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Synthesis Of LiTiMg-Ferrite For The Applications Of X Band

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***Abstract:** In this communication era the extensive use of ferrites open the different angle of research in the field of magnetic materials especially in ferrite materials. Li-Ferrites are the most versatile magnetic materials used for the high frequency microwave systems. The substituted lithium ferrites have been found most suitable for microwave device applications because of their inherent properties such as high Curie temperatures, high dielectric constant, high saturation magnetization & low dielectric losses. A composition of titanium substituted Li-ferrite with saturation magnetization 2200 Gauss has been synthesized and investigated for antenna applications in microwave frequency range. The material was prepared by solid state reaction technique (SSRT) and later studied for its electrical, magnetic & structural behaviors. It is observed that LiTiMg ferrite shows different magnetic behavior during DC biasing for microwave frequency antenna applications. The paper describes a precise description of LiTiMg-ferrite preparation, its characteristic plots and its potentials for microwave antenna application with a detailed study of nonreciprocal behavior of LiTiMg ferrite slab or substrate under magnetic biasing.*

***Keywords:** Substituted ferrite, microstrip antenna, microwave frequency range, electric & magnetic properties, tunable property.*

LIST OF SYMBOLS

δ = thickness of radome layer
α = attenuation constant
β = phase constant
β_o = propagation constant in vacuum
ε_r = dielectric constant
μ_{eff} = effective permeability
μ, k = permeability tensor components of μ_{eff}
K_d = ordinary propagation constant
K_e = extraordinary propagation constant
T = relaxation time
H_o = applied bias field
ΔH = magnetic resonance width of ferrite
ω = angular frequency of incident e-m-waves
ω_o = external magnetic field angular frequency
ω_m = internal magnetic field angular frequency
μ' = real part of permeability
μ'' = dissipative part of permeability
χ' = real part of susceptibility
χ'' = dissipative part of susceptibility
$4\pi M_s$ = saturation magnetization
Υ = gyromagnetic ratio (2.8 MHz / Oe.)

I. INTRODUCTION

In recent years the application of magnetic materials increases as per the high frequency requirement. Lithium Ferrite is one of the most versatile magnetic materials which are generally useful for microwave devices, such as isolators, circulators, gyrators and phase shifters. Different types of polycrystalline ferrites have their specific advantages as Li substituted ferrites has high dielectric constant, low sintering temperature etc. than other substituted ferrites. Some novel characteristics of polycrystalline ferrite over normal dielectric

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material make it very useful in the microwave antenna applications. In order to create miniaturization of antennas ferrites are the best and single suitable option. By using ferrite materials, the antenna size reduced considerably along with the reduction of surface wave excitation and the loss. Another dynamic reason for using the ferrite materials for the high frequency applications is that the applied external magnetic field changes the permeability of ferrite which depends upon the direction of the field. This nonreciprocal behavior is depending on one of the characteristics of ferrites materials known as magnetic resonance with (ΔH) [1-4].

In the present communication we report an investigation of Li substituted ferrite material which is prepared by Solid State Reaction Technique (SSRT) with considerations of antenna application. However no reports are available in literature on the influence of Ti in the Li substituted ferrite on the basis of X band antenna application requirements, while several studies have been reported with the addition of divalent, trivalent and tetravalent ions [5, 6]. In this paper an attempt has been made to manipulate properties of synthesized Li ferrite by doping Ti in view of nonreciprocal behavior of ferrites under magnetic field for antenna applications. Number of samples of same composition synthesized and investigated thoroughly for electric, magnetic and some physical properties.

II. MATERIAL PREPARATION

Here a typical composition of LiTiMg ferrite having room temperature magnetization ($4\pi M_s$) of 2200 Gauss (± 5%) & Curie temperature (T_c) of 500 ^{0}K (± 5%) has been synthesized using solid state reaction technique (SSRT). The ingredients required for the preparation were calculated on the basis of chemical formula.

$Li_{0.63}Zn_{0.1}Mn_{0.1}Ti_{0.36}Fe_{1.81}O_4$

Analytical grade chemicals were used for the preparation of the material. The stoichiometric ratio of the chemicals was thoroughly mixed in a polypropylene jar containing the zirconium balls & distilled water. In order to suppress the formation of Fe^{2+} ions in the ferrites and to influence megnetostriction due to being a John Teller ion, a small amount of Mn^{3+} ion was also incorporated in the basic composition [7, 8]. In order to avoid Lithia at high temperatures of sintering, Bi_2O_3 (0.25 wt %) was added as sintering aid [9]. The presintering of the mixed powder has been carried out at ~ 750^{o}C in a box furnace and soaking time was kept 4 hours. The sieved material was pressed in disk (antenna substrate) and toroidal shapes with the help of suitable dies and using hydraulic pressing technique at pressure of 10 ton/cm^2. The substrates and toroidals were finally sintered at 1050^{o}C for four hours. In order to get specific size and shape, the sintered sample was subjected to cutting, grinding, polishing etc.

The single-phase spinel nature of the samples was confirmed by X-ray diffraction (XRD) pattern (fig. 1) obtained by using Cu-K_α radiation. The microstructure studies of the sample were carried out by scanning electron microscopy (SEM).

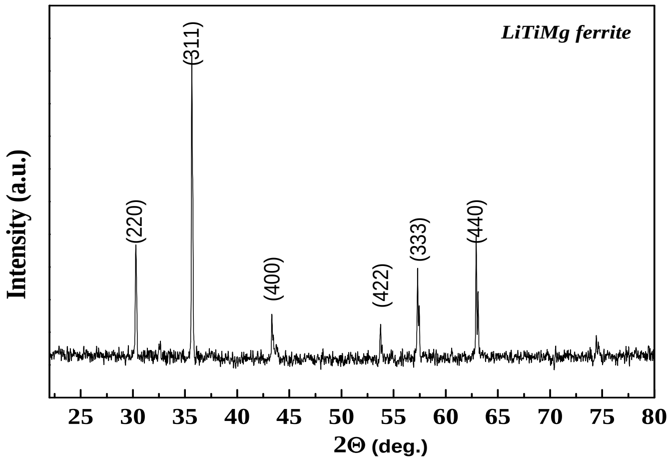

Figure 1: XRD patterns of the prepared LiTiMg ferrite

III. ELECTRICAL AND MAGNETIC PROPERTIES

The electrical and magnetic properties of LiTiMg ferrite substrate are précised in this communication. The dielectric measurements were conducted from 8 to 12 GHz by a VNA E8263B Agilent Technology impedance analyzer. Remanence and Coercive Force measure by B-H loop setup applied to coiled toroid sample at 50 Hz.

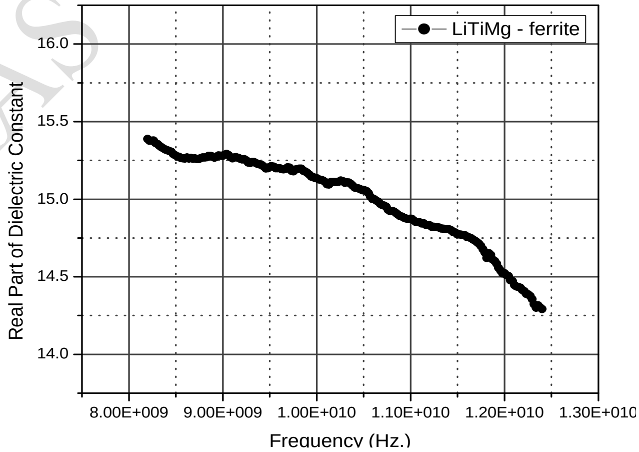

Figure 2: Dielectric constant of material

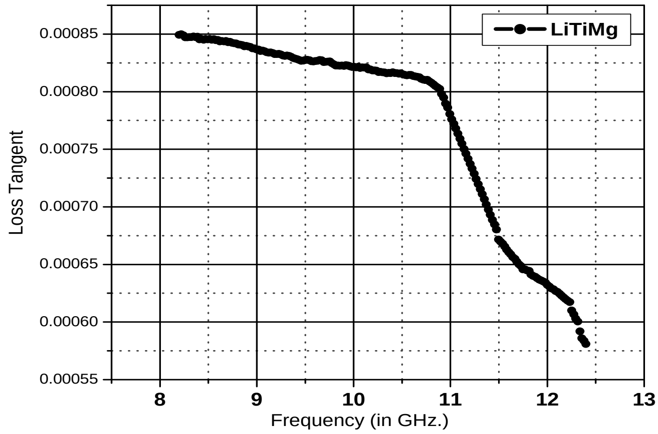

Figure 3: Loss Tangent of material

Vibrating Sample Magnetometer (VSM) was used to determine the magnetic properties of the samples. From the graph obtained from VSM shows the magnetic saturation ($4\pi M_s$) of material.

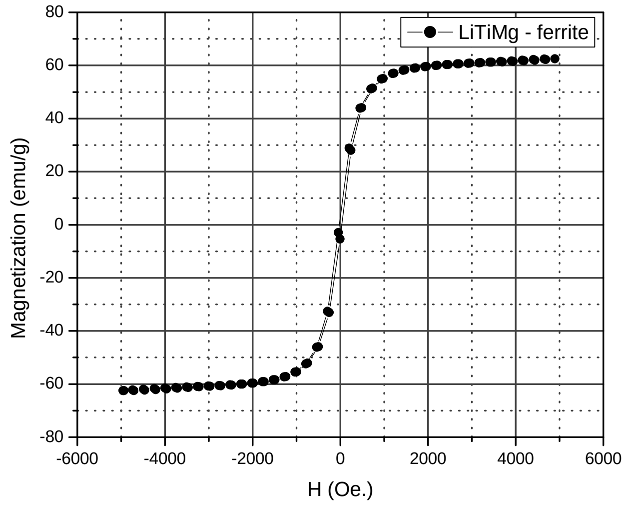

Figure 4: VSM data of dielectric constant

The Curie temperature for the LiTiMg ferrite samples has been determined by using a simple experimental setup based on gravity effect in the laboratory.

LiTiMg Ferrite Characteristics	Values
Magnetic Saturation ($4\pi M_s$)	2200 Gauss
Curie Temperature (T_c)	385^o K
Density (ρ)	4.21 grams/cm^3
Remanence	0.90
Coercivity	1.5
Dielectric Constant (ε)	15
Resonance Line Width (ΔH)	370 Oersteds
Loss Tangent ($\tan\delta$)	< 0.0005

Table 1: The electrical and magnetic properties of LiTiMg ferrite substrate

IV. THEORY FOR ANTENNA APPLICATION

The prepared LiTiMg - ferrite with high magnetic saturation and high Curie temperature is best fitted as a substrate for the high frequency microstrip antennas. For a biased ferrite substrate, a normal incident plane wave may excite two types or modes of waves on the basis of magnetic field direction with respect to substrate as follow:

A. MAGNETOSTATIC MODE OF WAVE

MSW are generated when external magnetic field applied to the perpendicular direction of the magnetic vector of EM waves. MSW are of two types (1) Surface MSW (2) Volume MSW. MSW will propagate perpendicularly on both sides to the EM wave's propagation [10-13].

Vol. MSW: $\mu_o\gamma H \le \omega \le \mu_o\gamma\sqrt{H(H+M_o)}$ (1)

Sur. MSW: $\mu_o\gamma\sqrt{H(H+M_o)} \le \omega \le \mu_o\gamma H\left(H+\frac{M_o}{2}\right)$ (2)

The absorption and transmission coefficients [9, 10], due to the generation of MSW in the ferrite slab are as follow:

$$P = \frac{2\beta_o\varepsilon_r(\alpha\sin 2\beta\delta + \beta\sinh(2\alpha\delta))}{\left[\begin{array}{c}\beta_o^2\varepsilon_r^2\left((\cos\beta\delta)^2 + (\sinh(\alpha\delta))^2\right)\\ +(\alpha^2+\beta^2)\left((\sin\beta\delta)^2 + (\sinh(\alpha\delta))^2\right)\\ +\beta_o\varepsilon_r(\alpha\sin 2\beta\delta + \beta\sinh(2\alpha\delta))\end{array}\right]} \quad (3)$$

$$T = \frac{8(\alpha^2+\beta^2)\beta_o^2\varepsilon_r}{\left[\begin{array}{c}\left[4\beta^2\beta_o^2\varepsilon_r^2 + (\alpha^2+\beta^2+\beta_o^2\varepsilon_r^2)^2\right]\cosh(2\alpha\delta)\\ +4\beta\beta_o\varepsilon_r(\alpha^2+\beta^2+\beta_o^2\varepsilon_r^2)\sinh(2\alpha\delta)\\ -\left[4\beta^2\beta_o^2\varepsilon_r^2 + (\alpha^2+\beta^2-\beta_o^2\varepsilon_r^2)\right]\cosh(2\beta\delta)\\ +4\alpha\beta_o\varepsilon_r(\alpha^2+\beta^2-\beta_o^2\varepsilon_r^2)\sin(2\beta\delta)\end{array}\right]} \quad (4)$$

where

$$\alpha = \beta_o\sqrt{\left(\frac{\varepsilon_r}{2}\right)}\sqrt{\left[\sqrt{(\mu'^2+\mu''^2)} - \mu'\right]}$$

$$\beta = \beta_o\sqrt{\left(\frac{\varepsilon_r}{2}\right)}\sqrt{\left[\sqrt{(\mu'^2+\mu''^2)} + \mu'\right]}$$

and

$\mu' = 1 + \chi' \qquad \mu'' = \chi''$

where

$$\chi' = \frac{\omega_m T(\omega_o+\omega)}{(\omega_o-\omega)^2T^2+1} \qquad \chi'' = \frac{\omega_m T}{(\omega_o-\omega)^2T^2+1}$$

with

$$T = \frac{2}{\gamma\times\Delta H} \quad and \quad \beta_o = \frac{\omega}{c}$$

B. QUASI TEM MODE OF WAVE

As discussed in [12-14], for a biased ferrite slab, a normal incident plane wave may excite two types of waves (ordinary and extraordinary wave). In the case of normal incident magnetic field biasing ordinary wave is same as the plane wave in the dielectric slab. On the other hand, the extraordinary wave is a TE mode polarized parallel to the biasing direction with its phase propagation constant K_e. In the case of extraordinary mode, the propagation constant dependence on the basic parameters is given as

$$\gamma_e = \alpha_e + j\beta_e = j\omega\sqrt{\mu_{eff}\,\varepsilon_r} \quad (5)$$

where μ_{eff} is the effective permeability

$$\mu_{eff} = \frac{\mu^2 - k^2}{\mu}$$

$$\mu = 1 + \frac{\omega_o\omega_m}{\omega_o^2 - \omega^2}$$

$$k = \frac{\omega\,\omega_m}{\omega_o^2 - \omega^2}$$

Where $\omega_o = \gamma H_o$, $\omega_m = \gamma 4\pi M_s$, H_o is the bias field, $4\pi M_s$ is the saturation magnetization, γ is the gyromagnetic ratio as $\gamma = 2.8$ MHz./Oe. In the case of extraordinary wave mode, the propagation constant dependence on the basic parameters is given as

$$\left(\frac{K_e}{K_d}\right)^2 = \frac{(\omega_o+\omega_m)^2 - \omega^2}{\omega_o(\omega_o+\omega_m) - \omega^2} \quad (6)$$

It is seen that, when μ_{eff} is negative, the wave is decaying even if the material is lossless. The frequency range of negative μ_{eff} is:

$$[\omega_o(\omega_o + \omega_m)]^{1/2} < \omega < (\omega_o + \omega_m) \qquad (7)$$

The frequency limits define the approximate range within and around which the ferrite exhibit interesting microwave characteristics.

V. RESULTS AND DESCRIPTION

When the ferrite layer is unbiased, or biased to a state where $\mu_{eff} > 0$, the antenna will transmit and receive as normal. When the ferrite is biased to the cutoff state where $\mu_{eff} < 0$, however, an incident wave will be transformed to quasi-TEM and magnetostatic waves, which largely absorb and attenuate the incident RF waves. From the graph fig. 5 it is evident that the absorbing power is max between 1800 Oe and 2000 Oe which is in good agreement of dispersion graph plotted for LiTiMg-ferrite substrate layer. The dispersion curve for the material has been plotted for the X band with 2150Oe magnetic field as shown in fig. 6.

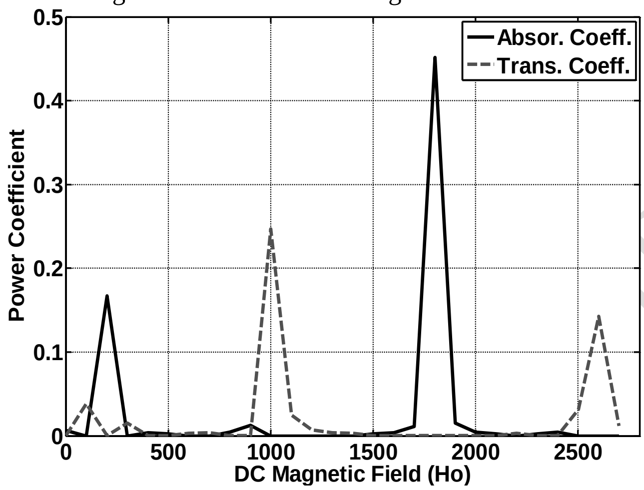

Figure 5: Comparison of transmission (T) and absorption (P) power coefficient with the varying DC magnetic field (H_o)

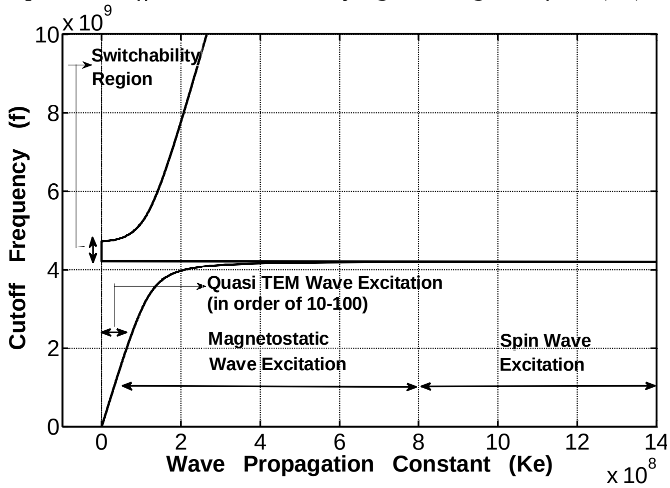

Figure 6: Dispersion curve (f Vs. k) of EM-Waves in LiTiMg for incident plane wave perpendicular to biased slab by 2150 Oe magnetic field in the X band frequency range

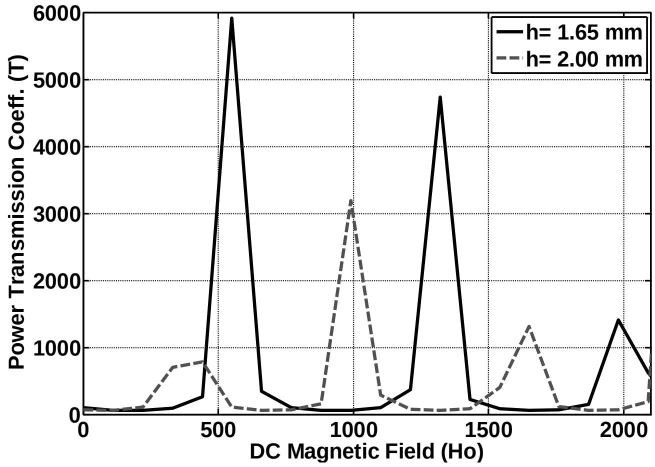

Figure 7: Comparison of transmission power coefficient (T) for h = 2mm & 1.65mm with the varying DC magnetic field (H_o) in the X band frequency range.

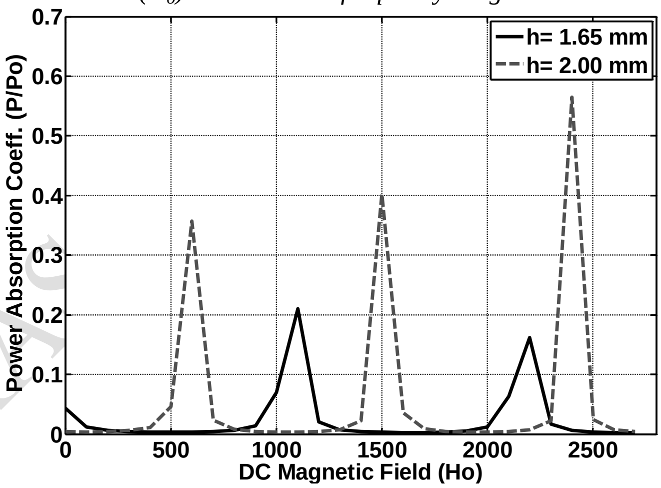

Figure 8: Comparison of absorption power coefficient (P) for h = 2 mm & 1.65 mm with the varying DC magnetic field (H_o) in the X band frequency range

It is clear that when ferrite substrate is magnetized the propagation constant (k) vary with frequency and the initial linear part of curve represents Pozar's quasi TEM wave excitation which is of very small order (10-100) in comparison of scale (10^8). The rest part of curve represents MSW and Spin wave excitation. Spin wave excitation is the result of exchange forces between atoms. In fig. 6 propagation constant behavior also confirm the switching off state of substrate layer for cutoff frequency (w) around 5 GHz.

From the fig. 5 we can also observe the transmitted power coefficient variation with varying external DC magnetic field. The amount of absorption and attenuation can be increased by operating the ferrite in a bias state to maximize power loss or by increasing the thickness of the ferrite substrate layer. Magnetic and dielectric losses will have the effect of increasing the amount of attenuation; as compared to the lossless state (although at the point of maximum cutoff the attenuation may actually decrease slightly with the addition of magnetic losses). The amount of absorption and attenuation can be increased by operating the ferrite in a bias state to maximize power loss or by increasing the thickness of the ferrite layer. Fig. 7 & 8 depict the comparison of transmission and absorption power coefficient respectively for h = 2 mm & 1.65 mm with the varying DC magnetic field (H_o).

VI. CONCLUSION

Here we have conclusion over preparation and characterization of substituted Li-ferrite with saturation magnetization 2200 Gauss. A precise description of ferrite preparation & its characteristic as well as study of nonreciprocal behavior of LiTiMg ferrite slab under magnetic biasing has also been presented. For the tunability and switchability of the antenna the magnetic resonance width of the material has been measured for the particular thickness of substrate. The high saturation magnetization and high Curie temperature of the LiTiMg ferrite fulfill the vital requirements of microstrip antenna during the long performance in adverse environmental conditions. The electrical and magnetical characteristics of LiTiMg ferrite are also dicussed in this communication. These characteristics fulfill almost all important requirements for designing and fabrication of microstrip antenna applications.

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