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Highly Efficient ZnTe Solar Cell with PbTe BSF

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***Abstract*— Zinc Telluride (ZnTe) is a very promising binary semiconductor material is chosen for the ultra-thin approach due to its high absorption coefficient, wider band gap of 1.42 eV and higher thermal stability. This paper illustrates the numerical analysis of the insertion of a thin Lead Telluride (PbTe) BSF layer between the ZnTe absorber layer and the back contact in the ultra-thin ZnTe solar cell is investigated by the wxAMPS simulation software. This PbTe BSF layer offers an extra hole tunneling action that produces a quasi ohmic contact near to the back contact and BSF region. The BSF layer minimizes the recombination losses and the quasi ohmic contact increases the carrier collection that improves the cell performance of the ZnTe solar cell. The simulated result was found 17.55% efficiency for the proposed ultra-thin cell without BSF and the improved cell efficiency was gained 22.15% for only 0.9 µm ZnTe layer with PbTe BSF layer. Besides, it was found higher thermal stability of the proposed cells where the temperature coefficient is of (-0.029%/°k).**

Keywords—ZnTe; AMPS; PbTe BSF; Power Conversion Efficiency.

I. INTRODUCTION

Conventional energy sources depletion whereas worldwide energy demand increasing day by day. Therefore to meet up this energy demands people are to look forward to renewable energy source which is potential energy source, earth-abundant and free from CO_2 emission. Solar energy is the most available and cheapest one. So, day by day research on solar photovoltaic cells is increasing undoubtedly. Presently the main challenges is reducing the layer thickness of uses less material in solar cell configuration as well as achieving low cost, higher performance, better thermal stability. In this regard, more research on getting into this research area wherein many researchers already numerically analysed the overall performance of different solar cell candidate such as CdTe [1], $MoTe_2$ [2, 3] SnS [4], GaAs [5, 6] , CdSe [7, 8], MoS_2 [9], AlSb[10] and FeS_2 [11].

ZnTe material can bring a new look into this research field. It has a band gap of 1.7 to 2.4 eV at room temperature, low electron affinity 3.53 eV and in modern optoelectronic technologies has been broadly used. It has a low cost, high absorption coefficient close to 10^5 cm^{-1} [12], excessive transparency in apparent and infrared zones and lower electrical resistivity [12] as well as it has a cubic crystal structure which lattice constant 6.101Å. Generally, ZnTe shows p-type behavior. So it can be used as a BSF for CdTe/ZnTe solar cell [13]. Pulsed laser deposition, molecular beam epitaxy, sputtering and thermal evaporation techniques can be applied to grow ZnTe thin film. Now it is a great challenge to fabricate the n-ZnO/p-ZnTe heterojunction structure due to its crystal structure and lattice mismatch. Adjoining CdS, lattice mismatch can be reduced where mismatch becomes 3.5%. So it got possible to fabricate ZnO/CdS/ZnTe heterojunction solar cell [14]. Hot wall vacuum evaporation process has been utilized to prepare n-CdSe/ p-ZnTe heterojunction solar cell [15]. A p-n structure is the fundamental structure of a solar cell. To establish an efficient and effective solar cell p-n structure selection should get the most priority. CdS/ZnTe arrangement has been selected as the most applicable one.

Reduction of cost and material consumption is desired to design a stable photovoltaic cell. Low resistive, stable and non-rectifying back contact formation is very costly. Addition of BSF has created a way to overcome this problem. Dey group investigated the cell performance of CdTe solar cell using PbTe BSF layer [16]. Besides, PbTe plays a useful role in the thermoelectric materials fabrication [16]. The band gap is 0.81 eV. It gets crystallized in the crystal structure of NaCl in which atoms of Pb occupy the cation and the anionic lattice is formed by Te. The importance of PbTe being an intermediate thermoelectric material has been proved. For power generation applications the PbTe system can be optimized the power factor improvement with the help of band engineering. It might be doped either p-type or n-type with proper dopants. PbTe is also frequently alloyed with tin to fabricate lead tin telluride, which is used as an infrared detector material.

Whole numerical analysis has been performed by wxAMPS software. Simulated results have been shown in the graphs, wherein the optimized absorber layer thickness is 0.9µm. Here 1100 nm material could have been preserved. Other performance parameters variation like fill factor, short circuit current density and open circuit voltage has been presented graphically varying absorber layer thickness, the doping concentration of the absorber layer and rising temperature.

II. MODELING AND SIMULATION

The ultra-thin ZnTe solar cell is composed with a large number of functional layers, so the electrical properties of the different functional layers cannot be derived from only the theoretical concept. Before performing this cell modeling and

simulation, the quantitative analysis was done on the cell behavior and performance parameters. The wxAMPS simulation program is used for numerically analyze the cell performance of different types of thin film solar cell wherein verify its cell efficiency and feasibility tested of the proposed structure. The solar cell simulator wxAMPS has been chosen because of its capability of stable and rapid simulations within a short period. Baseline structure was Al/ZnO/CdS/ZnTe/Pt and we have modified the structure adding a BSF layer of PbTe. Fig.1 shows the baseline structure without BSF

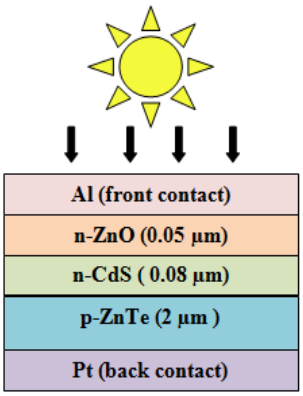

Fig. 1. Baseline structure without BSF [12]

Fig. 2 illustrated the modified cell structure Glass/ZnO/ CdS/ ZnTe /PbTe/Ni with PbTe BSF and replacing Pt back contact with Ni.

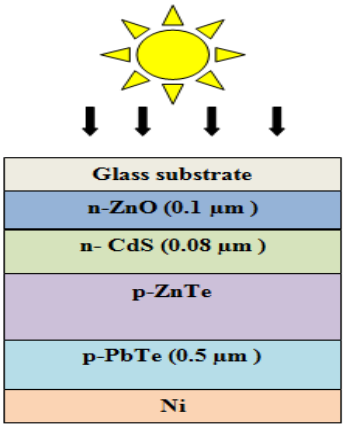

Fig. 2. Modified structure with BSF

Material parameters used in this simulation have been obtained from established paper [13, 16-18]. Thickness and the doping concentration of ZnTe absorber layer has been varied from 0.2µm to 5.2µm and from 10^{16} cm^{-3} to 10^{19} cm^{-3} respectively. Thermal stability has been observed by varying the operating temperature. Material parameters used in the simulation for observing performance parameters are mentioned in Table I.

Table I Material parameters used in the simulation

Parameters	p-PbTe	p-ZnTe	n-CdS	n-ZnO
W (nm)	0.5	0.1-8	0.08	0.05
E_g (eV)	.29	2.19	2.43	3.37
χ (eV)	4.6	3.73	4	4.45
ε/ε0	40	10.3	9.35	9
N_C (cm^{-3})	1e16	1.176e18	1.758e18	2.949e18
N_V (cm^{-3})	2e17	1.166e19	1.469e19	1.137e19
µc (cm^2/Vs)	1600	330	100	100
µp (cm^2/Vs)	600	80	25	25
N_D (cm^{-3})	0	0	1e18	1e18
N_A (cm^{-3})	8e19	2.16e19	0	0

III. RESULTS AND DISCUSSION

Optimization has to be performed to achieve the best result from our proposed structure so that material preservation, efficiency boost up and thermal stability is to be maintained for our designed cell model

A. Effect of absorber layer thickness

Fig. 3 presented the variation of the ZnTe absorber layer thickness from 600 nm to 5000 nm for the structure with PbTe BSF which showed higher performance parameters such as V_{oc}, J_{sc} and FF than the same cell without BSF due to minimize the recombination losses and enhanced the back contact formation with p-ZnTe.

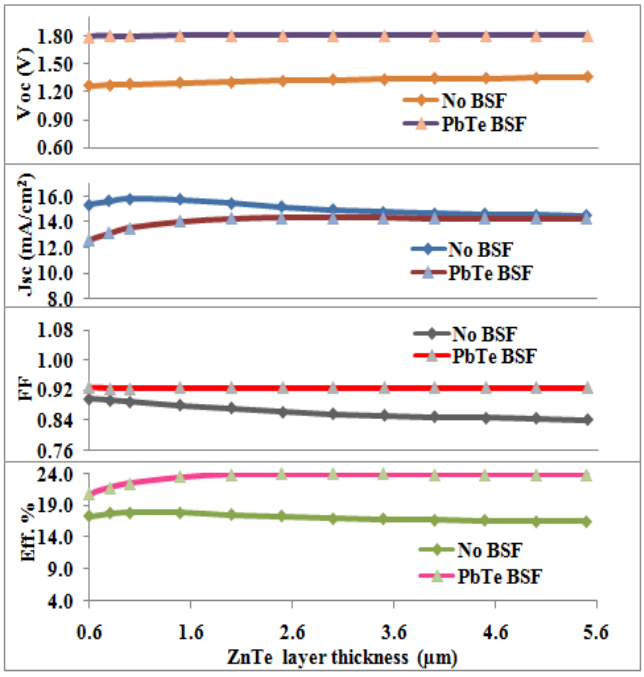

Fig. 3. Comparative study of performance parameters between cell structure with PbTe BSF and without BSF varying absorber layer thickness

In Fig. 3 it is observed that in baseline structure, the open circuit voltage of the cell increases with the increasing thickness of absorber layer linearly while the short circuit current density J_{sc} rises gradually with the increasing thickness of ZnTe absorber layer up to 1.0 µm and then decreases uniformly. But fill factor decreases with the increasing absorber layer thickness. With BSF open circuit voltage of the cell increases with the increasing thickness of absorber layer from 0.6 µm to 3 µm and after that remains constant whereas the short circuit current density J_{sc} rises continuously with the increasing thickness of ZnTe absorber layer up to 3.0 µm and then decreases. But fill factor decreases in accordance with the increasing absorber layer thickness up to 0.8 µm, increases up to 2.5 µm and then gradually decreases 23.8886% conversion efficiency has been achieved as the highest quantity for 3 µm. But for material preservation, only 0.9 µm thicknesses was used for the absorber layer to obtain the cell efficiency is 22.15% and 2100 nm material might have been preserved.

B. *Effect of absorber layer doping concentration*

The doping concentration of absorber layer has been varied from $2.16x10^{16}$ cm^{-3} to $2.16x10^{19}$ cm^{-3} to investigate the probability of highly efficient performance parameters based ZnTe solar cell illustrated in Fig. 4. Improved the conversion efficiency has been found with the increased doping concentration.

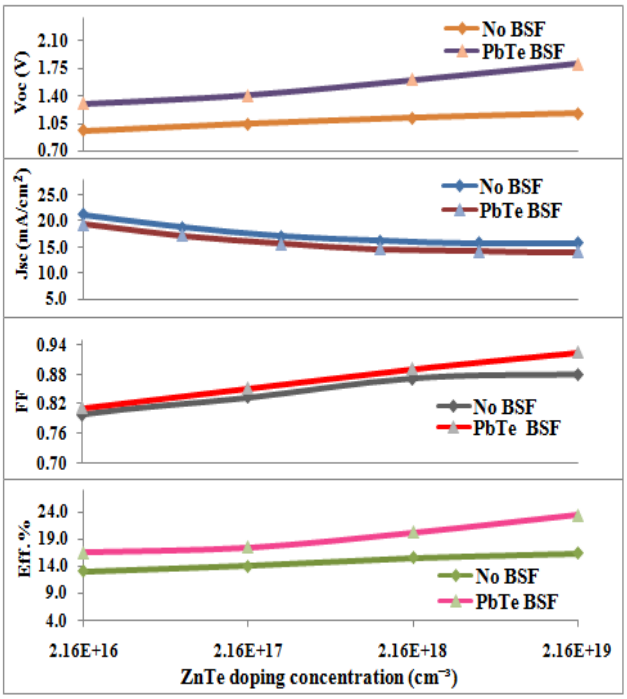

Fig. 4. Comparative study of performance parameters between cell structures with PbTe BSF and without BSF varying absorber layer doping concentration

For baseline structure, both fill factor, open circuit voltage (V_{oc}) increase while short-circuit current density decreases according to the improvement in the magnitude of absorber layer doping concentration. Consequently, power conversion efficiency upgrades mostly on the swiftly increasing extent of open circuit voltage and fill factor. For the cell with BSF, the short-circuit current density decreases whereas open circuit voltage, fill factor increase with the enhancement of doping concentration of the absorber layer. Consequently, power conversion efficiency boosts largely on the promptly increasing degree of the cell performance parameter open circuit voltage. Fig. 4 illustrated the effect on the cell performance parameters by varying the doping concentration of absorber layer for BSF and without BSF.

C. *Effect of temperature*

The operating temperature performs a precise notable part to inspect the solar cell performance. During the numerical analysis, the operating temperature was maintained at 25°C. The operating temperature shows a very significant role on the cell performances. At higher operating temperature, the parameters such as Eg, Nc and Nv will be changed hence the operating temperature shows a very significant role on the cell performances. To investigate the performance of the cells with and without BSF at higher operating temperature, the numerical analysis was carried out with higher cell operating temperature ranging from 273K (0°C) to 373K (100°C) are shown in Fig.5.

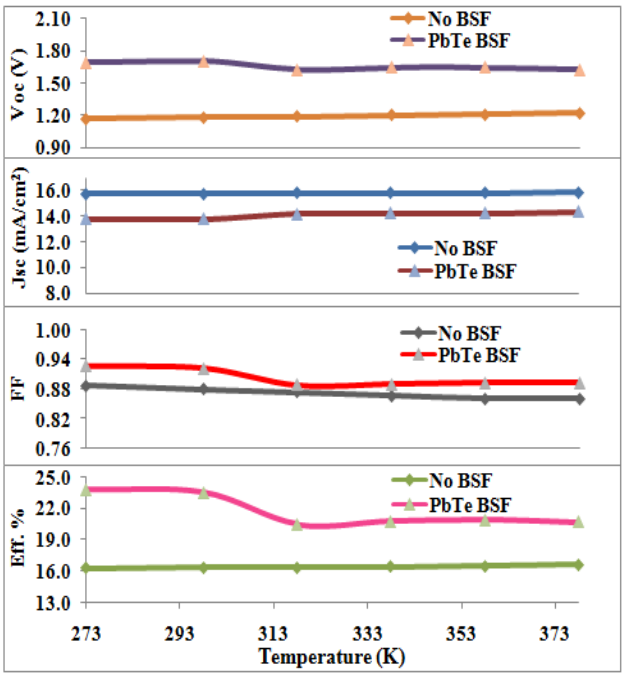

Fig. 5. Comparative study of performance parameters between cell structures with PbTe BSF and without BSF varying temperature

From Fig. 5 it is observed that the proposed cell structure with PbTe BSF layer and without BSF layer, the cell performance is deteriorated with the increases in operating temperature at a temperature coefficient (TC) of -0.029%/°K. This TC indicates the better thermal stability of the ZnTe solar cells at higher operating temperature, which is good agreement with related published works [12].

D. J-V characteristics curve for PbTe BSF and without BSF

The effect of the PbTe BSF layer on J-V characteristics curve is illustrated in Fig. 6. In figure it is observed that, the J-V curve was moved to the right side after the insertion of the PbTe BSF layer. Finally achieved the higher performance and better thermal stability of the proposed cell with PbTe BSF is more preferable than the without BSF layer. Fig. 6 shows the J-V characteristic curve for BSF and without BSF.

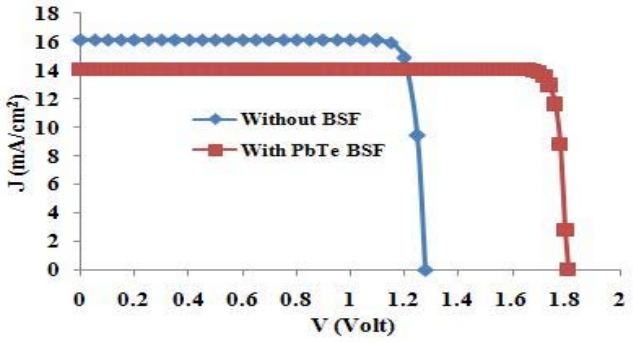

Fig. 6. Comparative study of J-V characteristics curve for PbTe BSF and without BSF

In above discussion, it has been cleared that the proposed cell (Glass/ n-ZnO / n-CdS / p-ZnTe/ p-PbTe /Ni) structure with 3µm ZnTe absorber layer and PbTe BSF provides the higher conversion efficiency is of 22.89% (V_{oc} = 1.81 V, J_{sc} = 14.30 mA/cm^2, and FF = 92.54%). The cell efficiency of 22.15% was achieved for only 0.9µm thick ZnTe absorber layer. Considering the ZnTe absorber layer thickness, around 67.33% materials preserved for the proposed cell structure with ultra-thin ZnTe solar cell. The wxAMPS results obtained from simulation have been shown in Table II to differentiate the performances with BSF layer and without BSF layer.

Table II Performance parameters for the cell without BSF and with BSF

Cell structure	VOC (V)	JSC (mA/cm2)	FF %	Efficiency %
Al/ n-ZnO/ n-CdS / p-ZnTe (2µm) / Pt [12]	1.81	7.01	78.84	10
Glass/ n-ZnO / n-CdS / p-ZnTe (2µm) /Ni	1.30	15.43	87.14	17.55
Glass/ n-ZnO / n-CdS / p-ZnTe (3µm) / p-PbTe /Ni	1.81	14.30	92.54	22.89
Glass/ n-ZnO / n-CdS / p-ZnTe (0.9µm) / p-PbTe /Ni	1.81	13.30	92.44	22.15

IV. CONCLUSION

The possibility of the higher cell performance on the ultra-thin ZnTe solar cell with PbTe BSF was explored by the numerical simulation. It was found from the numerical analysis that, ZnTe baseline case cell showed 17.55% cell conversion efficiency (V_{oc} = 1.30 V, J_{sc} = 15.43 mA/cm^2 and FF = 87.14%) without BSF layer. The potential candidate PbTe BSF material was examined for the effect of BSF layer with the conventional cell structure and the simulated result shows that, the higher cell conversion efficiency of 22.15% (V_{oc} = 1.81 V, J_{sc} = 13.30 mA/cm^2, and FF = 92.44%) within 900 nm ZnTe absorber layer. Moreover, the better thermal stability at a temperature coefficient (TC) of -0.029%/°K was found for the proposed ZnTe solar cell at higher operating temperature which showed the good agreement with related published work [12]

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REFERENCES

[1] Mrinmoy Dey, Maitry Dey, M. A. Matin and Nowshad Amin, "High Efficient and Stable Ultra-Thin CdTe Solar Cell with a Potential Copper Telluride BSF," *in Proc. of the 9th Int. Conf. on Electrical and Computer Engg.* Dhaka, Bangladesh, 20-22 Dec. 2016.

[2] Mrinmoy Dey, Maitry Dey, M. A. Matin and Nowshad Amin, "Enhancement the Performance of Molybdenum Telluride Solar Cells with Zinc Telluride BSF," *Int. Conf. on Innovations in Science, Engg. and Tech.,* Chittagong, Bangladesh, 28-29 October, 2016.

[3] Mrinmoy Dey, Maitry Dey, N. K. Das, A. K. S. Gupta, M. A. Matin and Nowshad Amin, "Performance Improvement of Highly Stable Molybdenum Telluride Solar Cells with CZT BSF," *in Proc. of the Int. Conf. on Electrical, Computer and Communication Engg.,* Cox's Bazar, Bangladesh, 16-18 Feb. 2017.

[4] Mrinmoy Dey, Maitry Dey, N. Rahman, I. Tasnim, R. Chakma, U. Aimon, M. A. Matin and Nowshad Amin, "Numerical Modeling of SnS Ultra-Thin Solar Cells," *in Proc. of the Int. Conf. on Electrical, Computer and Communication Engg.,* Cox's Bazar, Bangladesh, 16-18 Feb. 2017.

[5] Mrinmoy Dey, Nazia Rahman and Maitry Dey, "Device modeling and numerical simulation of highly efficient Gallium Arsenide solar cells," *in Proc. of the 3rd Int. Conf. on Electrical Information and Communication Tech.,* Khulna, Bangladesh, 07-09 Dec. 2017.

[6] Maitry Dey, Nazia Rahman, Iffat Tasnim, Mrinmoy Dey and Nipu Kumar Das, "Design and Numerical Analysis of Efficient Gallium Arsenide Solar Cell with Graphene as Window Layer Material," *in Proc. of the 2nd Int. Conf. on Electrical, Computer and Communication Engg.,* Cox's Bazar, Bangladesh, 07-09 Feb. 2019.

[7] Mrinmoy Dey, Mahmudul Hasan, Rahat Amin and Maitry Dey, "Numerical analysis of efficient cadmium selenide solar cell," *in Proc. of the 3rd Int. Conf. on Electrical Information and Communication Tech.,* Khulna, Bangladesh, 07-09 Dec. 2017.

[8] *Mrinmoy Dey, Mahmudul Hasan, Rahat Amin, Maitry Dey, N. K. Das, A. K. Sen Gupta, M. A. Matin and N. Amin*, "Design of Highly Efficient CdSe Solar Cell with CdS as Buffer Layer Material," *International Conference on Mechanical Engineering and Renewable Energy*, PI-387, CUET, Chittagong, Bangladesh, 18-20 Dec. 2017.

[9] Mrinmoy Dey, Md. Fahim Shahriar, Arman Ali, Maitry Dey and Nipu Kumar Das, "Design and Optimization of an Efficient Molybdenum Disulfide (MoS_2) Solar Cell with Tin Sulfide BSF," *in Proc. of the 2nd*

Int. Conf. on Electrical, Computer and Communication Engg., Cox's Bazar, Bangladesh, 07-09 Feb. 2019.

[10] Mrinmoy Dey, Rishita Chakma, Nazia Rahman, Maitry Dey, N. K. Das, A. K. Sen Gupta, M. A. Matin and Nowshad Amin, "Study of ultra-thin and stable alsb solar cell with potential copper telluride BSF," *in Proc. of the* IEEE Region 10 Humanitarian Tech. Conf. (R10-HTC-2017)*, pp. 811-814,* Dhaka , Bangladesh, 21-23 Dec. 2017.

[11] Mrinmoy Dey, Jannatul Ferdous, Sumaiya Binte Afsar, Maitry Dey and Nipu Kumar Das, "Design and Optimization of Efficient FeS_2 Solar Cell," *in Proc. of the 2nd Int. Conf. on Electrical, Computer and Communication Engg.,* Cox's Bazar, Bangladesh, 07-09 Feb. 2019.

[12] Othmane Skhouni, Ahmed El Manouni, Bernabe Mari and Hanif Ullah, "Numerical study of the influence of ZnTe thickness on CdS/ZnTe solar cell performance," *Eur. Phys. J. Appl. Phys*. (2016) 74: 24602.

[13] Mrinmoy Dey, Maitry Dey, M. A. Matin and N.Amin, "Design of High Efficient and Stable Ultra-Thin CdTe Solar Cells with ZnTe as a Potential BSF," *in Proc. of the 3rd Int. Conf. on Green Energy and Tech.,* Dhaka, Bangladesh, 11 Sep. 2015.

[14] T. Matsumoto, H. Kato, K. Miyamoto, M. Sano, and E. A. Zhukov, and T. Yao, *Appl. Phys*.Lett. 81, 1231 (2002)

[15] A K Pal, A Mondal and S Chaudhuri, "Preparation and characterization of ZnTe/ CdSe solar cells," vol.41, no.4-6, pp. 1460-1462, 1990.

[16] M. A. Matin and Mrinmoy Dey, "High Performance Ultra-Thin CdTe Solar Cell with Lead Telluride BSF," in *Proc. of the 3rd International Conference on Informatics, Electronics & Vision 2014,* pp. 1-5, Dhaka, Bangladesh, 23-24 May 2014.

[17] J. He, J. Xu, G. Liu, X. Tan, H. Shao, Z. Liu, J. Xu, J. Jiang, and H. Jiang, *RSC* Adv.5, 59379 (2015).

[18] Mrinmoy Dey, Maitry Dey, Samina Alam, Nipu Kumar Das, M. A. Matin and Nowshad Amin, "Study of Molybdenum Sulphide as a Novel Buffer Layer for CZTS Solar Cells," 3rd *Int. Conf. on Electrical Engineering and Information & Communication Technology,* Dhaka, Bangladesh, 22-24 Sep. 2016.

[19] Mrinmoy Dey, Maitry Dey, Samina Alam, A. K. S. Gupta, N. K. Das, M. A. Matin and Nowshad Amin, "Design of Ultra-Thin CZTS Solar Cells with Indium Selenide as Buffer layer," *in Proc. of the International Conference on Electrical, Computer and Communication Engineering ,* Cox's Bazar, Bangladesh, 16-18 February, 2017.