The effect of indium

by Johansah Liman

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The effect of indium oxide (In_2O_3) dopant on the electrical properties of $LiTaO_3$ thin film-based sensor

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ABSTRACT

The effect of the indium oxide (In_2O_3) dopant on the electrical properties of the lithium tantalate ($LiTaO_3$) thin film-based sensor was investigated in this study. $LiTaO_3$ thin film was made on p-type Si (100) substrates by applying the chemical solution deposition (CSD) method. The $LiTaO_3$ thin film was annealed at the temperature of 850 °C for 15 h. Surface morphology and elemental characterization analysis were obtained by using SEM-EDX (scanning electron microscopy–energy-dispersive X-ray spectroscopy). Then, the dielectric constant value and the photoresistive characteristic of $LiTaO_3$ thin film were measured to determine the effect of the In_2O_3 dopant on the electrical properties of the thin film. From the SEM-EDX measurement, it is observed that the surface of the thin film is still non-homogeneous; therefore, the electron flow will be obstructed. Based on the elemental atomic composition analysis, it appears that the Indium atoms have appeared in the LiTaO3 thin films doped by In_2O_3 2%, 4%, and 6%. From the results of thin film dielectric constant calculation, it can be seen that the dielectric constant value between undoped and In_2O_3-doped $LiTaO_3$ thin film does not change, which is 2.44. The photoresistive value shows that the Indium dopant decreases the resistivity but increases the conductivity of the thin film. Based on the photoresistive characteristic measurement results, it can be concluded that the LiTaO3 thin film can be used as a light sensor, and In_2O_3dopant can increase the conductivity of the $LiTaO_3$ thin film.

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$LiTaO_3$ thin film; In_2O_3 dopant; SEM-EDX spectroscopy; dielectric constant; photoresistive sensor

1. Introduction

The rapid development of innovative thin film technology is one principle factor in current smart material technology due to its material and cost efficiencies [1–3]. One of the primary goals of modern science and engineering that will have a big impact on technological applications is thin films with electronic semiconductor sensor due to their dielectric constant, dielectric loss, pyroelectric coefficient, and dielectric tunability properties [2,4–6]. Ferroelectric thin films are potentially important materials for electronic and optical electricity. One material that could be used in making a thin film is

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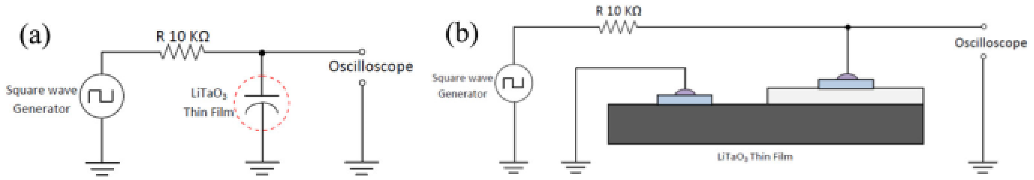

Figure 1. Step response measurement: (a) schematic, (b) circuit connection.

lithium tantalate ($LiTaO_3$) [5–12]. Materials like barium strontium titanate (BST) have high responsivity toward heat and light or $NaNO_2$ [4,13–16]. $LiTaO_3$ is ferroelectric material having an excellent of pyroelectric, piezoelectric, refractive, electro-optical, and non-linear optical properties. $LiTaO_3$ is suitable for applications to non-linear optics, integrated optics, optical coating, lasers, and sensors like light sensors [1,5,9].

In this paper, a thin film of $LiTaO_3$ was made by adding indium oxide (In_2O_3) dopant. The substrate used is p-type silicon material (100), using the chemical solution deposition (CSD) method. A CSD method is a method of making thin films by depositing chemical solutions on the substrate, followed by a spin coating technique with a rotating speed of 4000 rpm [9,10,17–20]. Scanning electron microscopy (SEM) is a microscope that uses the principle of electrons emitted on a sample. SEM could be used in evaluating the surface morphology and thickness of the as-deposited films. Energy-dispersive X-ray spectroscopy (EDX) is an analytical technique used to analyze elements or chemical characterization of $LiTaO_3$ thin films. The atomic composition contained in the sample was determined by EDX [1,3,21–23].

2. Experiments

In this research, $LiTaO_3$ thin film was grown on a p-type silicon substrate (100). The substrate was cut into a square size of 1 cm × 1 cm using a glass cutter. The substrate was cleaned by dipping in acetone using an ultrasonicator device for 15 min, repeated sequentially with methanol, and deionized water [9,22–27]. The $LiTaO_3$ solution was made by reacting [($LiTaO_3$), 99.99%], and 2,5 ml of 2-methoxyethanol [($CH_3OCH_2CH_2OH$)] as the solvent. Then, three types of solutions were produced with doping of 2%, 4%, and 6% In_2O_3 (99.99%). The solution was stirred using Vortex 3000. Furthermore, the solution mixture was put inside the ultrasonicator device for 30 min, which produced a homogenous $LiTaO_3$ solution. The solution was spin-coated on p-type Si(100) substrates at 4000 rpm speed for 30 s, and it was repeated three times (disposition and rotation) with a 1-min break in between by using CSD method [5–7,9,28]. Then, the annealing process was conducted in a furnace model Nabertherm type B410 for 15 h at 850 °C temperature.

Surface morphology and elemental characterization analysis were obtained by using SEM and EDX. Then, the process of mounting aluminum contacts as a medium in the measurement was conducted. Two aluminum contacts were mounted each on a p-type silicon substrate and a thin film layer with a size of 2 mm × 2 mm. Each aluminum contact will be connected to a copper wire using a silver paste. Afterwards, the dielectric constant value and the photoresistive characteristic were measured to determine the effect of the In_2O_3 dopant on the electrical properties of the thin film. The dielectric constant of the thin film can be obtained by finding the step response of the thin film.

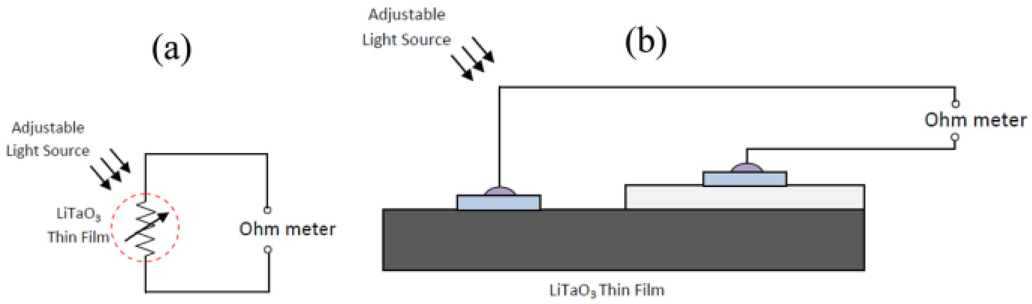

Figure 2. Photoresistive characteristics measurement: (a) schematic, (b) circuit connection.

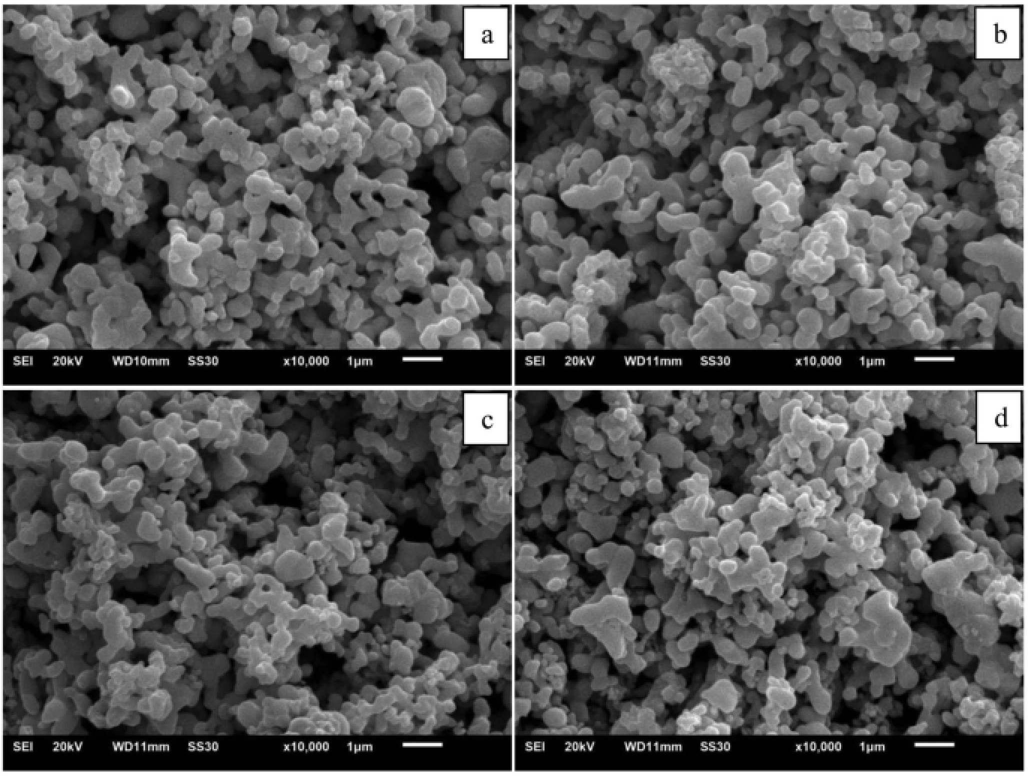

Figure 3. Surface morphology of LiTaO$_3$ at different doped concentrations: (a) undoped, (b) 2% In$_2$O$_3$ doped, (c) 4% In$_2$O$_3$ doped, (d) 6% In$_2$O$_3$ doped.

From the step response, we can get the time constant (τ) value of the thin film to calculate the dielectric constant (k) of the thin film. We can get the step response of the thin film by connecting the LiTaO$_3$ thin film in series with resistor and square wave generator. The step response, then, can be measured using an oscilloscope. The circuit schematic and connection of the thin film for the step response measurement carried out in this study are presented in Figure 1.

In order to measure the photoresistive characteristics of the thin film, an adjustable incandescent lamp as the light source was used. Then, the resistance of the thin film was measured by using digital Ohm meter. The circuit schematic and

Table 1. Undoped and In_2O_3-doped $LiTaO_3$ thin film elemental composition.

$LiTaO_3$ thin film	Element	keV	Mass%	Error%	Atom%	K
Undoped	O K	0.525	7.12	0.41	46.76	7.0286
	Ta M	1.709	77.65	0.33	45.11	82.8410
	Au M	2.121	15.24	0.59	8.13	10.1304
2% Indium doped	O K	0.525	6.93	0.37	45.82	6.8535
	In L	3.285	1.82	0.37	1.68	1.7481
	Ta M	1.709	72.84	0.29	42.60	78.5727
	Au M	2.121	18.41	0.50	9.90	12.8257
4% Indium doped	O K	0.525	7.49	0.42	47.29	7.2259
	In L	3.285	5.53	0.40	4.87	5.4352
	Ta M	1.709	70.48	0.33	39.37	75.6721
	Au M	2.121	16.50	0.55	8.47	11.6668
6% Indium doped	O K	0.525	9.56	0.40	53.97	9.2236
	In L	3.285	5.08	0.39	4.00	4.9785
	Ta M	1.709	70.73	0.31	35.32	75.5726
	Au M	2.121	14.63	0.53	6.71	10.2253

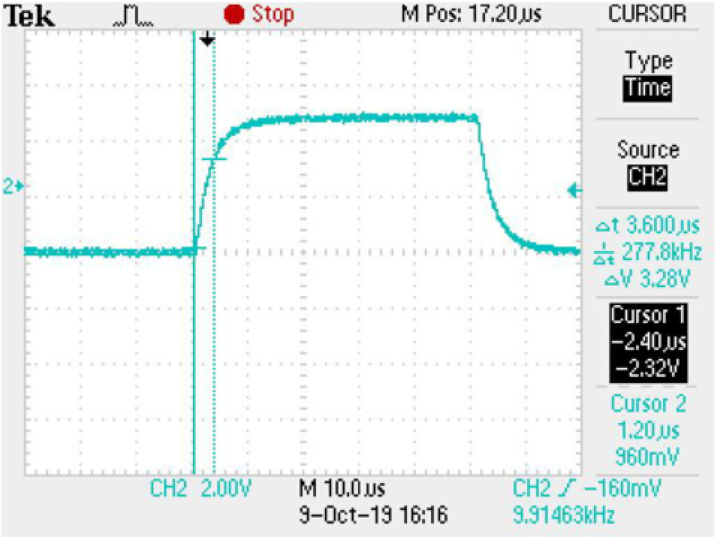

Figure 4. Step response of $LiTaO_3$ thin film.

connection of the thin film for photoresistive characteristics measurement are shown in Figure 2.

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3. Results and discussion

3.1. Surface morphology and elemental characterization analysis

Surface morphology and elemental characterization analysis were obtained by using SEM-EDX. The results of morphology analysis are presented in Figure 3, and elemental characterization measurement is in Table 1. The surface morphology measurement results show that the $LiTaO_3$ thin films with and without In_2O_3 doping have formed on the silicon substrate. However, the surface of the thin film is still non-homogenous, which causes the flow of electrons in the thin film can be inhibited. Meanwhile, from

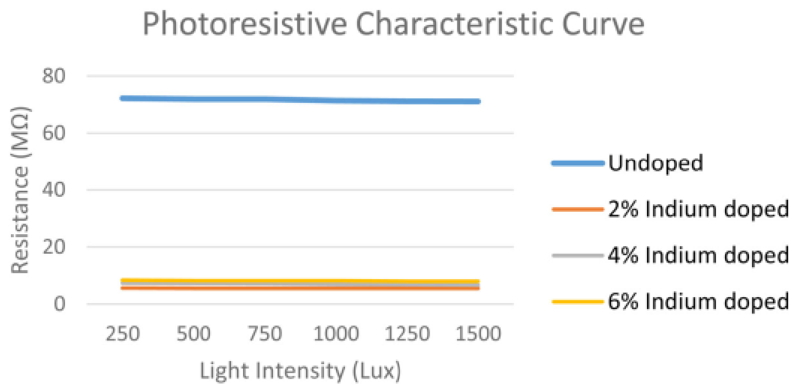

Figure 5. Photoresistive characteristic of undoped and In_2O_3-doped $LiTaO_3$ thin film.

the analysis of the elemental atomic composition, it appears that the Indium atoms have appeared in the $LiTaO_3$ thin film doped with In_2O_3. This result shows that the process of adding In_2O_3 dopants was done successfully.

3.2. Dielectric constant

The step response measurement results show that there is no difference in the value of the time constant (τ) between In_2O_3-doped and undoped $LiTaO_3$ thin film. Measured $LiTaO_3$ thin film time constant is $3.6\mu s$. The measurement result of the $LiTaO_3$ thin film step response can be seen in Figure 4.

From the measured time constant (τ), the thin film dielectric constant (k) can be calculated as follows:

Series RC circuit resistance $R = 10\ K\Omega = 10^4\ \Omega$;
Thin film area $A = 0.5\ cm^2 = 5 \times 10^{-5}\ m^2$;
Thin film thickness $d = 3\ \mu m = 3 \times 10^{-6}\ m$;
Permittivity of vacuum $\varepsilon_0 = 8.854 \times 10^{-12}\ F/m$

$$C = \frac{\tau}{R} = \frac{3.6 \times 10^{-6}\ \ s}{10^4\ \ \Omega} = 3.6 \times 10^{-10} F$$

$$k = \frac{Cd}{\varepsilon_0 A} = \frac{(3.6 \times 10^{-10}\ \ F)(3 \times 10^{-6}\ \ m)}{(8.854 \times 10^{-12}\ \ F/m)(5 \times 10^{-5}\ \ m^2)} = 2.44$$

3.3. Photoresistive characteristics

The result of the measurement of $LiTaO_3$ thin film photoresistive characteristics is shown in Figure 5. The results of the measurement show that the value of the resistance of the thin film decreases when the intensity of light hitting the surface of the thin film increases. Photoresistive characteristics measurement also indicates that $LiTaO_3$ thin film without In_2O_3 dopant has resistance value higher than 70 MΩ, whereas $LiTaO_3$ thin film with In_2O_3 dopant has resistance value below 10 MΩ. From the measurement results, it can be concluded that $LiTaO_3$ thin film can be used as a light sensor, and the addition of the In_2O_3 dopant can reduce the resistivity of the thin film or in other words, can increase the conductivity of the thin film.

4. Conclusion

$LiTaO_3$ thin film grown on the p-type silicon substrate (100) by CSD method with 2%, 4%, and 6% In_2O_3 doping at 850 °C annealing temperature was successfully made. Based on the results of photoresistive characteristic measurement, it can be concluded that $LiTaO_3$ thin film can be used as a light sensor, and In_2O_3 dopant can increase the conductivity of the $LiTaO_3$thin film.

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