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CHARACTERIZATION OF ELECTRICAL PROPERTIES IN PHOTODIODES BASED ON LITHIUM TANTALAT ($LITAO_3$) DOPING WITH NIOBIUM (NB) FOR LIGHT SWITCH APPLICATIONS

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Abstract

The lithium tantalate ($LiTaO_3$) material has ferroelectric properties at room temperature, which makes it suitable for use as a device in everyday life as it can be utilised as a light switch device. The purpose of this study is to determine the $LiTaO_3$ diode material which has optimal I-V characteristics for a light switch. The I-V characteristics needed to allow the material to be utilized as a light switch are decent differences in light and dark graphics. $LiTaO_3$ material is treated with niobium (Nb) and Si (100) p-type substrate using the Chemical Solution Deposition (CSD) or Sol-Gel method with the Spin-Coating technique with a rotation speed of 3000 rpm, and the molarity of a solution of 1.00 M. Four $LiTaO_3$ photodiodes are prepared with variations of 0%, 2.5%, 5%, and 7.5% Nb. Then the photodiode is annealed at a temperature of 1000° C. The annealised photodiode was characterized for its I-V characteristics with a Keithley I-V meter in dark and light conditions. The results of this study indicate that the provision of Nb pendants can affect the I-V characteristic curve of the $LiTaO_3$-based photodiodes. From this study, photodiodes made from $LiTaO_3$containing 5% Nb has better I-V characteristics compared to photodiodes made from $LiTaO_3$without bulk or those containing 2.5% and 7.5% Nb. Giving an alloyed Nb of 5% resulted in the best graph differences between dark and light among the others. Although the resulting current is quite small, it is not a problem considering that the photodiode will be applied to the light switch as the small current can be increased by the current amplifier circuit.

Keywords: Alloying, I-V characteristics, $LiTaO_3$, Niobium, Photodiode.

1. Introduction

The properties of materials such as piezoelectric and pyroelectric materials have the unique ability to generate electricity from voltage and temperature changes. They can be called "smart" materials with these capabilities. In this case, the material is said to be "smart" and must have a "control" or "process" that is very sensitive to changes in environmental conditions, in addition to actuator and sensing functions. Ferroelectric materials can exhibit many of these symptoms, so ferroelectric materials can be said to be "smart" materials [1].

Materials that have ferroelectric properties include $BaTiO_3$ [1], $SrTiO_3$ [2], $BaSrTiO_3$ [3], and $LiTaO_3$ [4]. The lithium tantalate ($LiTaO_3$) material has ferroelectric properties at room temperature [5], which makes it suitable for use as a device in everyday life such as making NVFRAM, DRAM, infrared sensors and can also be utilised as a light switch device [1].

Barium Strontium Titanate (BST) ferroelectric-based materials have been widely used as light switches [6-10]. Lithium tantalate ($LiTaO_3$) has a ferroelectric character at room temperature [5]. An essential characteristic of ferroelectrics is how they can spontaneously generate electrical polarity [11, 12]. Lithium Tantalate has a similar configuration of anions and cations to perovskite crystals, and spontaneous electrical polarity is easier in the structure of the perovskite crystal.

To produce a good thin film of lithium tantalate, it can be done by adding a niobium probe [4]. This niobium atom will replace the tantalum atom.

It is known that niobium has a higher electronegativity level than tantalum atoms so it can provide better polarity to ferroelectric materials [11]. It is expected that the exposure of lithium tantalate to niobium may provide more optimal electrical properties of ferroelectric thin film as a photodiode device.

There are several advantages of $LiTaO_3$ thin films. They can be produced by vacuum-free chemical solution (CSD) techniques, the cost of production is low, the characterization quality and electrical output also the optical properties and crystal properties are equivalent to $LiTaO_3$ thin films created using vacuum techniques. However, $LiTaO_3$ has a smaller spontaneous polarization value than BST [13, 14].

The ferroelectric $LiTaO_3$ thin film can be applied as a reliable light switch sensor compared to the ferroelectric $LiNbO_3$ thin film [8, 13, 14]. The quality of the characterization and output of the electrical properties, optical properties, and crystalline properties of the $LiTaO_3$ material is better than the quality of the characterization and output of the electrical properties, optical properties, and crystal properties of the previous $LiTaO_3$ material. The $LiTaO_3$ thin film can be applied as a reliable light switch sensor [15-17].

2. Methodology

2.1. Materials

The materials used in this study are $LiCH_3COO$ (lithium acetate) and Ta_2O_5 (tantalum pentoxide), Nb_2O_5 (Niobium pentoxide), solvent 2- methoxy ethanol [$H_3COCH_2CH_2OH$, 99%], Pt (200)/SiO_2/Si (100) substrate and p-type Si (100) substrate.

2.2. $LiTaO_3$ Film Making

2.2.1. Creating $LiTaO_3$Solvent

$LiTaO_3$ solvent is made by utilizing lithium acetate [$LiCH_3COO$, 99%] + tantalum pentoxide) [Ta_2O_5, 99,999%] as *precursor* and 2-methoxy ethanol [$H_3COOCH_2CH_2OH$, 99,9%] as solvents. Four types of solutions will be made, namely without Nb doping, 2.5%, 5% and 7.5% with Nb doping. The composition of the existing materials can be seen in the following Table 1:

Table 1. The composition of the existing materials.

No	Main material	Doping
1	0.1650 grams of $LiCH_3COO$ and 0.5524 grams of Ta_2O_5 dissolved in 2.5 ml of 2-methoxy methanol	Without Nb_2O_5
2	0.1650 grams of $LiCH_3COO$ and 0.5524 grams of Ta_2O_5 dissolved in 2.5 ml of 2-methoxy methanol	0.01475 grams of Nb_2O_5 (Niobium pentoxide)
3	0.1650 grams of $LiCH_3COO$ and 0.5524 grams of Ta_2O_5 dissolved in 2.5 ml of 2-methoxy methanol	0.0295 grams of Nb_2O_5
4	0.1650 grams of $LiCH_3COO$ and 0.5524 grams of Ta_2O_5 dissolved in 2.5 ml of 2-methoxy methanol	0.04425 grams of Nb_2O_5

All materials are mixed, the solvent is shaken for an hour (as shown in Fig. 1). After that, it is heated to make all the materials well-mixed. Finally, the solvent is filtered to produce a more homogeneous solvent.

Fig. 1. The process of shaking the solution using a shaking machine.

2.2.2. Preparing the substrates

This study used Pt (200)/SiO2/Si (100) and p-type Si (100) substrates. In film production, the cleanliness of the substrate surface is an absolute requirement to produce it well and efficiently.

Figure 2 shows Pt (200)/SiO2/Si (100) and p-type Si (100) substrates washed by immersing them in methyl alcohol and then vibrating with ultra-sonic for about

5 minutes (until clean). After this process, it is dried by using nitrogen gas for 1 minute [18].

Fig. 2. Pt (200) / SiO2 / Si (100) and p-type Si (100) substrates.

2.2.3. Growing the Film

Figure 3 shows a substrate placed on a spin coating reactor which has been insulated in the middle position, then dripped with one drop of the precursor solvent and rotated by a spin coating reactor at a rotating speed of 3000 rpm for 30 seconds. This process is performed 5 times to obtain 5 layers of the substrate. After that, the substrate is removed using tweezers and dried by placing it on the surface of the iron which has been heated for 1 hour at an approximate temperature of 120°C.

Fig. 3. Thin-film growth on the substrate.

2.2.4. Annealing Process

The annealing process is performed by applying the *furnace* Naberthem model Type 27. The substrates used are Pt (200)/SiO2/Si (100) and Si (100) type-p substrate. The annealing process is carried out gradually. The temperature of the furnace is regulated by increasing the temperature of 2,5°C per minute to the specified annealing temperature. Starting from room temperature until it reaches

550^0C and held constantly for 12.5 hours. The annealing process is presented in Fig. 4.

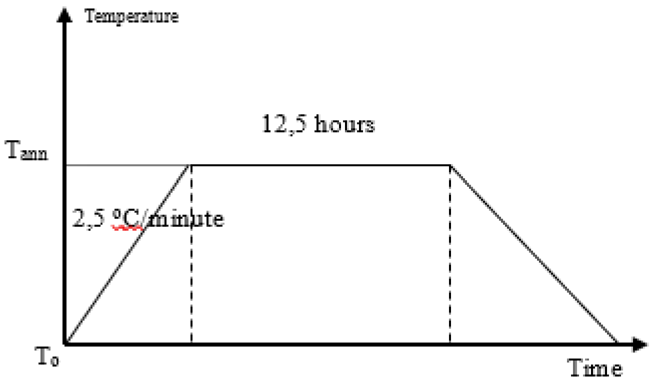

Fig. 4. Annealing process.

2.3. Characterization

The characterization is done using SEM and I-V characterization. The photodiode was characterized for its I-V characteristics with a Keithley I-V meter in dark and light conditions. For I-V characterization, the treatment of thin films is to attach cable fibres around the sides of the substrate as shown in the following Fig. 5.

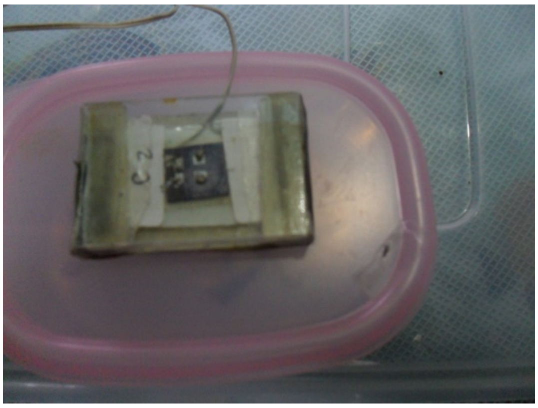

Fig. 5. The thin film has been attached with cable fibres.

The conditions carried out in the I-V characterization are dark and bright conditions from the existing light.

3. Result and Discussion

In this study, four samples of the $LiTaO_3$-based photodiode with Nb pending variations in the manufacturing process are taken to be characterized. Characterization performs using the characterization of I-V and SEM (Scanning Electron Microscope) characteristics of the photodiode. Figures 6-9 shows the characterization process is intended to determine the electrical properties of the $LiTaO_3$-based photodiode with the resulting Nb alloy.

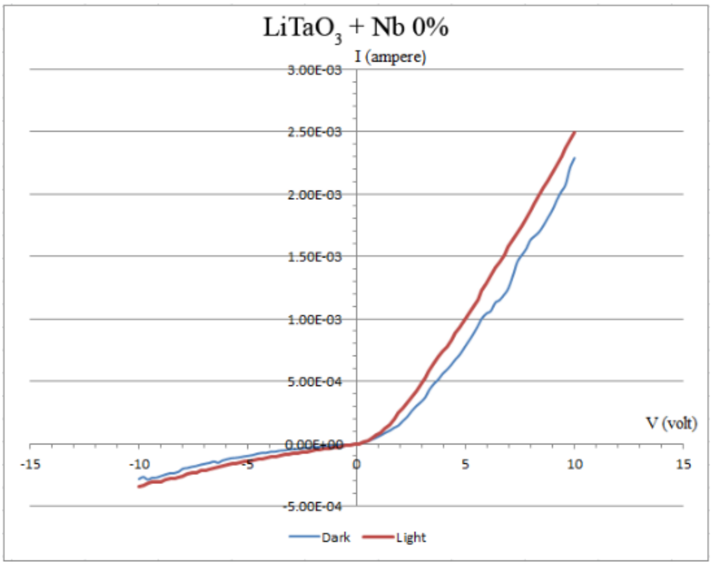

Fig. 6. I-V characteristic curve of a $LiTaO_3$ based photodiode without Nb.

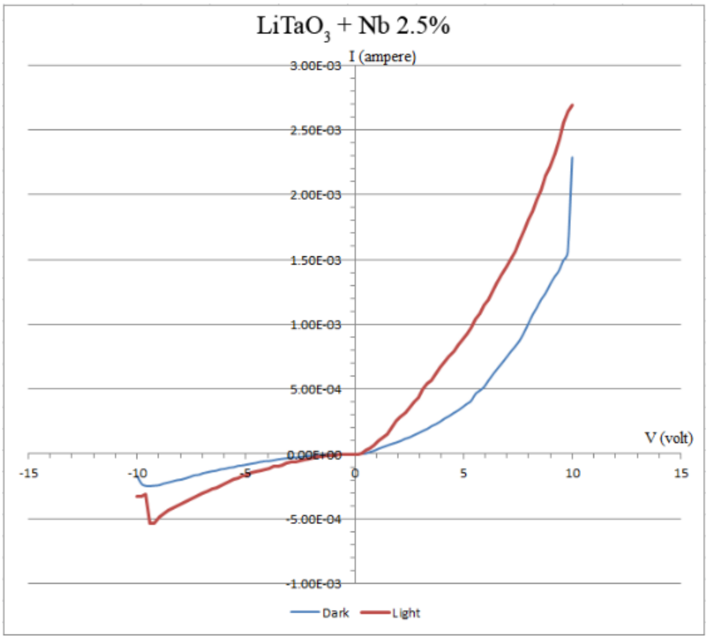

Fig. 7. I-V characteristic curve of a $LiTaO_3$-based photodiode with 2.5% Nb alloy.

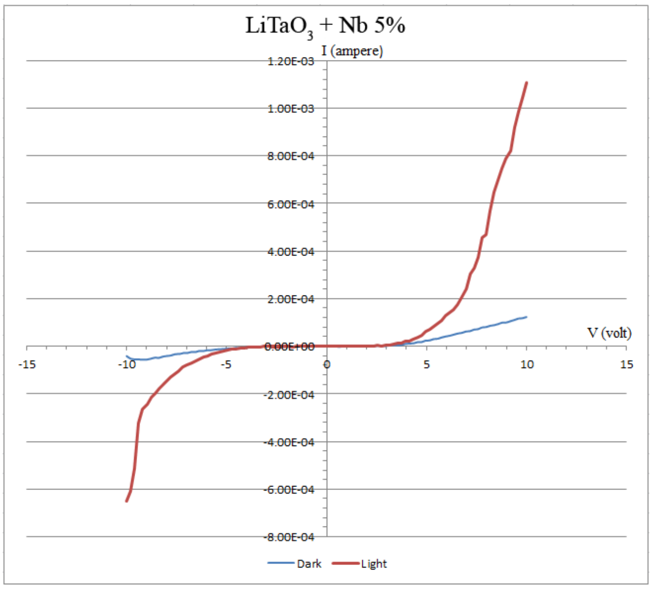

Fig. 8 I-V characteristic curve of a $LiTaO_3$-based photodiode with 5% Nb alloy.

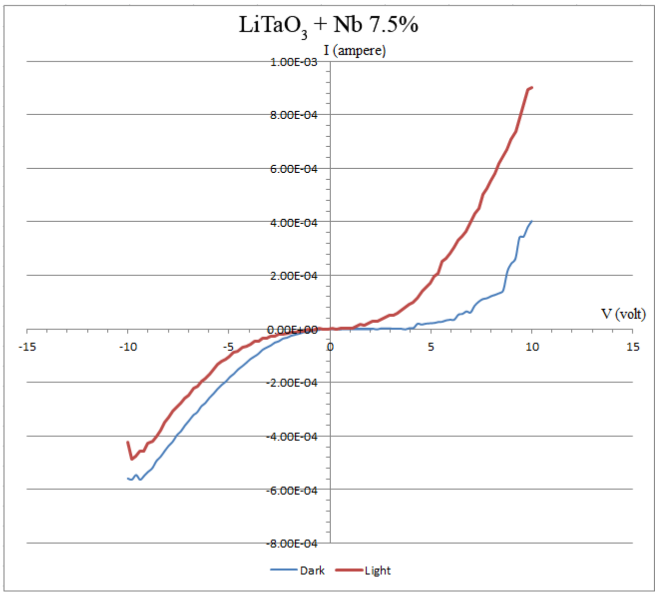

Fig. 9. I-V characteristic curve of a $LiTaO_3$-based photodiode with 7.5% Nb alloy.

From the results of the photodiode characterization, a current-voltage relationship curve is obtained that is similar to the characteristics of the diode curve for the entire sample made. The sample made is a connection between two different semiconductors, namely silicon and $LiTaO_3$ combined with Nb. The silicon used is a p-type semiconductor, while the $LiTaO_3$ thin layer combined with Nb is an n-type semiconductor. The p-type and n-type semiconductor junctions are known as p-n junctions [11]. With the p-n junction, the characteristics of the photodiode that are made are the same as the characteristics of the diode which is a combination of two electrodes, namely anode and cathode [12].

From the I-V characteristics formed, it can be seen that the application of the same voltage to the four photodiodes made shows different current values. The current value indicated by the I-V characteristics for the photodiode by giving 2.5% Nb is the greatest. However, the difference between light and dark is very subtle, so it is not very good to use as a light switch photodiode (Figs. 6 and 7). This is in line with the opinion [19] that the behaviour of the light switch is the result of a comparison between the energetic factor that supports the dark state and the entropic factor that supports the light state.

For samples with Nb above 5% (Fig. 9) the current is low. This is possible because of the increased saturation of the valence electrons in the sample so the electrons become difficult to move. From Fig. 8, it can be seen that giving a blend of 5% produces the best difference in graphics between dark and light among the others [15]. $LiTaO_3$ doped with Nb_2O_5 and increases optical bandgap values in the range of less than 3.5 eV [16]. Although the resulting current is quite small, this is not a problem given that the photodiode will be applied to the light switch because the small current can be increased by the current circuit amplifier.

Figures 10 to 13 show the SEM imaging results. From the data, it can be seen that the grain size of the samples without Nb alloys and those given an Nb alloy of 2.5% (Figs. 10 and 11) has a more even distribution than the others, so the mobility of electrons in the film can flow better with high conductivity. This is what causes the resulting current to be very large compared to other samples.

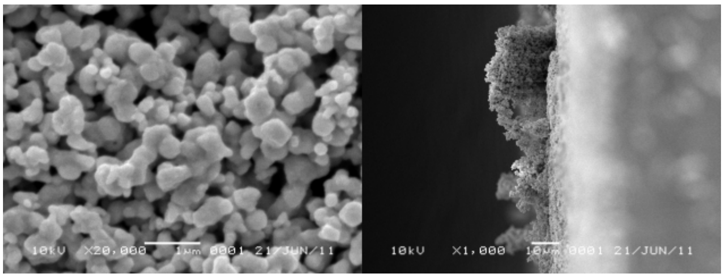

Fig. 10. SEM results for $LiTaO_3$ without Nb alloy.

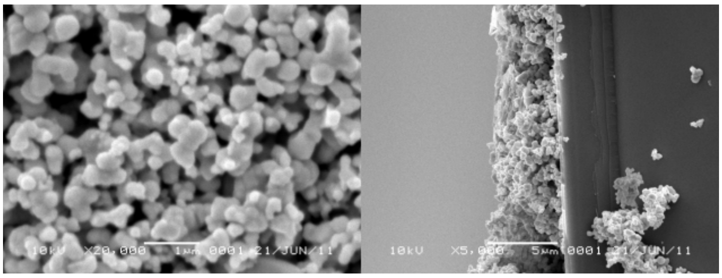

Fig. 11. SEM results for $LiTaO_3$ with 2,5% Nb alloy.

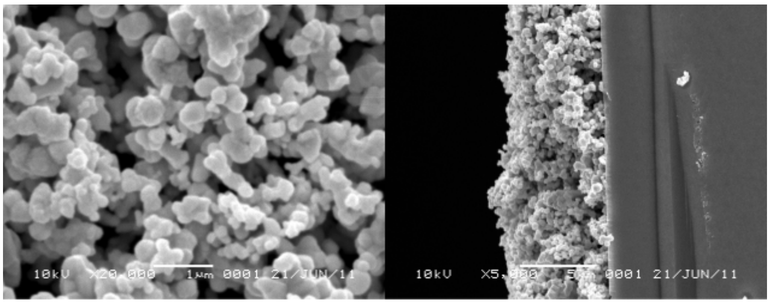

Fig. 12. SEM results for $LiTaO_3$ with 5% Nb alloy.

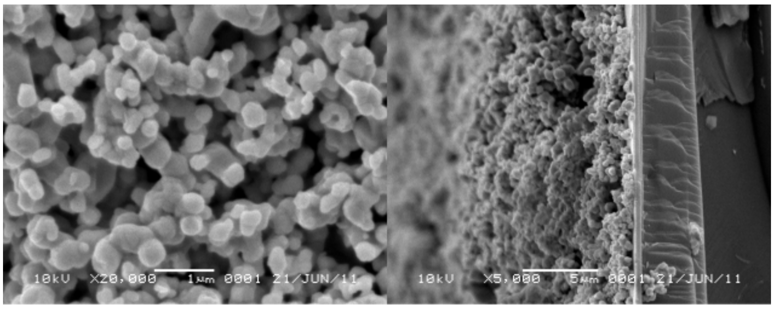

Fig. 13. SEM results for $LiTaO_3$ with 7,5% Nb alloy.

On the other hand, the uneven grain distribution in samples with Nb alloys above 5% (Fig. 13) has a positive impact in terms of differences in currents generated during dark and light conditions. This can be due to the presence of light entering through the gap, as a result, the p-type silicon substrate can absorb lighter so the drift current formed from photons on the p-type silicon substrate can be more and cause a significant difference compared to when the conditions dark.

Figure 12, the grain distribution is evenly distributed with a 5% Nb receptacle which has the impact of a good difference in lightness. This causes a smaller current which makes it optimal considering the photodiode that can be applied as a light switch [20].

4. Conclusions

The conclusion obtained from the research that has been done is that the provision of Niobium alloys can affect the I-V characteristic curve of the resulting $LiTaO_3$ photodiode, namely, the $LiTaO_3$ photodiode with 5% Nb absorption can be made as a photodiode for light switch applications. This can be indicated by the difference in the resulting current in dark and light conditions.

References

1. Kim, K.; and Song, Y.J. (2003). Integration technology for ferroelectric memory devices. *Microelectronics Reliability,* 43(3), 385-398.
2. Butler, K.T.; Davies, D.W.; Cartwright, H.; Isayev, O.; and Walsh, A. (2018). Machine learning for molecular and materials science. *Nature*, 559(7715), 547-555.

3. Velo, M.M.; Nascimento, T.R.; Scotti, C.K.; Bombonatti, J.F.; Furuse, A.Y.; Silva, V.D.; and Mondelli, R.F. (2019). Improved mechanical performance of self-adhesive resin cement filled with hybrid nanofibers-embedded with niobium pentoxide. *Dental Materials*, 35(11), 272-285.
4. Irzaman; Prawira, D.S.; Irmansyah; Yuliarto, B.; and Siregar, U.J. (2019). Characterization of lithium tantalate ($LiTaO_3$) film on the concentration variations of ruthenium oxide (RuO2) dope. *Integrated Ferroelectrics*, 201(1), 32-42.
5. Poghosyan, A.R. (2003). Optical control of domain structures in lithium tantalate crystals. *Journal of Optoelectronics and Advanced Materials*, V(3), 735-740.
6. Kurniawan, A.; Irzaman, B.Y.; Fahmi, M.Z.; and Ferdiansjah. (2020). Application of barium strontium titanate (BST) as a light sensor on led lights. *Ferroelectrics*, 554(1), 160-171.
7. Irzaman; Nuraisah, A.; Aminullah; Hamam, K.A.; and Alatas, H. (2018). Optical properties and crystal structure of lithium doped Ba0. 55Sr0. 45TiO_3 (BLST) thin films. *Ferroelectrics Letters Section*, 45(1-3), 14-21.
8. Irzaman; Siskandar, R.; Nabilah, N.; Aminullah; Yuliarto, B.; Hamam, K.A.; and Alatas, H. (2018). Application of lithium tantalate ($LiTaO_3$) films as light sensor to monitor the light status in the Arduino Uno based energy-saving automatic light prototype and passive infrared sensor. *Ferroelectrics*, 524(1), 44-55.
9. Hamdani, A.; and Komaro, M. (2019). A synthesis of ba x sr 1-x tio 3 film and characterization of ferroelectric properties and its extension as random access memory. *Materials Physics & Mechanics*, 42(1), 131-140.
10. Djohan, N.; Harsono, B.; Liman, J.; Hardhienata, H.; and Husein, I. (2020). The effect of indium oxide (In2O3) dopant on the electrical properties of $LiTaO_3$ thin film-based sensor. *Ferroelectrics*, 568(1), 55-61.
11. Zhang, N.; Zhao, C.; and Wu, J. (2019). Potassium sodium niobate ceramics with broad phase transition range: Temperature-insensitive strain. *Ceramics International*, 45(18), 24827-24834.
12. Thakre, A.; Kumar, A.; Song, H.C.; Jeong, D.Y.; and Ryu, J. (2019). Pyroelectric energy conversion and its applications—flexible energy harvesters and sensors. *Sensors*, 19(9), 2170.
13. Nandiyanto, A.B.D. (2019) Nano metal-organic framework particles (i.e., MIL-100 (Fe), HKUST-1 (Cu), Cu-TPA, and MOF-5 (Zn)) using a solvothermal process. *Indonesian Journal of Science and Technology*, 4(2), 220-228.
14. Irzaman; Prawira, D.S.; Irmansyah; Yuliarto, B.; and Siregar, U.J. (2019). Characterization of lithium tantalate ($LiTaO_3$) film on the concentration variations of ruthenium oxide (RuO2) dope. *Integrated Ferroelectrics*, 201(1), 32-42.
15. Jeon, J.W.; Jeon, D.W.; Sahoo, T.; Kim, M.; Baek, J.H.; Hoffman, J.L.; and Lee, I.H. (2011). Effect of annealing temperature on optical band-gap of amorphous indium zinc oxide film. *Journal of Alloys and Compounds*, 509(41), 10062-10065.

16. Ismangil, A.; and Jenie, R.P. (2015). Development of lithium tantallite ($LiTaO_3$) for automatic switch on LAPAN-IPB Satellite infra-red sensor. *Procedia Environmental Sciences*, 24(2015), 329-334.
17. Irzaman; Pebriyanto, Y.; Apipah, E.R.; Noor, I.; and Alkadri, A. (2015). Characterization of optical and structural of lanthanum doped $LiTaO_3$ thin films. *Integrated Ferroelectrics an International Journal*, 167(1), 137-145.
18. Yang, C.; Han, Y.; Qian, J.; and Cheng, Z. (2019). Flexible, temperature-Stable, and fatigue-endurable PbZr0. 52Ti0. 48O3 ferroelectric film for nonvolatile memory. *Advanced Electronic Materials*, 5(10), 1900443.
19. Brennaman, M.K.; Alstrum-Acevedo, J.H.; Fleming, C.N.; Jang, P.; Meyer, T.J.; and Papanikolas, J.M. (2002). Turning the [Ru (bpy) 2dppz] 2+ light-switch on and off with temperature. *Journal of the American Chemical Society*, 124(50), 15094-15098.
20. Baeg, K.J.; Binda, M.; Natali, D.; Caironi, M.; and Noh, Y.Y. (2013). Organic light detectors: Photodiodes and phototransistors. *Advanced Materials*, 25(31), 4267-4295.