2019 International Conference on Electrical, Computer and Communication Engineering (ECCE), 7-9 February, 2019

Design and Numerical Analysis of Efficient Gallium Arsenide Solar Cell with Graphene as Window Layer Material

Maitry Dey[1, 2], Nazia Rahman[3], Iffat Tasnim[3], Mrinmoy Dey[1, 2*] and Nipu Kumar Das[1, 2]

[1]Department of Electrical and Electronic Engineering, Chittagong University of Engineering and Technology, Chattogram-4349, Bangladesh

[2]Renewable Energy Laboratory (REL), Chittagong University of Engineering and Technology, Chattogram-4349, Bangladesh

[1]Department of Electrical and Electronic Engineering, Port City International University, Chattogram, Bangladesh

*mrinmoycuet@gmail.com

***Abstract*— Different semiconductor materials are used to design solar cell and among them, Gallium Arsenide (GaAs) has currently more preferable causes it has several unique properties such as flexibility, the wider and direct band gap of 1.42 eV, light weighted with a low-temperature coefficient. The photon absorption constant is higher in its so can easily trap the photons more efficiently which in turns increases the efficiency of the solar cell and its' temperature coefficient is low and show better performance at low light. Because of these properties, GaAs has obtained a good position in thin film photovoltaic cell in the market. Graphene is used as the window layer in GaAs solar cell in research work that was simulated by using numerical analysis. A structure of n-type Graphene with p-type GaAs absorber layer is designed by lower volume of material which contains more economic in present status. In this case Jsc, FF and Voc have been observed with 15.17% conversion efficiency has been found from the structure of Graphene with GaAs solar cell. Additionally, the performance has been found for the proposed model where increases the temperature decreases the normalized efficiency and it is around -0.031%/°C.**

Keywords—GaAs solar cell; Graphene; Cost Effectiveness; Photon absorption.

I. INTRODUCTION

The increasing trend of population puts a high requirement of energy which may arise various severe problems to the next generations. Coal, oil, gas etc. natural resources have been used to produce energy which is required to fulfil the demand of excessive population. 28% of the world's energy demand is produced by using coal [1]. But the formation rate of coal in the nature is very slower. So it can be seen that the usage rate of coal is far greater than the coal creation amount. If it happened constantly, formerly one day this storage coal will be finished and at the natural sources face to the same problem. Also different fossil fuels produce severe pollution in atmosphere which is an extreme problem.

As these sources are not renewable and also hazardous for health, so it has become an urgency to look for other resources of the energy that will be meet the present energy demand in the world. There are various kinds of non-conventional energy sources that are as tidal with wave energy, wind, hydropower, bio and solar energy etc. Among them solar energy is the best dependable sources in the renewable energy resources. For this reason this solar energy sources is very attractive and many researchers are already research and work in this sector for build up the sustainable, pollution free clean earth with lowest cost. More of the sun photon is incident on the earth in one year rather than uses by everybody in the world.

Thin film solar cell is made from materials of semiconductor only a few micrometres thick. The combination of using less material and cost effective manufacturing process are now make very attractive topic for researchers to progress the solar cell using it. Different categories of semiconductor material are usage for designing the solar cell where the film layer is in thin and above them gallium arsenide GaAs is the noble candidate in the solar cell of its unique characteristic where the performance of the cell is higher than others [2]. These types of solar cell are designing for the both single crystalline as well as multi-crystalline solar cell. The world power production capability for the PV cells was increased around 63 precent which had been growing in the one year that was differ with 2009 [3].

As a solar cell mainly used to different constructs of solar technology that are as silicon, organic and the thin film. But the development of solar power system is dependent on its economic system and its performance. If the cost will be lower for manufacturing as well as market share with higher performance then this solar power system is very promising for development on the present civilization in the world. According to the US market share if the tariff of solar share market could assumed to be $0.33per watt peak then it could only be prudent [4].

The photovoltaic influence in the semiconductor material had been firstly observed by Alexsa andre Edmond Becquere around 175 years ago where an electrode was converted into power generation. Later on dependent on this base of PV effect to design and fabricated this photovoltaic cell that had been produce the electricity. After that day by day this concept was continuously investigated for progresses the solar cell. In 1970, Zhores Alferov was exposed the first hetero-structure of GaAs that was functional for the solar cell according to USSR [5] and the highest performance in cell conversion efficiency was attained by using crystalline silicon solar cell in the early 1980s and in the early 1990s, GaAs solar cell placed in this position. GaAs solar cell that was mainly applicable for the satellite applications and afterwards Ge material with InGaP materials was used with in the GaAs solar cell to advance the dual and triple-junction solar cell. The highest conversion efficiency was noted at 28.8% for the single junction GaAs constructed solar cell [6]. Light energy that collected from sun is a recycling method which is used to achieve higher efficiency in the thin film design [7].

In proposed model, graphene is usage as window layer. Graphene consists of carbon atoms that arranged in a single layer for hexagons pattern. As it is made of carbon, which is abundant in nature, has made it relatively inexpensive material. Its' band gap is nearly zero, so this particles contains relatively less mass in it. Besides some prospective characteristics such as the strong structure, transparency for better device properties, conductivity and flexibility of graphene concerned the researchers for upgrading existing products and modeling new kinds of modeling for application of solar cell. It is collecting the electrical current that produced inside the solar cell but this amount of collection is not too more. If any appropriate way can be found to boost up the collecting level, then graphene will become one of the promising materials. For instance, grapheme oxide (GO) material is used for the boost up cell performance with grapheme causes it is contains lower conductivity but its transparency is more and act as a better charge collector which is musty useful for the solar cell.

Presently have more research on going in this field where many researchers are concerned to investigate the performance of promising candidate of different thin film solar cells such as CdS/CdTe [8- 13], CIGS [14], CdS/$MoTe_2$ [15-17], SnS, CZTS, and AlSb [18] that are considered for the potential material and suitable for as buffer layer to decrease the edge losses. The investigation to explore hidden potentiality of absorber layer is examined and the results are promising for CZTS based solar cells [19-21], SnS solar cell [22] and CdSe based solar cells [23, 24].

In this analysis, AMPS-1D simulation software is used to explore the hidden potentiality of Graphene/GaAs cell through the numerical analysis. The cell performance mainly dependent on the material parameter where the cell performance demonstrated by the different parameters of material that are as the thickness variation effect on the absorber layer, temperature effect on this cell and effect of doping concentration and lifetime as well as thermal stability.

II. MODELING AND SIMULATION

The constructional diagram of propound cell Graphene/GaAs is given in figure 1. This propound cell has been simulated using AMPS-1D software for calculation of modeling cell. Here in the AMPS-1D software using the lifetime term amid of two distinctive methods where first term is device modelling and the others is DOS model. A 60 nm window layer (graphene) is designed with a 1 µm GaAs solar cell.

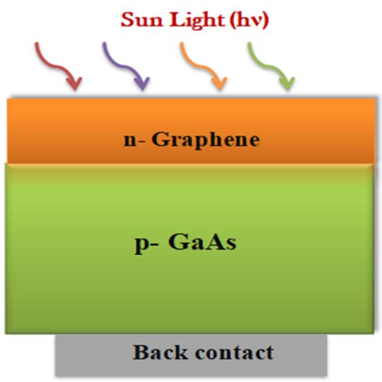

Fig.1: Schemed model of GaAs solar cell

The performance of the solar cell is generally described by four parameters are as short circuit current density that is denote by *Jsc*, power conversion efficiency is denoted by η, fill factor is denoted by *FF* and the open circuit voltage is *Voc*.

Short circuit current can be described as the following equation,

$$J_{SC} = \frac{Isc}{A} \qquad (1)$$

Here, I_{sc} = Short circuit current and A = Area

Again, other parameters can be described as following,

$$V_{oc} = \frac{kT}{q}\ln\left(\frac{I_L}{I_O}+1\right) \qquad (2)$$

$$FF = \frac{V_{mp} I_{mp}}{V_{oc} V_{sc}} \qquad (3)$$

In 2014, graphene was used with GaAs and obtained an efficiency of 14.46% using AMPS-1D software [25]. In here the thickness of absorber layer was around 2000 nm. If the buffer layer thickness was about 0.4 nm which arises problem during fabrication. The main purpose is fabricated the designing model in the lab and use it in practical field. So in our proposed model the buffer layer thickness is 60 nm and absorber layer is 1000 nm which is an optimized assumption. This model results efficiency to 15.17 %.

Table I shows the value of material parameters that are used to numerical analysis and observed the performance of the Graphene /GaAs solar cell. These values are found from the different sources that are data base, hypothesis and some cases this value are collected from the approximation. This parameters value is given in the table below:

TABLE I MATERIAL PARAMETERS OF SCHEMED MODEL USED FOR THE ANALYSIS OF GAAS SOLAR CELL

Parameters	n-Graphene	p-GaAs
Thickness (μm)	10-100	500-3000
n,p Carrier concentration (cm^{-3})	0	1×10^{16}
Mobility for Electron (cm^2/Vs)	9000	8500
Mobility for Hole (cm^2/Vs)	9000	400
Band gap (eV)	0.01	1.42
Density of state in conduction band (cm^{-3})	1×10^{21}	4.77×10^{15}
Density of state in valence band, (cm^{-3})	1.04×10^{21}	9×10^{16}
Electron affinity (eV)	4.10	4.07
Permittivity	6	12.90

The simulated result was achieved by using this table parameter value for the Graphene/GaAs solar cell. In this analysis, to investigated the solar cell performance by observing the influence of thickness in the absorber layer, and also examined the effect of doping concentration with lifetime. As the solar panel panel is installed in the roof top so the temperature effect is considered for the solar cell.

III. RESULTS AND DISCUSSION

A. *Event of GaAs layer thickness*

The proposed solar cell model has been simulated by AMPS-1D simulator and investigated the influence of layer thickness of the GaAs absorber layer to observe the cell performance like as efficiency and other parameters. In Fig. 2, the absorber layer thickness has been varied from the range of 500 nm to 4000 nm to achieve the better performance in this solar cell.

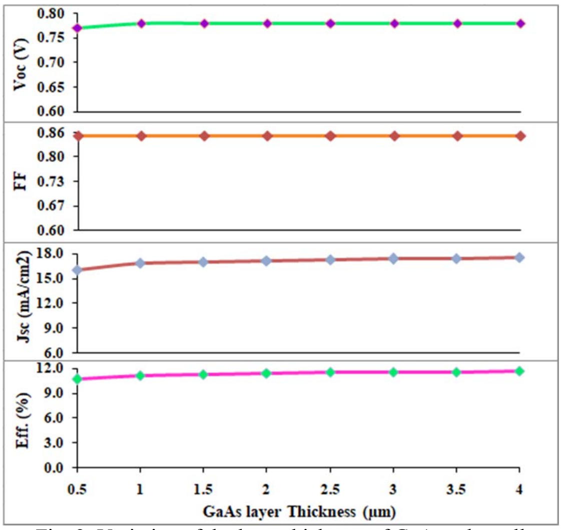

Fig. 2: Variation of the layer thickness of GaAs solar cell

From Fig. 2, it can be seen that the efficiency and current density are increased up to 2000 nm and then it becomes approximately saturated for the increased thickness. Because with the increased thickness, generation of electron-hole pairs will also increase, this further increases the power conversion efficiency. From the figure it can also be noticed that after 2000 nm the increasing rate of efficiency becomes saturated because most of the photons have been absorbed within 2000 nm. Therefore, to reduce the fabrication cost of this solar cell considering the material reservation 1000 nm for saving the material uses is taken as optimal thickness.

From the variation of absorber layer thickness it has been seen that in Fig. 2, *Voc* increases from 500 nm up to 1000 nm and after that it remains constant. On the contrary, FF remains constant. In the above figure thickness is varied from 500 nm to 4000 nm and observed that an efficient and optimized result is attained at 1 μm thick. For that reason the absorber layer thickness for GaAs solar cell is kept at 1μm thick which is ideal for thin film solar cell.

B. *Event of Doping Concentration*

In this schemed model doping has been selected for the GaAs absorber layer is p-type material that is observed by the following Fig. 3. From Fig. 3, it has been seen that the doping concentration varied from 1×10^{12} to 1×10^{17} cm^{-3} where the efficiency has an growing trend after 1×10^{14} cm^{-3} and after 1×10^{16} cm^{-3} it again decreases. On the contrary, current density shows a growing outcome with increased doping concentration. So considering the efficiency, 1×10^{16} cm^{-3} is taken as optimal doping concentration.

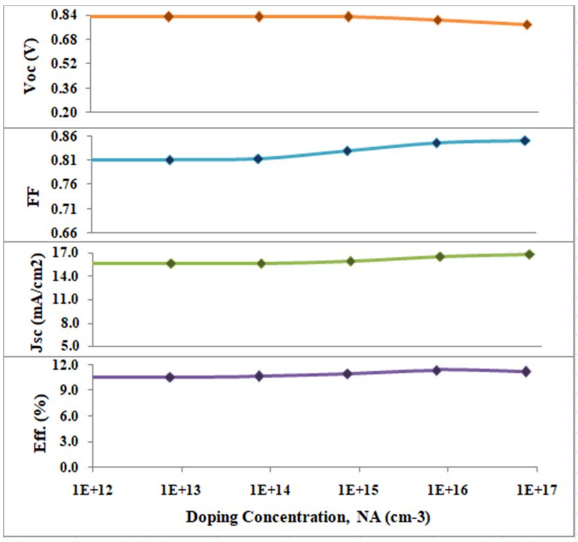

Fig.3 Event of doping concentration on *Voc, FF, Jsc* and efficiency

If the doping concentration rises in the solar cell then the inverse saturation current drops that are leading to a growth in the open circuit voltage and therefore the conversion efficiency also increases those shows in Fig. 3. This growth in the *Voc* and efficiency will be continued until the effect of the higher doping arises to perform. This high doping is influenced on the cell performance where the band gap is and the minority carrier life time is also reduced. In both cases the inverse saturation current decreases over after reaching a highest doping concentration occurred in the substrate.

The doping concentration has been almost same from 1×10^{12} to 1×10^{14} cm^{-3} for the FF parameters and after at 1×10^{14} cm^{-3} doping concentration has been rising a higher value and V_{oc} remains constant up to 1×10^{14} cm^{-3} and then it shows a decreasing trend with the doping concentration shows in Fig. 3. So by observing the output of Fig. 3 depicts an efficient result is obtained at 1×10^{16} cm^{-3} doping concentration.

C. Event of Temperature

In this case the cell performance is explored by temperature and find out the thermal stability where simulation is carried out by variation of the temperature from 20°C to 100°C. By observing the simulated result from Fig. 4 it is found that conversion efficiency is proportionally decreased with the increase of temperature causes of if the resistivity increases with decreases in the carrier concentration and mobility and current density remains constant.

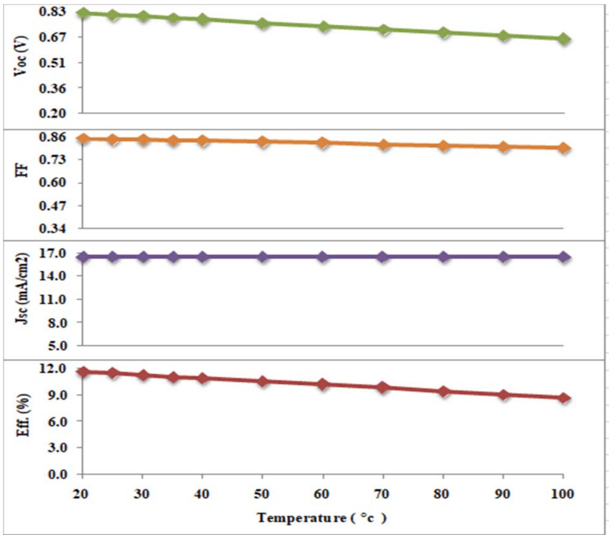

Fig. 4 Event of temperature variation on *Voc, FF,* Efficiency and *Jsc*

Both Fill factor and Voc shows a decreasing nature for high temperature. Among them Voc has a higher degrading nature with the increase of temperature. The performance of FF and Voc parameters for this solar cell degrades with the increase of temperature in Fig. 4. From the above figure it can be said that an efficient result is found for 20°C. But by considering the ambient condition it is kept at 25°C. To calculate the simulated result for the temperature and it is found that at -0.031%/°C of temperature coefficient. It represents that it has a better performance as it shows lower temperature gradient.

D. Event of Lifetime

To observe the cell performance from Fig. 5, it has been investigate the relationship between lifetime and efficiency as well as lifetime and current density where the lifetime is varied from 10 ns to 100 ns. It has been showed that both power conversion efficiency and short circuit current density remain constant. Means efficiency or current density does not vary with lifetime. By considering the ideal condition lifetime is selected as 100 ns.

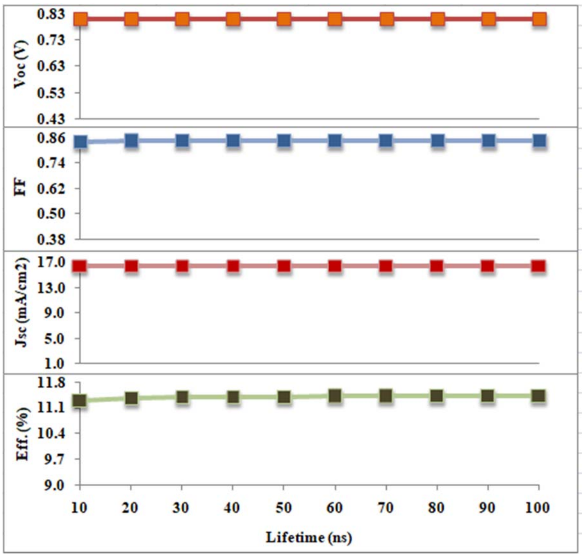

Fig. 5 Event of lifetime variation on *Voc, FF*, Efficiency and *Jsc*

The Fig. 5 shows the cell performance using both FF and *Voc* parameters where it has been seen that for the variation of the lifetime of solar cell the open circuit voltage remains approximately constant. On the contrary, lifetime has been varied from 10 ns to 100 ns where FF increases in a little amount from 10 ns to 20 ns and just after 20 ns it remains constant. So for observation the output lifetime is selected for 100 ns.

Table II shows the optimized result for the Graphene/GaAs solar cell where the cell efficiency is around 15.17 precent with 18.19 mA/cm^2 current density and for this solar cell FF is attained about 0.86 and for *Voc* is about 0.97 V.

TABLE II OPTIMIZED RESULT OF THE SCHEMED CELL

***Jsc* (mA/cm²)**	**Efficiency (%)**	**FF**	***Voc* (V)**
18.19	15.17	0.86	0.97

By considering the result of table II, J-V characteristics curve is drawn in the following Fig. 6.

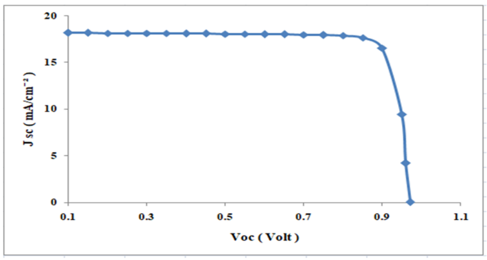

Fig. 6 J-V characteristics curve of proposed GaAs cell

From Fig. 6, it has been seen that the current density is almost same up to 0.8 volt and then suddenly falls to zero for maximum value of open circuit voltage whereas the maximum current density is ontained at zero open circuit voltage. Here in the above J-V curve the maximum open circuit voltage is found at 0.97 V and maximum current density is 18.19 mA/cm².

E. Optimized Results

By comparing the above figures obtained from the proposed cell, the thickness of each layer is determined in the following table.

TABLE III THICKNESS OF EACH LAYER OF OPTIMIZED SOLAR CELL

layer	**n-Graphene**	**p-GaAs**
Thickness(nm)	60	1000

IV. CONCLUSION

The prospective and encouraging window layer as Graphene with p-type GaAs layer which has been simulated with inspected by AMPS-1D software and a economic efficiency is attained for 1000 nm GaAs absorber layer and 60 nm Graphene window layer. It is found that the best conversion efficiency is 15.17% (J_{sc} = 18.19 mA/cm^2, FF = 0.86, V_{oc} = 0.97 V). The temperature coefficient of the propound cell was found -0.031%/°C. But to fabricate this solar cell model in practical field, some constraints must be considered to boost up the collecting level and at last to increase the power conversion efficiency.

ACKNOWLEDGMENT

This work has been supported by the Department of Electrical and Electronic Engineering (EEE) and Renewable Energy Laboratory (REL), Chittagong University of Engineering and Technology (CUET), Bangladesh.

REFERENCES

[1] Ideas for an Essay on Renewable Energy or Alternative Energy Essay Posted on July 23, 2012 by Essay Shark.

[2] Highly efficient single-junction GaAs thin-film solar cell on flexible substrate. Sunghyun Moon , Kangho Kim, Youngjo Kim, Junseok Heo & Jaejin Lee. Scientific Reports 6, Article number: 30107 (2016).

[3] W. P. Hirshman, “Surprise, surprise (cell production 2009: survey),” Photon International, pp. 176–199, 2010.

[4] T. P. Kimbis, “Solar energy technology program,” US Depart-ment of Energy, 2011, http://www1.eere.energy.gov/solar/ pdfs/solar program mypp 2008-2012.pdf.

[5] Alferov, Zh. I., V. M. Andreev, M. B. Kagan, I. I. Protasov and V. G. Trofim, 1970, ‘‘Solar-energyconverters based on p-n AlxGa1−xAs-GaAs heterojunctions,’’ Fiz. Tekh. Poluprovodn. 4, 2378 (Sov. Phys. Semicond. 4, 2047 (1971).

[6] *Yablonovitch, Eli; Miller, Owen D.; Kurtz, S. R. (2012). "The opto-electronic physics that broke the efficiency limit in solar cells". 2012 38th IEEE Photovoltaic Specialists Conference. p. 001556.*

[7] *Wang, X.; et al. (2013). "Design of GaAs Solar Cells Operating Close to the Shockley–Queisser Limit". IEEE Journal of Photovoltaics. 3 (2): 737.*

[8] 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 ICECE 2016,* Dhaka, Bangladesh, Dec. 2016.

[9] Mrinmoy Dey, Maitry Dey, M. A. Matin and Nowshad Amin, “Design of High Efficient and Stable Ultra-Thin CdTe Solar Cells with ZnTe as a Potential BSF,” in *Proc. of the ICGET 2015,*Dhaka, Bangladesh, Sep. 2015.

[10] Mrinmoy Dey, M. A. Matin and Maitry Dey, “Arsenic Telluride BSF for High Performance and Stable ultra-thin CdTe PV cell,” *International Journal of Research in Computer Engg. and Electronics,* vol. 4, no. 2, July 2015.

[11] Mrinmoy Dey, Maitry Dey, M. A. Matin and Nowshad Amin, “Design of high performance and ultra-thin CdTe solar cells with SnTe BSF from numerical analysis,” in *Proc. of the ICCIT 2015,* Dhaka, Bangladesh, Dec. 2015.

[12] Mrinmoy Dey, M. A. Matin, Nipu Kumar Das and Maitry Dey, “Germanium telluride as a BSF material for high efficiency ultra-thin CdTe solar cell,” in *Proc. of the IFOST 2014,* Cox’s Bazar, Bangladesh, Oct. 2014.

[13] M. A. Matin and Mrinmoy Dey, “High performance ultra-thin CdTe solar cell with Lead Telluride BSF,” in *Proc. of the ICIEV 2014,* Dhaka, Bangladesh, May 2014.

[14] M. Gloeckler, A. L. Fahrenbruch and J. R. Sites, "Numerical modeling of CIGS and CdTe solar cells: setting the baseline," Photovoltaic Energy Conversion, 2003. Proc. of 3rd World Conf. on, Osaka, Japan, vol. 1, pp. 491-494, 2003.

[15] Mrinmoy Dey, Maitry Dey, M. A. Matin and Nowshad Amin, “High performance and stable molybdenum telluride PV cells with Indium Telluride BSF,” in *Proc. of the ICDRET 2016,* Dhaka, Bangladesh, January 2016.

[16] Mrinmoy Dey, Maitry Dey, M. A. Matin and Nowshad Amin, “Design of Highly Stable and Efficient Molybdenum Telluride PV Cells with Arsenic Telluride BSF,” in *Proc. of the iCEEiCT 2016,* Dhaka, Bangladesh, Sep. 2016.

[17] Mrinmoy Dey, Maitry Dey, M. A. Matin and Nowshad Amin, “Enhancement the Performance of Molybdenum Telluride Solar Cells with Zinc Telluride BSF,” in *Proc. ICISET 2016,* Dhaka, Bangladesh, Oct. 2016.

[18] Mrinmoy Dey, Rishita Chakma, Nazia Rahman, Maitry Dey, N. K. Das, A. K. Sen Gupta, M. A. Matin, Nowshad Amin, “Study of ultra-thin and stable AlSb solar cell with potential copper telluride BSF,” in *Proc. of* R10-HTC-2017, Dhaka, Bangladesh, 21-23 Dec. 2017.

[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. ECCE 2017,* Cox’s Bazar, Bangladesh, 16-18 Feb. 2017.

[20] Mrinmoy Dey, Maitry Dey, Tama Biswas, Samina Alam, N. K. Das, M. A. Matin and Nowshad Amin, “Modeling of Cu_2ZnSnS_4 Solar Cells with Bismuth Sulphide as a Potential Buffer Layer,” in *Proc. ICIEV 2016,* Dhaka, Bangladesh, May 2016.

[21] 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,” in *Proc. iCEEiCT 2016,* Dhaka, Bangladesh, September 2016.

[22] 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 ECCE 2017,* Cox’s Bazar, Bangladesh, 16-18 Feb. 2017.

[23] Mrinmoy Dey, Mahmudul Hasan, Rahat Amin and Maitry Dey, “Numerical analysis of efficient cadmium selenide solar cell,” *in Proc. of the EICT 2017,* Khulna, Bangladesh, 07-09 Dec. 2017.

[24] 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*," in Proc. of the ICEME 2017,* Chittagong, Bangladesh, 18-20 Dec. 2017.

[25] S. J. Gong, Q. C. Peng and X. W. Zhao, “Simulation of graphene-GaAs Schottky barrier solar cell with AMPS-1D,” *Journal of Materials Research Innovations*, 2015.