J_{sc} And V_{oc} Optimization of Perovskite Solar Cell With Interface Defect Layer Using Taguchi Method

Mohd Shaparuddin Bahrudin
URND Sdn. Bhd.
Universiti Tenaga Nasional
Kajang, Malaysia
shaparuddin@yahoo.com

Siti Fazlili Abdullah
Department Of Electronics And Communication Engineering
Universiti Tenaga Nasional
Kajang, Malaysia
siti@uniten.edu.my

Ibrahim Ahmad
Department Of Electronics And Communication Engineering
Universiti Tenaga Nasional
Kajang, Malaysia
Aibrahim@uniten.edu.my

Ahmad Wafi Mahmood Zuhdi
Department Of Electronics And Communication Engineering
Universiti Tenaga Nasional
Kajang, Malaysia
wafi@uniten.edu.my

Azri Husni Hasani
URND Sdn. Bhd.
Universiti Tenaga Nasional
Kajang, Selangor, Malaysia
Azri.Husni@uniten.edu.my

Fazliyana Za'abar
URND Sdn. Bhd.
Universiti Tenaga Nasional
Kajang, Selangor, Malaysia
fazliyana@uniten.edu.my

Mazin Malik
Center Of Graduate Studies
Universiti Tenaga Nasional
Kajang, Selangor, Malaysia
Abatshy91@hotmail.com

M. Najib Harif
Faculty of Applied Sciences
Universiti Teknologi Mara
Shah Alam, Malaysia
najib@ns.uitm.edu.my

Abstract*—This paper is a study on Perovskite Solar Cell to optimize open circuit voltage, V_{oc} and short circuit current density, J_{sc} for maximum efficiency at variation depth of interface defect layer (IDL). The Perovskite Solar Cell structure is simulated with combinations of IDL at 6nm, 8nm and 10nm of thickness sandwiches on both side of the solar cell absorber layer. Taguchi Method using L_9 Orthogonal Array with Larger-The-Better (LTB) was used on finding most effective value on three material parameters: Cadmium Sulfide (CdS) as an electron transport layer (ETL), Perovskite absorber layer ($CH_3NH_3PbI_3$) and Copper Telluride (CuTe) as hole transport layer (HTL) in order to achieved best V_{oc} and J_{sc} values. The works was done by simulating a numerical model using Analysis Of Microelectronic and Photonic Structures (AMPS-1D) software. Using ANOVA, it was discovered the Perovskite absorber layer thickness is vital in affecting the increasing and decreasing on both V_{oc} and J_{sc}. Taguchi predicted a 200nm of thickness for best J_{sc} but predicted 300nm for best V_{oc}. The thickness of 200nm is selected for cost effectiveness. Taguchi method also predicted CdS and CuTe are considered slightly significant on improving the efficiency. Post Taguchi optimization approach shows Perovskite Solar Cell with $CH_3NH_3PbI_3$ absorber layer has average power conversion efficiency of 20.7% on any combination of mentioned IDL thickness. With the aid of Taguchi method, a stable Perovskite Solar Cell efficiency with variation IDL thickness is achieved.

Keywords*— *Device simulation, Perovskite, Interface Defect Layer, Taguchi Method

I. INTRODUCTION

This Perovskite Solar Cell is a one of thin film solar cell type that is thriving in its development [1]. With power conversion efficiency of over 20% made the solar cell performance on par with the Silicon-based solar cell that is currently dominating the market as well on par with its other second generation thin film cell counterparts.

The most commonly studied Perovskite absorber is Methylammonium lead Trihalide ($CH_3NH_3PbX_3$, where X is a halogen ion such as I−, Br−, Cl−), with an optical band gap between 1.6eV and 2.3eV depending on halide content [2].The combination of material thus far has been the efficient and low cost to produce.

The aim of this paper is to optimize Perovskite Solar Cell's J_{sc} and V_{oc} to achieve maximum fill factors (FF) and consequently better power conversion efficiency. According to Roldan-Carmona et al, an increase of thickness raised the J_{sc} from 18.5(mA/cm^2) to 23.6(mA/cm^2) but only achieved 1.04V of V_{oc} from 1.06V initially [4]. Feng et al, also reported as the thickness of Perovskite absorber layer increases, the J_{sc} also progressed until it saturated when the thickness reaches 1μm. V_{oc} however will slightly decrease due to more charge recombination activity occurred in thicker film [5].

Another factor affecting the V_{oc} is Interface Defect Layer (IDL). It is one of the main factors affecting the electrical properties of Perovskite include the active layer and their interface [6]. The IDL's are expressed into two separate additional layers, an interface IDL_1 between the buffer and absorber layers, and another interface IDL2 between the absorber and HTM layers. The existence of the IDL in Perovskite film play a critical role in determining the performance of the device, as the photoelectrons generated in this layers and the charge recombination behaviors here can become dominant in determining the V_{oc}, J_{sc}, FF and as well as the Efficiency of the device.

The optimization is done utilizing Taguchi Optimization Method. It is an orthogonal array based statistical method developed by Genichi Taguchi in the 60's originally used for improving the quality of manufactured goods in industry. However, in the recent years, the method also applied in engineering researchers as a robust design method [6].

II. METHODOLOGY

The physical device structure of Perovskite Solar Cell is as shown in FIGURE 1.The absorber used for this study is Methylammonium Lead Triiodide ($CH_3NH_3PbI_3$)

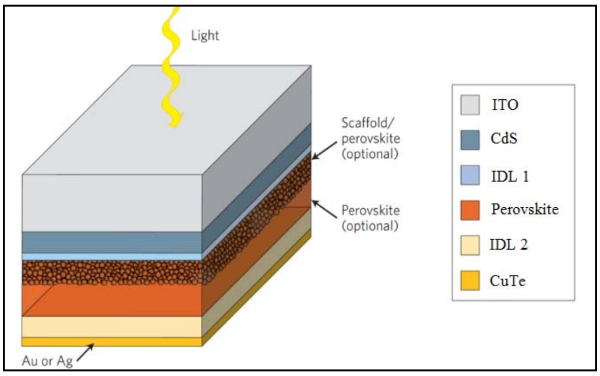

Fig. 1. Pervoskite solar cell structure

A. Material Parameters

The sample structure of the solar cell profile is a modified mathematical model calculated by Takashi Minemoto et al with IDL layers added to its structure [7]. There are three main materials, Cadmium Sulfide (CdS) buffer layer, Perovskite Absorber layer and Cuprum Telluride (CuTe) Hole Transport layer are respectively assigned with three different thickness values. These values are later to be optimized by Taguchi. Both IDLs are varied into three level of thickness, 6nm, 8nm and 10nm. The experiments were done by AMPS-1D simulator.

B. Taguchi Optimization Method

Taguchi method assisted in identifying the most dominant factors that influence the both J_{sc} and V_{oc} when a variation of main parameters and variation of IDL thickness applied in the experiments. This is done by forming all the parameters values into an Orthogonal Array (OA). There are several types of OA tabulated in Taguchi Method [8]. In this paper, L9 Orthogonal Array is utilized.

C. L9 Orthogonal Array

The basis for using L9 Orthogonal array (L9 OA) is because there are three parameters involved that became the Control Factors (CF) and L9 OA is capable to take up to four maximum numbers of CF [9]. These factors are CdS layers, Perovskite Absorber layers, and CuTe layers. Each CF is defined with 3 levels of values as shown in TABLE 2.

TABLE 1. CONTROL FACTORS PARAMETERS AND THEIR LEVEL

Symbol	Parameters (Thickness)	Unit	Level 1	Level 2	Level 3
A	Cadmium Sulfide (CdS)	nm	60	80	100
B	Perovskite ($CH_3NH_3PbI_3$)	nm	200	300	400
C	Copper Telluride (CuTe)	nm	100	150	200

These level of values are technically determined a minimum, medium and maximum configuration of Perovskite Solar Cell that produced good efficiency but not fundamentally optimized or economically fitting. Taguchi Method is used to identify the optimum configuration values from mentioned combinations for best efficiency result.

D. Interface Defect Layers as Noise Factor

In Taguchi Method, Noise factor (NF) is defined as an external parameter that cannot be controlled. The values of NF can be defined statistically but the actual values in a specific situation cannot be known [9].

In this study, IDL is chosen as NF since it uncontrollably occurs on unspecified condition during Perovskite solar cell operation. The L9 OA support maximum up to three noise factors [9], but in the case of this study, only two are utilized since there only two NF's became the focus of the study. The first noise factors is designated as IDL1, an interface defect layer occurred on the top part of Perovskite Absorber layer. The second noise factor is IDL2, another interface defect layer occurred at the bottom part of Perovskite Absorber layer. Both IDL1 and IDL2 layer configuration are as in TABLE 3.

TABLE 2. NOISE FACTORS AND THEIR RESPECTIVE LEVEL

Symbol	Parameters (Thickness)	Unit	Level 1	Level 2	Level 3
D	IDL1	nm	6	8	10
E	IDL2	nm	6	8	10

E. Experiment layout on L9 OA

L9 OA systematically organized the experiment that needs to be done and reduced their numbers. The results are then studied using Signal-to-Noise (S/N) ratio and ANOVA analysis. As its name implied, the L9 OA required nine experiments. TABLE 4 showed the experimental layout of the L9 Orthogonal Array. This layout is important to be used later for ANOVA.

TABLE 3. EXPERIMENTAL LAYOUT USING L9 ORTHOGONAL ARRAY

. Exp. No	Control Factor Level		
	Cadmium Sulfide (CdS)	***Perovskite ($CH_3NH_3PbI_3$)***	***Copper Telluride (CuTe)***
1	A_1	B_1	C_1
2	A_1	B_2	C_2
3	A_1	B_3	C_3
4	A_2	B_1	C_2
5	A_2	B_2	C_3
6	A_2	B_3	C_1
7	A_3	B_1	C_3
8	A_3	B_2	C_1
9	A_3	B_3	C_2

TABLE 4 shows how the configuration of NF for each experiments. The NF configuration is arranged on repetition basis to ensure all variation IDL thickness is covered. Given that there are three level of NF's as shown in TABLE 3, the configuration of NF's is varied nine times in each nine experiments [9]. That mean there are total of 81 experiments run with the configuration provided by both Tables.

TABLE 4. NOISE FACTORS CONFIGURATION FOR EACH REPETITION

Exp. Repetition	Noise Factors Configuration	
	IDL 1	***IDL 2***
1	1	1
2	1	2
3	1	3
4	2	1
5	2	2
6	2	3
7	3	1
8	3	2
9	3	3

III. Result and Discussion

TABLE 5 and TABLE 6 show the result for current density and open circuit voltage respectively in Perovskite solar cell run on the L9 OA with the NFs.

TABLE 5 CURRENT DENSITY (J_{SC}) FROM RESPECTIVE EXPERIMENT

	Repetitions								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	25.94	25.86	25.73	25.82	25.68	26.02	25.64	25.98	25.90
2	26.31	26.18	25.99	26.14	25.96	26.37	25.92	26.34	26.21
3	25.94	25.81	25.63	25.78	25.60	26.01	25.56	25.98	25.85
4	26.25	26.16	26.01	26.12	25.97	26.33	25.93	26.29	26.20
5	26.54	26.40	26.20	26.37	26.17	26.60	26.14	26.57	26.43
6	25.72	25.61	25.44	25.57	25.41	25.79	25.37	25.76	25.64
7	26.56	26.46	26.30	26.42	26.26	26.63	26.22	26.59	26.49
8	26.20	26.08	25.90	26.05	25.87	26.27	25.84	26.24	26.11
9	25.88	25.76	25.59	25.72	25.55	25.94	25.52	25.91	25.79

TABLE 6 OPEN CIRCUIT VOLTAGE (V_{OC}) FROM RESPECTIVE EXPERIMENTS

	Repetitions								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	0.99	0.99	0.98	0.99	0.99	0.99	0.99	0.99	0.99
2	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
3	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
4	0.99	0.99	0.98	0.99	0.99	0.99	0.99	0.99	0.99
5	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
6	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
7	0.99	0.99	0.98	0.99	0.99	0.99	0.99	0.99	0.98
8	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
9	0.98	0.98	0.97	0.98	0.98	0.98	0.98	0.98	0.98

As mentioned in methodology, there are nine experiments and nine repetitions with different NF configuration as explained in TABLE 3 and TABLE 4.

The values conceived from the experiments is used to calculate the signal to noise (S/N) ratio. Analysis on S/N ration performance determined which CF affecting J_{sc} and V_{oc} the most.

Analysis on S/N ratio performance determined which CF affecting. There are three categories of S/N ratio performance characteristic, i.e. lower-the-best, nominal-the-best and larger-the-best [9]. For this study, since largest Jsc and Voc is the objective so larger-the-best characteristic is selected. The S/N ratio for higher-the-best can be expressed as:

$$\eta = -10\ \log_{10}\left(\frac{1}{n}\sum(Y_1^2 + Y_2^2 + \cdots + Y_n^2)\right) \quad (1)$$

Where Y is the experimental values and n is the number of experiments. By applying equation (1), the S/N ratio (η) for the efficiency is calculated and listed in TABLE 8.

TABLE 7. (S/N) RATIO RETRIEVED FROM ALL EXPERIMENTS

Experiment No.	**Signal-To-Noise (S/N) ratio (dB) for Larger-The-Better**	
	Current Density (Jsc)	***Open Circuit Voltage (Voc)***
1	28.25	-0.11
2	28.35	-0.15
3	28.23	-0.18
4	28.35	-0.12
5	28.43	-0.16
6	28.16	-0.20
7	28.44	-0.12
8	28.32	-0.17
9	28.21	-0.20

From the results, individual value of S/N ratio (Larger-The-Better) for each Level of Control Factors and the Overall Mean is calculated . Those S/N ratio values are summarized in TABLE 9 for both J_{sc} and V_{oc}.

TABLE 8 (S/N) RATIO FOR JSC AND VOC

	Control Factors Parameters	**Signal to Noise (S/N) Ratio (dB) for Larger-The-Better**			**Overall Mean (dB)**
		Level 1	***Level 2***	***Level 3***	
J_{sc}	CdS	28.28	28.31	28.32	28.30
	Perovskite	28.35	28.37	28.20	
	CuTe	28.24	28.30	28.37	
V_{oc}	CdS	-0.15	-0.16	-0.17	-0.16
	Perovskite	-0.12	-0.16	-0.20	
	CuTe	-0.16	-0.16	-0.15	

From the summarized results in TABLE 9 , two Factor Effect graphs are plotted base on each Control Factor's level S/N Ratio values on both tables. These two plots are represented as Figure 2(a) and Figure 2(b).

Both Figures shows the selection for the best level on each factor effects that yield the best result can be decided. Fundamentally, the larger the S/N ratio the better the result would be. However, there is a disparity between factor effect points that influence the J_{sc} and V_{oc}. In Figure 2(a) stated that while increasing the CdS thickness have little improvement on the J_{sc}, but cause a small reduction on the V_{oc}. On the thickness of Perovskite layer, Figure 2(a) mentioned that 300nm yield a better result than 200nm thickness for J_{sc}, however, yield the worst result for V_{oc} in Figure 2(b). Figure 2 also asserted that increasing in CuTe thickness is better for J_{sc} but produce insignificant improvement on V_{oc}.

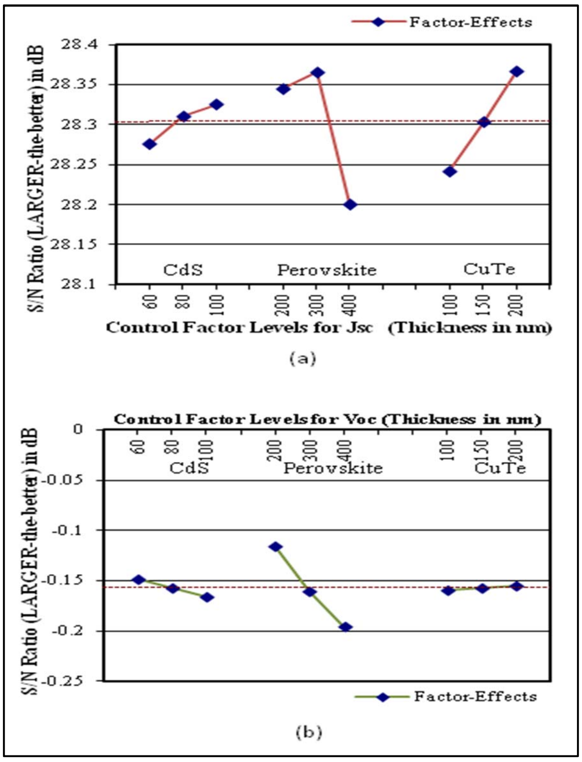

FIG. 2 FACTOR EFFECT PLOT FOR (A) J_{sc} (B) V_{oc}

A. Analysis of variance (ANOVA)

Analysis of Variance or ANOVA is a common statistical technique to determine the percentage the contribution of each factor for the result [10]. ANOVA is capable to verify which control factors that significantly affect the performance of the solar cell. It is done by calculating the Degree of Freedom (DF) given by

$$DF = t - 1 \quad (2)$$

Where t is the total sum of square for each CF given by

$$SS_t = \sum_{i=n}^{n} (\eta_i - m)^2 \quad (3)$$

Where n is a number of the experiment repeated, η_i is the mean of S/N ratio for the i-th experiment and m is the average of nine η_i values. In order to find the ratio percentage, the sum of square of each factor has to be determined. For example, CF for CdS thickness, labeled by symbol A in TABLE 1, its SS_{cf} is given by

$$SS_{cf} = 3[(mA_1 - m)^2 + (mA_2 - m)^2 + (mA_3 - m)^2] \quad (4)$$

Where m is the average of nine η_i values. Equation (4) is repeated for the rest of control factors for both J_{sc} and V_{oc} to determine their respective SS_{cf}. Then, the variance is determined by calculating the mean square (MS) given by

$$MS = \frac{SS}{DF} \quad (5)$$

Next step is to determined the percentage of each factor effect. It is given by

$$Factor\ Effect\ (\%) = \frac{SS_{cf}}{SS_t} \quad (6)$$

Equation (6) is repeated for the all factors effect also for both J_{sc} and V_{oc}. Finally the results on the ANOVA is summarized in TABLE 11.

TABLE 9. RESULT OF ANOVA FOR BOTH JSC AND VOC

	Control Factors	DF	SS	MS	Factor Effect on SNR (%)
J_{sc}	CdS	2.0	0.00	0.00	5.02
	Perovskite	2.0	0.05	0.02	63.26
	CuTe	2.0	0.02	0.01	30.37
V_{oc}	CdS	2.0	0.00	0.00	4.64
	Perovskite	2.0	0.01	0.00	95.04
	CuTe	2.0	0.00	0.00	0.32

According to ANOVA, The percentage of the S\N ratio indicates the priority of the factor level for best result [9]. Thus, the factor with the highest percentage and with the smallest means square among all factors will have great contribution [10]. First CF representing CdS thickness layer affecting only 5.02% on J_{sc} improvement for its best level and only 4.64% improvement for the V_{oc}. This is considered negligible by ANOVA as any selection on its factor levels insignificantly improve both J_{sc} and V_{oc}. So 80nm thickness (Level 2) is selected as it's in the middle that balance the performance between two results.

Perovskite layer thickness is found to be the major factor that affecting both J_{sc} and V_{oc} with factor effect on SNR at 63.26% and 95.04% respectively. The percentage of factor effect on SNR for V_{oc} is regarded higher than the one in J_{sc}, so for level selection, level 1 (Perovskite thickness layer of 200nm) is selected. For the last CF, at only 0.32%, the CuTe thickness is obviously posing almost zero influence on V_{oc}. But ANOVA asserted that it is the second most dominant factor that influences the performance of J_{sc} (at 30.37%). It is obvious for this third CF, level 3 (CuTe thickness of 200nm) is selected.

The ANOVA predicted the SNR range for J_{sc} is between 28.16dB and 28.35dB while SNR range for V_{oc} is between -0.17dB and -0.06dB. The best level selection of each control factors is then finalized in TABLE 12.

TABLE 10. BEST SETTING SELECTION FOR RESPECTIVE PARAMETER

Control Factor Parameters	Best Level	Best Value (nm)
CdS thickness	2	80
Perovskite thickness	1	200
CuTe	3	200

B. Confirmation run

A confirmation experiment is done to retrieve final efficiency base on parameters value on TABLE 12 in order to validate the analysis [10]. The experiment is again repeated nine times, similar to OA L9 experiments mentioned in the methodology to cater variation of NF's arranged in TABLE 4. The results on the Jsc and Voc from the experiment is laid out in TABLE 13 along with the efficiency and calculated S/N Ratio (Larger-The-Better) using equation (1).

TABLE 11. RESULT OF THE CONFIRMATION EXPERIMENTS

Noise Factors (NF) combination									Avg
1 (1,1)	**2 (2,2)**	**3 (3,3)**	**4 (1,2)**	**5 (2,3)**	**6 (3,1)**	**7 (1,3)**	**8 (2,1)**	**9 (3,2)**	
J_{sc} (mA/cm^2)									
26.56	26.42	26.23	26.39	26.20	26.62	26.16	26.59	26.45	26.41
V_{oc} (V)									
0.99	0.99	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Efficiency (%)									
20.71	20.53	20.29	20.56	20.33	20.63	20.36	20.67	20.49	20.51

The results show the J_{sc} is averaging at 26.40 mA/cm2 despite the variation of IDLs. These shows at 200nm of thickness, the current density of the Solar Cell can be maintained despite variations of IDL's. It is clear that due to the thickness of IDL's layers and the selection of thinner absorber layer by Taguchi Optimization Method, the V_{oc} is relatively very low, achieving lower than 1.0V. But the V_{oc} of the Solar Cell is maintained at stable 0.99V despite being exposed to a variation of IDL's thickness situations. The SNR for the J_{sc} and V_{oc} are 28.30 and -0.16 respectively. Both values are within the ANOVA predicted values mentioned previously. As far as efficiency is concerned, the result of the Taguchi optimization approach yield an impressive average power conversion efficiency of 20.51% even with IDL's layers up to 10nm of thickness on both side of CH3NH3Pbl3 Absorber layer.

C. Result comparison

TABLE 12. RESULT COMPARISON (IDL AT 10NM THICKNESS)

Paper Author	Bizuneh-Genene	Feng Juan et. Al.	Taguchi Method result
J_{sc} (mA/cm^2)	20.3	24.03	26.23
V_{oc} (V)	1.05	1.04	0.99
Efficiency (%)	18.5	20	20.53

TABLE 14 outlined the Taguchi Method result and its comparison with two most recent result from two others sources. Both using numerical simulation method. Each result represent the J_{sc} and V_{oc} of the solar cell and their respective efficiency when the IDL thickness occurred at 10nm on both top and bottom of the Perovskite absorber layer. The results concluded optimization with Taguchi Method yield best J_{sc} value with only 5 to 6% loss of V_{oc}. Perhaps, better V_{oc} can be achieved with slightly increased of the absorber layer for future development.

IV. CONCLUSION

In conclusion, the optimum solution in achieving maximum efficiency of Perovskite solar cell with a variation of IDL is a success by utilizing Taguchi Method. The method accurately predicted that Perovskite absorber layer is critical that influence both J_{sc} and V_{oc} that lead to best power conversion efficiency regardless the thickness of IDL that will otherwise drag the efficiency down. It also revealed that both CdS and CuTe present a very minor to none role that influence on the V_{oc} and increase thickness on CuTe bring an improvement on the J_{sc}. By using Taguchi optimization approach, a better understanding of parameters that govern the efficiency of CH3NH3PbI3-based solar cell devices is realized. With this knowledge, further improvements in device performance can be accomplished in future.

ACKNOWLEDGMENT

The authors would like to thanks to Professor Dr. Nowshad Amin from Universiti Kebangsaan Malaysia (UKM) for his expertise and experience on Perovskite Solar Cell as well providing the AMPS software that was used in the project and Dr. Fauziyah binti Salehuddin from Universiti Teknikal Melaka (UTeM) for her knowledge sharing on Taguchi Optimization method.

REFERENCES

[1] Huang, Like, et al. *Electron transport layer-free planar perovskite solar cells performance enhancement perspective from device simulation.* s.l. : Elsivier B.V, 2016. pp. 1038-1047. Vol. 157.

[2] Askari, Mohammad Bagher, Mirzaei, Abadi Vahid Mahmoud and Mirhabibi, Mohsen. *Types of Solar Cells and Application.* Tehran : Science Publishing Group, 2015. Vol. 3. 2330-8494.

[3] Qi Chena, Nicholas De Marcoa, Yang (Michael) Yanga, Tze-Bin Songa, Chun-Chao Chena, Hongxiang Zhaoa, Ziruo Honga, Huanping Zhoua, Yang Yanga. Under the spotlight: The organic–inorganic hybrid halide perovskite for optoelectronic applications. 2015, Vol. 10, 3.

[4] K.S. Rahman, M. A. Islam, M. S. Hossain, M. M. Alam, K. Sopian, N. Amin. The Effect of Cu2Te as the back Surface field Layer in CdS/CdTe Solar Cells. August 2013, pp. 61-68.

[5] C. Rolda´n-Carmona, P. Gratia, I. Zimmermann, G. Grancini,a P. Gao, M. Graetzelb, Mohammad Khaja Nazeeruddin. High efficiency methylammonium lead triiodide perovskite solar cells: The relevance of non-stoichiometric precursors. 2015, Vol. 8, 2015.

[6] *Numerical Simulation: Towards the design of high-efficiency planer perovskite solar cells.* Feng, Liu, et al. 104, Beijing : AIP Publishing LLC, 2014.

[7] Si Fengjuan, Tang Fuling, Xue Hongtao,Qi Rongfei. Effects of defect states on the performance of perovskite solar cells. 2016, Vol. 37, 7.

[8] J.L. Rosaa, A. Robina, M.B. Silvab, C.A. Baldana, M.P. Peresd. Electrodeposition of copper on titanium wires: Taguchi experimental design approach. Brazil : Journal of Materials Processing Technology, 2009, Vol. 209.

[9] Genichi, Taguchi. *System Of Experimental Design (Jikken Keikakuho).* 3rd Edition. Tokyo : Maruzen, 1978.

[10] Phadke, Madhav. *Quality Engineering using Robust Design.* s.l. : Pearson Education, 2008.

[11] F. Salehuddin, I. Ahmand, F. A. Hamid, A. Zaharim, H. A. Elgomati, B. Y. Majlis, P. R. Apte. *Optimization of HALO Structure Effect In 45 nm P-type MOSFETs Device Using Taguchi Method.* Kuala Lumpur : s.n., 2011. pp. 296-302. Vol. 5.

[12] *The effect of skin-depth interfacial defect layer in perovskite solar cell.* Difer, Bizuneh Gebremichael and Mola, Genene Tessema. 215, Berlin : Springer-Verlag, 2016, Vol. 122.

[13] Islam, Mohammad Aminul, Amin, Nowshad and Sulaiman, Yusuf. *A Comparative Study Of Bsf Layers For Ultra-Thin Cds:O/Cdte Solar Cells.* Bangi : Chalcogenide Letters, 2011. pp. 65-75. Vol. 8.

[14] M. A. Matin, M. U. Tomal, A. M. Robin, N. Amin. Numerical Analysis of Novel Back Surface Field for High Efficiency Ultrathin CdTe Solar Cells. s.l. : Hindawi Publishing Corporation, 2013, Vol. 2013.

[15] Minemoto, Takashi and Murata, Masashi. Impact Of Work Function Of Back Contact Of Perovskite Solar Cell without Hole Transport Material Analyzed By Device Simulation. November 2014, Vol. 14, 11, pp. 1428-1433.

[16] Mohammad I. Hossain, Fahhad H. Alharbi, Nouar Tabet. Copper oxide as inorganic hole transport material for lead halide perovskite based solar cells. August 2015, Vol. 120, 2015, pp. 370-380.

[17] Yijie Xia, Kuan Sun, Jingjing Changa, Jianyong Ouyang. Effects of organic inorganic hybrid perovskite materials on the electronic properties and morphology of poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate)and the photovoltaic performance of planarperovskite solar cells. 2015, Vol. 3, 2015.