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High permeability and low power loss of Ti and Zn substitution lithium ferrite in high frequency range

Vivek Verma [a], S.P. Gairola [a], Vibhav Pandey [a], J.S. Tawale [a], Hua Su [b], R.K. Kotanala [a,*]

[a] National Physical Laboratory, Dr. K.S. Krishnan Road, New Delhi 110012, India

[b] State Key Laboratory of Electronic Thin Films and Integrated Devices, University of Electronic Science and Technology of China, Chengdu 610054, China

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ABSTRACT

The effect of Zn and Ti on the magnetic, power loss and structural properties of $Li_{0.5}Zn_xTi_xMn_{0.05}Fe_{2.45-2x}O_4$ ferrites ($x = 0.0$ to 0.30 in step of 0.05)+0.5 wt% Bi_2O_3, prepared by standard ceramic technique, has been investigated. Complex permeability ($\mu^* = \mu' - j\mu''$) has been analyzed at room temperature in frequency range from 1 to 10^3 MHz. It was found an enhancement in permeability with Ti and Zn concentration in $Li_{0.5}Zn_xTi_xMn_{0.05}Fe_{2.45-2x}O_4$ and exhibits the maximum value 106 for $x = 0.20$ sample. Complex permeability of these ferrites exhibits stable frequency response up to 7 MHz beyond which the real part decreases sharply and imaginary part increases to have a peak at the relaxation frequency. Power loss measurements have been carried out in induction condition ($B = 10$ mT) in frequency range of 50 kHz to 3 MHz. Power loss has been found to be quite low with the substitution of Ti and Zn in lithium ferrite.

1. Introduction

Pure and substituted lithium ferrites are low cost materials and have important magnetic and electrical properties for technological applications. Ferrites assume special significance in the field of electronics and telecommunication industry because of their novel electrical properties which make them useful in radio-frequency circuits, high quality filters, rod antennas, transformer cores, read/write heads for high digital tapes and other devices [1–3]. Mn–Zn ferrites and Ni–Zn ferrites are well known materials for power electronic equipments. Development of a high quality, low cost and low loss for high frequency ferrite materials for power applications is an ever challenging aspect for investigation. Substituted lithium ferrites may be useful material for such applications because of their high saturation magnetization and low power loss (P_{cv}) [4,5]. Magnetic and electrical properties of ferrites were found to be sensitive to their composition and processing techniques. The main types of losses encountered in ferrites are eddy current loss, hysteresis loss and residual loss. Consequently the requirements of a power ferrite are high resistivity to keep the eddy current losses low, high permeability to reduce hysteresis losses and a high resonance frequency to reduce the residual losses, which consist mainly of resonance–relaxation losses [6,7]. In this work we have studied the effect of Zn and Ti on the microstructure, permeability and power loss of lithium ferrites.

2. Experimental

Polycrystalline samples of substituted lithium ferrite with the stoichiometric formula $Li_{0.5}Zn_xTi_xMn_{0.05}Fe_{2.45-2x}O_4$ ($x = 0.0$ to 0.30 in step of 0.05) were prepared by conventional ceramic technique. A small amount (0.5 wt%) of Bi_2O_3 was also added to reduce the sintering temperature, which prevents the volatilization of Lithia and enhances the densification [8]. The starting materials were AR grade Li_2CO_3, Fe_2O_3, ZnO, MnO_2, TiO_2 and Bi_2O_3. An appropriate amount of these materials were taken and ground/mixed thoroughly. The resultant mixtures were dried and calcined at 750 °C for 10 h. The powder was ground and pressed in the form of pellets and toroids using a small amount of PVA as a binder with an applied pressure of 10 ton. The final sintering was carried out at 1050 °C for 5 h. Heating and cooling rate was controlled at 5 °C/min. 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 ($\lambda = 1.5406$ Å).

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[*] Corresponding author. Tel.: +91 11 45608599.
E-mail address: rkkotnala@nplindia.org (R.K. Kotanala).

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Power loss and permeability response in frequency range of 1 MHz–1 GHz were measured by *B–H* analyzer (IWATSU, SY 8232) and Agilent 4284/Agilent 4285 respectively. Toroid shape samples (i.d. = 5.5 mm, o.d. = 11 mm, $t = 3$ mm) were used to calculate the power loss and permeability. Magnetic measurements were performed at room temperature using vibrating sample magnetometer (Lake Shore 7304) for all samples. Resistivity of samples was calculated by two probe method using KEITHLEY 4200 SCS.

3. Results and discussion

The X-ray diffraction patterns of the samples $Li_{0.5}Zn_xTi_xMn_{0.05}Fe_{2.45-2x}O_4$ with $x = 0.0$, 0.05, 0.10, 0.15, 0.20, 0.25 and 0.30) are shown in Fig. 1, which represents the typical spinel structure. The $(h\,k\,l)$ values corresponding to the diffraction peaks are marked in figure. The lattice parameters '*a*' for the sintered samples calculated from the (3 1 1) diffraction peak, are shown in Table 1. Lattice constant increases with the Ti and Zn concentration up to $x = 0.20$, because Zn^{2+} (0.82 Å) is replaced by the Fe^{3+} (0.67 Å) from tetrahedral side and Ti^{4+} (0.60 Å) to Fe^{3+} (0.67 Å) from octahedral site [9,10] but it begins to decrease with further substitution which may be due to Ti^{4+} start to replace Fe^{3+} from tetrahedral site also [11].

Complex permeability ($\mu^* = \mu' - j\mu''$) response curves for Zn and Ti substituted $Li_{0.5}Zn_xTi_xMn_{0.05}Fe_{2.45-2x}O_4$ ferrites for frequency range 10^6–10^9 Hz have been shown in Fig. 2(a) and (b). It is observed that the value of real part of permeability (~28) of $Li_{0.5}Mn_{0.05}Fe_{2.45}O_4$ sample increases with the concentration of Ti and Zn in $Li_{0.5}Zn_xTi_xMn_{0.05}Fe_{2.45-2x}O_4$ and attains the maximum value of ~106 for $x = 0.20$ sample. Complex permeability of these ferrites exhibits stable frequency response up to 7 MHz beyond which the real part decreases sharply and imaginary part increases to have a peak at the relaxation frequency. The change in permeability for different compositions is defined on the dependence of permeability, saturation magnetization and average grain size is expressed by following relation (1) [12]:

$$\mu_i \propto \mu_0 M_s^2 D_m/[K_1 + (3/2)\lambda_s \sigma]\beta^{1/3}\delta \qquad (1)$$

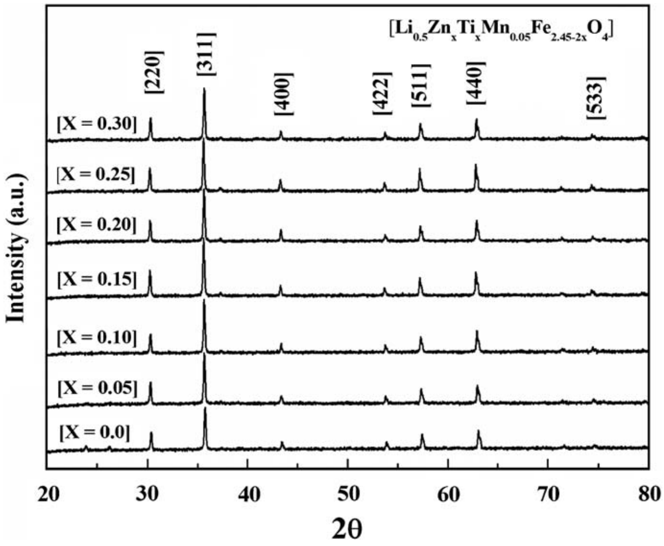

Fig. 1. X-ray diffraction patterns of $Li_{0.5}Zn_xTi_xMn_{0.05}Fe_{2.45-2x}O_4$.

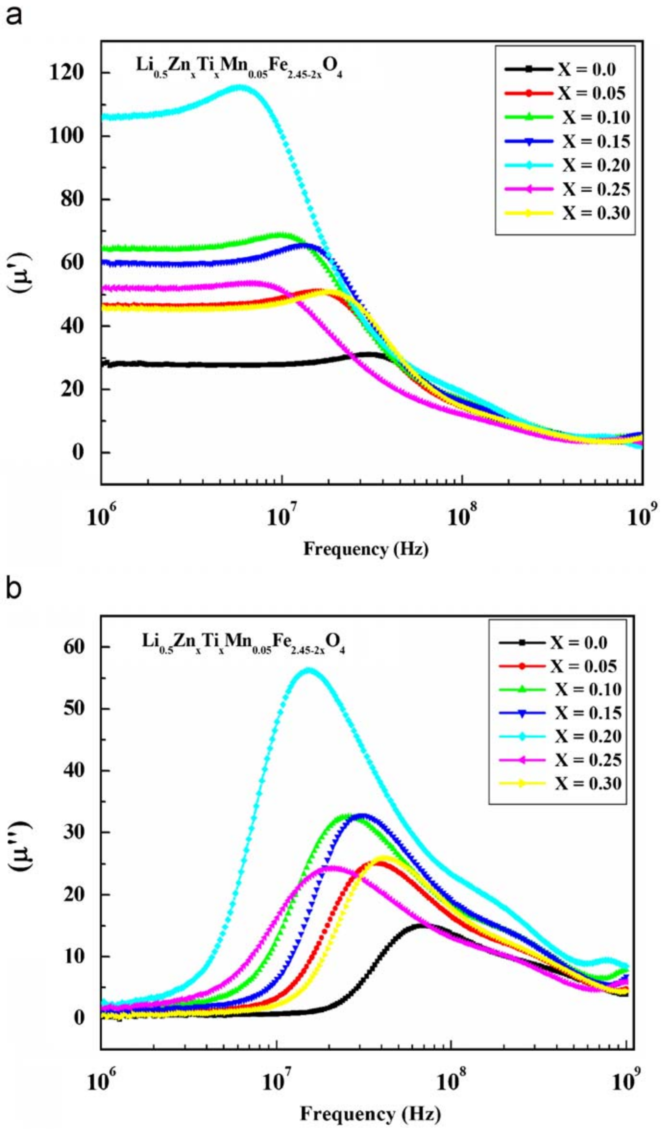

Fig. 2. Complex permeability curves of (a) real and (b) imaginary part of $Li_{0.5}Zn_xTi_xMn_{0.05}Fe_{2.45-2x}O_4$.

Table 1
Microstructure and magnetic properties of $Li_{0.5}Zn_xTi_xMn_{0.05}Fe_{2.45-2x}O_4$ samples.

Composition $Li_{0.5}Zn_xTi_xMn_{0.05}Fe_{2.45-2x}O$	Lattice constant (Å)	Permeability (μ) at frequency 1 MHz	Saturation magnetization (emu/g)	Grain size (μm)
$x = 0.00$	8.321	27.9	58.5	3.9
$x = 0.05$	8.342	46.5	56.2	6.1
$x = 0.10$	8.347	64.4	55.9	6.4
$x = 0.15$	8.358	59.8	51.9	7.0
$x = 0.20$	8.357	105.5	52.6	7.8
$x = 0.25$	8.348	51.4	54.5	6.2
$x = 0.30$	8.340	45.5	40.9	5.1