The Effect of Indium Oxide

by Nani Djohan

The Effect of Indium Oxide (In_2O_3) Dopant on The Electrical Properties of $LiTaO_3$ Thin Film Based Sensor

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The Effect of Indium Oxide (In_2O_3) Dopant on The Electrical Properties of $LiTaO_3$ Thin Film Based Sensor

Abstract: The effect of the Indium Oxide (In_2O_3) dopant on the electrical properties of $LiTaO_3$ thin film based sensor was investigated in this study. $LiTaO_3$ thin film was made on p-type Si (100) substrates by Chemical Solution Deposition (CSD) method. The $LiTaO_3$ thin film was annealed at the temperature of 850°C for 15 hours. Surface morphology and elemental characterization analysis was obtained by using SEM-EDX. Then, the dielectric constant value and the photoresistive characteristic of $LiTaO_3$ thin film were measured to determine the effect of the Indium Oxide dopant on the electrical properties of the thin film. From the results of SEM-EDX measurement, the surface of the thin film is still non-homogeneous, so that the electron flow will be obstructed and from the elemental atomic composition analysis, it appears that the Indium atoms have appeared in the LiTaO3 thin films that was doped by Indium Oxide 2%, 4% and 6%. From the results of thin film dielectric constant calculation, it can be seen that the dielectric constant value does not change between In_2O_3 doped and undoped $LiTaO_3$ thin film, which is 2.44. While from the photoresistive value, it is seen that the Indium dopant decreases the resistivity and increases the conductivity of the thin film. Based on the results of the photoresistive characteristic measurement, it can be concluded that the LiTaO3 thin film can be used as a light sensor and In_2O_3 dopant can increase the conductivity of the $LiTaO_3$ thin film.

Keywords: $LiTaO_3$ thin film; In_2O_3 dopant; SEM-EDX spectroscopy; dielectric constant; Photoresistive sensor

1. Introduction

Rapid development of innovative thin film technology is one of the principle factor of the current smart material technology due to its material and cost efficiencies [1-3]. One of the major goals of modern science and engineering that will have a big impact on technological applications is thin films include electronic semiconductor sensor due to their dielectric constant, dielectric loss, pyroelectric coefficient, and dielectric tunability properties [2,4,5,6]. Ferroelectric thin films are potentially important materials for electronic and optical electricity. One of the material could be used in making a thin film is Lithium Tantalate ($LiTaO_3$) [5-12]. As compared to materials like Barium Stronsium Titanate (BST) has high responsivity towards 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, sensor like light sensor [1,5,9].

In this paper, we have made a thin film of Lithium Tantalate ($LiTaO_3$) by adding Indium Oxide (In_2O_3) dopant. The substrate used is p-type silicon material (100), using the CSD method (Chemical Solution Deposition). A CSD method is a method of making thin films by depositing chemical solutions on the substrate, followed by 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 were determined by EDX [1,3,21-23].

2. Experimental

In this research, Lithium Tantalate ($LiTaO_3$) thin film was grown on p-type silicon substrate (100). The substrate was cut into a square size of 1 cm × 1 cm using a glass cutter. We have cleaned the substrate by dipping in acetone using ultrasonicator device for 15 minutes were 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, we produce three types of solution with doping 2%, 4%, and 6% indium oxide [(In_2O_3), 99,99%]. The solution was stirred using Vortex

3000. Futhermore, the solution mixture inside ultrasonicator device for 30 minutes which produced a homogenous $LiTaO_3$ solution. The solution was spin coated on p-type Si(100) substrates at a speed of 4000 rpm for 30 seconds were repeated three times (disposition and rotation) with one minutes break in between by using Chemical Solution Deposition (CSD) method [5-7, 9, 28]. The next step, annealing process was conducted in a furnace model Nabertherm type B410 for 15 hours at temperature of 850ºC.

Surface morphology and elemental characterization analysis was obtained by using Scanning Electron Microscopy (SEM), and Energy-Dispersive X-Ray Spectroscopy (EDX). The next step is the process of mounting aluminum contacts as a medium in the measurement. 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 cooper wire using a silver paste. Afterwards, the dielectric constant value and the photoresistive characteristic were measured to determine the effect of the Indium Oxide dopant on the electrical properties of thin film. The dielectric constant of the thin film can be obtained by finding the step response of the thin film. From the step response, we can get the time constant (τ) value of the thin film which can be used 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 can then 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 given in Figure 1.

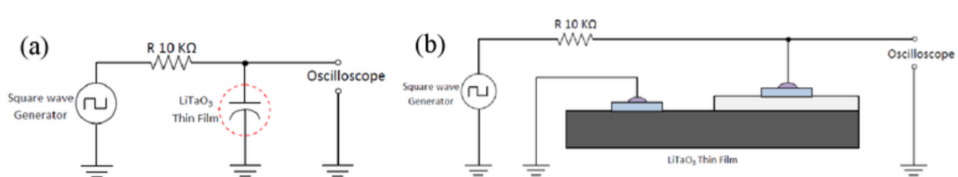

Figure 1. Step response measurement (a) Schematic, (b) Circuit connection

To measure the photoresistive characteristics of the thin film, we use adjustable incandescent lamp as the light source. Then the resistance of the thin film was measured by using digital Ohm meter. The circuit schematic and connection of the thin film for photoresistive characteristics measurement are shown in Figure 2.

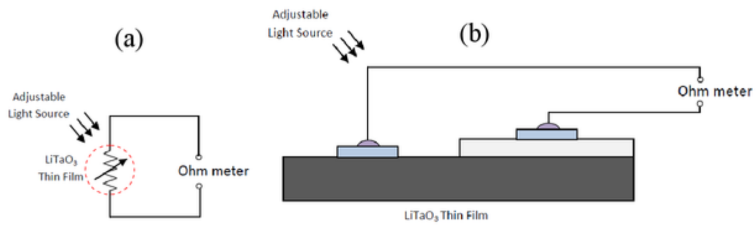

Figure 2. Photoresistive characteristics measurement (a) Schematic, (b) Circuit connection

3. Results and Discussion

3.1 Surface morphology and elemental characterization analysis

Surface morphology and elemental characterization analysis was obtained by using SEM-EDX. The results of morphology and elemental characterization measurement can be seen in Figure 3 and Table 1 respectively. From the surface morphology measurement results we can see that the $LiTaO_3$ thin films with and without In_3O_2 doping have formed on silicon substrate, but the surface of thin film is still non homogeneous, which causes the flow of electrons in the thin film can be inhibited. Meanwhile, from the analysis of elemental atomic composition, it appears that the Indium atoms have appeared in the $LiTaO_3$ thin film doped with In_2O_3. This shows that the process of adding In_2O_3 dopants has been successfully done.

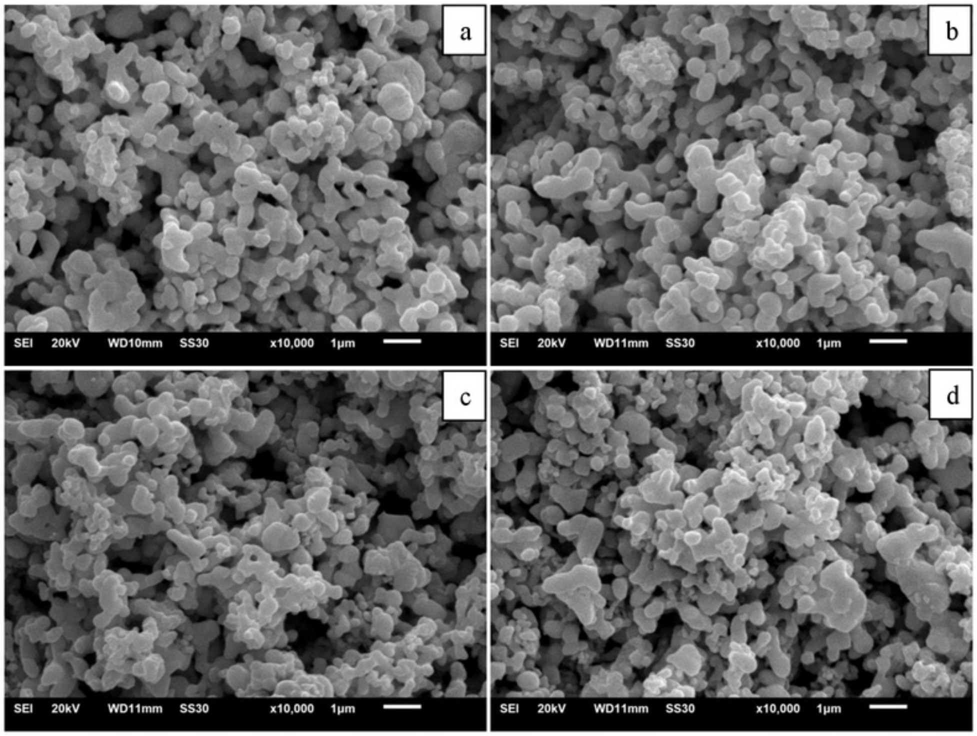

Figure 3. Surface Morphology of $LiTaO_3$ at different doped concentrations (a) Undoped, (b) 2% In_2O_3 doped, (c) 4% In_2O_3 doped, (d) 6% In_2O_3 doped

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

LiTa 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

3.2 Dielectric Constant

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

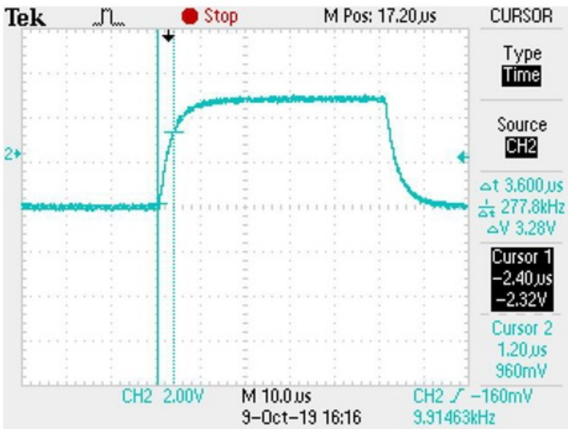

Figure 4. Step response of $LiTaO_3$ thin film

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

Series RC circuit resistance R = 10KΩ = $10^4\Omega$;

Thin film area A=0.5 cm^2 = $5x10^{-5}m^2$;

Thin film thickness d=3μm = $3x10^{-6}$m;

Permittivity of vacuum ε_0=$8.854x10^{-12}$ F/m

$$C = \frac{\tau}{R} = \frac{3.6x10^{-6}s}{10^4\Omega} = 3.6x10^{-10}F$$

$$k = \frac{Cd}{\varepsilon_0 A} = \frac{(3.6x10^{-10}F)(3x10^{-6}m)}{(8.854x10^{-12}\,{}^{F}/_{m})(5x10^{-5}m^2)} = 2{,}44$$

3.3 Photoresistive Characteristics

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

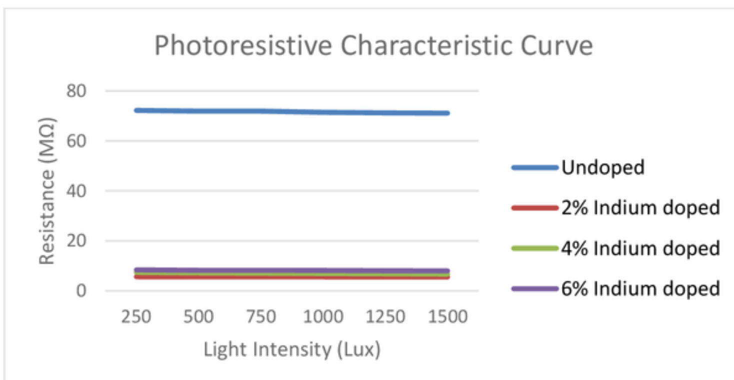

Figure 5. Photoresistive characteristic of undoped and In_2O_3 doped $LiTaO_3$ thin film

4. Conclusion

We have successfully made $LiTaO_3$ thin film grown on p-type silicon substrate (100) by CSD method with 2%, 4% and 6% In_2O_3 doping at 850°C annealing temperature. 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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References

[1] Irzaman, M Zuhri, Novitri, Irmansyah, A A Setiawan and H Alatas: Surface Morphology Properties Doped RuO_2 (0, 2, 4, 6%) of Thin Film $LiNbO_3$, *IOP Conf Ser.:* 1282 (2019) 012040, 2019.

[2] Irzaman, H Syafutra. R Siskandar, Aminullah amd H Alatas: Modified Spin Coating Method for Coating and Fabricating Ferroelectric Thin Films as Sensors and Solar Cells, INTECH, 2017.

[3] R Grissa, V Fernandez, N Fairley, J Hamon, N Stephant, J Rolland, R Bouchet, M Lecuyer, M Deschamps, D Guyomard and P Moreau: XPS and SEM-EDX Study of Electrolyte Nature Effect on Li Electrode in Lithium Metal Batteries, ACS Publications, September 2018.

[4] B Harsono, J Liman, A Kurniawan, J Iskandar, E Rohaeti, Irzaman: $Ba_{0.5}Sr_{0.5}TiO_3$ based Photodiode Application as Light Sensor for Automatic Lighting Control System, Integrated Sci-Tech, 2015.

[5] N Djohan, R Estrada, D Sari, M Dahrul, A Kurniawan, J Iskandar, H Hardhienata, and Irzaman: The effect of annealing temperature variation on the optical properties test of $LiTaO_3$ thin films based on Tauc Plot method for satellite technology, *IOP Conf. Ser.: Earth Environ. Sci,* Vol. 54(1), No. article 012093, February 2017.

[6] N Djohan, R Estrada, F. I. W. Sari, A Kurniawan, J Iskandar, M Dahrul, H Hardhienata, and Irzaman: Classification of undoped and 10% Ga_2O_3-doped $LiTaO_3$ thin films based on electrical conductivity and phase characteristic, *ARPN J. Eng. Appl. Sci*., Vol 12 (12), pp. 3779-3782, June 2017.

[7] R Estrada, N Djohan, D Pasole, M Dahrul, A Kurniawan, J Iskandar, H Hardhienata, and Irzaman: The optical band gap of $LiTaO_3$ and Nb_2O_5 – doped $LiTaO_3$ thin films based on Tauc Plot method to be applied on satellite, *IOP Conf. Ser.: Earth Environ. Sci.,* Vol 54 (1), No. article 012092, February 2017.

[8] R. Estrada, N. Djohan, G. C. Rundupadang, A. Kurniawan, I. Iskandar, M Dahrul, H. Hardhienata, Irzaman: Electrical Properties Test of Dielectric Constant and Impedance Characteristic Thin Films of $LiTaO_3$ and 10% Ga_2O_3-doped $LiTaO_3$, *ARPN Journal of Engineering and Applied Sciences.* 12: 3813-3816 (2017).

[9] N Djohan, R Estrada, N Sevani, H Hardhienata and Irzaman: Crystalline Structure and optical properties of thin film $LiTaO_3$, *IOP Conf Ser.: Earth Environ.*Sci. 284012039, 2019.

[10] N Djohan, R Estrada, N Sevani, H Hardhienata, Irzaman: The Optical Band Gap Based on K-M Function on layer of $LiTaO_3$ with Variation Treatment of Annealing Temperature, ICSGTEIS 2018, October 2018.

[11] F. I. W. Sari, N Djohan, A Kurniawan, E Rohaeti, Irzaman: Analisis Energy Gap dan Indeks Bias $LiTaO_3$ Didadah Ga_2O_3 Berdasarkan Metode Reflektansi, Proseding Seminar Nasional Fisika dan Aplikasinya, November 2015.

[12] G. C. Rundupadang, R Estrada, A Kurniawan, E Rohaeti, Irzaman: Sifat Optik $LiTaO_3$ Didadah Ga_2O_3 Berdasarkan Metode Tauc Plot, Proseding Seminar Nasional Fisika dan Aplikasinya, November 2015.

[13] J Liman, B Harsono, A Kurniawan, J Iskandar, E Rohaeti, Irzaman: Making Photodiode Based on $Ba_{0.5}Sr_{0.5}TiO_3$ Thin Film on P-type Si (100) Substrate with Chemical Solution Deposition (CSD) Method, Integrated Sci-Tech, 2015.

[14] J. Liman, B Harsono, T. T. Rohman, U Trimukti, M Khalid, E Roharti, Irzaman: Uji Sifat Optik Film Tipis $Ba_{0.5}Sr_{0.5}TiO_3$ Di Atas Substrat Corning Glass 7059, Proseding Pertemuan Ilmiah XXIX Jateng & DIY, April 2015.

[15] Y. A. Bonga, J. Liman, A Kurniawan, E Rohaeti, Irzaman: Analisis Energy Gap dan Indeks Bias Film Tipis $Ba_{0.5}Sr_{0.5}TiO_3$ Didadah Ga_2O_3 Berdasarkan Metode Reflektansi, Proseding Seminar Nasional Fisika dan Aplikasinya, November 2015.

[16] A Parapa, B Harsono, A Kurniawan, E Rohaeti, Irzaman: Sifat Optik Film Tipis $Ba_{0.5}Sr_{0.5}TiO_3$ Didadah Ga_2O_3 Berdasarkan Metode Tauc Plot, Proseding Seminar Nasional Fisika dan Aplikasinya, November 2015.

[17] Irzaman, H Darmasetiawan, H Hardhienata, R Erviansyah, Akhiruddin, M Hikam, P Arifin. Electrical Properties of Photodiode BST Thin Film Doped with Ferrium Oxideusing Chemical Deposition Solution Method. J. At. Indonesia, Batan. 2010. 6(2), 57–62. (in Indonesia).

[18] Irzaman, H Syafutra, H Darmasetiawan, H Hardhienata, R Erviansyah, F Huriawati, Akhiruddin, M Hikam, P Arifin. Electrical Properties of Photodiode Ba0.25Sr0.75TiO3 (BST) Thin Film Doped with Ferric Oxide on p-type Si (100) Substrate using Chemical SolutionDeposition Method. At. Indonesia. 2011. 37(3), 133–138. (in Indonesia).

[19] Irzaman, H Syafutra, E Rancasa, A W Nuayi, T G N Rahman, N A Nuzulia, I Supu, Sugianto, F Tumimomor, Surianty, O Muzikarno, Masrur. The Effect of Ba/Sr ratio on Electrical and Optical Properties of Bax Sr(1-x)TiO3 (x = 0.25; 0.35; 0.45; 0.55) Thin Film Semiconductor. Ferroelectrics. 2013. 445(1), 4–17.

[20] Irzaman, AMaddu, H Syafutra, A Ismangil. Test on Electrical Conductivity and Dielectric of Lithium Tantalite (LiTaO3) Doped by (Nb2 O5) using Chemical Deposition Method. In: Proceedings of National Workshop on Physics. 2010. pp. 175−183. (in Indonesia)

[21] Y Motemani, C Khare, A Savan, M Hans, A Paulsen, J Frenzel, C Somsen, F Műcklich, G Eggeler and A Ludwig: Nanostructured Ti-Ta Thin Films Synthesized by Combination Glancing Angle Sputter Deposition, IOP Publishing, 2016.

[22] C Zhao, X Zhang, M Lv, M Zhang, D Wang, Z Zhang, D Fang, J Wang: A Novel Photocatalyst, Y_2SiO_5;Pr^{3+},Li/Pt-$Nanb_xTa_{1-x}O_3$, for Highly Efficient Photocatalytic Hydrogen Evolution Under, Jurnal of Molecular Liquids 277 (2019) 1-9. 2019

[23] A Abdel-Ghany, R. S. El-Tawil, A. M. Hashem, A. Mauger, C. M. Julien: Improved Electrochemical Performance of $LiNi_{0.5}Mn_{0.5}O_2$ by Li-enrichment and AlF_3 Coating, Materialia 5 (2019) 100207, 2019.

[24] Irzaman, R Siskandar, N Nabilah, Aminullah, B Yuliarto, K A Hamam, and H Alatas. Application of lithium tantalate ($LiTaO_3$) films as light sensor to monitor the light status in the Arduino Uno base energy-saving automatic light prototype and passive infrared sensor. *Ferroelectric.* 2018.

[25] Irzaman, H Sitompul, Masitoh, M Misbakhusshudur, and Mursyidah. Optical and structural properties of lanthanum doped lithium niobate thin films. *Ferroelectric.* 2016.

[26] Irzaman, R Siskandar, Aminullah, Irmansyah, and H Alatas. Characterization of $Ba_{0.55}Sr_{0.45}TiO_3$ films as light and temperature sensors and its implementation on automatic drying system model *Integr. Ferroelectric.* 2016.

[27] Irzaman, I R Putra, Aminullah, H Syafutra, H Alatas. Development of ferroelectric solar cells of barium strontium titanate ($Ba_xSr_{1-x}TiO_3$) for subtituting conventional battery in LAPAN-IPB Satellite (LISAT). *Procedia Environ. Sci.* 2016.

[28] Irzaman, Irmansyah, H Syafutra, A Arif, H Alatas, Y Astuti, Nurullaeli, R Siskandar, Aminullah, G P A Sumiarna, and Z A Z Jamal. Effect of annealing times for $LiTaSiO_5$ thin films on structure, nano scale gain size and band gap. 2014.

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PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11