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Study of Dielectric properties of Magnetoelectric Composite

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Abstract: The ferrite-ferroelectric magnetoelectric (ME) composites with composition (1-x) Ni0.5Cu0.3Zn0.2Fe2O4+ (x) BaTiO3 in which x = 0, 0.2, 0.4, 0.6, 0.8 and 1 mol were prepared by conventional ceramic solid state reaction. The magnetoelectric (ME) composite possess two coupled order parameter in the same material and gives ME effect with variation of magnetic field changes and vice versa. In the present work an attempt is made to prepare ME composite materials consisting ferroelectric phase as a BaTiO3 and ferrite phase as Ni0.5Cu0.3Zn0.2Fe2O4. The presence of constituent phases in the composites was confirmed by x-ray diffraction studies. The dielectric measurements of the composites carried out HP LCR meter/ Impedance analyzer at room temperature in the range 1Hz-1MHz. It is found that as ferroelectric composition in the composite increases the dielectric properties also increases because ferroelectrics posses high dielectric properties than ferrite.

Key Words: Dielectric, Composites, X-ray diffraction, ferrite, ferroelectric.

I. INTRODUCTION

The magnetoelectric (ME) effect is observed as a produced property of piezoelectric and magnetostrictive effect [1, 2]. It is very important to select a suitable combination of ferrite and ferroelectric material to get ME effect. In order to obtain better ME effect, the magnetostrictive coefficient of ferrite phase and piezoelectric coefficient of ferroelectric phase must be high. The resistivity of both phases must be high [3]. Leak current of the composite is low. Thus the composites retain not only ferroelectric and ferromagnetic properties, but also ME coupling effect. The magnetoelectric effect is coupled two field effect in which the application of either a magnetic field or electric field induces electric polarization or magnetization. Like other coupled response, the magnetoelectric effect in composite has recently attracted much attention owing to the significant interest in use of the magnetoelectric composites for broadband magnetic field probes, transducers, novel actuators, sensors, capacitive/inductive passive filters for telecommunication etc which exhibit large magnetoelectric effect and an exceptionally flat frequency response [4-8]. The dielectric, ferroelectric and ferromagnetic properties have important influence on ME signal. So it is important to study the fundamental properties of the composites. In the present work, BaTiO3 is selected as a ferroelectric phase. It was well known that BaTiO3 exhibits a better piezoelectric properties and high dielectric constant. Dielectric loss is another important property that provides information about energy dissipation within ferrite materials. In general, ferrites exhibit relatively high dielectric loss at low frequencies and lower dielectric loss at high frequencies. The high dielectric loss observed at low frequencies is attributed to charge carrier hopping and space-charge polarization processes. Electrons hop between Fe^{2+} and Fe^{3+} ions located at octahedral lattice sites, resulting in electrical conduction and energy dissipation. As frequency increases, these hopping processes become less effective because the charge carriers cannot respond rapidly enough to the changing electric field. Consequently, dielectric loss decreases with increasing frequency. Ferrites with low dielectric loss are highly desirable for high-frequency applications because they minimize energy wastage and improve device efficiency.

The dielectric properties of ferrites are significantly affected by their chemical composition. Different metal ions occupying the tetrahedral and octahedral sites influence the polarization and charge transport mechanisms. Nickel ferrite ($NiFe_2O_4$) generally exhibits moderate dielectric constant and high resistivity, making it suitable for high-frequency applications. Zinc ferrite ($ZnFe_2O_4$) often shows a relatively higher dielectric constant due to enhanced polarization effects. Cobalt ferrite ($CoFe_2O_4$) is known for its excellent magnetic properties and moderate dielectric behavior, while manganese ferrite ($MnFe_2O_4$) exhibits higher dielectric constants because manganese ions facilitate electron hopping. Mixed ferrites such as Ni-Zn, Mn-Zn, and Co-Zn ferrites have gained considerable attention because their dielectric properties can be tailored by varying the composition. Such compositional modifications allow researchers to optimize ferrites for specific technological applications.

Microstructural characteristics such as grain size, grain boundaries, porosity, and density also play a crucial role in determining dielectric behavior. Larger grain sizes generally enhance dielectric constant because they reduce the number of grain boundaries that impede charge carrier movement. Grain boundaries act as resistive barriers and influence space-charge polarization. When grain size decreases, the number of grain boundaries increases, leading to greater resistance and altered dielectric response. Porosity is another important factor affecting dielectric properties. The presence of pores reduces the effective dielectric constant because air trapped within the pores has a much lower dielectric constant than the ferrite matrix. Therefore, highly dense ferrite materials usually exhibit better dielectric performance than porous samples.

Sintering temperature is an important processing parameter that affects the microstructure and dielectric characteristics of ferrites. As the sintering temperature increases, grain growth occurs, porosity decreases, and the overall density of the material improves. These structural changes often result in higher dielectric constant values and improved dielectric performance. However, excessively high sintering temperatures may cause abnormal grain growth and undesirable phase formation, which can negatively affect dielectric behavior. Therefore, optimizing sintering conditions is essential for achieving the desired dielectric properties.

Recent advancements in nanotechnology have led to extensive research on nanostructured ferrites. Ferrite nanoparticles exhibit unique dielectric behavior due to their small particle size, large surface area, and enhanced grain boundary effects. Nanoferrites often possess higher resistivity, improved dielectric stability, and lower dielectric losses compared with their bulk counterparts. The increased surface-to-volume ratio in nanoparticles significantly influences polarization and charge transport mechanisms. These unique characteristics make nanoferrites promising candidates for advanced electronic devices, microwave systems, magnetic sensors, biomedical applications, and energy storage technologies.

EXPERIMENTAL:

The components of present composites are $BaTio_3$ as ferroelectric phase and $Ni_{0.5}Cu_{0.3}Mg_{0.2}Fe_2O_4$ as a ferrite phase with general formula $(1-x)Ni_{0.5}Cu_{0.3}Mg_{0.2}Fe_2O_4+ (x) BaTiO_3$ in which x = 0, 0.2, 0.4, 0.6, 0.8 and 1 mol were prepared by conventional solid state reaction. The ferrite phase was prepared by NiO, CuO, MgO, and Fe_2O_3 in required molar proportions. These oxides were mixed and grind in agate mortar for couple of hours. The ferroelectric phase was prepared by using BaO and TiO_2 as starting materials. These oxides are also mixed and grind in agate mortar. The required ferrite and ferroelectric molar proportions were mixed and grind for 3 hour ME composite preparation. The grind powder mixture was pressed into pellets using hydraulic press. The pelletized sample was final sintered at 850^o for 24 hour in programmable furnace and slow cooled to room temperature to yield the final product.

2. CHARACTERIZATION AND PROPERTY MEASUREMENT

The crystal structures of composites and their constituent phases were determined by XRD technique using Philips X-ray diffraction using Cu-K_α radiation. The dielectric properties were measured using HP 16451B dielectric text fixture with an HP LCR meter/ Impedance analyzer.

4. RESULT AND DISCUSSION:

Fig.1 shows the XRD pattern of composites with x=0.8.

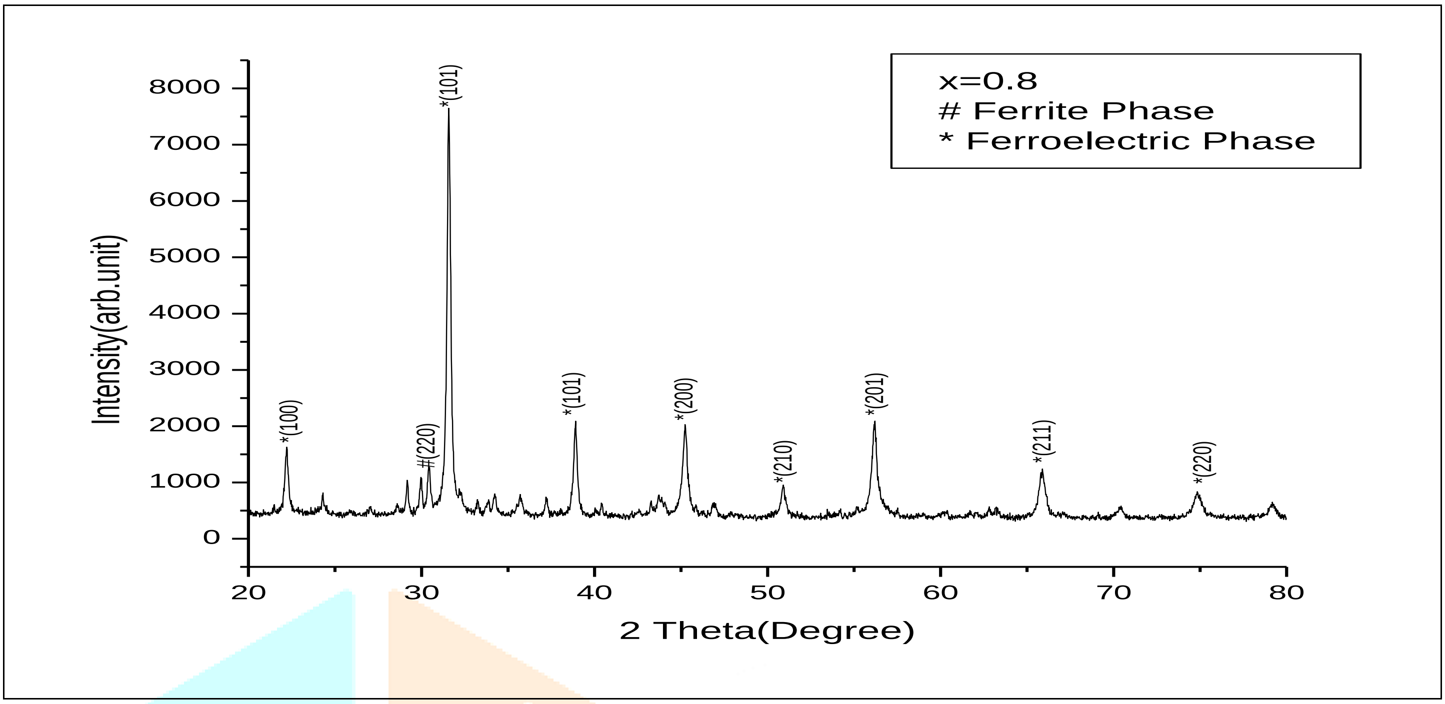

Fig.1 XRD Patterns of (1-x) $Ni_{0.5}Cu_{0.3}$ $Zn_{0.2}$ Fe_2O_4+(x) $BaTiO_3$ for x=0.8

The peaks are characteristics of both ferrite and ferroelectric phases. The intensity as well as number of ferroelectric peaks increases with increase in ferroelectric content in composites. It may be due to increase of molar percentage of ferroelectric.

5. DIELECTRIC PROPERTIES:

Fig.2 shows the variation of dielectric constant with frequency. It is observed from figure that the dielectric constant decreases exponentially with increase in frequency. At higher frequency the dielectric constant remains constant; this may be due to the inability of electric dipoles to follow up the fast variation of the alternating applied electric field. The variation of dielectric loss and dielectric loss tangent (tan δ) as a function of frequency is shown in Fig.3 and Fig.4. Both the dielectric loss and dielectric loss tangent decreases with increase in frequency and it shows same behavior as that of variation of dielectric constant with frequency.

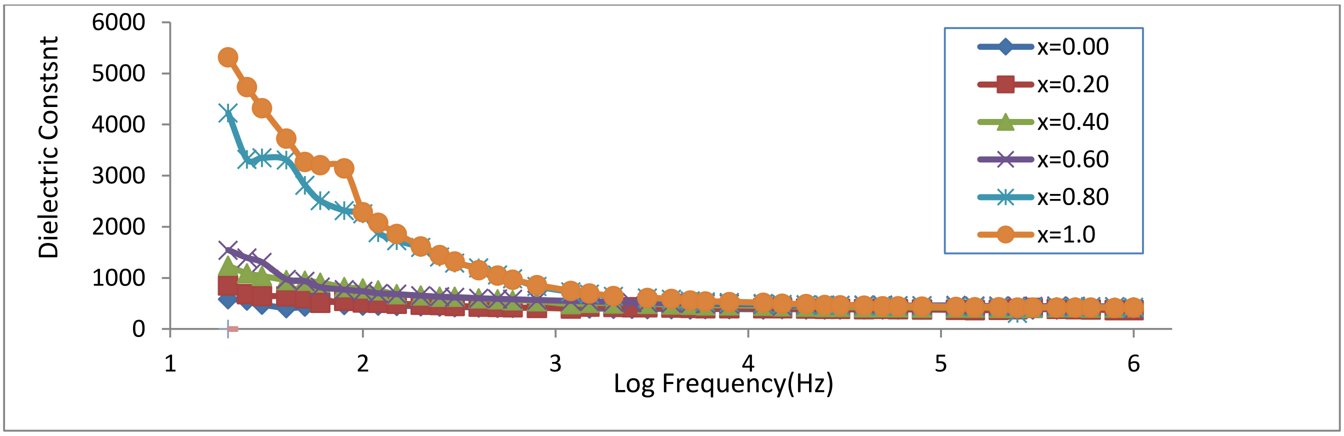

Fig.2 Frequency dependent variation of dielectric constant of (1-x)$Ni_{0.5}Cu_{0.3}Zn_{0.2}Fe_2O_4$ +(x)$BaTiO_3$

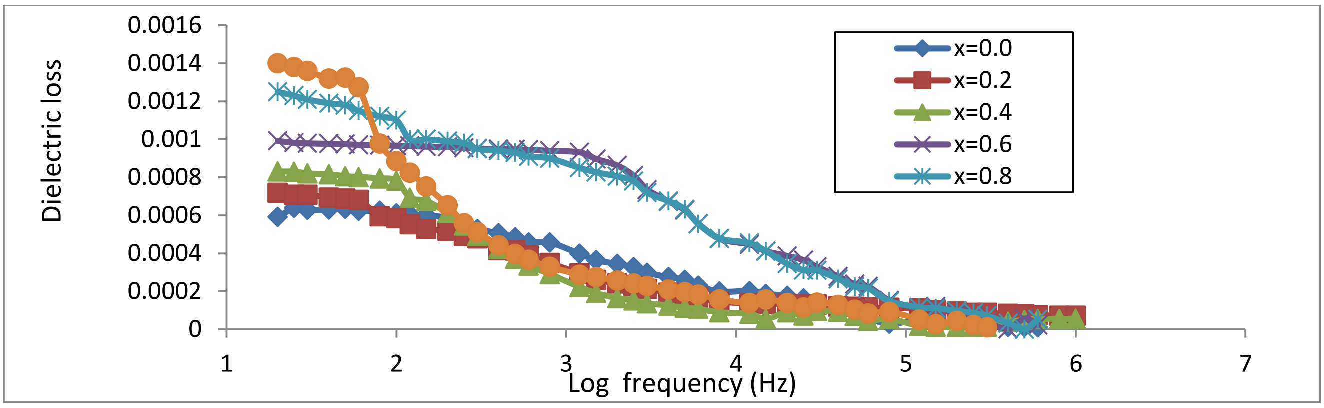

Fig.3 Variation of Dielectric loss with frequency of (1-x) $Ni_{0.5}Cu_{0.3}Zn_{0.2}Fe_2O_4$ + (x)$BaTiO_3$

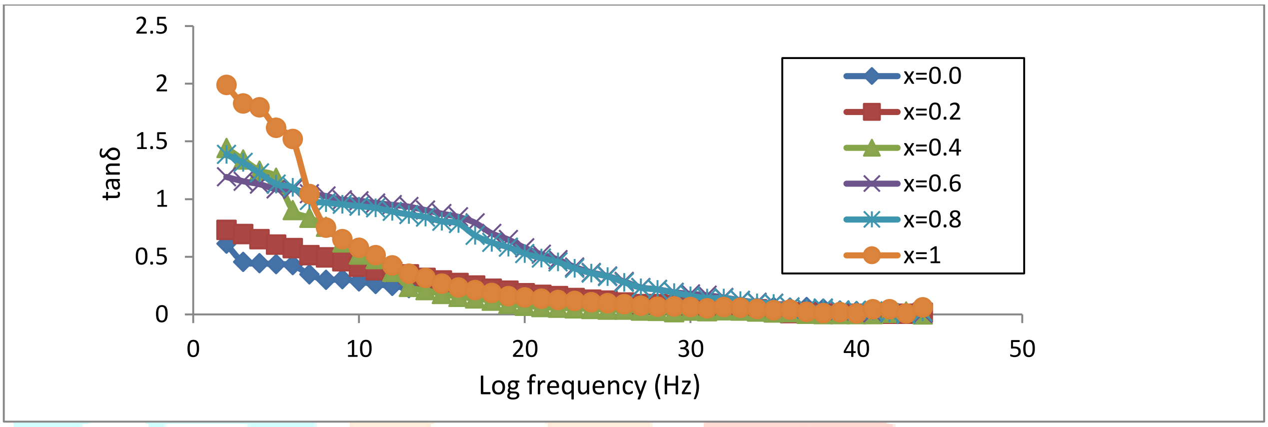

Fig. 4 Variation of dielectric loss tangent (tan δ) with frequency of (1-x)$Ni_{0.5}Cu_{0.3}Zn_{0.2}Fe_2O_4$ +(x)$BaTiO_3$

6. CONCLUSION

The magnetoelectric (ME) composites are prepared successfully by standard ceramic method. The XRD pattern shows presence of both ferrite and ferroelectric phases. The intensity and number of ferroelectric peaks are observed to increases with increase in ferroelectric content in the composites. Dielectric constant decreases exponentially with increase in frequency. At higher frequency the dielectric constant remains constant this is due to the inability of electric dipoles to follow up the fast variation of the alternating applied electric field. Dielectric constant, dielectric loss and dielectric loss tangent were decreases with increase in frequency.

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