

# Electrical and magnetic properties of magnesium-substituted lithium ferrite

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## Abstract

Magnesium-substituted lithium ferrite of different composition ( $\text{Li}_{0.5}\text{Fe}_{2.5-x}\text{Mg}_x\text{O}_{4-\delta}$ ) were prepared for  $x = 0.0$ – $1.0$  by conventional ceramic technique. The crystal structure characterization and morphology were investigated by X-ray diffraction (XRD), scanning electron microscopy (SEM). Initial permeability and quality factor were measured in the frequency range of 1 kHz to 100 MHz. The permeability decreased gradually from  $\mu$  ( $f = 10$  MHz) = 34.0 for  $\text{Li}_{0.5}\text{Fe}_{2.5}\text{O}_4$  to  $\mu$  ( $f = 10$  MHz) = 11.5 for  $\text{Li}_{0.5}\text{Fe}_{1.5}\text{Mg}_{1.0}\text{O}_4$ . Electrical conductivity measurements were carried in the range of 250–700 °C in air. The maximum electrical conductivity,  $\sigma_{700\text{ }^\circ\text{C}} = 0.1274$  S/cm has been found to be for  $\text{Li}_{0.5}\text{Fe}_{2.5}\text{O}_4$  specimen. With increasing Mg-substituted content, the decreased in the electrical conductivity.

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## 1. Introduction

Spinel ferrites have potential applications in electrical components such as memory devices and microwave devices over a wide range of frequency due to their high resistivity and loss behavior [1]. The family of substituted lithium ferrites have attracted the attention of scientists for a long time and have been developed as a replacement for yttrium iron garnet (YIG) owing to their low cost [2]. Lithium ferrites are important components of microwave devices such as isolators, circulars, gyrators, and phase shifters and memory cores owing to their high Curie temperature, high saturation magnetization, and hysteresis loop properties, which offer performance advantage over other spinel structures [3–6]. Since the number of ferric ions on A and B sites is unequal in lithium ferrite, the calculated magnetic moment is not just that of lithium ions, but is given by the difference in the magnetic moment of ions on A and B sites. Consequently, lithium ferrite possesses a higher Curie temperature than other spinel ferrites [7].  $\text{Li}_{0.5}\text{Fe}_{2.5}\text{O}_4$  is an inverse spinel with the  $\text{Li}^+$  and three-fifths of the  $\text{Fe}^{3+}$  ions occupying the octahedral B sites of the cubic spinel structure

of the general formula  $\text{AB}_2\text{O}_4$  [8]. Moreover, lithium ferrite have been also promising substitutes for Ni–Cu–Zn ferrites in advanced planar ferrite devices, because of their low sintering temperature, high Curie temperature and excellent electromagnetic properties at high frequency [9]. Magnesium-substituted lithium ferrites have been used in many electronic devices for high frequency because of their high electrical resistivity, high Curie temperature and low cost [10]. In this study, we reported (1) the relationship between lattice constant between dopant content of Mg, in which the variation of lattice is related with the substitution sites of  $\text{Mg}^{2+}$ , (2) the relationship between the initial permeability with frequency, (3) determination of Curie temperature via the Arrhenius plots for electrical conductivity of Mg-substituted lithium ferrite, and (4) the microstructure dependence on the dopant content of Mg.

## 2. Experimental procedure

### 2.1. Preparation of magnesium-substituted lithium ferrites

Magnesium-substituted lithium ferrites  $\text{Li}_{0.5}\text{Fe}_{2.5-x}\text{Mg}_x\text{O}_{4-\delta}$  with  $0.0 \leq x \leq 1.0$  were prepared following the conventional ceramic method. Samples were prepared from reagent-grade powders of  $\text{Li}_2\text{CO}_3$ ,  $\text{MgO}$ , and  $\text{Fe}_2\text{O}_3$ . Appropriate proportion of these compound were taken and ball-milled for 12 h in distilled

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water in order to mix them thoroughly and improved the homogeneity. The resulting mixtures were dried, and calcined at 700 °C for 4 h. Subsequently the whole mixture was remilled for 6 h and dried. The dried and sieved powder was pressed in the form of pellets using a small amount of PVA as binder with an applied uniaxial pressure of 1000 kgf/cm<sup>2</sup>. The pellets sample was then finally sintered at 1200 °C for 4 h in air and furnace cooled.

## 2.2. Characterization of the materials

Computerized X-ray powder diffraction (XRD; Rigaku D/Max-II, Tokyo, Japan) analysis, together with Cu K $\alpha$  radiation with  $\lambda = 0.15405$  nm was used to identify the crystalline phase and calculated lattice parameter. The morphological features of the magnesium-substituted lithium ferrites were carried out using a scanning electron microscope (SEM; Hitachi S-3500H, Tokyo, Japan). The electrical conductivity measurements were made at various temperatures in the range of 250–700 °C in air by the DC two probes technique. Pellet specimens (10 mm in diameter and 2 mm in thickness) were used for electrical conductivity measurement. Two Ag leads were attached on the sample with Ag paste and fired at 800 °C. Activation energy for conduction was obtained by plotting the ionic conductivity data in Arrhenius relation for thermally activated conduction. The initial permeability ( $\mu_i$ ) of magnesium-substituted lithium ferrite were measured on impedance analyzer (Agilent 4194A, Santa Clara, CA, USA) in the frequency range of 1 kHz to 100 MHz; 15 turns of coil were wound around the sintered toroidal specimens with dimension of 14 mm outer diameter, 7 mm inner diameter, and 3 mm thickness. All the measurements were carried out at room temperature.

## 3. Results and discussion

Unlike other spinel-type ferrites, lithium ferrite exists in two different crystalline forms. The  $\alpha$ -phase has an FCC inverse spinel structure with space group of  $P4_332$  and  $\alpha$ -phase is an ordered phase in which the Li<sup>+</sup> and Fe<sup>3+</sup> ions are ordered in the 1:3 ratio in the octahedral B sites of the cubic spinel structure, whereas the remaining Fe<sup>3+</sup> ions occupy the tetrahedral A sites. Whereas the  $\beta$ -phase is a disordered phase where the Li<sup>+</sup> and Fe<sup>3+</sup> ions are randomly distributed in the octahedral interstices and the space group is  $Fd\bar{3}m$  [11–13]. Fig. 1 showed the X-ray diffraction patterns of the magnesium-substituted lithium ferrites specimens sintered at 1200 °C for 4 h. It was evident that the magnesium-substituted lithium ferrite specimens contain only the  $\alpha$ -phase. All the peaks in the pattern were matched well with JCPDS card (No. 38-0259). No  $\beta$ -phase was detected in the XRD patterns of samples. The presence of  $\alpha$ -phase is due to the fact that during the usual ceramic method of synthesis of the bulk ferrite, a slow cooling process from above 755 °C yields the ordered phase [11].

The introduction of Mg<sup>2+</sup> ions into pure lithium ferrite can cause a small shift to a lower diffraction angle in the lithium

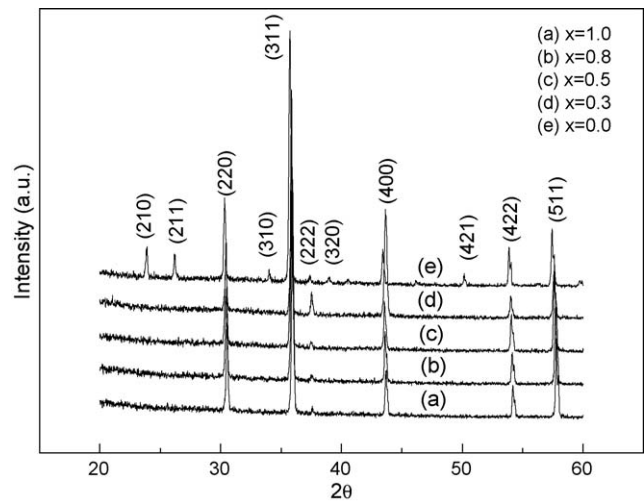


Fig. 1. X-ray powder pattern of magnesium-substituted lithium ferrites sintered at 1200 °C for 4 h.

ferrite peaks. This shift was indicative of the change in lattice parameter. Fig. 2 showed the dependence of the lattice constant on Mg-substituted content. The result revealed that the lattice constant increased gradually with increasing content of magnesium substitution in the range of  $0.0 < x < 0.5$ , and in the range of  $0.5 < x < 1.0$ , the lattice constant markedly increased as  $x$  increases. Generally, as the Mg-substituted content increase, the lattice constant increased. It was due to the fact that different radii of Fe<sup>3+</sup> (0.64 Å), Mg<sup>2+</sup> (0.71 Å), and Li<sup>+</sup> (0.76 Å) in an oxide solid solution with a spinel-type structure. When doped with larger size of Mg<sup>2+</sup> ions in the spinel lithium ferrite, causing the spinel lithium ferrite swell. Doping Mg<sup>2+</sup> ions in a spinel-type structure will induce uniform strain in the lattice as the material is elastically deformed [14]. This effect causes the lattice plane spacing to change and the diffraction peaks shift to a lower  $2\theta$  position. Noticeably, the lattice parameter was nonlinearly dependent on Mg-substituted concentration for Li<sub>0.5</sub>Fe<sub>2.5-x</sub>Mg<sub>x</sub>O<sub>4- $\delta$</sub> . We can define the chemical formulas of (Fe<sub>1.0</sub>) [Li<sub>0.5</sub>Fe<sub>1.5</sub>]O<sub>4</sub> and (Fe<sub>1.0-y</sub>Li<sub>y</sub>)

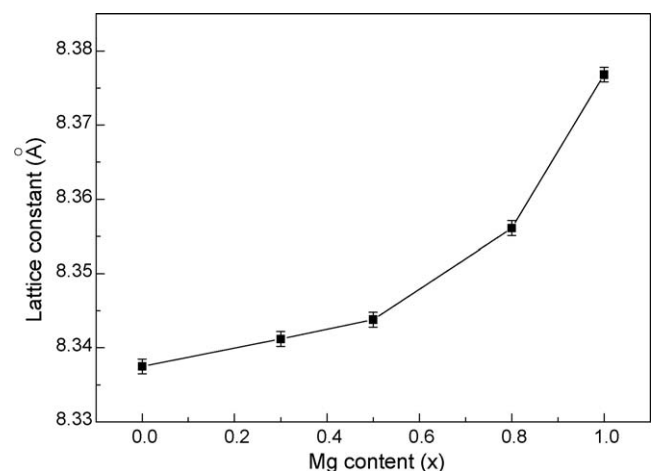


Fig. 2. Dependence of lattice constant vs dopant content of Mg.

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