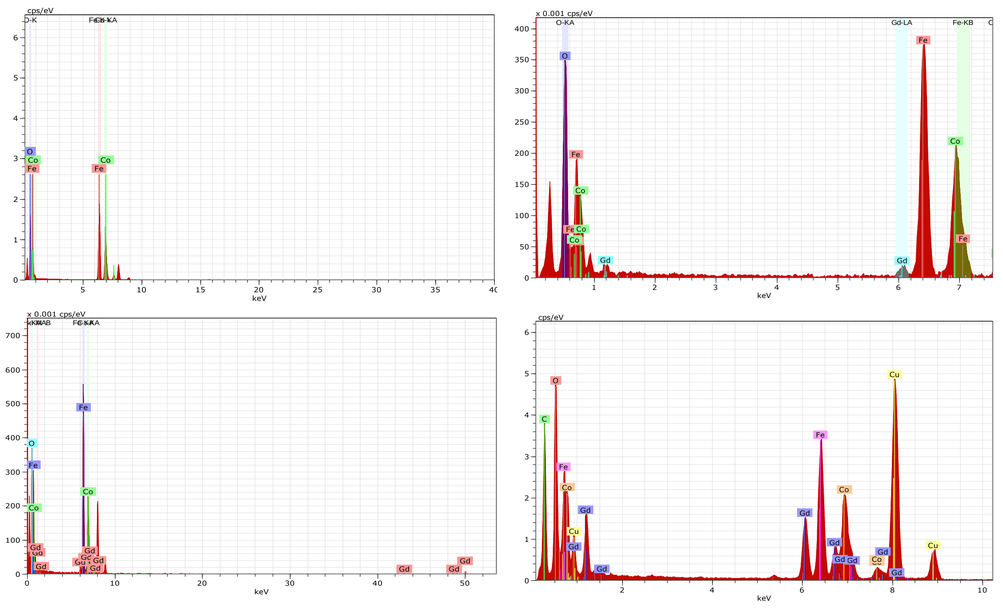


Structural characterisations



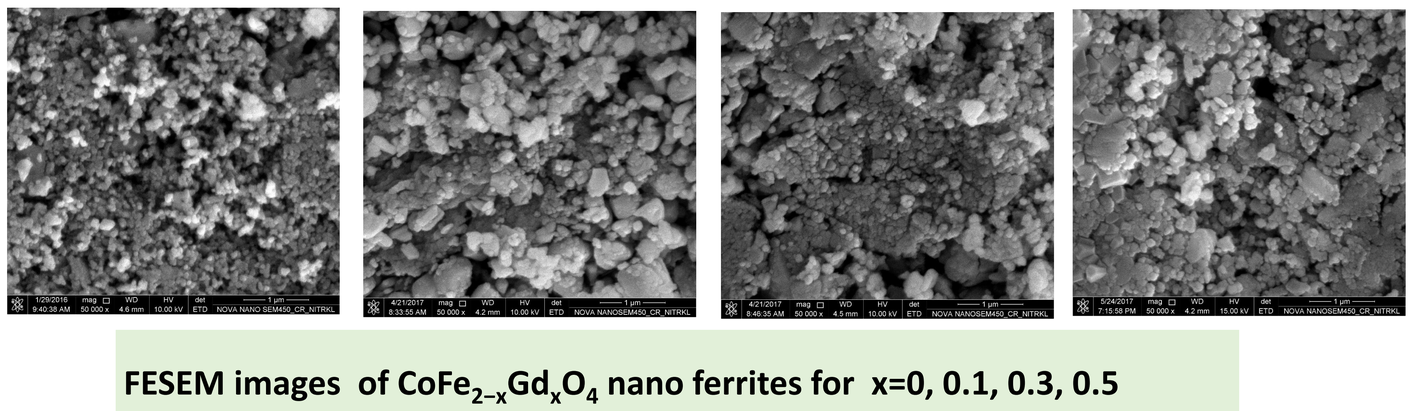
XRD patterns of $CoFe_{2-x}Gd_xO_4$ nano ferrites for x=0, 0.1, 0.3, 0.5

Elemental analysis by EDX

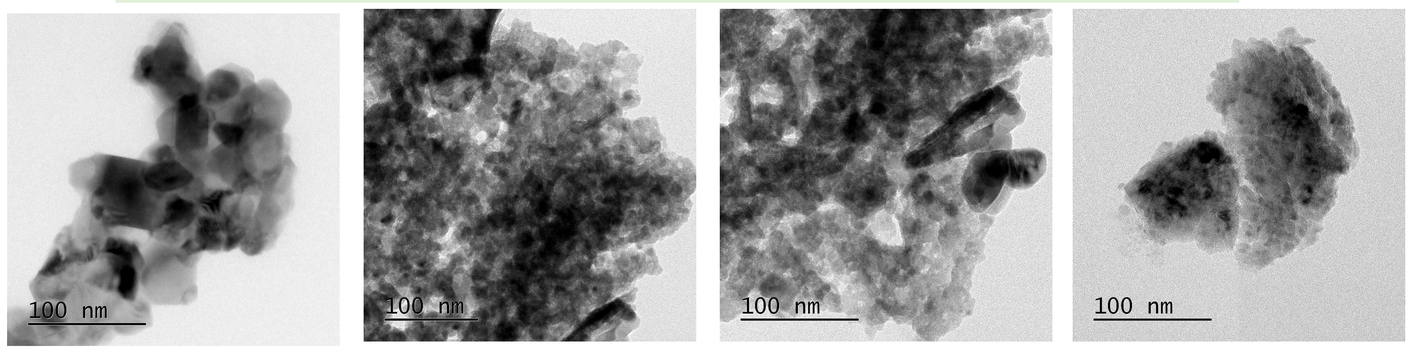


EDX patterns of $CoFe_{2-x}Gd_xO_4$ nano ferrites for x=0, 0.1, 0.3, 0.5

Morphological analysis



FESEM images of $CoFe_{2-x}Gd_xO_4$ nano ferrites for x=0, 0.1, 0.3, 0.5



TEM images of $CoFe_{2-x}Gd_xO_4$ nano ferrites for x=0, 0.1, 0.3, 0.5

Dielectric analysis

Complex Impedance/Complex electric modulus study

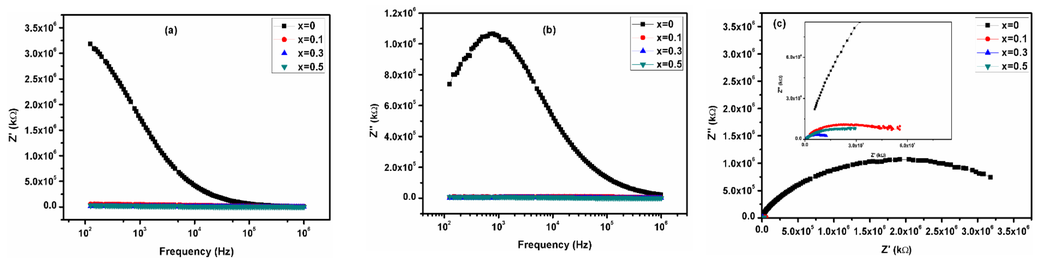


Figure: (a) real part of impedance with applied frequency, (b) imaginary part of impedance with applied frequency (c) the complex impedance plane plots (Cole-Cole) for $CoFe_{2-x}Gd_xO_4$ (x=0, 0.1, 0.3, 0.5)

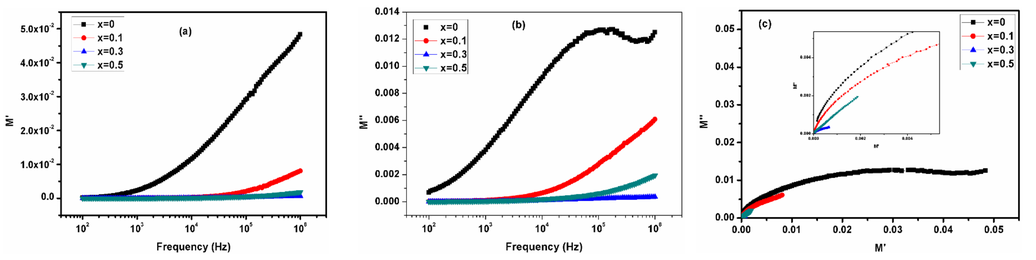


Figure: (a) real part of modulus with applied frequency, (b) imaginary part of modulus with applied frequency (c) the complex modulus plane plots (Cole-Cole) for $CoFe_{2-x}Gd_xO_4$ (x=0, 0.1, 0.3, 0.5)

Conclusion

- $CoFe_{2-x}Gd_xO_4$ (x=0, 0.1, 0.3, 0.5) nano ferrites has been synthesized by sol-gel auto combustion technique.
- All the synthesised samples are purely cubic spinel ferrites with Gadolinium hydroxide [$Gd(OH)_3$] and Fe_2O_3 as impure phase at higher Gd concentration.
- With increase in Gd^{3+} concentration, lattice constant and crystallite size increases.
- TEM images show that the nanoparticles are single crystal, roughly spherical, homogenously distributed, and less agglomerated. The EDS images confirmed the formation of homogenous particles with uniform distribution and increased stoichiometry with Gd content.
- Gd^{3+} substitution have tailored the relaxation behavior making the resonance frequencies lower than the pure cobalt ferrites. Thus the rare earth (Gd^{3+}) doped Co-ferrites found an application in in EMI shielding due to high resistivity and low losses.

References

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