Phasor diagrams of thin film of LiTaO$_3$ as applied infrared sensors on satellite of LAPAN-IPB

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Abstract

Thin film had been manufactured to determine Phasor diagram Thin Film as an application of infrared sensor on the LAPAN IPB satellite. Phasor diagram could be stated as a quantity of vector, which rotated on its starting point that could be described as a vector which its rotational angle was equal to its phase angle on the horizontal axis (X axis). The thin film was manufactured by CSD (chemical solution deposition) Method and Spin coating technique with annealing temperature 600°C and a rotational speed of 3000 rpm for 30 seconds. The test by LCR meter in 600 KHZ – 1 MHZ resulted in value of inductance (L), capacitance (C), resistance (R), and impedance (Z). From the result of LCR metre calculation, Phasor diagram is acquired. The electrical characteristics of thin film LiTaO$_3$ at 600, 700 and 900 kHz frequency have capacitative Phasor diagram, while at 800, 1000 kHz frequency it has inductive Phasor diagram. The result of this study is the information of electrical characteristics of thin film LiTaO$_3$ to support sensor data of satellite sensors.

Keywords: thin film of LiTaO$_3$; LCR meter; Phasor diagrams; infrared sensor; satellite.

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1. Introduction

Technological development has occurred in many countries, especially in developed countries which have conducted a long research on the latest technology. One of the technologies which explored by the researchers is the Material Science. Science and technology of thin layers (Thin Film) plays an important role in the high-tech industry that will be the main focus of companies’ competitiveness in the future [1]. Thin layer technology (Thin Film) plays an important role in high-tech industries for manufacturing products, therefore a high quality and efficient products will be produced. While the main study of thin layers already exist in microelectronics, such as the number of most applications that thrive on communications, optical electronics, and other various coatings.

In the period of last 30 years studies of thin films mainly crystal LiTaO$_3$ and its characteristics as a ferroelectric material and pyroelectric has became the main focus. LiTaO$_3$ ferroelectric crystals have an excellent ferroelectric and pyroelectric characteristics. A good LiTaO$_3$ ferroelectric characteristics is used on electronical devices and optical devices. Also, LiTaO$_3$ material is widely used on a high temperature transducers, lasers, electronic filters, and non-linear optical crystals [2]. As a material with its own advantages and good characteristics in ferroelectric and pyroelectric, Ferroelectric material is the material which has a special characteristics as spontaneously polarized dialectric and the ability to change the direction of its internal electricity. The polarization which is caused by the terrain work resulting on the asymmetry of ferroelectric crystal structure and it occurs spontaneously [3, 4]. To measure the properties of a material a dialectric tool LCR Meter is used [5].

2. Methods

In this research a method LiTaO$_3$ Chemical Solution Deposition (CSD) was used to create a thin layer. The reason for using this method was because this method had several advantages and benefits such as stoichiometry control, homogeneity, it could be made at relatively low temperatures and relatively low cost [6]. CSD method is a method of making thin film layer by means of chemical solutions deposed over the prepared substrate using a spin coating at a certain rotation speed. LiTaO$_3$ film layer formed by doping with La$_2$O$_3$ and then synthesized by the method of Chemical Solution Deposition (CSD). One of the ingredients to make a photodiode is silicon, since silicon has a distinctive characteristics, it has become the material that mostly made for the photodiode. Silicon can be used at a wavelength of 400-1000 nm, with a low interference (noise), and a small response time [7]. Several methods are widely used in the manufacture of thin film such as by solid state reaction [8], molten salt [9], the polymeric precursor method [10] Sol-gel or Chemical Solution Deposition (CSD) [11], metal organic chemical vapor deposition [12], combustion methods [13], the Czochralski method [14] and liquid phase epitaxy [15] pyrosol process [16].

3. Experimental

First, the used substrate, p-type (100), was cut into 1x1 cm pieces, then the cutted substrate pieces were cleaned by deionized water for 10 minutes, then the surface of the silicon was drained. To speed up the drying process, a hot plate with temperature 100°C was used for 1 hour. A thin layer of the film would be formed by LiTaO$_3$ powder (tantalum oxide of lithium acetic acid) and 2.5 ml dissolved 2-metoxiethanol [11, 17]. Second, the growth of LiTaO$_3$ films on the surface of the reactor using cutting CSD was spinned at speed of 3000 RPM [11, 17]. The surface of the Spin Cutting disc was cleaned, then the silicon substrate which had been cut was placed on the surface of the Spin cutting disc. The substrate was attached on its top with 1/3 section was closed and 2/3 section opened then spin cutting was activated for 30 seconds at 3000 RPM along with 3 drops dripping LiTaO$_3$ solution on the substrate for 30 seconds. Finally, substrate was put on the hot plate to reduce the evaporation of existing solution on the substrate [11,17].

The result of the LiTaO$_3$ thin films growth, which were heated over a hot plate, were continued to annealing process which aimed to accelerate the rate of diffusion solution substrate LiTaO$_3$ on silicon. Annealing rate process was conducted constantly at 1.7°C/min by using a furnace-type brands vulcane TM 3-130 [11]. The heating process was started from temperature 27°C and a constantly rise at 1.7°C/minute until the annealing temperature of 600°C for 8 hours. The thickness of thin film which was increased, was also calculated before and after the annealing process with volumetric method [11]. After the process of the growth and annealing was completed, the next process
was making a contact with an area of 1 mm² with aluminium content of 99.99%. Then attached a small and delicate wire with silver adhesive on contact. After successfully grew the thin films by means LiTaO₃ then it was characterized by HIOKI 3532-50 LCR Meter LCR HiTESTER brands.

4. Results and Discussion

From the results of measurement using type LCR Meter, LCR Meter HIOKI 3532-50 LCR HiTESTER brands. The quantity that we could get related to the amount of such as value of impedance, capacitance, inductance and resistance as well as the data processing in Induction and reactance capacitance reactance. The equation used to obtain the value of the equation for the impedance (Z)

\[
Z = \sqrt{R^2 + (X_L - X_C)^2}
\]  

(1)

By getting the data value of the frequency (f), the inductance (L), capacitance (C) of the LCR meter we could determine the induction reactance (\(X_L\)) and capacitance reactance (\(X_C\))

Resistor element

For an ideal resistor, we could assume that the frequency has no effect on the impedance level.

Inductor element

For ideal inductor, the induction reactance (\(X_L\)) equation can be written as follows:

\[
X_L = \omega L
\]  

(2)

Capacitor element

For ideal capacitor, capacitance reactance (\(X_C\)) equation can be written as follows

\[
X_C = \frac{1}{2\pi fC}
\]  

(3)

From the equation above shows that the value of the induction reactance and reactance capacitance depends on the value of \(\omega = 2\pi f\) and value of each of Induction (L) and capacitance (C). In Inductor reactance (\(X_L\)) is proportional to the frequency and the inductance value, while the capacitance reactance is inversely proportional to frequency and capacitance values.

The resistance value of a semiconductor material could be changed by supplying dopants (impurities) into the semiconductor material. The addition of dopants in a semiconductor material called doping [6]. The effect of adding doping concentration could improve the quality of the thin layers desirable. Extra Doping can also increase the electrical conductivity and transparency as desired [6]. The resistance value of a semiconductor material can be changed by supplying dopants (impurities) into the semiconductor material. Because effect of doping concentration is increase electrical conductivity, the resistance decrease. The dielectric constant (\(\varepsilon'\)) increases with the increase in temperature owing to the enhancement of polarization in these materials and the increase in degree of crystallinity. The temperature dependence of conductance observed indicated the variable range hopping of charge carriers are responsible for conduction [18].

Changes in the value of capacitance at a frequency depending on the temperature. The decline in the value of capacitance with an increase in frequency at all temperatures. It shows that the average decline for a frequency region lower than the high frequency. [5] The capacitance and loss factor analyse the dielectric properties. The decrease of capacitance (C) with increase of frequency is attributed to the trapping of charge carriers due to gap states density in the form amorphous films [5]. Decrease of capacitance with increasing frequency is also attributed to the increasing inability of the dipoles to orient themselves in a rapidly varying electric field and slow release of charge carriers from relatively deep traps. Increase of capacitance above room temperature is partly due to the expansion of the lattice and partly due to the excitation of charge carriers present at the imperfection sites [18].
Table 1. Phasor diagrams thin film LiTaO$_3$ at 600 °C

<table>
<thead>
<tr>
<th>Frequency (KHz)</th>
<th>$X_I$ (Ω)</th>
<th>$X_c$ (Ω)</th>
<th>$R$ (Ω)</th>
<th>Phasor diagrams</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>218</td>
<td>323</td>
<td>30.1</td>
<td>Capacitative</td>
<td>$X_c$ (Ω) $&gt;$ $X_I$ (Ω)</td>
</tr>
<tr>
<td>700</td>
<td>5</td>
<td>6</td>
<td>30.6</td>
<td>Capacitative</td>
<td>$X_c$ (Ω) $&gt;$ $X_I$ (Ω)</td>
</tr>
<tr>
<td>800</td>
<td>997</td>
<td>963</td>
<td>30.3</td>
<td>Inductive</td>
<td>$X_I$ (Ω) $&gt;$ $X_c$ (Ω)</td>
</tr>
<tr>
<td>900</td>
<td>510</td>
<td>620</td>
<td>30.3</td>
<td>Capacitative</td>
<td>$X_c$ (Ω) $&gt;$ $X_I$ (Ω)</td>
</tr>
<tr>
<td>1000</td>
<td>178</td>
<td>174</td>
<td>29.6</td>
<td>Inductive</td>
<td>$X_I$ (Ω) $&gt;$ $X_c$ (Ω)</td>
</tr>
</tbody>
</table>

From the table above we know the characteristics of thin film LiTaO$_3$ to frequency variation. At 600, 700, and 900 kHz frequency thin film LiTaO$_3$ have capacitative Phasor diagram, while at 800, 1000 kHz frequency thin film LiTaO$_3$ have inductive Phasor diagram. The results of this study we get information electrical characteristics of thin film LiTaO$_3$ to support sensor data of satellite sensors.

5. Conclusions

In this research we create thin film of LiTaO$_3$ by method Chemical Solution Deposition (CSD). We measure thin film of LiTaO$_3$ using type LCR Meter HIOKI 3532-50 LCR HiTESTER brands. We know the characteristics of thin film LiTaO$_3$ to frequency variation. At 600, 700 and 900 kHz frequency thin film LiTaO$_3$ have capacitative Phasor diagram, while at 800, 1000 kHz frequency thin film LiTaO$_3$ have inductive Phasor diagram. The results of this study we get information electrical characteristics of thin film LiTaO$_3$ to support sensor data of satellite sensors.

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