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Recent Study of Nanotechnology Application in Efficiency Enhancement for Solar Energy System Development

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***Abstract*—The establishment of the renewable energy transition roadmap has led to the utilization of solar energy in decreasing the dependencies on electricity generation using thermal coal. Since the development of the solar farm requires a lot of investment, the solar panel must be able to capture maximum photons from sunshine to generate more electricity. Because of this, the study related to solar energy shifted to developing an efficient solar energy harvesting from sunlight. The attention of the study of the solar cell falls on the improvement of the efficiency of photon capturing ability using several nanotechnology applications. In this paper, a recent study of nanotechnology application in efficiency enhancement for solar energy system development is reviewed with the latest literature. The aim of this review is to identify the research gap found in the latest literature that could outline the issues in preparing further improvement planning to enhance the efficiency of the solar energy system.**

***Index Terms*—Nanotechnology, Solar Energy System.**

I. Introduction

NANOTECHNOLOGY is the study for the development of nanoscale materials with diameters ranging from 1 to 100 nanometers. This nanomaterial is either in solid materials or chemical substances. The main objective of having the nanomaterial is to develop a small-scale device which used to increase the strength of the materials, manipulating the reactivity of the chemical composition of the materials, and changing the conductivity properties of the materials [1]. Nanotechnology can be defined as an engineered nanomaterial in producing a specific function in a wide range of applications of engineering, manufacturing, medical, and energy-based system including solar energy system development.

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In preserving nature and keeping the balance between the need for electrical power and reducing carbon emissions, researchers had been developing a new approach to providing an alternative solution for energy generations. A renewable energy source such as hydro-dam, wind, and solar could deliver a safe and sustainable energy production chain that can reduce the dependencies on thermal coal generators. Since it was first discovered as one of the electricity generators, the study on solar energy had shifted into the efficiency study [2].

The research involves in solar energy development is aimed to increase the sunlight absorption rate of the solar cells, increase the conversion of solar to electrical energy efficiency, discovering new materials to reduce the manufacturing cost and process, and develop robust photovoltaic materials which can be expanded into different scales and adaptable in different localities.

The study on solar energy system involves in developing a small-scale system to allow a preliminary study conducted in order to observe the amount of solar energy potential before massive construction of solar farm take place at the specific location [3-4]. This requires not only small-scale devices but delivers measurement exactly the same as the real-size solar panels. Fig.1 below shows the solar energy potential tracking system.

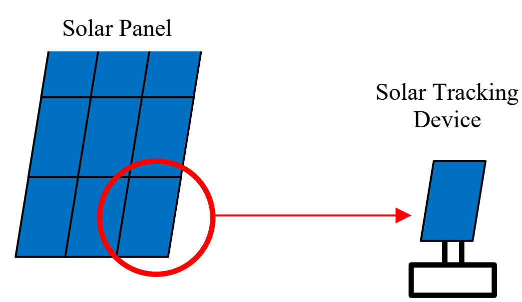

Fig. 1 Solar energy potential tracking system.

Based on Fig.1, the small-size device constructed for the small-scale solar energy potential tracking system is retrieved from a portion of the real-size device.

In this paper, the recent trends on nanotechnology applications are reviewed and analyzed to discover the gap and possible improvements that can be performed to enhance efficiency and other related issues.

II. SOLAR ENERGY SYSTEM

The history of solar energy starts in 1839 by French physicist, Edmond Becquerel with the discovery of the photovoltaic effect [5]. The involvement of materials of sodium sulphates as solar energy storage in 1939 by Maria Telkes. In the same year, Russell Shoemaker Ochs discover the electrical conductivity of a semiconductor when examining a cracked silicon sample [6]. In 1954, Calvin Fuller, Gerald Pearson, and Daryl Chapin from Bell Labs had built the world's first practical silicon-based solar cell [7]. Based on the Periodic Table, Silicon has 14 protons in the center and 14 electrons in the circle as shown in Fig.2 below.

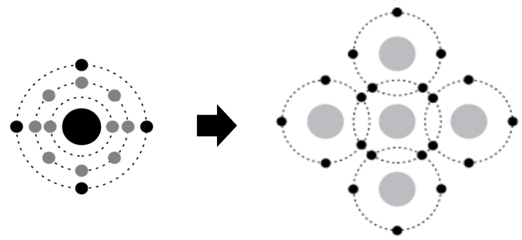

Fig. 2 Atomic structure of silicon.

The number of atoms in the outermost circle indicates that a half-full. Because of this, the silicon will always combine together to fill the empty space in the outermost circle. This combination form is defined as a crystalline structure form [8]. With this combination, there is no possible movement of the electrical current. To create the 'free carrier' of the electron, the silicon is dopped with another element such as phosphorous a shown in Fig.3 below.

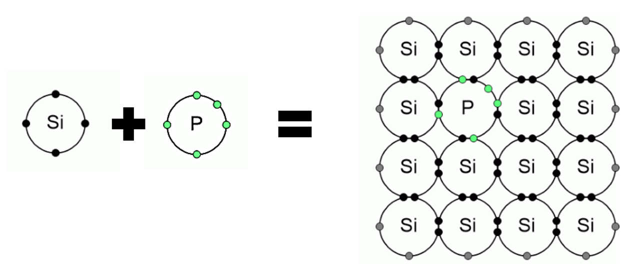

Fig. 3 Phosphorous dopped silicon structure.

With phosphorus, the extra electron immediately becomes a 'free carrier' which able to carry an electrical current. This whole process is called the doping process which can be defined as adding an impurity to the element. The doping process of silicon with phosphorus is defined as n-type silicon because it results in excessive electrons, while the doping process of silicon with a smaller number of electrons such as Boron results in excessive holes is defined as p-type silicon. Both n-type and p-type semiconductor is applied in the solar panel development. The n-type semiconductor is used in the surface layer of the solar panel while the p-type semiconductor is used in the second layer of the solar panel as shown in Fig.4 below.

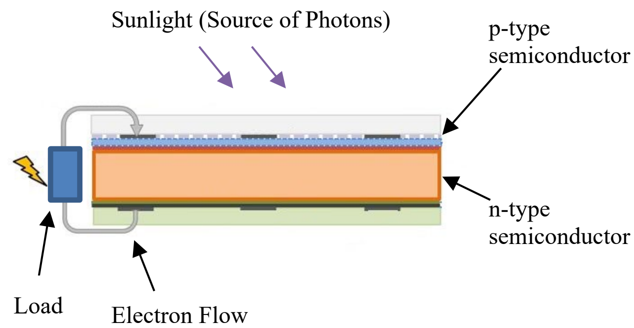

Fig. 4 Cross-sectional diagram of solar cells.

Based on Fig.4, when the sunlight shines on the p-type semiconductor materials, it creates an imbalance sequence and initiates the movement of the electrons and holes. This continues in the second layer consists of an n-type semiconductor with the movement of the holes and electrons. Entire movement for the act of electrons and holes balance is what generates the electricity [9].

Solar cells made from a silicon wafer. The construction of solar cells must be skinny as possible to produce the maximum value from its crystal structure. This will enhance its efficiency in captures and produces more electricity. There are two types of crystalline solar panels; monocrystalline and polycrystalline as shown in Fig.5 below.

Fig. 5 Crystalline solar panels.

Monocrystalline refers to single-crystal silicon while polycrystalline refers to multi-crystal silicon [10]. Further comparison of this crystalline is shown in Table I below.

TABLE I
COMPARISON OF THE CRYSTALLINE

Key Metrics	Monocrystalline	Polycrystalline
Aesthetics	Black-hue solar cells	Blue-ish solar cells
Life-span	25 years	25 years
Cost	More expensive	Less expensive
Efficiency	More efficient	Less efficient

Another type of silicon form in the solar panels is amorphous silicon. Amorphous silicon applied in the development of flexible solar panels and widely used in thin-film solar panels [11]. These non-crystalline silicon cells are bendable and applied in a substrate such as glass, metal, and plastic. Even thou that it presents versatility, amorphous solar cells are not efficient compared to crystalline cells.

III. Nanotechnology Application

A. Literature Search

Based on a literature search, it is found that recent studies on nanotechnology materials and fabrication of solar cells are focusing on graphene materials, perovskite composition, and Quantum Dot materials. A more advanced study had been established in using a hybrid approach of combining all approaches together in developing a solar cell. The aim of the study and approach is to introduce the new type of nanomaterial combination and establish an improvement in the fabrication process of the nanomaterial to gain high-efficiency results and proposing a new cheaper material to reduce the cost of manufacturing. This paper will review these nanomaterials as shown in Fig.6 in order to get a view of the recent work progress with some new approaches associated with it.

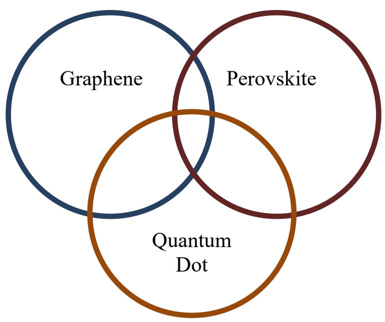

Fig. 6 The nanomaterials in solar cell development.

B. Graphene

Study on the material had bought the intention towards the development of solar cell using graphene. Graphene consists of single-layer carbon atoms which bonded together infusing into the orientation of a honeycomb pattern [12] as shown in Fig.7.

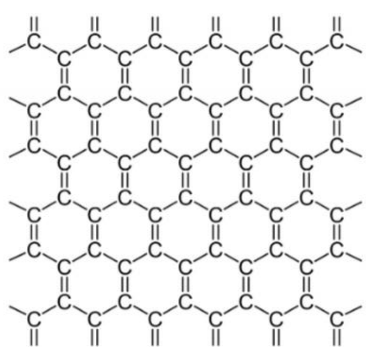

Fig. 7 Illustration of Graphene atomic structure.

It is an extremely strong material but comes in almost transparent materials. Despite being flexible, graphene has the most conductive materials for electricity and heat [13]. Because it is made of carbon, it is relatively the most inexpensive material. Application of it can be found in construction materials for buildings, aerospace, and many more. Graphene has an extremely high surface area to volume ratio which makes it suitable to be used in a component such as batteries and even in supercapacitors construction. Although graphene is an excellent conductor, it is ineffective at collecting the electrical current generated inside the solar cell [14]. The current study conducted to seek a solution by adding other materials to enhance its performance such as the fabrication of graphene oxide.

N. Bahare et al. [15] present the hybrid combination of nickel sulfide (NiS), graphene oxide (GO), and polypyrrole for the preparation of platinum-free dye-sensitized solar cell using two-step electrochemical deposition method on Fluorine-doped Tin Oxide for the Counter Electrode. The hybrid combination results lowest resistance value for transfer charge in maximum exchange current value. The results show that the proposed combination gained the Power Conversion Efficiency (PCE) of 6.32%.

G. Lalsingh et al. [16] present a novel hybrid poly-ethylene dioxythiophene: poly styrenesulfonate-graphene oxide (PEDOT: PSS-GO) composite as hole transportation material to enhanced the performance of Ternary -blend Polymer solar cell. As a result, PEDOT: PSS-GO had improved the PCE of 7.1%.

K. Muhammad et al. [17] present a new K-Azo organic compound to increase the electrical and optical performance of graphene oxide (GO) and the nanostructured films of reduced GO (rGO). In this paper, a new chemical vapor method had been introduced for synthesis process for both GO and rGO. Based on the results, it is shown that the K-Azo sensitizer application on GO and rGO manage to increase their conductivity profile.

C. Perovskite

Perovskite composition as shown in Fig.8 is formulated from calcium titanate (CaTiO3) compound that has a bonding ABX3 molecular structure where A and B refer to cations while X is referred to as an anion [18].

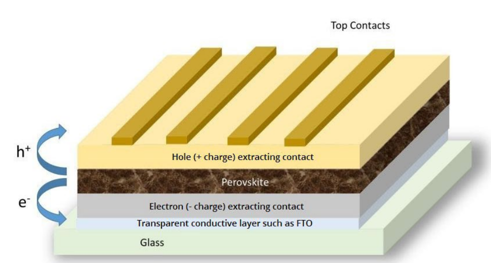

Fig. 8 Illustration of Perovskite solar cell.

Based on this compositional flexibility, various studies had been conducted using a large number of different combinations of elements for produced the perovskite structures. Solar cells using semiconductor materials to convert light into electricity. By using the perovskite approach, different materials can be used to develop the thin-film solar cell other than the expensive material of silicon. A recent study had recorded an increasing efficiency of the perovskite approach surpassing the efficiency of conventional silicon cells. This notably the right track in seeking alternative materials in reducing the cost without neglecting the efficiency performance.

D. Zhenghong et.al [19] present the interfacial toughening for perovskite solar cells using iodine-terminated self-assembled monolayers to enhance the PCE. This is done to increase the adhesion strength for the gap between the electron transport layer and halide Perovskite thin film. This also contributes to mechanical reliability enhancement. The result shows the PCE is increased from 20.2% to 21.4%.

A. Erdi et.al [20] present the α-FAPbI3 perovskite stabilization phase using passivation agent of 2,3,4,5,6-Pentafluorobenzyl Phosphonic Acid (PFBPA). The implementation of PFBPA not only manage to improve the PCE to 22.5% but also laminated the perovskite layer and maintained the humidity level of the solar cell for a long-term stability enhancement.

D. Xingdong et.al [21] present the new approach of using Pyridine-functionalized hole transport material to increase the efficiency of the perovskite solar cell. The hole transport material developed using two phenothiazine; PTZ-Py and PTZ-Bz in passivating the perovskite surface defect and increase the PCE by 19.9%. Later, this PTZ-Py had been interface with Spiro-OMeTAD and manage to obtain the PCE of 22.1%.

K. Manish et.al [22] performed a simulation study on the PCE of the inorganic lead-free double perovskite material of La2NiMnO6 solar cells. The optimization is based on the First Principal Density Functional Theory calculation method with TiO2 as an electron transport layer and CuI as the hole transport layer. This optimization manages to obtain a PCE of 15.42%.

D. Quantum Dot

In seeking a low-cost material, non-toxic copper-based quantum dots had been discovered to deliver both longevity and efficiency. Quantum Dot defined as tiny spheres of semiconductor material with diameter in the range of 2-10 billionths meter [23]. It has the potential to boost the light to energy conversion efficiency by generating more electron-hole pairs per incoming photon from the sunlight. The study had been widely conducted in developing a new method such as hot-electron extraction and carrier multiplication to enable a solution-processed semiconductor Quantum Dot solar cell. Besides improving the efficiency of the energy conversion and lowering the cost, another improvement that had been considered is producing the thinnest and light-weight solar panels.

S. Han et.al [24] present the secondary deposition approach using the formation of a metal-oxyhydroxide layer on pre-sensitized photoanodes of the Quantum Dot. This experiment uses the MgCl2-ZnCuInSSe Quantum Dot sensitized TiO2 film electrodes. The increase of Quantum Dot loading and light-harvesting capacity enhancement, photocurrent, and photovoltage observed a significant improvement. The PCE results of the proposed Quantum Dot had increased from 13.54% to 15.31%.

D. P. Vinoth et.al [25] present the simple method for C-axis orientation preparation for ZnO nanorod thin films. The sol-gel dip coating and spin coating method had been used to generate the seed layer. The results show that the spin coating technique produces a well-grown single-crystalline of ZnO nanorods. These ZnO nanorods had been constructed in solar cells by using CdSe Quantum Dots and manage to obtain a PCE result of 2.82%.

S. Han et.al [26] had reported that the performance of the Quantum Dot sensitized solar cell is based on the photoelectronic properties. In the experiment results based on ZnCuSSe-quinary alloyed Quantum Dot using cation-anion co-alloying strategy, the ability to tailor the critical properties of photoelectronic can be achieved. The results show that quinary alloyed Quantum Dot using cation-anion alloying manage to obtained a PCE result of 14.4% compared with single anion or cation quaternary alloyed Quantum Dot.

E. Combination of Graphene-Perovskite-Quantum Dot

The possible combination of nanomaterials had embarked on a new path in producing a significant improvement on the PCE result of the solar cells. H. R. Mohseni et.al [27] present the combination of the reduced graphene oxide – polyaniline composite in mesoporous TiO2 precursor solution to improve the performance of triple-cation perovskite solar cells. This combination results in a PCE of 16.48% compared with pure mesoporous TiO2.

C. Meitong et.al [28] present the graphene – Cu2-XSe composite prepared as the counter electrode for the Quantum Dots sensitized solar cells. Based on the results, it is shown that the combination of graphene - Cu2-XSe improved the PCE by 6.66% compared with bare Cu2-XSe with 5.95%. This shows that the combination of the high conductivity of graphene and high catalytic activity of Cu2-XSe produce high-efficiency Quantum Dots sensitized solar cells.

W. J. Chan et.al [29] present a combination of graphene-Quantum Dots in interfacial and passivating layers for porous silicone (PSi) solar cells. This combination produces the PCE results of 13.66%. The application of graphene as an interlayer had also deployed by A. C. Luigi et.al [30] in incorporating the potassium-doped graphene oxide as an interlayer between mesoporous TiO2 and perovskite layer. The combination produces the PCE results of 18.3%.

IV. Discussions

Based on the literature search on the recent trends of nanomaterial application on solar energy system development, it is shown that various studies had conducted in combining the three main nanomaterials of graphene, perovskite, and Quantum Dots configuration. This nanotechnology covers the functional studies which directly influences the efficiency of solar cells in developing a nanomaterials configuration to uncover less expensive materials, increasing the absorption of the photon from the sunlight, improving the efficiency of the solar cells in light-energy conversion, and improving the durability of the solar cells by nanocoating applications. The advancement of nanotechnology application in solar cells is divided into three categories as shown in Fig. 9 below.

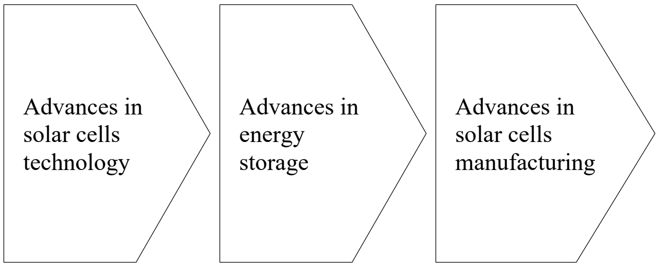

Fig. 9 Advancement of nanotechnology in solar cells.

The key objective in the solar cell's technology is to discover an alternative way of efficiency improvement with cost-effective materials. This includes the lifespan of the solar cells and getting the most of the sunlight to produce a maximum volume of electricity. Currently, the solar cells are approximately having on 15% of the ability in retrieving sunlight. That is why the study on PCE enhancement is carried out to retrieve another 85% of the sunlight. The study involves the application of light-sensitive nanoparticles for new materials development of the semiconductor in order to take full advantage of receiving all the light as much as possible.

Besides increasing the efficiency of the energy retrieval mechanism, the study is also conducted to develop energy storage for solar energy. This is an important aspect as the photovoltaic system only produces electricity in the presence of the sun. In order to keep generating and delivering electricity, the solar cells must actively retrieve light and store it in energy storage. To have good efficiency of storage, several studies had been conducted using different types of technology to reduce the cost and at the same time preserving the energy efficiency. Molten Salt Storage Technology uses an inorganic salt for energy transfer materials in a photovoltaic system. The solar energy is transferred into solar thermal using heat transfer fluid. This technology enables the solar plant to handle high temperatures of approximately 500°C and eventually results in high output power. Another leap in solar energy storage study is the introduction of a built-in battery mechanism for the individual solar panel. This design helps in reducing the needs of other full-scale storage systems.

The cost is always an issue whenever new technology or application to be deployed. Nanotechnology is becoming a key element in driving the advancement of solar cell manufacturing. This includes the development of cheaper material but with a high-efficiency performance. The thin-film technology had been introduced using a narrow coating of cadmium telluride. But this cadmium telluride becomes highly unstable during the manufacturing process with the use of cadmium chloride. That is why the study had been conducted in replacing the cadmium chloride with magnesium chloride which recovered from seawater. By doing this, the efficiency of solar cells can be increased up to 15% and at the same time lowering the manufacturing cost.

The advancement of technology also brings a new path in developing newly enhanced features of solar energy systems. There is a recent study that implements the solar energy system into building construction, transportation, and communication application. This will contribute to more challenges in preparing the solar cell which can accommodate those needs.

Based on the recent nanotechnology application on solar cell fabrication, graphene, perovskite, and Quantum Dot are shown as recent materials which had been experimented with for solar cell fabrication. The study was carried out by implementing the combination of more than one material which had given a significant improvement compared with the application of the single material. However, based on the PCE results, the perovskite provides good results followed by Quantum Dots and graphene.

V. Conclusions

This paper reviewed the recent study of nanotechnology application in solar energy system development, especially in solar cell construction. The aim of the advanced research on solar cells is to have an efficient electricity generation process. Currently, the solar cells used in the photovoltaic system could only produce 15% electricity. Making 85% losses in retrieving the sunlight. Based on the literature, there are three most studied materials used in developing solar cells consists of graphene, perovskite, and Quantum Dots. The aim of the study is also to retrieve high-efficiency materials at a lower cost. There are also studies done by researchers in combining these materials to obtain high PCE values. PCE stands for Power Conversion Efficiency (PCE). This will be the scale for the materials in the electricity generation from the solar cells. Based on the literature, the perovskite materials had produced compromising PCE values compared with graphene and Quantum Dots. Thus, for further improvement of the PCE values, the consideration will be on the enhancement of the perovskite materials.

Acknowledgment

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References

[1] K. Ibrahim, S. Khalid, and K. Idrees, "Nanoparticles: Properties, Applications and Toxicities," *Arab. J. Chem.*, vol. 12, pp 908-931, 2019.

[2] G. Dolf, B. Francisco, S. Deger, D. B. Morgan, W. Nicholas, and G. Ricardo, "The Role of Renewable Energy in the Global Energy Transformation," *Ener. Stra. Rev.*, vol. 24, pp 38-50, 2019.

[3] O. Brian, A. John, and M. Grey, "Small-Scale Use of Solar Power in Remote, Developing Regions: A Case Study," *J. Sust. Dev.*, vol. 4, 2011.

[4] M. Ratan and P. Srinjoy, "Design and Feasibility Studies of a Small Scale Grid Connected Solar PV Power Plant," *Ener. Proc.*, vol. 90, 2016.

[5] L. Daniel, "The New Paradigm of Photovoltaics: From Powering Satellites to Powering Humanity," *Comp. R. Phys*, vol. 18, 2017.

[6] B. Jayesh, P. Amrat, and P. Kaushik, "A Review on History and Power From Sunshine and Storage of it," *Int. J. Adv. Res. Eng., Sci. Tech.*, vol. 2, no. 9, 2015.

[7] L. Youn-Jung, K. Byung-Sung, S. M. Ifitiquar, P. Cheolmin, and Y. Junsin, "Silicon Solar Cells: Past, Present and the Future," *J. Korea. Phys. Socie,* vol. 65, pp 355-361, 2014.

[8] S. Rabindra and P. Venkateswarlu, "Chapter 4 – Making of Crystalline Silicon Solar Cells," in Solar PV Power: Design, Manufacturing and Applications from Sand to Systems, Academic Press, pp 71-134, 2021.

[9] S. S. R. Mohd, B. W. Santosh, S. L. Suvarna, V. F. Pooja, and T. Anil, "A Review Paper on Electricity Generation from Solar Energy," *Int. J. Res. App. Sci. Eng. Tech.*, vol. 5, pp 1884-1889, 2017.

[10] L. A. Dobrzanski, M. Szczesna, M. Szindler, and A. Drygala, "Electrical Properties Mono and Polycrystalline Silicon Solar Cells," *J. Achi in Mat. Manu. Eng.,* vol. 59, no. 2, 2013.

[11] T. Soderstrom, F. J. Haug, V. Terrazzoni-Daudrix, and C. Ballif, "Optimization of Amorphous Silicon Thin Film Solar Cells for Flexible Photovoltaics," *J. Appl. Phys.,* vol. 103, 2008.

[12] Y. Gao, L. Lihua, B. L. Wing, and C. N. Man, "Structure of Graphene and Its Disorders: A Review," *Sci. Tech. Adv. Mater.*, vol. 19, no. 1, pp 613-648, 2018.

[13] B. Claudia et.al, "Production and Processing of Graphene and Related Materials," *2D Mater.,* vol. 7, no. 2, 2020.

[14] D. Santanu, S. Pitchaimuthu, S. K. Yong, and C. Wonbong, "Graphene Synthesis and Application for Solar Cells," *J. Mater. Res.*, vol. 29, no. 2, pp 299-319, 2014.

[15] N. Bahare, G. Shahram, and R. H. Sayed, "Nanostructured Nickel Sulfide / Graphene Oxide-Polypyrrole as Platinum-free Counter Electrode for Dye-sensitized Solar Cell," *J. Photochem. Photobio. A: Chem.*, vol. 405, 2021.

[16] G. Lalsingh, S. Kuldeep, V. S. C. Reddy, and K. Kusum, "Improved Performance of Ternary Blend Polymer Solar Cells via Work Function Tuning and Suppressed Interface Recombination using Hybrid PEDOT:PSS-Graphene Oxide Hole Transport Layer," *Appl. Surf. Sci.*, vol. 540, no. 1, 2021.

[17] K. Muhammad, J. Erdawaty, K. S. Siti, W. L. Foo, D. H. Nguyen, A. Awais, A. Anees, N. Zainab, S. Muhamamd, and Q. Ahsanulhaq, "Organic Sensitization of Graphene Oxide and reduced Graphene Oxide Thin Films for Photovoltaic Applications," *Int. J. Ener. Res.*, 2021.

[18] A. A. A. Torimtubun, A. C. Augusty, E. Maulana, and L. Ernawati, "Affordable and Sustainable New Generation of Solar Cells: Calcium Titanate ($CaTiO_3$)-based Perovskite Solar Cells," *3rd i-TREC,* 2018.

[19] D. Zhenghong, K. Y. Srinivas, C. Min, A. Ali, Q. Yue, and P. P. Nitin, "Interfacial Toughening with Self-Assembled Monolayers Enhances Perovskite Solar Cell Reliability," *Science*, vol. 372, no. 6542, pp 618-622, 2021.

[20] A. Erdi, E. S. Ahmed, S. Faranak, and A. Seckin, "Moisture-Resistant $FAPbI_3$ Perovskite Solar Cell with 22.25% Power Conversion Efficiency through Pentafluorobenzyl Phosphonic Acid Passivation," *Chem. Sust. Ener. Mater.*, vol. 14, no. 4, pp 1176-1183, 2021.

[21] D. Xingdong, W. Haoxin, C. Cheng, L. Hongping, T. Yi, L. Qijun, D. Liming, Y. Xichuan, and C. Ming, "Passivation Functionalized Phenothiazine-based Hole Transport Material for Highly Efficient Perovskite Solar Cell with Efficiency Exceeding 22%," *Chem. Eng. J.,* vol. 410, 2021.

[22] K. Manish, R. Abhishek, K. Arvind, and A. Avneesh, "Theoretical Evidence of High Power Conversion Efficiency in Double Perovskite Solar Cell Device," *Opti. Mater.*, vol. 111, 2021.

[23] B. Debasis, Q. Lei, T. Teng-Kuan, and H. H. Paul, "Quantum Dots and Their Multimodal Applications: A Review," *Materials,* vol. 3, 2010.

[24] S. Han, L. Yu, Z. Zhengyan, R. Huashang, W. Wenran, F. Yueping, P. Zhenxiao, and Z. Xinhua, "Improving the Efficiency of Quantum Dot Sensitized Solar Cells beyong 15% via Secondary Deposition," *J. Amer. Chem. Soc.*, vol. 143, no. 12, pp 4790-4800, 2021.

[25] D. P. Vinoth, V. Saraswathi, N. Muthukumarasamy, S. Agilan, P. Balraju, and V. Dhayalan, "C-axis Oriented ZnO Nanorods based Quantum Dot Solar Cells," *Opti. Mater.,* vol. 112, 2021.

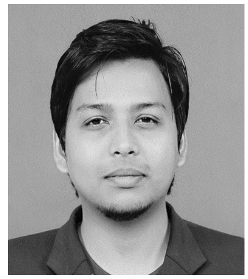
[26] S. Han, L. Yu, Z. Mengsi, R. Huashang, P. Zhenxiao, and Z. Xinhua, "Zn-Cu-In-S-Se Quinary "Green" Alloyed Quantum-Dot-Sensitized Solar Cells with Certified Efficiency of 14.4%," *Ange. Chemie Int. Edi.*, vol. 60, no. 11, pp 6137-6144, 2021.

[27] H. R. Mohseni, M. Dehghanipour, N. Dehghan, F. Tamaddon, M. Ahmadi, M. Sabet, and A. Behjat, "Enhancement of the Photovoltaic Performance and the Stability of Perovskite Solar Cells via the Modification of Electron Transport Layers with Reduced Graphene Oxide/Polyaniline Composite," *Solar Energy*, vol. 213, pp 59-66, 2021.

[28] C. Meitong, D. Zhonglin, Z. Yanying, L. Lin, J. Shujie, A. Fahad, and S. Shichen, "Enhanced Photovoltaic Performance of Quantum Dot-Sensitized Solar Cells using Graphene/ $Cu_{2-X}Se$ Composite Counter Electrode," *J. Alloy Comp.*, vol. 851, 2021.

[29] W. J. Chan, H. S. Dong, and C. Suk-Ho, "Porous Silicon Solar Cells with 13.66% Efficiency achieved by Employing Graphene-Quantum Dots Interfacial Layer, Doped-Graphene Electrode, and Bathocuproine Back-surface Passivation Layer," *J. Alloy. Comp.*, vol. 877, 2021.

[30] A. C. Luigi et.al, "Air-processed Infrared-Annealed Printed Methylammonium-Free Perovskite Solar Cells and Modules Incorporating Potassium-Doped Graphene Oxide as an Interlayer," *ACS Appl. Mat. Inter.*, vol. 13, no. 10, pp 11741-11754, 2021.



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