CHAPTER 7

SUMMARY AND FUTURE SCOPE

Nanotechnology is a worldwide developing field of science works on materials with particle size less than 100 nm. The importance of nanomaterials is due to their enhanced behaviour achieved due to the large surface area and quantum confinement. Nanoferrites are more distinguishably featured nanomaterials as they are nontoxic and biocompatible which leads to a wide range of applications in all the fields. They are used in inductor cores, sensor devices, imaging instruments, catalysis, information storage devices and so on. Nanoferrites possess large magnetic permeability, low magnetic loss, high resistivity, low eddy current losses etc.

7.1 Summary

Manganese ferrites possess partially inverse spinel structure and hence are used for biomedical applications. Thus many mixed manganese ferrites have been synthesized to enhance the properties. The present research work is carried out mainly based on the following objectives:

(i) Synthesizing divalent metal ions (Mg^{2+}, Zn^{2+} and Cu^{2+}) substituted manganese ferrites and trivalent metal ions (Al^{3+}) substituted copper manganese ferrites.

(ii) Investigating the structure, size, shape and morphology of as-synthesized samples.

(iii) Characterizing the samples for optical, magnetic and electrical properties.

All the test samples; magnesium manganese ferrites (MMF), zinc manganese ferrites (ZMF), copper manganese ferrites (CMF) and copper manganese aluminium ferrites (CMAF) were synthesized by chemical co-precipitation method with final pH=11 maintaining a temperature of 70 ^{o}C and dried at 150 ^{o}C.

The powder X-ray diffraction studies confirm the cubic spinel crystalline structure of all the synthesized samples. The average crystallite size is calculated to be 18 nm for MMF, 19 nm for ZMF, 22 to 34 nm for CMF and 15 nm for CMAF. Large values of porosity, specific surface area and microstrain are obtained due to the nanosize of the synthesized particles. Smaller the crystallite size larger will be the porosity thereby it enhances the behaviour of the ferrites. Of the synthesized nanoferrites the CMAF nanomaterials has large value of porosity (33.67 %). For all the synthesized mixed nanoferrites the values of crystallite size and microstrain obtained from Williamson-Hall plots agree well with the values determined through Scherrer's relations. Comparing CMAF and CMF (at X=0.5), the CMAF has good structural property with high intensity peaks and reduced size.

The HRTEM images shows spherical shape for all the samples and the crystallite size observed agrees fairly well with the XRD results. The SAED pattern shows good crystallinity of the synthesized samples. Also SEM images obtained further confirm the spherical morphology and few agglomerations are observed due to strong magnetic interactions between the ferrite particles. The EDAX pattern gives well defined peaks for the elements present in the synthesized ferrites with no impurity peaks confirming the desired formation of nanoferrites and hence confirms the purity of the samples.

The presence of the two sublattices of spinel ferrites are confirmed from the FTIR spectra. The absorptions around wavenumber 600 cm^{-1} are due to the functional vibrations at the tetrahedral sites. The absorptions around wavenumber 400 cm^{-1} are due to vibrations at the octahedral sites. The affinity of the divalent metal ions (Mg^{2+}, Zn^{2+}, Cu^{2+}, Mn^{2+})

towards any one of the site is identified from the strong absorption. The FTIR spectra of CMF nanoferrites show the affinity of copper towards the octahedral site since the absorption at the octahedral sites has become sharper as Cu^{2+} content increases. The CMAF shows a deeper absorption at the tetrahedral site showing that the Al^{3+} ions occupy the tetrahedral sites.

The band gap energies are calculated from the UV-Vis absorption spectra. The band gap energy calculated using Tauc's relation shows that of all the samples, CMAF has least value (5.49 eV) and CMF (X=0.75) has largest value (6.09 eV) showing the semiconducting behaviour of all the synthesized samples. The refractive index and the optical dielectric constant increases with decreasing band gap energies. Thus the CMAF nanoparticles possess better optoelectronic behaviour.

The hysteresis curves obtained using vibrating sample magnetometer shows that all the synthesized samples are soft magnetic ferrites. The saturation magnetization is large for CMF (X=0.5) nanoferrites (53.6 emu/g) and MMF has the least value (25.7 emu/g). The ZMF shows very low coercivity (6 G) revealing excellent superparamagnetic property and CMF with X=0.75 has large value of coercivity (117 G). The effect of Cu^{2+} substitution shows an increasing value of magnetization upto X=0.5 and then decreases showing the affinity of less magnetic moment Cu^{2+} towards the octahedral site which replaces the Fe^{3+} ions. The $Cu_{0.5}Mn_{0.5}Al_{0.5}Fe_{1.5}O_4$ shows a reduction in the value of saturation magnetization (41.06 emu/g) and coercivity (41.83 G) compared to $Cu_{0.5}Mn_{0.5}Fe_2O_4$ (53.606 emu/g and 60.81 G respectively). Thus the substitution of non magnetic Al^{3+} on CMF (X=0.5) shows that the magnetic property is unaffected and the reduced coercivity improves the magnetic behaviour of the sample.

The dielectric measurements show that the dielectric constant and dielectric loss decreases with increase in frequency and the values are found to increase with increase in temperature for all the synthesized samples. The large values of dielectric constant and low values of dielectric loss exhibits the good dielectric property of all the synthesized samples. The CMAF possesses least value of dielectric constant compared to other synthesized nanoferrites. Of the Cu^{2+} mixed manganese ferrites, the dielectric constant is larger for CMF with X=0.5 and CMF with X=0 has comparatively least value of dielectric constant. The dielectric constant decreases with decrease in particle size. The value of dielectric loss is least for MMF followed by CMAF, ZMF and then for CMF. The AC conductivity of all the samples increases with increasing frequency and temperature. The increase is very rapid at higher frequencies (> 0.1 MHz). The activation energy calculated from Arrhenius plot is high for MMF (0.39 eV) followed by CMF (X=0.5) with activation energy 0.341 eV and hence more energy is required to activate them compared to the other synthesized nanoferrites. The activation energy is least (0.185 eV) for CMAF nanocrystallites.

7.2 Suggestions for future work

In the present research activity good structural, optical, magnetic and electrical properties have been observed for all the synthesized samples. This reveals the importance of these nanoferrites for various applications. Many further development of the present research work can be carried out to improve their behaviour for better and novel applications. The following are a few suggestions for further development of the research work on mixed nanoferrites:

- Suitable surfactants (sodium dodecyl sulphate, cetyl trimethyl ammonium bromide) can be added to reduce agglomeration.
- The reaction temperature, pH of starting solution and pH of final precipitate can be varied and the obtained materials can be studied comparatively.
- The synthesized materials can be calcined at different temperatures and their properties can be studied.

- Other divalent metal ions (Co^{2+}, Ni^{2+}, Cd^{2+}), trivalent ions (Cr^{3+}, La^{3+}, Ga^{3+}) and their mixtures can be used to synthesize mixed nanoferrites.
- The synthesized nanoferrites can be compared with nanoferrites synthesized by other techniques such as sol-gel method, hydrothermal method, microemulsion method etc.
- The synthesized materials can be subjected to other analysis techniques such as photoluminescence, photocatalytic activity, Raman scattering, electron paramagnetic resonance (EPR), electron spin resonance (ESR), thermal studies and Mossbauer studies.