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ME interactions in magnetic permeability of ferrite - ferroelectric composites

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ABSTRACT

The Magneto-electric effect is conversion of magnetic energy into electric energy and vice–versa. This effect is exhibited by the ferrite and ferroelectric composites. Neither the ferrite nor the ferroelectric can exhibit this phenomenon independently. The intermediate stage in the conversion of the two energies is mechanical energy. Thus, the efficiency of intermediate stage of conversion process can affect the process and also the innate properties of both the phases in the composite. In this paper, it is reported that the application of electric field to the $CuFe_2O_4$ – $BaTiO_3$ composites increases the permeability of $CuFe_2O_4$ phase in the composite.

KEYWORDS

Permeability;
Magnetoelectric effect;
Ferrite – ferroelectric composites.

INTRODUCTION

Magnetoelectric (ME) effect in composites is a phenomenon in which application of magnetic field induces strain in the magnetic phase, which in turn causes a stress in the ferroelectric phase resulting in generation of electric voltage and the converse is also true[1-8]. Many papers report the direct ME effect[1-6,8]. To date, not even a single paper reporting the converse effect is published. Hence in the present communication, an attempt is made to report the variations in the permeability of ferrite phase on application of external electric field to the composite as a result of product property of the composites. In this particular case, the product property is the product of electrostriction exhibited by electric phase and piezomagnetic effect of the magnetic phase. The $CuFe_2O_4$ is chosen as ferrite because the Cu^{+2} being a Jahn-Teller ion can provide good elastic coupling for the process of piezomagnetic effect and the other phase $BaTiO_3$ is popular ferroelectric.

EXPERIMENTAL

$xCuFe_2O_4$ – (1-x) $BaTiO_3$ composites by varying x as 15,30,45,60and 70 in mole percent were prepared by conventional double sintering method. Porosity in the samples was calculated using liquid immersion technique. The variation of permeability with frequency for these materials were determined using HPLCR meter 4284A model in the presence and absence of electric poling field of 1KV/cm. Electromechanical coupling coefficient of the composites was also evaluated by resonance-antiresonance method.

RESULTS AND DISCUSSIONS

The X-ray Diffractogram of a representative composite is already reported elsewhere[6]. TABLE 1, gives the structural, electromechanical and magnetic data on the composites. From the TABLE 1, it is clear that the particle size of both the phases is also dependent on the mole ratios of the components in the composites. The particle size obtained for the phases in the composites is almost equal for mole ratios of 55% $BaTiO_3$ – 45%$CuFe_2O_4$ ensuring a good mechanical contact between the two phases. This is also asserted by very low porosity in this particular composition (TABLE 1). These results on the variations in particle size and porosity for composites with different mole ratio are similar to that reported earlier[8].

TABLE 1 : Structural, electromechanical and magnetic data on composites

Mole % ferrite phase	Particle size Ferrite in nm	Particle size of ferroelectric phase in nm	Percentage Porosity	Relative permeability in the absence of electric field	Relative permeability in the presence of poling electric field of 1KV/cm	Electromechanical Coupling coefficient (K_p)
15	40	156	18	112	333	0.265
30	72	141	15	208	417	0.288
45	122	132	12	413	602	0.304
60	91	125	13	201	324	0.241
70	103	106	16	86	103	0.208

The variation of relative permeability (μ_r) with frequency (f) for composites with different mole ratios is shown in the figure 1 in absence of electric field and similar variations for the same samples on application of electric field is shown in the figure 2. All the samples show frequency independent variation irrespective of their mole percent and also when measured in presence or absence of electric field. However an enhancement in the values of relative permeability is noted from figure 2 and also from TABLE 1. The frequency independent variation of μr suggests a magnetic application of these materials in the frequency range 100 – 1MHz. An appreciable increase in the relative permeability of the composites on application of electric field is the result of piezomagnetic effect of the $CuFe_2O_4$ phase in the composite. The permeability in the magnetic materials is due to domain wall displacement and domain rotation. The large domains grow in size at the cost of small domains. This growth is assisted by the strain induced in the electric phase of the composite by an applied electric field[9]. Moreover, the local interactions between the electric dipoles and the magnetic dipoles in the composite are also responsible for the rise in permeability values. The applied electric field tries to orient electric dipoles in its field direction this in turn influence the surrounding magnetic dipoles due to dipolar field effects[10]. The sample with near equal mole ratio shows the highest value of permeability (μ_r) in both the cases [figure 1 and figure 2]. It is obvious as ME interactions are more in this particular composition. Moreover, matching of the particle size of the component phases and low porosity also ensures good mechanical coupling between the participating phases.

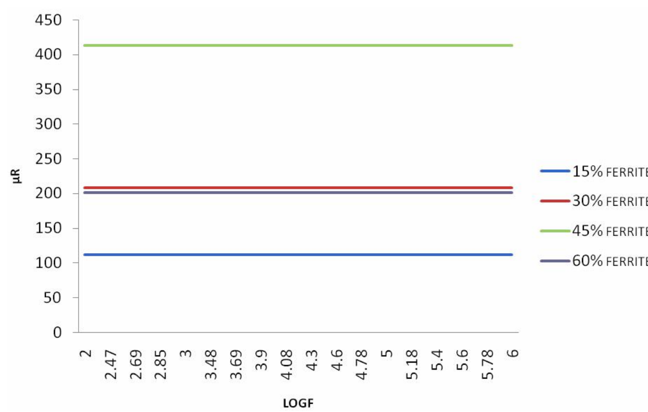

Figure 1 : Variation of relative permeability (μ_r) of composites with frequency in absence of electric poling field

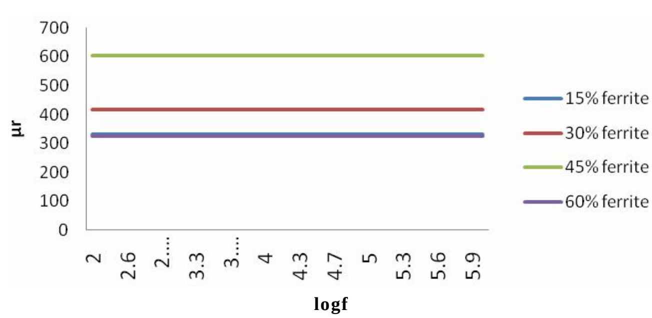

Figure 2 : Variation of relative permeability (μ_r) of composites with frequency in presence of electric poling field

The electromechanical coefficient (K_p) measured for the samples also shows a systematic trend concomitant with the variation in permeability as evinced from the columns 6 and 7 in TABLE 1. The electromechanical coupling coefficient thus asserts our result on the permeability measured in the presence of electric field.

CONCLUSIONS

It is well known that permeability of ferrite material depends upon its composition and also microstructural parameters. But the present paper for the first time reports increase of relative permeability of ferrite phase in composite due to the stress of the surrounding electric phase in the presence of electric field and also due to interactions between magnetic and electric dipoles. This result in turn is verified by the electromechanical coefficients measured for different composites. This paper is unique as it is for the first time an attempt is made to report the changes in magnetic parameter due to the application of electric field and the result is also interpreted in terms of the electromechanical coupling parameter.

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