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Al doped spinel and garnet nanostructured ferrites for microwave frequency C and X- band applications

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ABSTRACT

Spinel and garnet nanostructured ferrites have been used for various potential applications. Single phase spinel and garnet nanoferrites have been used for different applications in many fields. Ni-Zn ($Ni_{0.5}Zn_{0.3}Al_{0.2}Fe_2O_4$) ferrite with spinel structure and YAIG ($Y_{2.8}Al_{0.2}Fe_5O_{12}$) ferrite with garnet structure were synthesized using sol-gel technique. The structural, morphological and magnetic studies were done for spinel and garnet nanoferrites. X-ray diffraction (XRD), scanning electron microscopy (SEM) and vibrating sample magnetometer (VSM) were used to investigate the structural, morphological and magnetic properties of the spinel and garnet nanoferrites respectively. Single phase spinel and garnet nanocrystalline ferrites were confirmed from XRD analysis. Circular and cubic shape morphology was observed for spinel and garnet nanoferrites respectively. Static magnetic characteristics of the Al doped spinel and garnet nanoferrites (saturation, remanence, coercivity and magnetic squareness) were measured from the hysteresis loops. Dynamic magnetic properties such as initial permeability, Q factor and magnetic losses of the Al doped spinel and garnet nanoferrites were also evaluated from magnetic measurements. Spinel and garnet nanoferrites prepared at low temperature may have potential in industrial and technological applications e.g. transformers, switching, cores, filters, sea bed logging, MLCI's, microwave absorption bio medical applications and microwave frequency (C and X) band applications.

1. Introduction

Nanoferrites with better magnetic properties are promising materials because of their use in multipurpose industrial and technological fields [1]. Magnetic nanoferrites with potential characteristics have potential applications such as magnetic storage discs, refrigeration, permanent magnets, recording heads, ferrofluids, magnetic separation, microwave absorbers, switching, cores, magnetic shielding, oscillators, phase shifters, filters, microwave devices and high frequency devices and applications [2]. These nanoferrites have been suggested to use in the electronic, electromagnetic bio medical and pharmaceutical industrial and technological fields [3,4].

Spinel and garnet nanoferrites are soft magnetic materials and have potential applications in different fields. Generally, spinel nanoferrites have cubic structure with two lattice sites and are represented by tetrahedral (a) and octahedral sites (b) respectively. However, the garnet nanoferrites have extra sites (dodecahedral-c cite) in addition to tetrahedral and octahedral sites [5]. The cations at their sites are more important because of their lattice interactions which may be helpful for the tuneable properties of nanoferrites [6]. Among spinel and garnet ferrites, Ni-Zn and YIG ferrites have potential applications because of their better electromagnetic performance, high remanence, low coercivity (Hc), large resistivity, chemical stability, large saturation magnetization (Ms) and good EM compatibility [7–10].

Low cost and easy fabrication of spinel and garnet nanoferrites made them potential candidates for many applications. Super exchange interactions of spinel and garnet nanoferrites at the lattice sites are the main reasons for the improvement of properties [11,12]. Sol-gel, sol-gel auto combustion method, self-combustion, co-precipitation, reverse micelle, micro-emulsion, glass crystallization, precursor and hydrothermal methods have been reported for the fabrication of nanoferrites [13]. Recently, sol gel auto combustion has been paid much attention due to the better homogeneity, morphology and outcomes of the prepared nanoferrites.

Rare earth Ce doped Cu spinel ferrites were prepared using molten salt method. Spinel phase was investigated for lower concentration of

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Ce contents in spinel ferrite. However, the nanoparticles size was found to be decreased with increasing Ce contents. The doped spinel ferrites were tested for LPG sensing applications [14]. Rare earth (RE) doped Mg-Mn spinel ferrites with composition (Mg0.5Mn0.5RE0.1Fe1.9O4) where 'RE' = Ce, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Yb and Lu were synthesized using glycol thermal method. It was found that the magnetization increased whereas coercive fields were decreased with the rare earth substitution. However, the Gd doped spinel ferrite showed higher magnetization as compared to other doped spinel ferrites [15].

Al doped Ni-Zn ferrite ($Ni_{0.7}Zn_{0.3}Al_xFe_{2-x}O_4$, where $0.0 \le x \le 0.5$) nanoparticles were synthesized by chemical method. XRD confirmed the single-phase structure of the prepared Al doped Ni-Zn samples. Magnetization and coercivity was found to decrease with Al contents in the Ni-Zn spinel ferrites [16]. Al doped YIG (Al-YIG) was prepared using citrate-nitrate combustion method. It was noticed that saturation magnetization and Curie temperature decreased with Al contents in YIG ferrite [17]. Al doped YIG and un-doped YIG were synthesized using micro-emulsion technique. It was found that Al doped YIG has lower static and dynamic properties as compared to un-doped YIG nanoferrites. The suggested use of these nanoferrites was in the fields of switching and electromagnetic wave absorbers [18].

Recently, spinel and garnet based nanoferrites are being focussed by the researchers because of their extensive applications in various fields. Substitution of metal cations in spinel and garnet based structures will be helpful to tune the structural, electrical and magnetic properties. It is expected that the doping of paramagnetic elements in ferrites play major role in the improvement of structure, magnetic and electromagnetic properties of the ferrites. The lower cost of ferrites with low eddy current and magnetic losses are important for the industrial and technological applications. Thus, paramagnetic ions in spinel and garnet ferrite may result better structural and magnetic parameters for variety of applications.

In this work, Comprehensive study on the spinel and garnet nanoferrites has been done. Ni-Zn with composition ($Ni_{0.5}Zn_{0.3}Al_{0.2}Fe_2O_4$) and garnet with ($Y_{2.8}Al_{0.2}Fe_5O_{12}$) were prepared using sol gel auto combustion technique. XRD analysis and SEM analysis were used to study the phase, structural and morphological properties of the Al doped spinel and garnet nanoferrites. Dynamic magnetic properties were determined using LCR vector network analyser. However, static magnetic properties such as magnetic hysteresis loops were evaluated using VSM. The major objective of the present study is to establish comparative study of the Al (aluminium) doped spinel and garnet nanoferrites.

2. Experimental procedure

2.1. Materials used for synthesis purpose

Spinel nanoferrite with composition of $Ni_{0.5}Zn_{0.3}Al_{0.2}Fe_2O_4$ and garnet nanoferrites ($Y_{2.8}Al_{0.2}Fe_5O_{12}$) were synthesized via sol-gel auto combustion technique. Nickel nitrate ($Ni(NO_3)_2.6H_2O$), iron nitrate ($Fe(NO_3)_3.9H_2O$), zinc nitrate ($Zn(NO_3)_2.6H_2O$), yttrium nitrate ($Y_3(NO_3).6H_2O$), aluminium nitrate ($Al(NO_3)_3.6H_2O$) and nitric acid (HNO_3) with the purity of 99.99% were used. Citric acid ($C_6H_8O_7.H_2O$) and ammonia (NH_3) were also used for gelation and neutralization of the solution.

2.2. Preparation of Al doped spinel and garnet nanoferrites

Nickel nitrate ($Ni(NO_3)_2.6H_2O$), aluminium nitrate ($Al(NO_3)_3.6H_2O$) and iron nitrate ($Fe(NO_3)_3.9H_2O$), were dissolved in HNO_3. However, for the preparation of garnet nanoferrites, metal nitrates of yttrium nitrate ($Y_3(NO_3).6H_2O$), aluminium nitrate ($Al(NO_3)_3.6H_2O$) and iron nitrate ($Fe(NO_3)_3.9H_2O$) were dissolved in HNO_3. The citric acid with required molarity was poured in de ionized water to make solution. Solution was mixed with the nitrate solution. The solutions stirred on stirrer at 230 rpm for 24 h. The addition of ammonia was done to maintain the pH of prepared solution. The temperature of hot plate increased from room temperature to 80 °C. The occurrence of gel appeared and then it was allowed to combust gel on the hot plate with increase in temperature at 120 °C respectively. The gel was kept in heating oven and was dried at 100 °C. The dried gel was ground for 6 h. Spinel nanoferrite sample was sintered at 700 °C whereas garnet nanoferrites were sintered at 850 °C respectively. The toroidal shape samples of the Al doped spinel and garnet nanoferrites were prepared for the measurement of static magnetic measurements of the samples.

2.3. Characterizations of the Al doped spinel and garnet nanoferrites

XRD patterns were recorded employing X-ray Diffractometer to determine crystalline structure, phase and purity of spinel and garnet samples. The structural analysis was done through scanning electron microscopy. The dynamic and static magnetic properties of spinel and garnet nanoferrites were investigated using LCR vector network analyser and VSM respectively. Q factor, Initial permeability, magnetic losses, saturation, remanence, and coercivity were determined using the magnetic data measured from LCR network analyser and hysteresis loops. For the measurements of Q factor initial permeability, and magnetic losses, the Ls and Q values were measured from the LCR network analyser.

The initial permeability (μ_i) (H/m) is calculated using the equation;

$$\mu_i = \frac{2\pi Ls}{N^2\mu_o t\ln\left(\frac{Do}{Di}\right)} \quad (1)$$

Where, μ_o is the permeability constant ($4\pi x 10^{-7}$ H/m), t is the thickness and N is number of winding respectively. The dimensions of D_1 (outer diameter), D_0 (inner diameter) and 't' (thickness) of toroidal shape samples was 0.5 cm, 0.25 cm and 0.25 cm respectively.

3. Results and discussion

3.1. Characterization of materials

3.1.1. X-ray diffraction analysis

X-ray diffraction patterns of the spinel and garnet structure are presented in Fig. 1. The structural analysis of the spinel ($Ni_{0.5}Zn_{0.3}Al_{0.2}Fe_2O_4$) and garnet nanoferrites ($Y_{2.8}Al_{0.2}Fe_5O_{12}$) are confirmed from the recorded patterns. XRD patterns revealed the single phase cubic structure of spinel and garnet nanoferrites. The patterns of

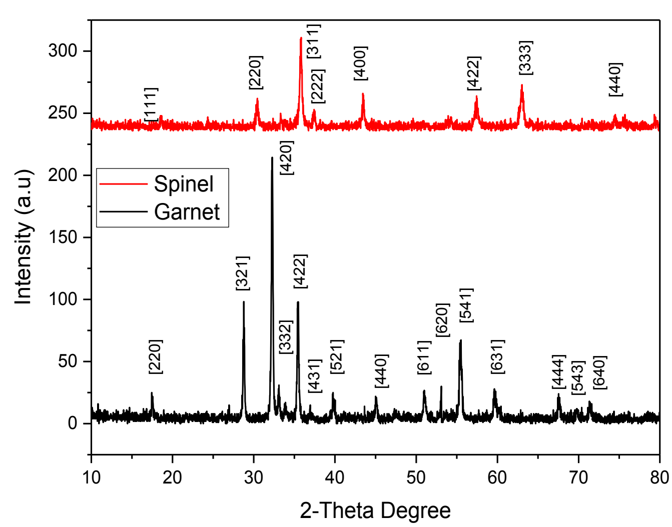

Fig. 1. XRD patterns of Al doped spinel and garnet nanoferrites.