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Study of cole–cole plot of lithium substituted manganese ferrites

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ABSTRACT

Polycrystalline ferrites, $Li_{0.5-0.5x}Mn_xFe_{2.5-0.5x}O_4$ (where x=0.0, 0.1, 0.3, 0.5, 0.7, 0.9 and 1.0), were prepared by using ceramic method. The impedance measurements have been determined in the frequency range 100 Hz–1 MHz. The complex impedance spectra shows the presence of two semicircles for x=0.0, 0.5, 0.7, 0.9 and 1, and only one semicircle for x=0.1 and 0.3. The analysis of the data shows that the resistive and capacitive properties of the Mn ferrite are mainly due to processes associated with grain and grain boundaries.

KEYWORDS

Ferrite;
Ceramic;
Complex impedance.

INTRODUCTION

Polycrystalline ferrites have very important structural, magnetic, electrical and dielectric properties that are dependent on various factors, such as method of preparation, substitution of cations and microstructure[1,2]. Introduction of a relatively small amount of foreign ions can change the properties of ferrites[3]. It can provide us with information for obtaining a high-quality ferrite for particular applications. Modification in electric and magnetic properties of lithium ferrites by substitution of different ions has been extensively studied[4-6].

Lithium ferrite $Li_{0.5}Fe_{2.5}O_4$ is a unique member of the spinel class of ferrimagnets and is dominating the field of microwave applications because of its rectangular and square hystersis loop characteristics, high curie temperature, large value of saturation magnetization, low microwave dielectrics and low costs[7].

In this article, we report the influence of Mn substitution on the impedance properties of $Li_{0.5-0.5x}Mn_xFe_{2.5-0.5x}O_4$ ferrite as a function of frequency at room temperature.

EXPERIMENTAL TECHNIQUE

Polycrystalline specimens of $Li_{0.5-0.5x}Mn_xFe_{2.5"0.5x}O_4$ (x = 0, 0.1, 0.3, 0.5, 0.7, 0.9 and 1.0) were prepared by using the standard ceramic technique. The starting analytical reagents (Fe_2O_3, Li_2CO_3 and MnO) with high purity were mixed and grounded in a very fine powder. The mixtures were presintered at 750æ%C for 10 h. The powders were then re-grounded, compressed in the toroidal shape and finally sintered at 1200 °C for 10 hrs in static air. Then they were cooled gradually to room temperature with rate of 2°C/minute. Impedance measurements were conducted at room temperature over 100 Hz - 1 MHz by using a RLC (Model PM6306 FLUKA). Disk samples of 13 mm in diameter and 3–5 mm in thickness were used for the measurement with silver electrode.

RESULTS AND DISCUSSION

Impedance spectroscopy is considered to be an important tool to investigate the electrical properties of ferrites as the impedance of grains can be separated from the other impedance sources, such as impedance of electrodes and grain boundaries. The impedance response in polycrystalline materials is normally comprised of the grain, the grain boundary and the material electrodes interface processes in order of decreasing frequency. The Cole – Cole plot is particularly useful for the material that posses one or more well separated relaxation processes with comparable magnitudes and obeys the Debye or Cole –Cole functional forms[8].

Figure 1 shows the measured complex impedance spectrum for Li-Mn ferrites. It is observed that the plot is composed of two overlapping semicircles for x=0.0, 0.5, 0.7, 0.9 and 1. The first semicircle at the low fre-

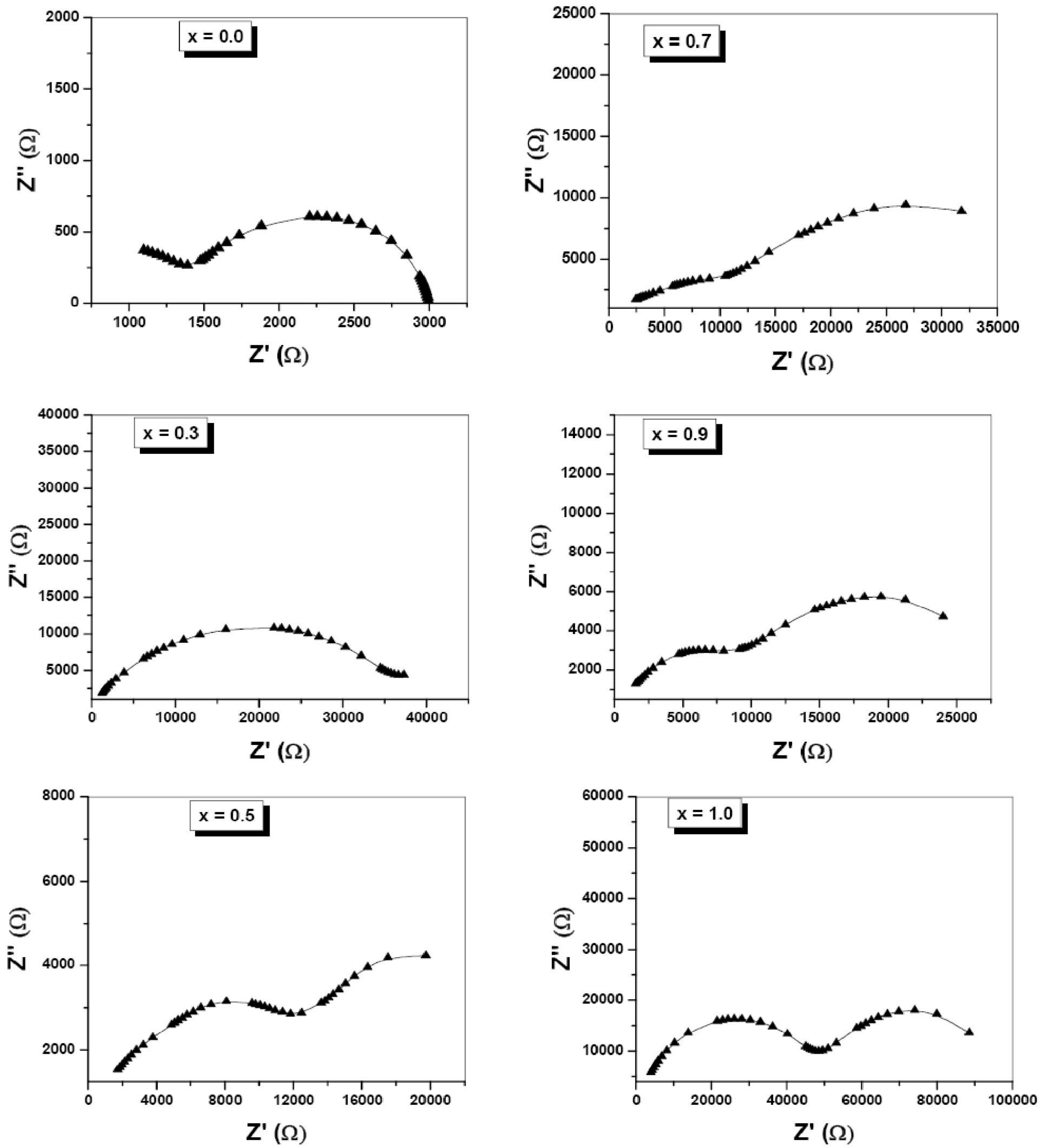

Figure 1 : Cole – Cole plots for $Li_{0.5+0.5x}Mn_xFe_{2.5-0.5x}O_4$ (x=0.0, 0.3, 0.5, 0.7, 0.9 and 1) at room temperature.

quency range represents the resistance of the grain boundary. The second semicircle at the high frequency range represents the resistance of the grain (bulk). Since the relaxation time of grain and grain boundary are different, the impedance spectroscopy allows separation of two, thus resulting in separate semicircle. But only single semicircle was obtained for the samples with x=0.1and 0.3, which suggests a predominance of the contribution from the grain boundary and that contribution from the grain is not resolved for these samples. Hence, conductivity in these two samples is mainly due to the grain boundary contribution.

The complex impedance has been calculated from the relation:

$$Z^* = R(1 - j\omega RC) \;/\; (1 + \omega^2 R^2 C^2)$$

so that the real and imaginary components are

$$Z' = R/(1 + \omega^2 R^2 C^2)$$

and

$$Z^{''} = \omega R^2 C/(1 + \omega^2 R^2 C^2)$$

The mean relaxation times for the grain and grain boundary processes are calculated from the inverse of the peak frequencies ω_g and ω_{gb}, respectively.

Since, $\tau_g = \frac{1}{\omega_g} = R_g C_g$

$$\tau_{gb} = \frac{1}{\omega_{gb}} = R_{bg} C_{gb}$$

so that the capacitances (C_g and C_{gb}) can be calculated.

The experimental data has been analyzed using complex nonlinear least square fitting method in order to obtain the best fit. The various impedance parameters calculated have been tabulated in TABLE 1. It is observed that the grain boundary resistances are higher than those of the grain. This can be due to the fact that the atomic arrangement near the grain boundary is disordered due to the increase in electron scattering.

From the microstructure point of view, it is well known that the ferrite sample is composed of parallel conducting regions (grain) separated by resistive regions (grain boundaries). The obtained results for x=0.0, 0.5, 0.7, 0.9 and 1 can be approximately modeled by an ideal equivalent circuit based on two parallel R–C elements in series. Figure 2a shows the proposed model for the analysis the impedance spectroscopy data for x=0.0, 0.5, 0.7, 0.9 and 1, where, the parameters R_{gb} and C_{gb}, correspond to the resistance and capacitance

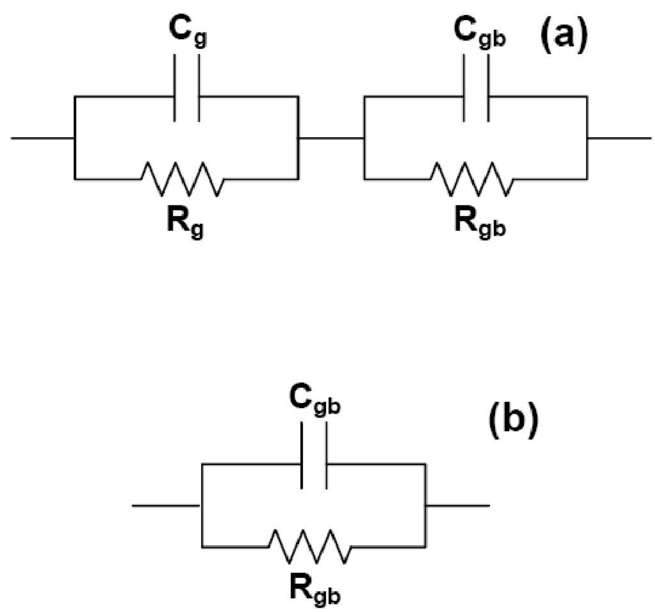

Figure 2 : The equivalent circuit model (a) for x=0.0, 0.5, 0.7, 0.9 and 1 (b) for x=0.1 and 0.3

TABLE

	x=0.0	x=0.1	x=0.3	x=0.5	x=0.7	x=0.9	x=1.0
R_g (Ω)	2320	-	-	12000	9480	9090	4780
R_{gb} (Ω)	3290	2889	3809	18880	36720	22210	5854
C_g (pF)	-	-	-	0.66	0.56	0.58	0.48
C_{gb} (pF)	4.84	6.89	2.79	0.45	14.45	23.89	90.67
τ_g (10^{-6} s)	-	-	-	7.96	5.31	5.31	2.27
τ_{gb} (10^{-4} s)	0.16	19.9	10.61	0.08	5.31	5.31	5.31
φ_g (deg.)	34	-	-	31	53	32	25
φ_{gb} (deg.)	26	32	42	22	40	29	29
α_g	0.378	-	-	0.344	0.589	0.356	0.28
α_{gb}	0.289	0.36	0.47	0.244	0.44	0.32	0.32

of the grain boundary, respectively and R_g and C_g, correspond to the resistance and capacitance of the grain, respectively. Figure 2b shows the proposed model for the analysis the impedance spectroscopy data for x=0.1 and 0.3.

CONCLUSION

Manganese substituted lithium ferrite were prepared by using the standard ceramic method. Impedance measurement analysis confirmed that the conduction is due to grain and grain boundaries for x=0.0, 0.5, 0.7, 0.9 and 1. Meanwhile the conduction is due to grain boundaries for x=0.1 and 0.3.

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