Electrical properties test of dielectric constant and impedance characteristic thin films of $LiTaO_3$ and 10% Ga_2O_3 doped $LiTaO_3$

by Richie Estrada

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ELECTRICAL PROPERTIES TEST OF DIELECTRIC CONSTANT AND IMPEDANCE CHARACTERISTIC THIN FILMS OF $LiTaO_3$ AND 10% Ga_2O_3 DOPED $LiTaO_3$

Richie Estrada[1], Nani Djohan[1], Gaby Charla Rundupadang[1], Ade Kurniawan[2] ,Johan Iskandar[2], Muhammad Dahrul[2], Hendradi Hardhienata[2] and Irzaman[2]
[1]Department of Electrical Engineering, Krida Wacana Christian University, Jakarta, Indonesia
[2]Department of Physics, Bogor Agricultural University, Bogor, Indonesia
E-Mail: richie.estrada@ukrida.ac.id

ABSTRACT

This study aims to investigatedielectric constant and impedance characteristic of thin films made from $LiTaO_3$ without (0%) and with doping (10%) Ga_2O_3. The solubility of $LiTaO_3$ for the purpose of this study is regulated at 1 M by using 2-methoxyethanol [($CH_3OCH_2CH_2OH$)] as solvent. The growth of thin films on 7059 corning glass substrate was processed by Chemical Solution Deposition (CSD) method. By using a spin coater device on a speed of 3000 rpm for 30 seconds, the substrate is then annealed in furnace at a temperature of 550 °C for eight hours. To create aluminum contacts, the thin films were then further processed by involving Metal Organic Chemical Vapor Deposition (MOCVD) technique. The final thin films weremeasured by LCR meter to provide certain data such as: inductance, capacitance and resistance values in range frequency from 50 Hz to 5 MHz. The study concludes that the film thickness (made from $LiTaO_3$ without (0%) and with doping (10%) Ga_2O_3) as separator material between two aluminum contacts that embedded on 7059 corning glass substrate was affected not only by dielectric constant but also by magnitude of impedance that contributes to providing information about ionic phenomenon.

Keywords: dielectric constant, impedance characteristic, thin film, $LiTaO_3$, Ga_2O_3.

INTRODUCTION

Ferroelectrics are dielectric materials [1] that have permanent electric dipoles which exhibit a spontaneous electric polarization even without the influence an electric field [2-4]. Furthermore, the polarization requires two steady conditions at minimum,as well as the capability to be switched from one condition to another when an electric field is applied [4]. Spontaneous polarization is obtained through the extrapolation by withdrawing line at the saturated linear region until intersecting the polarization axis [4]. Therefore, the application of an appropriate electric field not only can be reverse the direction of the polarization, but also can change the magnitude of polarization [3, 4]. In addition, the electric polarization of a material also can be influenced by temperature (called pyroelectricity), stress (called piezoelectricity) or light (called electro-opticity) [3-5].

Lithium tantalate ($LiTaO_3$) is crystalline ferroelectric which exhibits excellent pyroelectric, piezoelectric, electro-optical and non-linear optical properties [6-8]. The crystal structure of $LiTaO_3$(rhombohedral structure of space group R3c) is an important part to observe the electrical properties in form of dielectric and impedance on thin films [6, 8-11]. Based on literature, the electrical properties of thin film is very affected by phenomenon of ions and also dopant diffusion inside crystalline structure on substrate [12-15]. The aim of this study is to investigate the dielectric constant and impedance characteristic of each thin layer (undoped and 10% Ga_2O_3 doped $LiTaO_3$) on 7059 corning glass substrates, using LCR meter (HIOKI 3532-50 LCR HiTESTER) as a measurement device.

METHODOLOGY

Lithium tantalate ($LiTaO_3$) is formed by mixing the chemicals powder between lithium acetate [Li (CH_3COO)] and tantalum pentoxide [(Ta_2O_5)] by utilizing the balance of chemical equation [16]:

$$2Li(CH_3COO) + Ta_2O_5 + 4O_2 \rightarrow 2LiTaO_3 + 4CO_2 + 3H_2O$$

Based the balance of chemical equation with solubility that has been regulated at 1 M, the mass composition of lithium acetate powder [Li(CH_3COO), 99.99% purity] is 0.1650 g and tantalum pentoxide powder [(Ta_2O_5), 99.8% purity] is 0.5524 g [16, 17]. In addition, the gallium oxide powder [(Ga_2O_3), 99.998% purity] is used as a doping with a mass of 0.0590 g (10% from the mass of $LiTaO_3$) [16].

The mass composition which is obtained from calculation of lithium acetate powder, tantalum pentoxide powder and gallium oxide powderwas weighed by using analytical scale (ADAM equipment). The chemicals powder is mixed and dissolved in 2.5 ml 2-methoxyethanol [($CH_3OCH_2CH_2OH$)] to produce two types of solution ($LiTaO_3$ and $LiTaO_3$ + 10% Ga_2O_3). Thesolutions were sonicated by using ultrasonicator device (BRANSON 2510) for 90 minutes to obtain the homogeneous solutions.

The layer of thin film from two types of solution, which were already homogeneous on 7059 corning glass substrates dimensionless 1 × 1 cm^2, were then processed by Chemical Solution Deposition (CSD) method using a spin coater on speed of 3000 rpm for 30 seconds. Each of thin layer wastreated three times coating process (deposition and rotation) with interrupt time for one

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minute, then annealed in furnace (VULCAN ™ 3-130) at a temperature of 550°C for eight hours.

The next fabrication was by creating contact made from aluminum material dimensionless 2 x 2 mm^2 at 7059 corning glass substrate and layer of thin films using Metal Organic Chemical Vapor Deposition (MOCVD) technique. The aluminum contacts were utilized as a surface for mounting the fine copper wire (see Figure-1). Probe of LCR meter (HIOKI 3532-50 LCR HiTESTER) connected at the ends of fine copper wire were utilized to get the data in form of inductance, capacitance and resistance values at a range frequency of 50 Hz - 5 MHz.

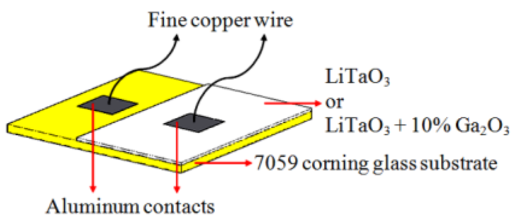

Figure-1. Structure of thin film.

RESULT AND DISCUSSIONS

In this study, the measurements of thin films were carried out on a frequency range from 50 Hz to 5 MHz, by using LCR meter (HIOKI 3532-50 LCR HiTESTER) and presented in the form of curves inductance, capacitance and resistance as a function of frequency (seeFigure-2, Figure-4). The dielectric constant of thin films can be calculated by using the following formula (1) [9]:

$$\varepsilon = \frac{C\,d}{\varepsilon_0 A} \qquad (1)$$

with:

C = capacitance value (from measurement values)
d = film thickness (1×10^{-6} m)
ε_0 = the vacuum permittivity (8.8542×10^{-12} F/m)
A = aluminum contact surface area (4×10^{-6} m^2)

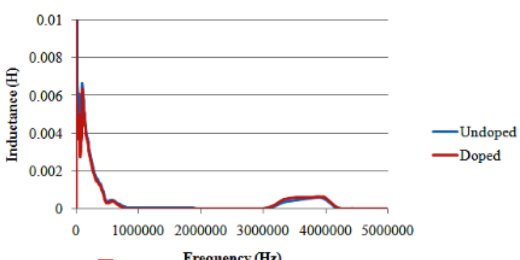

Figure-2. Curve of inductance as a function of frequency.

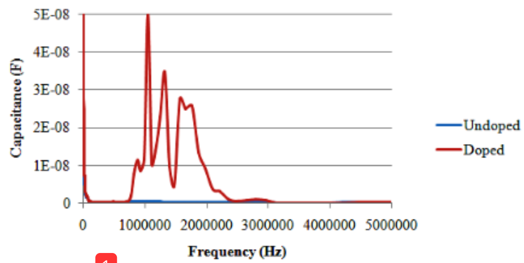

Figure-3. Curve of capacitance as a function of frequency.

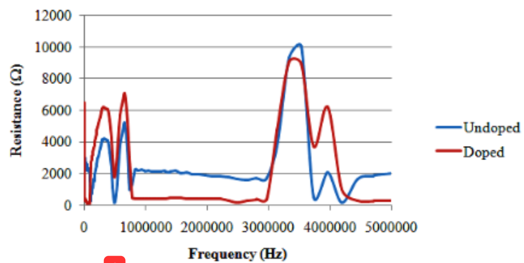

Figure-4. Curve of resistance as a function of frequency.

Formula (1) implies that the dielectric constantas a function of frequency can be presented in form of curve (Figure-5). Figure-5 shows that Ga_2O_3 as doping material can produce fluctuation of dielectric constant value and therefore, it is concluded that ion from Ga_2O_3 experiencing vibrations inside the crystal structure of $LiTaO_3$.

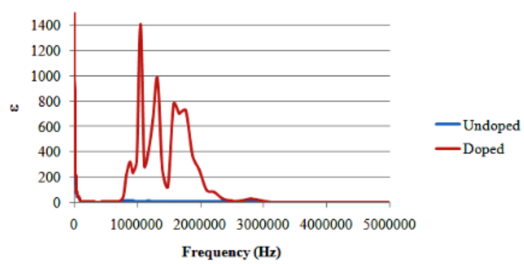

Figure-5. Curve of dielectric constant as a function of frequency.

Impedance (denoted Z) is a complex number with resistance as real part and reactance (inductive and capacitive) as imaginary part. Based on measurement values of inductance, capacitance and resistance as a function of frequency (see Figure-2, Figure-4), the magnitude of impedance (|Z|) for thin films at each frequency can be calculated by using the following formula (2), (3) and (4) [10]:

$$X_L = 2\,\pi\,f\,L \qquad (2)$$

$$X_C = \frac{1}{2\,\pi\,f\,C} \qquad (3)$$

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$$|Z| = \sqrt{R^2 + (X_L - X_C)^2} \quad (4)$$

with:

f = frequency (from 50 Hz to 5 MHz)
L = inductance value (from measurement values)
C = capacitance value (from measurement values)
R = resistance value (from measurement values)
X_L = inductive reactance
X_C = capacitive reactance

Formula (4) implies that the magnitude of impedance as a function of frequency can be presented in form of curve (Figure-8). Figure-8 shows that fluctuation curve of thin films between undoped and 10% Ga_2O_3 doped $LiTaO_3$ describes the ion motion on specific range frequency.

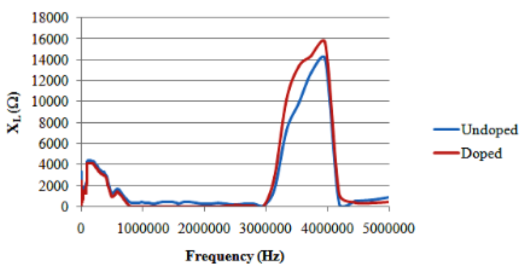

Figure-6. Curve of X_L as a function of frequency.

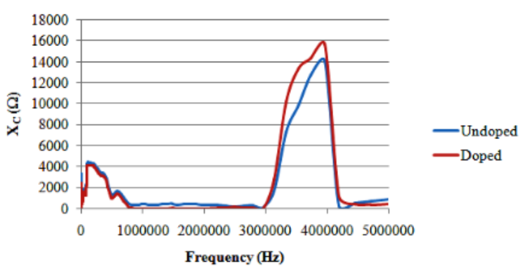

Figure-7. Curve of X_C as a function of frequency.

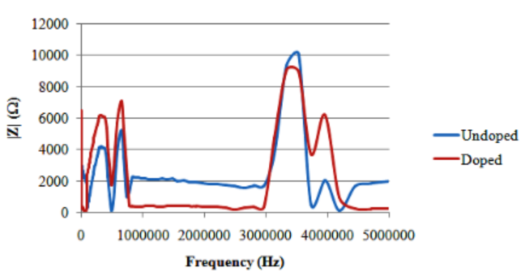

Figure-8. Curve of |Z| as a function of frequency.

CONCLUSIONS

In this study, the curve that represents dielectric constant and impedance values of thin film is used to describe ionic vibration, as well as ionic motion corresponds to a change of frequency on a range of 50 Hz to5 MHz. Based on the results of this study, it can be concluded that the film thickness (made from $LiTaO_3$ without (0%) and with doping (10%) Ga_2O_3) as separator material between two aluminum contacts that embedded on 7059 corning glass substrate was affected not only by dielectric constant but also by magnitude of impedance that contributes to providing information about ionic phenomenon.

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