Structural, Magnetic Properties of Soft and Hard Ferrites and their EMI Shielding Application in X-Band Frequency Range

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***Abstract* - Different soft and hard ferrites like li0.35cd0.3fe2.35o4 (li-cd), li0.35zn0.3fe2.35o4 (lizn), ni0.35zn0.65fe2o4 (ni-zn) and bafe12o19 (bfo) have been prepared by sol-gel technique. The xrd patterns confirm the phase formation of ferrites. Emi properties in a frequency range of 8.2 ghz to 12.2 ghz (x-band) have been investigated for all composites of ferrites-wax in 80-20 wt% ratio. The different properties like complex permeability (μ∗), complex permittivity (ε∗) and shielding effectiveness have been studied by vector network analyzer (vna). Magnetic properties of ferrites have been investigated by vsm at room temperature. Saturation magnetization of li0.35cd0.3fe2.35o4 and li0.35zn0.3fe2.35o4 (80 emu/g and 67 emu/g) have been found greater than ni0.35zn0.65fe2o4 and bafe12o19 (61 emu/g and 48 emu/g). Real part of dielectric constant of licd and lizn ferrite is greater than nizn ferrite but real part of permeability of nizn ferrite is found greater in x-band frequency range.**

Keywords: sol-gel; permeability; dielectric; composite; magnetization; x-band

1. INTRODUCTION

With the advancement of electronic technologies a special attention has been focused upon the development of new materials and microwave technology for the application in the field of shielding and stealth technology. Magnetic granular composites consisting of magnetic particles embedded in a dielectric matrix have been widely used in electromagnetic application such as electromagnetic shielding materials. With the fast advancement in wireless communication and defence industries, radar absorbing materials are becoming more and more important. Therefore, demands to develop thinner EM wave absorbers with wider absorbing band-widths are ever increasing [1,2]. Microwave shielding has been applied to various systems such as computers, mobile phones, aircraft avionics and stealth technology. EM wave energy can be completely absorbed and dissipated into heat through magnetic losses and dielectric losses if the characteristic impedance of free space is matched with the input characteristic impedance of an absorber. In general soft ferrites are utilized in power electronic equipments because of their high saturation magnetization, high Curie temperature and low power loss [3]. Ferrites have been used as absorbing materials in various forms, e.g. sheet, paints, films, ceramic tiles and powders load in matrix composites or mixed with conducting materials [4]. Among the soft ferrites, Ni-ferrite, Li-ferrites have been widely utilized as electromagnetic wave absorbing materials in the VHF/UHF region [5]. Nickel-zinc ferrites are a well-known class of technologically important ferrite used as microwave absorbing materials [6]. The hexagonal ferrites like Ba-ferrite are suitable for RAM due to large value of permeability, magnetization as well as good dielectric properties at microwave frequencies. X-band frequency radar has been of great interest to the military sector because it allows for high resolution imaging and greater precision target identification. There are different frequently used EM wave absorbers including ferrites, conducting fibers, ferromagnets, carbon nano-tubes etc. [7, 9]. Microwave absorption properties are highly dependent on magnetic properties. According to the previous work, among different Li-Cd ratios in the $Li_{0.5-x/2}Cd_xFe_{2.5-x/2}O_4$ the $Li_{0.35}Cd_{0.3}Fe_{2.35}O_4$ possesses excellent magnetic properties [10] and also similar behaviour has been observed in Li-Zn and Ni-Zn ferrites. In the present work, we have studied the structural, magnetic properties of soft (NiZn, LiZn and LiCd) and hard (BFO) ferrites and their microwave absorbing properties in X-band frequencies.

2. EXPERIMENTS

The different ferrites have been prepared by citrate precursor technique. The analytical grade metal nitrate and citric acid were used as raw materials. A stoichiometric amount of $Fe(NO_3)_3.9H_2O$, $LiNO_3$, $Zn(NO_3)_2.6H_2O$, $Ba(NO_3)_2$, $Cd(NO_3)_2.4H_2O$ in their respective compositions was dissolved in deionised water and mixed with the aqueous solution of citric acid in 1:1 molar ratio of cation to citric acid. The resultant mixture was slowly evaporated and then dried at 60 ^{0}C with stirring until brown viscous liquid was obtained, which was then dried at 80 ^{0}C. The obtained powders of soft ferrite were annealed at 900 ^{0}C and Ba-ferrite at 1100 ^{0}C for 5 h with a heating and cooling rate of 5 ^{0}C/min. We made a composite of ferrite and wax having the ratio 80%-20% respectively. The size of the sample was 25mm x 13mm x 2mm. The ferrite-wax composites were inserted into a standard coaxial sample holder and the reflection coefficient (S_{11} parameter) and transmission coefficient (S_{12} parameter) were measured by an Agilent E8362B vector network analyzer (VNA) in frequency range of 8.2-12.2 GHz.

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The structural characterization of samples was carried out by the X-ray diffraction (XRD Rigaku Miniflex II, step size = 0.02) technique using CuKα radiation (λ = 1.5406 Å). Magnetic measurements were carried out using vibrating sample magnetometer for all samples at room temperature. The magnetic properties like saturation magnetization (Ms), coercivity (Hc), retentivity (Mr) were evaluated from M-H curves.

3. RESULTS AND DISCUSSION

The X-ray diffraction of the $Li_{0.35}Cd_{0.3}Fe_{2.35}O_4$, $Li_{0.35}Zn_{0.3}Fe_{2.35}O_4$, $Ni_{0.35}Zn_{0.65}Fe_2O_4$ and $BaFe_{12}O_{19}$ ferrite powder has been shown in Figure 1. The presence of peaks (220), (311), (222), (400), (422), (511), (440) and (533) in diffraction pattern confirm the formation of spinel cubic structure [11]. All synthesized samples of soft ferrites are showing single phase formation, which were sintered at 900 ^{0}C. Barium ferrite ($BaFe_{12}O_{19}$) represents a hexagonal phase without any extra phase formation sintered at 1150 ^{0}C as shown in Figure 1.

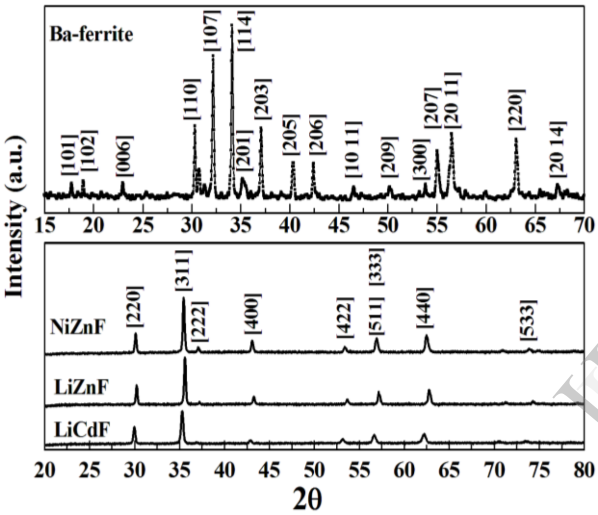

Figure 1. X-ray diffraction patterns of Ba-ferrite, NiZn, LiZn and LiCd ferrites.

M-H curves of different ferrites have been shown in Figure 2. LiCd ferrite exhibited the maximum saturation magnetization (80 emu/g) compared to NiZn, LiZn and Ba-ferrites (67 emu/g, 61 emu/g and 48 emu/g). Figure 3 illustrates the variation of complex permittivity in microwave X-band frequencies (8.2 GHz-12.2GHz). The real and imaginary parts of permittivity are almost independent of frequency. A small decay is observed at a higher frequency range of 10-12 GHz. The highest permittivity value (7.3) is observed for Ba-ferrite wax composite while LiCd and LiZn ferrite-wax composites show higher values than NiZn composites. Permeability response of different ferrites-wax composites is shown in Figure 4. Permeability value of NiZn ferrite-wax composite is higher than LiCd and LiZn ferrite-wax composites. The Ba-ferrite-wax composite exhibited maximum value of permeability among the samples.

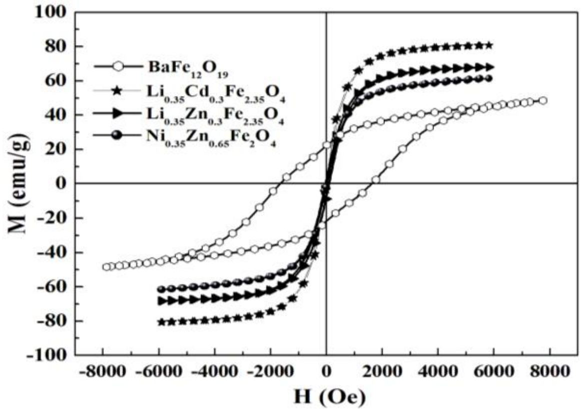

Figure 2. M-H curves of Ba-ferrite, NiZn, LiZn and LiCd ferrites.

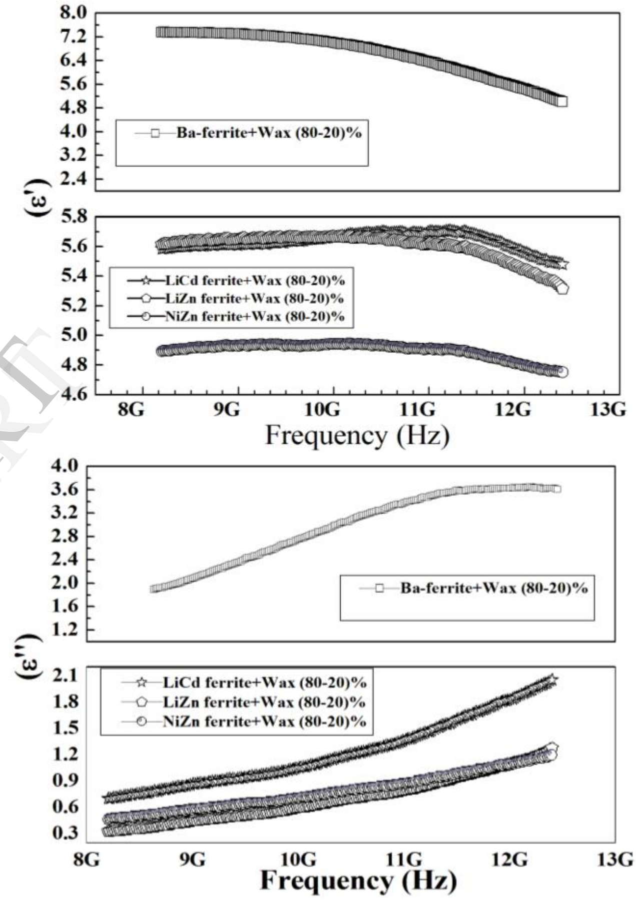

Figure 3. Permittivity responce of Ba-ferrite, NiZn, LiZn and LiCd ferrite-wax composites.

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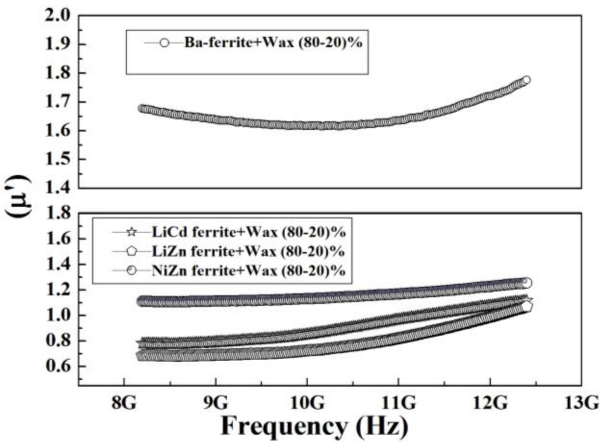

Figure 4. Permeability responce of Ba-ferrite, NiZn, LiZn and LiCd ferrite-wax composites.

The EMI shielding effectiveness (SE) of a material is defined as the ratio of transmitted power to incident power and is given by SE (dB) = −10 log (P_t /P_0), where P_t and P_0 are the transmitted and incident electromagnetic powers respectively. For a shielding material, total $SE=SE_R+SE_A+SE_M$, where, SE_R is due to reflection, SE_A is due to absorption and SE_M is due to multiple reflections. In a two port network, S parameters S_{11} (S_{22}), S_{21} (S_{12}) represent the reflection and transmission coefficients $T=|E_T/E_I|^2=|S_{21}|^2=|S_{12}|^2$, and $R=|E_R/E_I|^2=|S_{11}|^2=|S_{22}|^2$. The absorption coefficient is defined as $A = 1-R-T$. Here, A is given with respect to the power of the incident EM wave. If the effect of multiple reflections between both interfaces of the material is negligible, the relative intensity of the effective incident EM wave inside the material after reflection is treated equal to $1-R$. Hence, the effective absorbance (A_{eff}) can be described as $A_{eff} = (1-R-T) / (1-R)$ with respect to the power of the effective incident EM wave inside the shielding material [13]. It is convenient to express the reflectance and effective absorbance in the form of −10 log(1−R) and −10 log(1−A_{eff}) in decibel (dB), respectively, which results in SE_R and SE_A as $SE_R=-10\log(1-R)$ and $SE_A = -10\log(1-A_{eff}) = -10\log[T/(1-R)]$.

Figure 5. shows the response of EMI shielding effectiveness with frequency for different ferrites and wax composites. The contribution to the SE values mainly comes from the absorption rather than reflection in the case of ferrite/wax composites. It is clear from Figure 5 that LiCd ferrite has the higher SE_A of 33.3 dB at 8.2 GHz but decreases with the frequency. The same behaviour is shown by all soft ferrites/wax composites. In the case of hard ferrite composites it is observed that the SE_A is almost constant in the X-band with the value of ~12 dB. According to classical electromagnetic theory the EMI shielding effectiveness can be expressed as:

$$SE\ (dB) \approx 10\log(\sigma_{ac}/16\omega\mu_r\varepsilon_o) + 20\,(d/\delta)\log e \qquad (1)$$

The first term in Eq. (1) is shielding effectiveness due to reflection and second is due to the absorption of the electromagnetic wave. Therefore from Eq. (1) shielding effectiveness due to reflection and absorption can be expressed by Eqs. (2) and (3), respectively.

$$SE_R\ (dB) = 10\log(\sigma_{ac}/16\omega\mu_r\varepsilon_o) \qquad (2)$$

$$SE_A\ (dB) = 20\,(d/\delta)\log e = 20d\,(\omega\mu_r\sigma_{ac}/2)^{1/2}\log e \qquad (3)$$

Where d is the thickness of the shield, μ_r is the relative magnetic permeability, δ is the skin depth, $\sigma_{ac} = \omega\varepsilon_o\varepsilon''$ is the frequency dependent conductivity; ε″ is the imaginary part of permittivity (loss factor tanδ), ω is the angular frequency, and ε_o is the permittivity of the free space. From equation 2 and 3, it is observed that with the increase in frequency, the SE_A values increases while the contribution to the reflection loss decreases. Dependence of SE_A and SE_R on conductivity and permeability reveals that the material possessing higher conductivity and magnetic permeability can achieve better absorption properties.

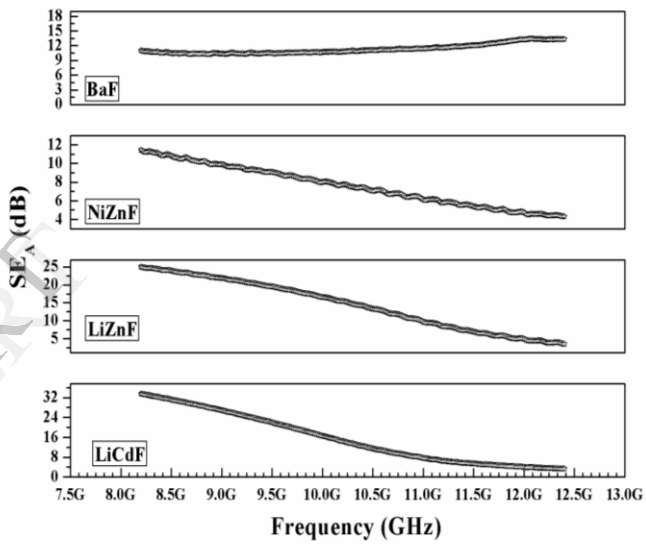

Figure 5. Shielding effectiveness due to absorption of Ba-ferrite, NiZn, LiZn and LiCd ferrite-wax composites.

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4. CONCLUSIONS

$Li_{0.35}Cd_{0.3}Fe_{2.35}O_4$, $Li_{0.35}Zn_{0.3}Fe_{2.35}O_4$, $Ni_{0.35}Zn_{0.65}Fe_2O_4$ and $BaFe_{12}O_{19}$ have been prepared by sol-gel technique. The structural, magnetic and microwave properties of different ferrites have been investigated. From above results and discussion it can be concluded that LiCd and LiZn ferrites are more useful for EMI shielding applications in X-band frequency region but Ba-ferrite exhibited most constant nature (SE_A) among all ferrites. It can be concluded from the results that soft/hard ferrites and wax composites are promising potential candidates for use as radar absorbing materials in X-band.

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