Review Article: Nickel Aluminium Ferrites

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ABSTRACT: Ferrites are technologically useful materials due to their unique electric, dielectric and magnetic properties. Nickel ferrites and substituted nickel ferrites are one of the most attractive classes of materials for researchers. Present paper covers the characterization results of Nickel-Aluminium ferrites using X-ray diffraction (XRD), Fourier transform-infrared spectroscopy (FTIR), Raman spectroscopy, scanning electron microscopy (SEM), vibrating sample magnetometer (VSM), Mössbauer spectroscopy and LCR-meter. The preparation of Nickel Aluminium ferrites using many available methods of preparation and comparison of results of such studies is need of the present day. This data helps in providing interesting and useful study for application of Nickel Aluminium ferrites.

Keywords: Ni-Al ferrites, XRD, FTIR, SEM and VSM

INTRODUCTION

Ferrites represents an important class of technological materials .Ferrite in nanometre scale size show many unusual and interesting properties because of their unique electric, dielectric and magnetic properties which are different from bulk materials. Substituted Nickel ferrites have been extensively used in electronic devices because of their remarkable properties [1, 2]. Substituent plays an important role in determining the variations of the physical properties since the substitution of impurity ions can produce new ferrites composition with better properties [3]. High electrical resistivity is an important property for the material to be used in data storage devices. Nickel Aluminium ferrites possess high electrical resistivity, low eddy current and dielectric losses which makes it suitable to be used at microwave frequencies applications [4, 5].

In this paper, the research being done in last two decades in the field of Ni-Al ferrites and the results of the researches are briefly described.

Ferrites

Ferrites are the ceramic containing compounds with the formula of $Me^{2+}Fe_2^{3+}O_4$ where Me^{2+} is the divalent metal such as Mn, Co, Ni, Cu, Mg, Zn or Cd [6]. Ferrites are classified as Hard and Soft ferrites on the basis of their magnetic behaviour and according to the crystal structure ferrites are of three types mainly Spinel, Garnets and Hexaferrites. Soft ferrites are usually the kind of magnetic material of high magnetic initial permeability. Spinel ferrites are the cubic ferrites comes under the umbrella of soft ferrites, possessing the crystal structure of natural spinel $MgAl_2O_4$ [7]. The unit cell structure of spinel ferrite with octahedral and tetrahedral sites is as shown figure 1.

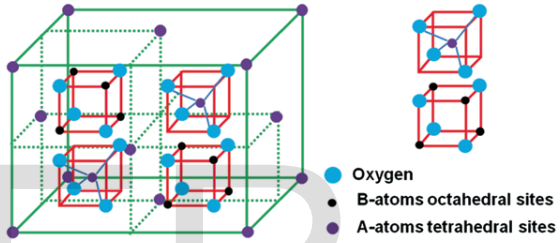

Fig.1 The unit cell structure of spinel ferrite

Nickel ferrite has totally inverse spinel structure with half of the ferric ions on tetrahedral sites and the rest occupy the octahedral sites [8]. In Ni-Al ferrites, the nickel ions occupy the octahedral sites, while some of the aluminium ions prefer to occupy the tetrahedral sites and rest are stable in the octahedral sites [9].

Methods of Preparation

In early 90's Ni-Al ferrites are prepared using standard ceramic method. The development of new techniques of synthesis of materials with time gives various methods of synthesis to investigators. Several investigators applied methods like Sol-Gel method, Calcination method, Combustion route method, powder conventional method, Co-precipitation method and Solid state reaction technique for the synthesis of Ni-Al ferrites with chemical formula $NiAi_xFe_{2-x}O_4$. Here the concentration of aluminium is changed by changing the value of x and a ferrite with new composition is prepared by various researchers, for the different study of the physical properties.

Results and Discussion of Ni-Al studies

X-ray diffraction: XRD studies of Ni-Al ferrites verified the Cubic spinel structure, since all the members of the same series as of aluminium also show cubic spinel structure. Figure shows the XRD pattern for for different concentration of Aluminium in Nickel ferrite [19]. A decrease in the lattice constant is noted by the researchers on increasing the Al concentration in Ni-Al ferrites due to smaller ionic radius of Al3+ then ionic radius of Fe3+ and Ni2+. Al3+ has a strong site preference for octahedral sites. The unit cell shrinks as there is partial replacement of Fe3+ by Al3+ on octahedral site. On increase of temperature the resistivity of Ni-Al ferrites decreases, like semiconductors while resistivity increases with increase in Al content [10, 11]. The transition temperature shifts to lower temperature with increasing Al content. The activation energy of conductivity in the paramagnetic region is higher than that in the ferromagnetic region [11].

X-ray density is higher than the apparent density for same composition. The porosity increases with Al content in Ni-Al ferrite [12, 13]. Thus the XRD studies explain the lattice parameter, structure and phase determination of Ni-Al ferrite.

SEM: Remarkable changes in the microstructure of undoped and Al doped Ni ferrite was revealed. The heat treatment causes agglomeration in fine crystal of ferrite powder [14]. With the increasing amount of alumina there is increase in surface area and decrease in total pore volume and mean pore volume of Ni ferrite [15], the average grain size decreases due to the formation of aluminium oxide at grain boundaries, inhibiting the grain growth [16, 17]. Figure 3 shows the Scanning electron microscopy (SEM) image of the typical sample (x = 0.6) [14]. This gives the idea of shape and surface morphology of Al doped Ni ferrite.

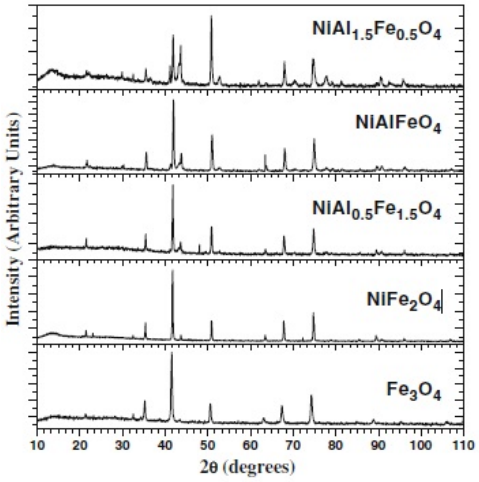

Fig.2 X-ray diffraction patterns for the Aluminium substituted Nickel ferrite samples.

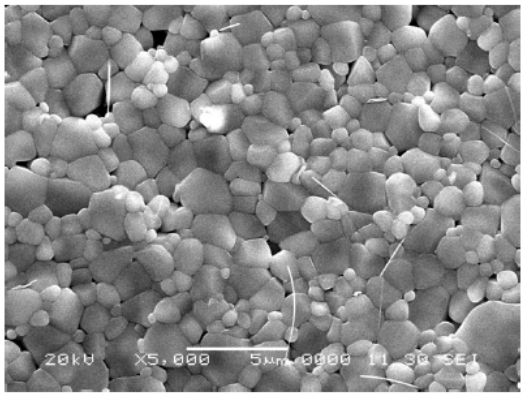

Fig.3 Scanning electron microscopy (SEM) image of Aluminium substituted Nickel Ferrite.

Raman spectroscopy: The Raman spectra show the five active modes for Ni-Al ferrites. All the five modes shift towards the higher wave number side as Al content increases which attribute to the lower atomic mass of Al3+ ion as compared to Fe3+ ion [13].

Infra red spectroscopy: IR studies of Ni-Al ferrite shows the presence of two strong absorption band one attributed by stretching vibration mode of metal-oxygen in tetrahedral sites and other assigned to octahedral group complexes, which is the common feature of spinel ferrite [10, 13]. The difference in the position of two strong bonds is due to the difference in the bond length of Fe-O at tetrahedral and octahedral sites. An additional very weak band also appears in IR spectra of Ni-Al ferrite due to divalent metal ion oxygen complexes in octahedral sites. The intensity of this weak band goes on decreasing with increasing Al content and later vanishes completely. The frequency of the band increases with the increase in Al content due to distribution of Ni, Al and Fe ion over tetrahedral and octahedral sites. The force constant on the tetrahedral and octahedral sites found to be increase with increasing Al content [14].

Mössbauer spectroscopy: Mossbauer spectroscopy for ferrite with no aluminium substitution shows two isomer shift sextet components, component with higher field value is associated with Fe3+ ions in octahedral sites and with lower field value is associated with Fe3+ ions in tetrahedral sites. With the Al substitution an additional quadrupole component appears. As the Al content increases the line width of the outer absorption lines of the spectrum corresponding to the tetrahedral sites increases [18, 19]. The figure 4 shows the Mössbauer spectra for Aluminium substituted Nickel ferrite [19].

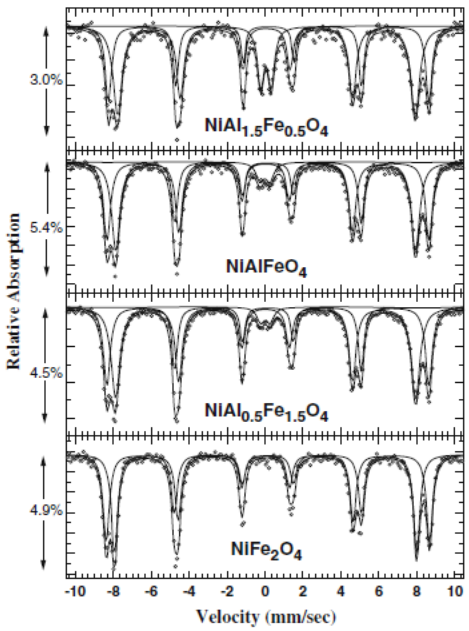

Fig.4 Mössbauer spectra of the Aluminium substituted Nickel ferrite samples

VSM: The magnetic studies on Ni-Al show that the magnetization decreases with increasing Al content. As the Al concentration increases the particle size decreases, also the interaction between the tetrahedral and octahedral sites is weak which weakens the magnetic coupling since Al ion carry zero magnetic moment. Thus the value of saturation magnetization and remanence magnetization reduces because of replacement of Fe3+ by Al3+ ions weaken the sub lattice interaction and lowers the magnetic moment of unit cells. There is reduction in the values of magnetic coercivity as the grain size reaches below the critical single domain size and the Al3+ has zero angular momentum which weak the spin-orbital coupling resulting in magnetic anisotropy. The reduction in the Curie point is noted with decreasing particle size and weakening of exchange interaction between tetrahedral and octahedral sub-lattice sites [15, 16]. The studies explain that magnetic property of Ni ferrite changes extremely with Al concentration.

LCR meter: As the Al content increases the resistivity increases [10] and therefore there is decrease in equivalent series resistance of Ni-Al ferrite. The Al oxide reduces the eddy current by decreasing grain size, increasing the grain boundary resistivity and increasing the activation energy for hopping length hence increases electrical resistivity [16].
Further in electrical properties of Ni-Al ferrites the d.c. conductivity decreases with increasing Al concentration [12]. This explains the effect of substitution of Al on dielectric behaviour of Ni ferrite.

Conclusion

Ni-Al ferrite is an interesting field of research for scientists, with their popular microwave applications. The substitution of Al in Ni ferrite brought about promising changes in the electrical, magnetic and physical properties which show that we can produce new ferrite with better properties by substitution of impurities. From the present review it is concluded that there are lots of studies needed to be done by using different methods of preparation of Ni-Al ferrite with different ferrite composition to know the effect of preparation techniques on the properties of ferrite.

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