OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 4, No. 3, March 2010, p. 328 - 331

Study of magnetic properties of substituted LiTiZn-ferrite for microwave antenna applications

N. K. SAXENA, N. KUMAR[a], P. K. S. POURUSH, S. K. KHAH[b*]
Microwave Lab, Department of Physics, Agra College Agra-282002, India
[a]Solid State Physics Laboratory, Lucknow Road, Delhi 110007, India
[b]Department of Physics, Jaypee University of Information Technology, Waknaghat, Solan-173215, India

Ferrite is one of the most versatile magnetic materials which is frequently 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 which can be used 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 LiTiZn ferrite shows different magnetic behavior during DC biasing for microwave frequency antenna applications. The paper describes a precise description of LiTiZn-ferrite preparation, its characteristic plots with a detailed study of nonreciprocal behavior of LiTiZn ferrite slab or substrate under magnetic biasing.

(Received October 27, 2009; accepted March 12, 2010)

Keywords: Substituted ferrite, Microwave frequency range, Electric & magnetic properties, Tunable property

1. Introduction

The integration of ferrite technology into microstrip printed circuit antenna has numerous advantages and potential applications. In recent years it has been observed that 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 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 depends on one of the characteristics of ferrites materials known as magnetic resonance with (ΔH) [1-4].

In the present communication a Li based material has been 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]. Number of samples of same composition were synthesized and investigated thoroughly for electric, magnetic and some physical properties.

2. Material preparation

A typical composition of LiTiZn 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).

2.1 Stoichiometric ratio

The ingredients required for the preparation of these ferrites were calculated on the basis of chemical formula.

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

2.2 Preparation process

The stoichiometric ratio of the chemicals was thoroughly mixed in a polypropylene jar containing the zirconium balls & distilled water was used as a mixing agent. A small amount of Mn^{3+} ion was also incorporated in the basic composition in order to suppress the formation of Fe^{2+} ions in the ferrites and to influence megnetostriction being a John Teller ion [7, 8]. In order to avoid Lithia at high temperatures of sintering, Bi_2O_3 (0.25 wt %) was added as sintering aid [9]. Analytical grade chemicals were used for the preparation of the material. 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. The heating and cooling cycle of the samples was carried out in the air atmosphere of furnace. The sintered sample so obtained was subjected to cutting, grinding, polishing etc. in order to get specific size and shape. The important material properties such as magnetic and electrical properties were studied.

2.3 Crystal nature

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

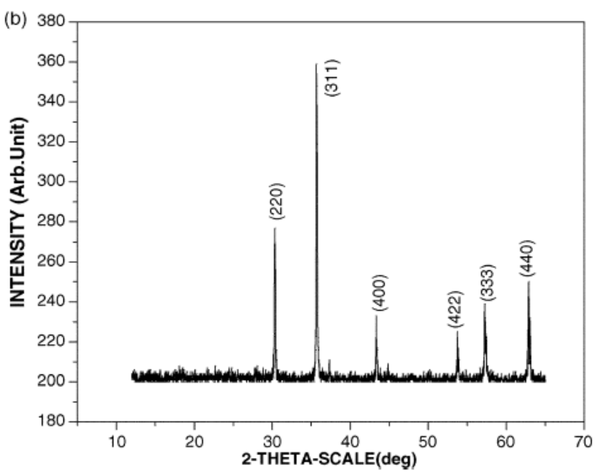

Fig. 1. XRD patterns of the prepared $Li_{0.63}Mn_{0.1}Ti_{0.26}Fe_{2.01}O_4$ ferrite.

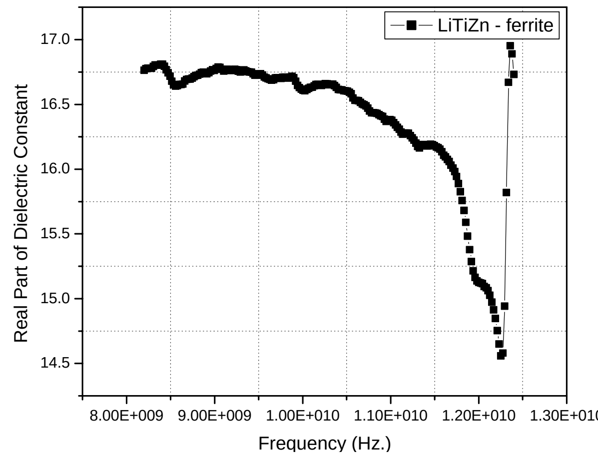

Fig. 2. Dielectric constant of material.

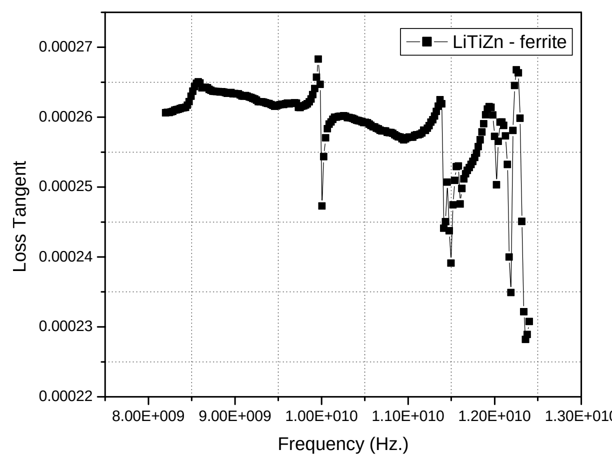

Fig. 3. Loss tangent of material.

3. Electrical and magnetic properties

The electrical and magnetic properties of LiTiZn ferrite substrate is précised under following subtitles:

3.1 Electrical properties

For dielectric measurements, rectangular pellets of size 25mm × 13mm × 7mm were used. The dielectric measurements were conducted from 8 to 12 GHz by a HP 4192A impedance analyzer. The value of the real part of dielectric constant (ε') of the ferrite samples was calculated using formula: $\varepsilon' = Ct/\varepsilon_0 A$, where ε_0 is the permittivity of free space = 8.854×10^{-12} F/m, C is the capacitance of specimen, t is the thickness of specimen in square meter. Remanence and Coercive Force were measured by B-H loop setup applied to coiled toroid sample at 50 Hz.

3.2 Magnetic and physical properties

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

The Curie temperature for the LiTiZn ferrite samples has been determined by using a simple experimental setup based on gravity effect in the laboratory. The ferrite specimen is made to attach itself to a bar magnet through a mild steel rod due to the magnetic attraction and combination is suspended inside the furnace. A chromel-alumel thermocouple is attached with the sample holder to read the temperature of the specimen. As the temperature of the system is increased, at a particular temperature the specimen losses its spontaneous magnetization and becomes paramagnetic.

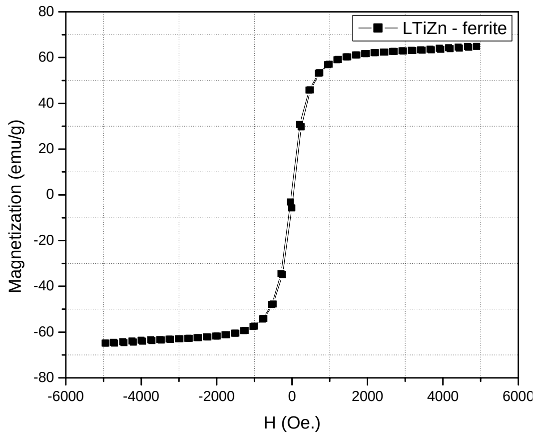

Fig. 4. VSM data of dielectric constant.

Table 1. The electrical and magnetic properties of LiTiZn ferrite substrate.

LiTiZn Ferrite Characteristics	Values
Magnetic saturation ($4\pi M_s$)	2200 Gauss
Curie temperature (T_c)	385°K
Density (ρ)	4.21 grams/cm^3
Remanence	0.90
Coercity	1.5
Dielectric constant (ε)	16
Resonance line width (ΔH)	370 Oesterds
Loss tangent (tan δ)	< 0.0005

The prepared LiTiZn - ferrite with high magnetic saturation and high Curie temperature is best fitted as a substrate for the high frequency microstrip antennas.

4. Results and discussion

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.

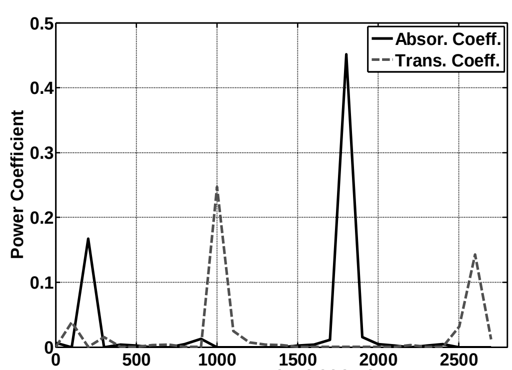

Fig. 5. Comparison of transmission (T) and absorption (P) power coefficient with the varying DC magnetic field (H_o).

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 with the dispersion graph plotted for LiTiZn-ferrite substrate layer. The dispersion curve for the material has been plotted for the X band with 750Oe magnetic field as shown in Fig. 6.

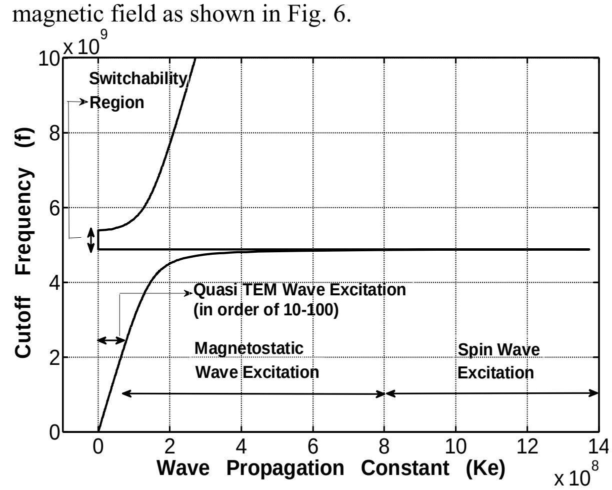

Fig. 6. Dispersion curve (f Vs. k) of EM-Waves in LiTiZn for incident plane wave perpendicular to biased radome layer by 1850 Oe magnetic field in the X band frequency range.

It is clear that when ferrite substrate is magnetized the propagation constant (k) varies 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.

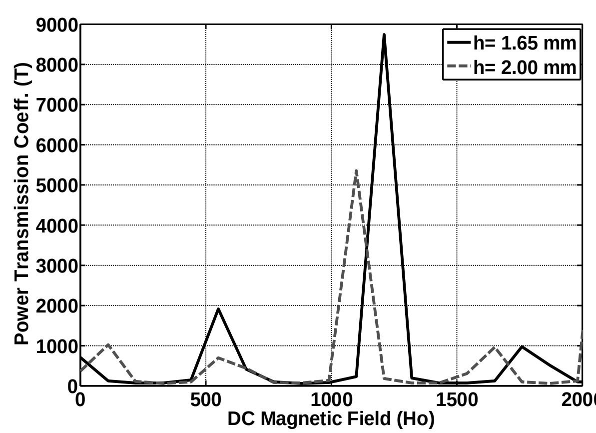

Fig. 7. Comparison of transmission power coefficient (T) for h(Height of sample) = 2mm & 1.65mm with the varying DC magnetic field (H_o) in the X band frequency range.

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). Figs. 7 and 8 depict the comparison of transmission and absorption power coefficient respectively for height of sample h = 2 mm & 1.65 mm with the varying DC magnetic field (H_o).

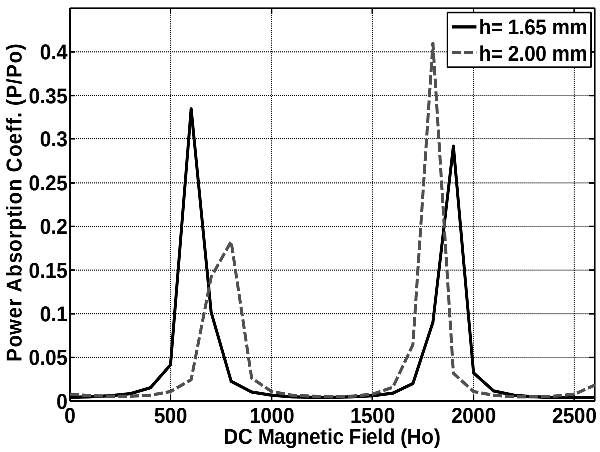

Fig. 8. Comparison of absorption power coefficient (P) for h = 2 mm & 1.65 mm with the varying DC magnetic field (H_o) in the X band frequency range.

5. Conclusions

A composition of titanium substituted Li-ferrite with saturation magnetization 2200 Gauss has been synthesized and investigated for microwave antenna applications. A precise description of LiTiZn-ferrite preparation and its characteristic plots as well as a detailed study of nonreciprocal behavior of LiTiZn ferrite substrate under magnetic biasing has also been presented. The high saturation magnetization and high Curie temperature of the prepared material, fulfill the vital requirements of microstrip antenna during the long performance in adverse environmental conditions. For the tunability and switchability of the antenna the magnetic resonance width of the material has been measured for the particular thickness of substrate. Obtained characteristics of LiTiZn-ferrite as shown in Table 1 fulfill the almost all important for designing and fabrication of microstrip antenna applications.

Acknowledgements

The authors are grateful to Dr. R Muralidharan, Director "Solid State Physics Laboratory, Timarpur, Delhi" for providing necessary facilities, encouragement and motivation to carry out this work.

References

[1] D. M. Pozar, IEEE Trans. AP **40,** 1084 (1992).
[2] L. Dixit, P. K. S. Pourush, IEE Proc. Microwave and Antennas Propagation **147**(2), 151 (2000).
[3] K. K. Tsang, R. J. Langley, IEE Proc. Microwave Antenna Propagation **145**(1), 49 (1998).
[4] J. C. Batchelor, R. J. Langley, Electronic Letters **33**(8), 645 (1997).
[5] D. Ravinder, J. Appl. Phys. **75,** 6121 (1994).
[6] C. Yang, Magn. Magn. Mater. **116,** 231 (1992).
[7] L. G. Van Uitert, Proc IRE **44,** 1294 (1956).
[8] Pran Kishan, D. R. Sagar, S. N. Chatterjee, L. K. Nagpaul, N. Kumar, K. K. Laroia, Adv In Ceramics **16,** 207 (1985).
[9] B. S. Randhawa, H. S. Dosanjh, N. Kumar, Journal of Radio Analytical and Nuclear Chemistry **274**(3), 581 (2007).

*Corresponding author: sunil_khah@rediffmail.com