Materials Today: Proceedings 66 (2022) 1295–1302

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Performance and efficiency of different types of solar cell material – A review

J. Dhilipan[a], N. Vijayalakshmi[a], D.B. Shanmugam[a], R. Jai Ganesh[b,*], S. Kodeeswaran[c], S. Muralidharan[d]

[a] Department of Computer Applications, SRM IST, Ramapuram Campus, Chennai, India
[b] Department of EEE, K.Ramakrishnan College of Technology, Trichy, India
[c] School of Electrical Engineering, SASTRA Deemed to be University, Thanjavur, India
[d] Department of EEE, Mepco Schlenk Engineering College, Sivakasi, India

ARTICLE INFO

Article history:
Available online 21 May 2022

Keywords:
Renewable energy
Solar cell
Challenges
Classification of solar cell materials
Comparison

ABSTRACT

Owing to the rapid increase in industrialization and population, global energy demand is at an extreme, whereas traditional fossil fuels such as coal, natural gas and oil, etc. are quickly exhaust. It is predicted that in the next 200–300 years, fossil fuels, particularly oil, will be depleted. The alternative source of energy is renewable energy. Many households are converting to pure, renewable electricity sources as the cost of renewable energy begins to fall. Amongst which, residential solar is among the most accessible and abundant. Fossil fuels create toxic emissions that influence the quality of water, air and soil and are concerned about global warming, another justification for choosing solar energy. Solar energy has been produced from the sun and eliminates the hassle, confusion and cost of fueling a generator powered by gas or diesel. However some of the challenges that solar cells undergo are dependent on the nature of the materials and are especially susceptible, at even low concentrations, to chemical and structural deficiencies. Materials supply and production control to achieve low prices. Durability and material ageing at the level of solar cells and modules are also a concern, as this influences the technology's reliability and ultimately the cost. This review paper discusses the recent production of cells in direct to build the efficiency of various types of conventional solar cells more effective and comparative.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Thermal Analysis and Energy Systems 2021.

1. Introduction

1.1. History of solar cell

In 1958, solar cells from the vanguard satellite were first used in space application. Through the use of solar cells, mission duration could be increased as an alternative energy source instead of a battery. In 1959, the U.S. used an arm-shaped solar array in a satellite called Explorers 6, which was made up of 9600 Hoffman solar cells and became a common feature. The cost of solar cells was quite high at the moment, because in space missions, only performance matters here. The price of solar panels fell as the semiconductor industry moved to Integrated Circuits in 1960, resulting in the development of layer crystals. The price of solar cells decreased to $100 per watt in 1971. The U.S. opened a solar panel testing facility in 1969 for space missions called Research Applied to National Requirements, operated by the National Science Foundation's Advanced Solar Energy Research and Development Division. Until 1977, this initiative continued and research grants on the production of solar power for Surface Electrical energy systems. In the mid-1970s, oil firms placed emphasis on starting power companies and were the main producers for decades. During the early 1980s, ARCO Shell, Exxon, Mobil and Amoco had all formed their main divisions. All of this improves use of solar energy, reduces the energy consumption, and improves solar cell efficiency. As per Bloomberg New Energy Finance results, the cost of solar cells was drastically reduced from $96 per watt in the 1970s to $68 per watt in 2016, due to design improvements and high performance. As the electronics industry moves to larger crystals, ordering devices is simpler.

* Corresponding author.
E-mail addresses: hod.mca.rmp@srmist.edu.in (J. Dhilipan), vijayaln@srmist.edu.in (N. Vijayalakshmi), shanmugd@srmist.edu.in (D.B. Shanmugam), jaiganesh.ram@gmail.com (R. Jai Ganesh), kodikrct@gmail.com (S. Kodeeswaran), yes_murali@yahoo.com (S. Muralidharan).

https://doi.org/10.1016/j.matpr.2022.05.132
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the International Conference on Thermal Analysis and Energy Systems 2021.

1.2. About photovoltaic cells

Photovoltaic cells are a system with a pretty huge potential for growth. According to solar energy forecasts, large surface regions of low-cost high-efficiency solar cells could be built in places with intense sunlight such as the deserts. The basic total mass and low cost enable effective thin film manufacturing where a viable production system can be seen as thermal evaporation. Thermal evaporation has also already been reported in adhesives of indium-copper-selenide-gallium cells. The creation of columnar crystals with large crystal sizes at cold temperatures tends to provide all the semiconducting crystals with strong electrical conductivity. In large quantities, the solar cells are combined and need an affordable medium, like soda lime glass. Using that same material limits potential temperature extremes of the substrate. At a moderate surface temperature of 450 °C, the co-evaporation of In, Ga, Cu, and Se has generated good results. Investigators have been motivated to search for alternate photon absorbing materials by the diminishing global supplies of indium and gallium. Cu2ZnSn(S, Se) 4 (CZTS), that has a kesterite structure, is one potential candidate, where any two atoms of In or Ga in the chalcopyrite structure are substituted by atoms of Zn and Sn. A very much better performance of the CZTS cell has been enabled by the co-evaporation of Cu, Zn, Sn and Se. In Fig. 1 [61], the cross - section of the deposited thin films can be seen.

The huge-area solar cell evaporation industry has a demand for the deposition of uniform coating thicknesses at low deposition temperature. For the increasing solar cell development market, new linear forms of evaporation were created. An illustration is Vacuum processing technique, a linear vapour source that obsesses the vapour flow with vapour shaping guides. The specifications are sheet metal plates that guide vapour to the increasing surface from higher vapour pressure areas, as shown in Fig. 2 [62].

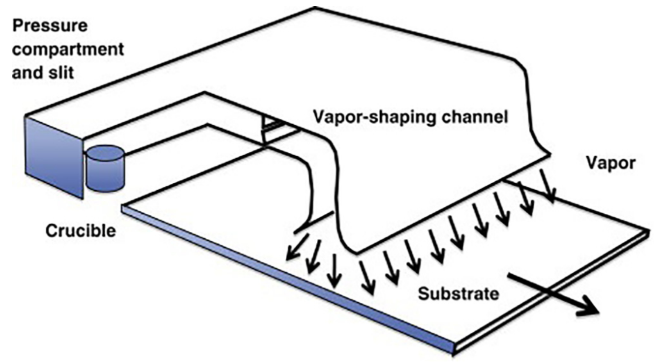

Fig. 2. Schematic of the VPT linear vapour source.

1.3. Mathematical model of solar cell

A single diode connected in parallel with a light produced current source, I_{ph}, is an appropriate photovoltaic cell, where its output current, I, can be represented as.

$I = I_{ph} - I_s[\exp(E/nE_T) - 1]$ (1).where I_{ph} = Photo current; E_T =-Thermal voltage $E_T = kT_C/q$; n = Ideality factor; I_s = Saturation current; T_C = Cell working Temperature;

The equivalent circuit of a functional PV cell is Fig. 3 [71]. R_S is implemented in this analogous model in order to accept voltage drops and internal losses due to current flow, and R_{sh} takes the leakage current to the ground into account when the diode is biased in reverse.

$$I = I_{ph} -- I_0[\exp(E + IR_s)/nE_T) - 1] -- (E + IR_s)/R_{sh} \tag{2}$$

where I_{ph} = Photo current; E_T = Thermal voltage $E_T = kT_C/q$; n = Ideality factor; I_s = Saturation current; T_C = Cell working Temperature; I_0 = output current; R_s = Series Resistance R_{sh} = Shunt resistance.

2. Classifications of solar cell materials

The coated silicon semiconductor materials are used to design solar cells or photovoltaic cells. These types of cells classified into 1st, 2nd and 3rd generation solar cells. Silicon wafer materials used in first generation, thin film materials used in second generation and third generation includes emerging photovoltaic cells. Ongoing research work developments based on solar cells are mainly in third generation type cells. Due to the usage and demand the researchers focus the development of solar cells.

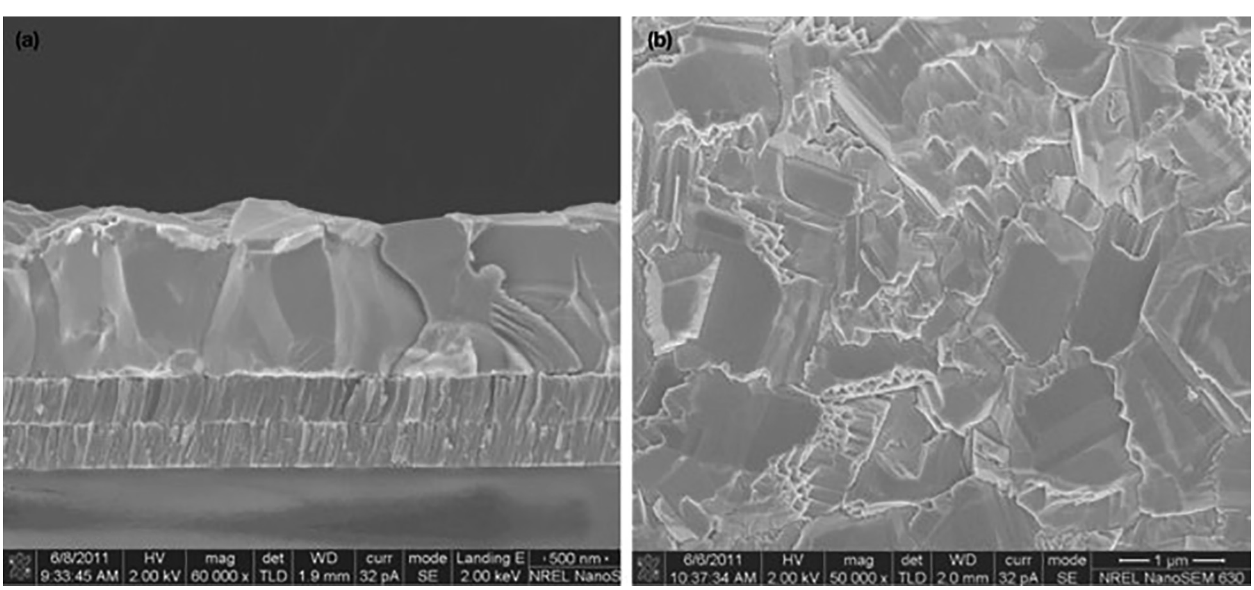

Fig. 1. Electron microscopy scanning: (a) cross-sectional and (b) co-evaporated CZTS film plan view.

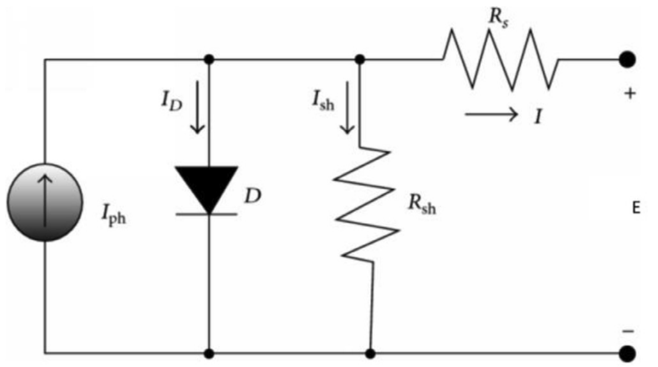

Fig. 3. Equivalent Circuit of PV cell.

2.1. Mono-crystalline& poly-crystalline silicon solar cell

Single silicon cell used to form a mono-crystalline type cell and more than one cell were used to form a poly-crystalline cell. These modules are formed of a cylindrical alloy of silicon developed in the same manner as a semiconductor from either a single crystal of high purity silicon. Mostly mono-crystalline cells are in black color, because of high light interaction [1]. Polycrystalline cells are blueish in colour, in a different manner to the light reflecting off the silicon fragments in the cell. Wafers are mounted in rows and columns to create a rectangle in order to create a mono crystalline and poly-crystalline, as seen in Fig. 4. [63] The advantages of mono-crystalline cell give higher efficiency and better performance, but the drawback is high cost. Compared with mono-crystalline, poly crystalline cells cost low, the disadvantage is it has lower efficiency.

2.2. Thin film solar cell – second generation solar cell

A thin-film solar cell [6] would be a solar cell of the second generation which comprises of one or even more thin film layers of photovoltaic grounded substrate, such as glass, metal and plastic. For most industrial uses, this type of cell has been utilized. The efficiency of the thin film solar cell is based on the selected semiconductor [3]. Performance enhancement experiments are also going on to speed up the technology. Fig. 5 [64] shows the pictorial representation of thin film solar cell. The IV Characteristics of Thin-film solar cell was shown in Fig. 6. [65].

2.2.1. Amorphous silicon thin film solar cell

A very well-developed thin film technology that utilizes a non-crystalline allotropic process of silicon is amorphous silicon. Method of plasma-enhanced chemical vapour processing used to manufacture this form of solar cells. Just 1 μm of silicon forms a very thin film on a surface with a combination of silane and hydrogen for deposition. The transparent layer [3] is covered with glass, plastic or metal. These cells require low temperature for processing a production with requires low silicon material. It is low cost and flexible to process. This cell can able to absorb low level light which includes ultraviolet and infrared radiation to produce the output power from solar cells and band gap of this cell is 1.7 eV. The IV Characteristics of Amorphous silicon Thin-film solar cell was shown in Fig. 7 [66].

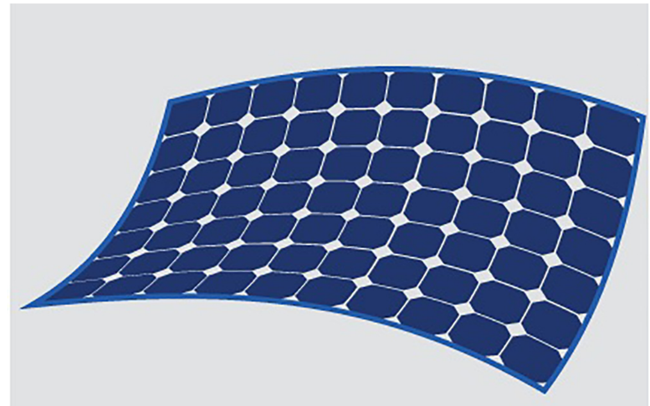

Fig. 5. Thin-film solar cell.

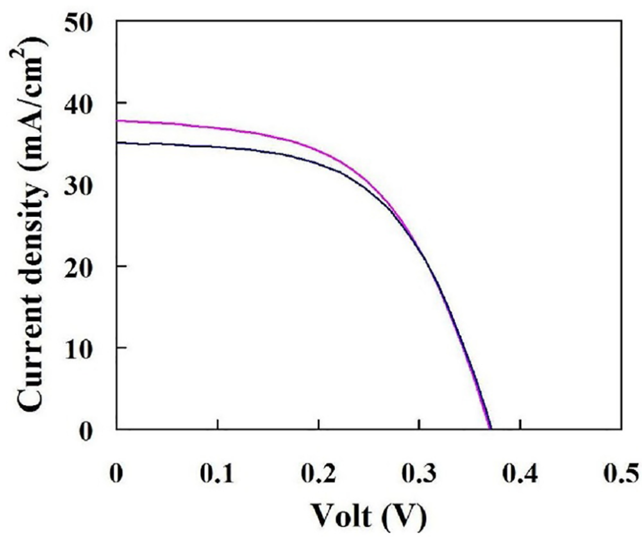

Fig. 6. IV Characteristics of Thin-film solar cell.

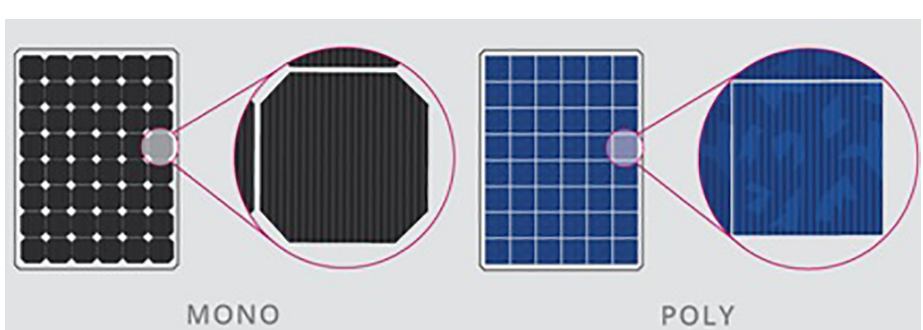

Fig. 4. Mono-crystalline& Poly-crystalline cells.

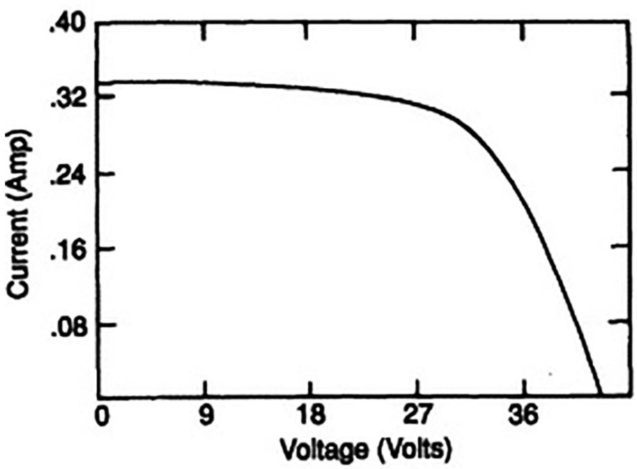

Fig. 7. IV Characteristics of Amorphous silicon Thin-film solar cell.

2.2.2. Cadmium Telluride (CdTe) thin film solar cell

To shape this type of cell, cadmium telluride is used in a thin semiconductor layer designed to generate electrical power from sunlight [4]. These thin film cells are less costly than traditional crystalline silicon solar cells, which is the greatest achievement. The IV Characteristics of Cadmium Telluride (CdTe) Thin Film solar cell was shown in Fig. 8 [60].

2.2.3. Copper indium gallium selenide solar cells (CIGS solar cells)

To design this type of solar cell, copper, indium, gallium and selenium were used. This cell type are mounted with an electrode in the front and back side to capture the current because of the high absorption coefficient and strongly absorbs sunlight. The IV Characteristics of Copper indium gallium selenide solar cell was shown in Fig. 9 [59].

2.3. Nano scale materials based solar cell

Fig. 10 [67] shows the Schematic diagram of Nano scale solar cells. Solar cell made of nanotechnology that captures both sunlight and interior light and transforms it to power. Plastic is formed from nano scale titanium particles covered with photovoltaic dyes

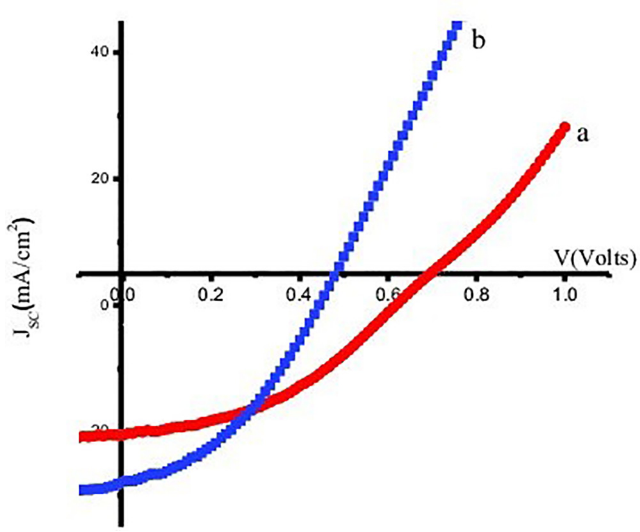

Fig. 8. IV Characteristics of Cadmium Telluride (CdTe) Thin Film solar cell.

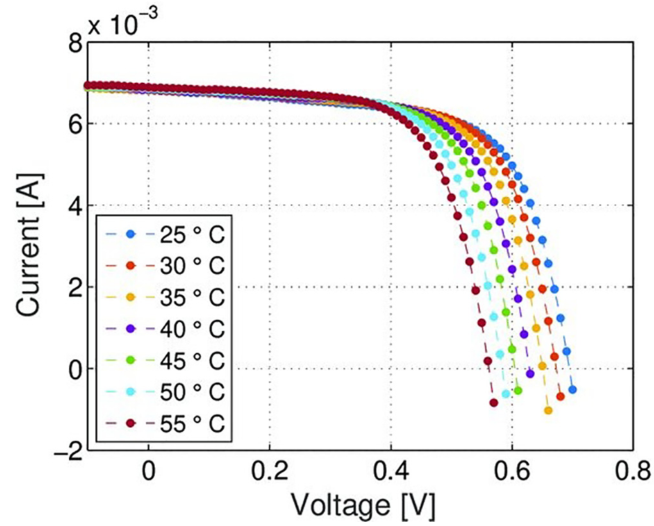

Fig. 9. IV Characteristics of Copper indium gallium selenide solar cell.

that create electricity whenever exposed to light. Nanotechnology is a really innovative field and it is used to build a high-energy conversion solar cell. The following points were considered for energy conversion rate: (i) to reduce the scattering rate, the scattering lengths should be equal to nano crystallite dimension; and (ii) to increase the density nanostructures have high absorption coefficient. By varying the band gap, the size of the structures changes which is used to absorb the particular range of energy. Periodic arrays of individual nanostructures with a uniform size of less than 20 nm need to be produced to achieve these advantages at a non-cryogenic temperature.

2.4. Polymer or organic solar cell

Fig. 11 [68] shows that indium tin oxide (ITO) used as a anode, which consists of glass substrate coated layer. Then this layer covered by a hole transport layer such as 3, 4-ethylenedioxythiophene or polystyrene sulfonate. Based on the semiconductor material used it is differing from normal silicon solar cells [6].Organic solar cell made up of carbon-based organic compounds which is applied in thin layer. Whereas the crystalline silicon material used to form silicon solar cells. It is the major difference between organic and silicon solar cells. The IV Characteristics of organic Solar Cell was shown in Fig. 12 [58].

2.5. Dye sensitized solar cells (DSSC) or light absorbing dye

Fig. 13 [69] shows the Structure of DSSC. This cell is a photo electrochemical device developed for the formation of a photosensitized anode and an electrolyte [7]. The benefits of this cell are easy to manufacture by commonly using roll-printing methods, it is nearly transparent and versatile to use in distinct systems but does not use in glass-based structures, and low cost materials have been used. The IV Characteristics of light absorbing dye solar cell was shown in Fig. 14 [57].

2.6. Concentrated solar cell

In order to reduce the focus of sunlight these cells are uses curved mirrors or lenses and to increase the efficiency of cells, solar trackers and cooling system are used by this cell [8]. Most of the research focuses on to increase the usage and areas of isolation.

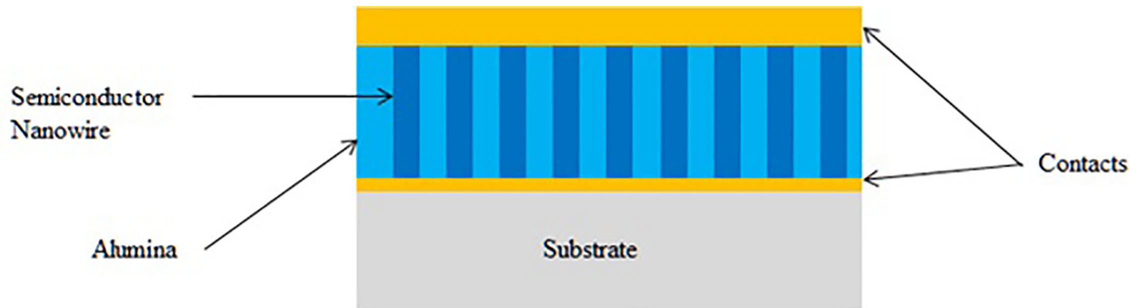

Fig. 10. Schematic diagram of Nano scale solar cells.

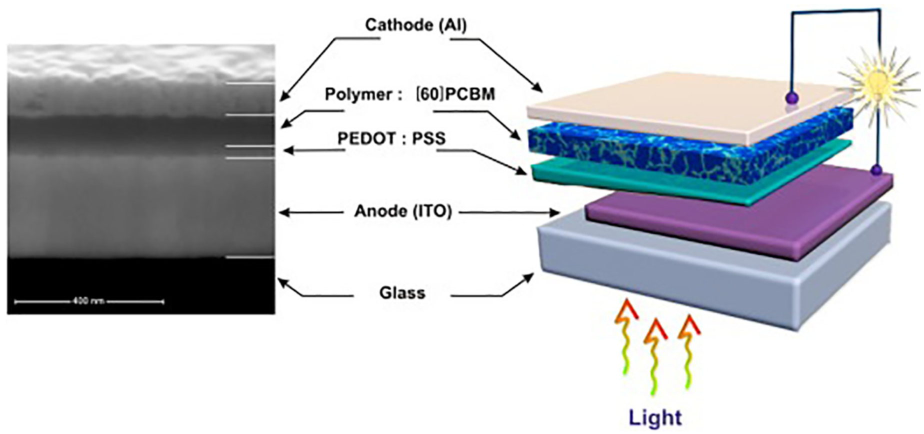

Fig. 11. Structure of polymer solar cell.

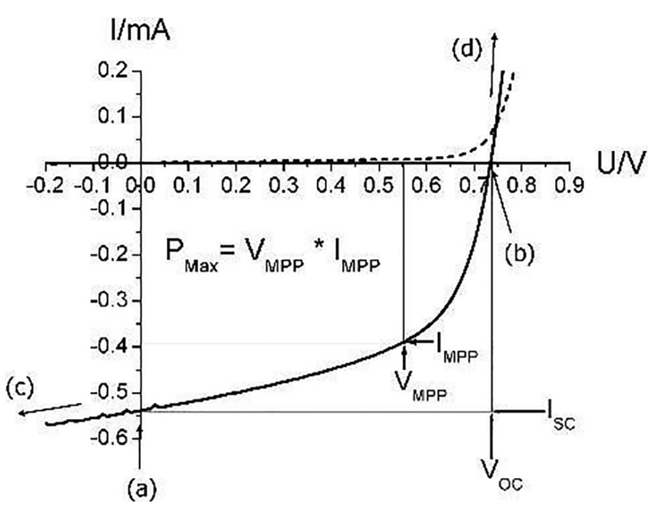

Fig. 12. IV Characteristics of Polymer solar cell.

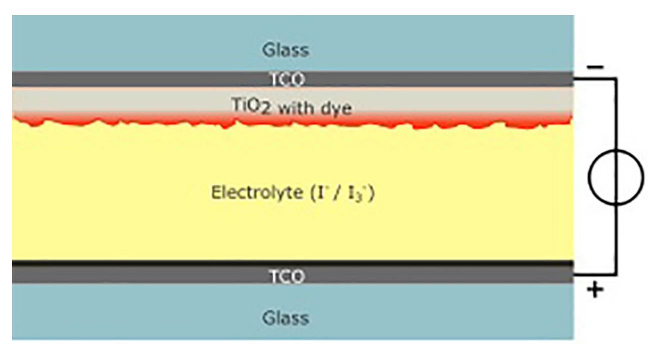

Fig. 13. Structure of DSSC.

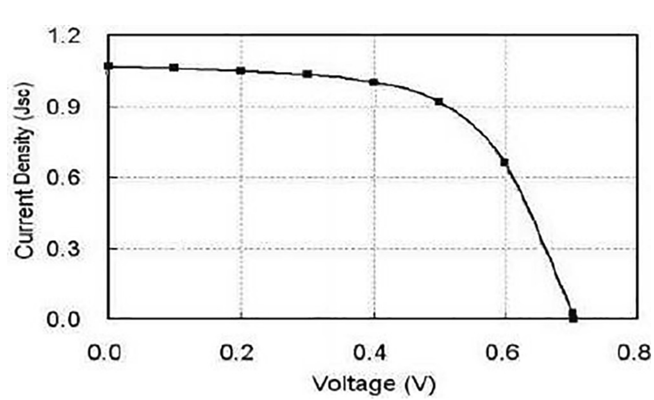

Fig. 14. IV Characteristics of Light absorbing dye solar cell.

The IV Characteristics of concentrated solar cell was shown in Fig. 15 [56].

2.7. Transparent solar cell

Generating electricity from solar cell by placing in windows, car's sun roof and glass roof of the office building is one of the best projects [9]. This technology is good and the difficulty of this method is generating electricity by passing the sun light in transparent cell that means it cannot absorb sun light to produce the electricity from solar cell. To reduce this problem semitransparent

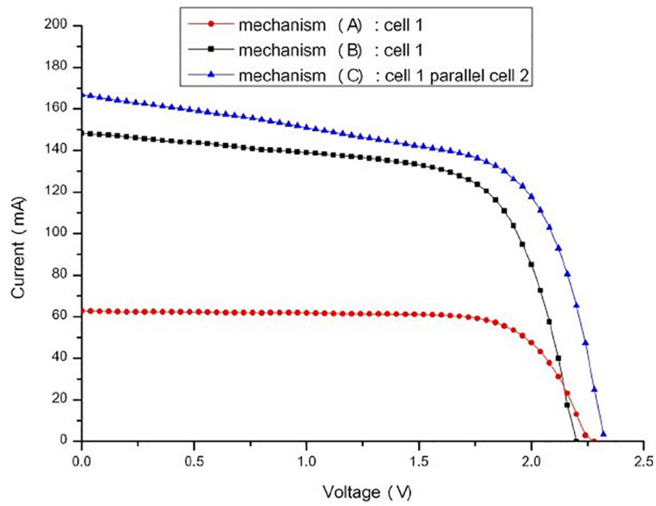

Fig. 15. IV Characteristics of Concentrated solar cell.

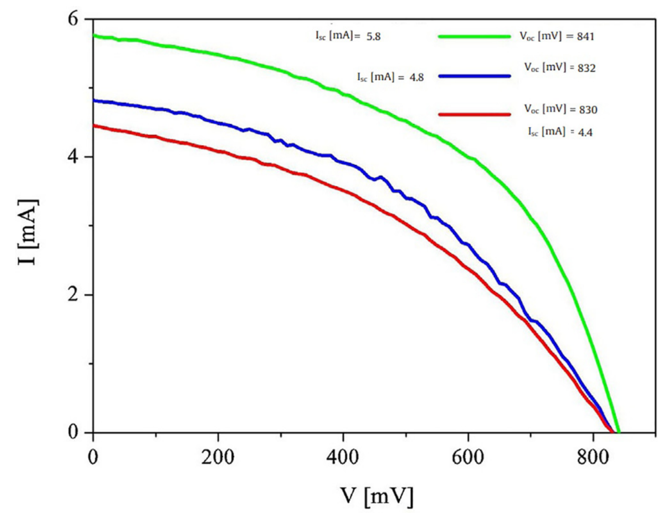

Fig. 17. IV Characteristics of Perovskite solar cell.

and fully transparent solar cell are used in this technology. Semi transparent solar cell absorbs sunlight, whereas fully transparent solar cells absorb ultraviolet light instead of sun light and generate electricity. The IV Characteristics of transparent solar cell was shown in Fig. 16 [55].

2.8. Perovskite solar cells

Perovskite film with 500 to 1000 nm used to form this type of cells. It is low cost and recorded efficiency of 25.2% [10]. It is the latest method that applies in solar cell to develop electricity. The MIT lab discovers this method in 2016 and it proves the efficiency of 23.3%. The IV characteristics of Perovskite solar cell was shown in Fig. 17 [70].

3. Comparison of solar cell efficiency

Solar panels weren't all created equal. Functionality, look, cost, materials, usage, and size are all different. The sorts of solar panels you'll really need your house or business are determined by a variety of criteria, including roof size, usage, affordability, and efficiency. The following are some of the most important criteria that influence the sort of solar panels you should use for your business or home installation:

- The area available for mounting on the roof or on the ground.
- Economy.
- Priorities in terms of aesthetics.
- The photovoltaic panels system's dimension.

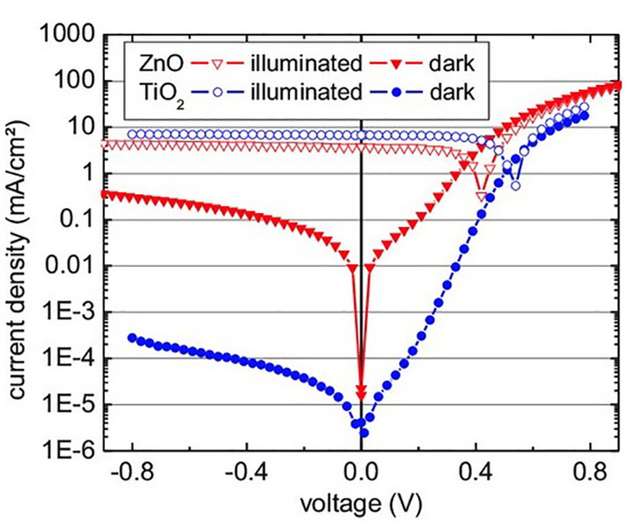

Fig. 16. IV Characteristics of Transparent solar cell.

If you've a limited amount of space, Monocrystalline solar panels are indeed the best option. Polycrystalline cells, from the other side, are appropriate when money is tight. Since of their short lifespan, thin-film solar cells are by far the most frequent in power purchase agreements. They're also perfect for large-scale or community-based solar energy systems.

Table 1 stated the performance of individual cell based on its Module efficiency, Cell efficiency, cost/watts and its thickness. From the discussion it is observed that cell efficiency of the Multi junction having good efficiency. At the same time the module efficiency looks at the rate of 11.6%. The respective cell cost and its thickness was tabulated. For the better performance we can choose mono crystalline silicon cell because its having 26.1% of cell efficiency and 24.4 % of module efficiency. But the drawback was its cost and its thickness. In future we may seek for low cost and small dimension cell for better efficient one like 3rd type generation cell. Since solar energy is a new technology, it experiences significant changes in a brief span of time. Many economic studies evaluating the implementation of different solar panels are now being reviewed. As a result, what is effective now may become obsolete in a year. When deciding on any solar panels, we must keep a close eye upon that sector and conduct extensive study.

4. Conclusion

In this review article, it is mentioned that the process of getting solar energy is very easy, but an effective and useful solar cell material is also needed. Researchers usually focus on building the nano scale solar cell material and transparent solar cell material due to the high energy conversion efficiency, and these also consume less area. Polymer solar cells are also a viable choice, but a real problem is their degradation over duration.. From the chapter 2 and 3, the performance and comparison of various cells has clearly studied. Based on the discussion in future the solar cell efficiency can only improved by multi junction techniques (Third Generation). There are so many barriers to the solar industry, including

Table 1
Comparison of different types of Solar cell.

Classification	Cell efficiency %	Module efficiency %	Cost/ Watts	Thickness
1st generation: wafer based				
Mono crystalline silicon	26.1	24.4	Rs. 41–47	0.3 mm
Poly crystalline silicon	22.3	19.9	Rs. 28–35	200 μm
2nd generation: thin- film				
Amorphous silicon	13.6		Rs.30–35	0.2–0.5 μm
CdTe	22.1	18.6	Rs.34–40	80–100 nm
CIGS	22.9	19.2	Rs.32–35	0.5 μm
3rd generation: emerging technologies				
Polymer PV	12.6	11.6	Rs.37–40	80–100 μm
Perovskite	23.3		Rs.27–32	200–400 nm
Multi-junction	46.0		Rs.36–38	500 nm

reducing the cost of development, public awareness and the best technology. So that we can now conclude the need for solar energy is the necessity of the day because new research on solar cells can allow a global change.

CRediT authorship contribution statement

J. Dhilipan: Data curation, Writing – original draft. **N. Vijayalakshmi:** Visualization, Investigation. **D.B. Shanmugam:** Supervision. **R. Jai Ganesh:** Conceptualization, Methodology, Software. **S. Kodeeswaran:** Software, Validation. **S. Muralidharan:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] A.M. Bagher, M.M.A. Vahid, M. Mohsen, Types of solar cells and application, Am. J. Opt. Photon. 3 (5) (2015) 94–113.
[3] K.L. Chopra, P.D. Paulson, V. Dutta, Thin-film solar cells: an overview, Prog. Photovoltaics Res. Appl. 12 (23) (2004) 69–92.
[4] https://www.greenmatch.co.uk/blog/2019/09/types-of-solar-panels.
[6] T. Kim, S. Lim, S. Yun, S. Jeong, T. Park, J. Choi, Design strategy of quantum dot thin-film solar cells, Small 16 (45) (2020) 2002460, https://doi.org/10.1002/smll.v16.4510.1002/smll.202002460.
[7] A.S. Shikoh, A. Polyakov, A quantitative analysis of the research trends in perovskite solar cells in 2009–2019, Phys. Status Solidi A 217 (23) (2020) 2000441, https://doi.org/10.1002/pssa:v217.2310.1002/pssa:202000441.
[8] T. Jiang, Z. Xu, C. Meng, Y. Liu, X. Tang, In-depth analysis of the internal energy conversion of nuclear batteries and radiation degradation of key materials, Energy Technol. 8 (12) (2020) 2000667, https://doi.org/10.1002/ente.v8.1210.1002/ente.202000667.
[9] S.H.A. Jaffery, J. Kim, G. Dastgeer, M. Hussain, A. Ali, S. Hussain, J. Eom, S. Hong, J. Jung, Thickness-dependent, gate-tunable rectification and highly sensitive photovoltaic behavior of heterostructured GeSe/WS 2 p–n Diode, Adv. Mater. Interfaces 7 (23) (2020) 2000893, https://doi.org/10.1002/admi.v7.2310.1002/admi.202000893.
[10] W.D. Cyrs, H.J. Avens, Z.A. Capshaw, R.A. Kingsbury, J. Sahmel, B.E. Tvermoes, Landfill waste and recycling: Use of a screening-level risk assessment tool for end-of-life cadmium telluride (CdTe) thin-film photovoltaic (PV) panels, Energy Policy 68 (2014) 524–533.
[55] H. Schmidt, T. Winkler, M. Tilgner, H. Flügge, S. Schmale, T. Bülow, J. Meyer, H.-H. Johannes, T. Riedl, W. Kowalsky, Semi-transparent inverted organic solar cells, Proc SPIE 10 (1117/12) (2009) 826114.
[56] H.-C. Chen, L.-B. Chang, Effect of placing GaAs solar cells on the optical rod prism of a concentrated photovoltaic, J. Renew. Sustain. Energy 5 (4) (2013) 043102, https://doi.org/10.1063/1.4812649.
[57] A.U. Rehman, F. Aslam, H.A. Khan, Analyze the absorption properties and I-V characterization of dye sensitized solar cell using ruthenium dye, Am. J. Eng. Appl. Sci. 7 (4) (2014) 387–390, https://doi.org/10.3844/ajeassp.2014.387.390.
[58] H. Hoppe, N.S. Sariciftci, Organic solar cells: an overview, J. Mater. Res. – J. Mater. Res. 19 (7) (2004) 1924–1945, https://doi.org/10.1557/JMR.2004.0252.
[59] M. Bronzoni, L. Colace, A. De Iacovo, A. Laudani, G. Lozito, V. Lucaferri, M. Radicioni, S. Rampino, Equivalent circuit model for Cu(In, Ga)Se2 solar cells operating at different temperatures and irradiance, Electronics 7 (11) (2018) 324, https://doi.org/10.3390/electronics7110324.
[60] Maria Albor-Aguilera, J.M. Márquez, M.A. Trujillo, Y. Kuwahara, Morales Rueda, Vigil-Galán Giovanni, Osvaldo, Influence of CdS thin films growth related with the substrate properties and conditions used on CBD technique, Energy Procedia 44 (2014) 111–117, https://doi.org/10.1016/j.egypro.2013.12.016.
[61] A. Jeong, G. Kim, W. Jo, D. Nam, H. Cheong, H. Jo, D.-H. Kim, S.-J. Sung, J.k. Kang, D. Lee, Local current transport and surface potential of photovoltaic Cu(In, Ga) Se2 thin films probed by multi-scale imaging methods*, Adv. Nat. Sci.: Nanosci. Nanotechnol. 4 (2013), https://doi.org/10.1088/2043-6262/4/1/015007 015007.
[62] Keqi Zhang, Ralph Faber, Large linear copper thermal evaporation source for CIGS solar cell applications, https://pdf4pro.com/cdn/large-linear-copper-thermal-evaporation-source-for-cigs-4704a1.pdf.
[63] https://www.cedgreentech.com/article/monocrystalline-cells-vs-polycrystalline-cells-whats-difference.
[64] https://news.energysage.com/types-of-thin-film-solar-panels/.
[65] Miga Jung, Jialiang Huang, Rhett Evans, Sergey Varlamov, Martin Green, Full area laser doping for next generation of C-SI thin-film solar cells on glass substrate, 2013. https://doi.org/10.4229/28thEUPVSEC2013-3DV.1.13.
[66] J. Meier, U. Kroll, S. Benagli, L. Fesquet, J. Steinhauser, D. Borello, J.-B. Orhan, Y. Djeridane, E. Vallat, M. Fecioru-Morariu, B. Mereu, J. Kalaš, J. Hoetzel, P. Losio, M. Kupich, O. Kluth, T. Eisennammer, D. Weidman, S. Marjanovic, G. Kohnke, From R&D to mass production of micromorph thin film silicon PV, Energy Procedia 15 (2012) 179–188, https://doi.org/10.1016/j.egypro.2012.02.021.
[67] N. Cavassilas, F. Michelini, M. Bescond, Modeling of nanoscale solar cells: The Green's function formalism, J. Renewable Sustainable Energy 6 (1) (2014) 011203, https://doi.org/10.1063/1.4828366.
[68] Wileen Wong Kromhout, Tandem polymer solar cells that set record for energy-conversion, https://phys.org/news/2012-02-tandem-polymer-solar-cells-energy-conversion.html.
[69] N. Jamalullail, I.S. Mohamad, M.N. Norizan, N. Mahmed, Enhancement of energy conversion efficiency for dye sensitized solar cell using zinc oxide photoanode, IOP Conf. Ser.: Mater. Sci. Eng. 374 (2018), https://doi.org/10.1088/1757-899X/374/1/012048 012048.
[70] Gawlińska - Nęcek, Katarzyna, Iwan, Agnieszka, Starowicz, Zbigniew, Kulesza-Matlak, Grazyna, Stan-Glowinska, Katarzyna, Janusz, Marta, Lipinski, Marek, Boharewicz, Bartosz, Tazbir, Igor, Sikora, Andrzej, Searching of new, cheap, air- and thermally stable hole transporting materials for perovskite solar cells. Opto-Electronics Review. 25, 2017, 274–284. https://doi.org/10.1016/j.opelre.2017.07.004.
[71] Rajasekaran, Madhumitha, R. Vinothkumar, C. Aravind. Voltage regulation in mircogrid using adaptive controller, 1–5, 2014. https://doi.org/10.1109/ICGCCEE.2014.6922363.

Further reading

[2] N. Rathore, N.L. Panwar, F. Yettou, A. Gama, A comprehensive review of different types of solar photovoltaic cells and their applications, Int. J. Ambient Energy 42 (10) (2021) 1200–1217, https://doi.org/10.1080/01430750.2019.1592774.
[5] D.E. Carlson, C.R. Wronski, Amorphous silicon solar cell, Appl. Phys. Lett. 28 (11) (1976) 671–673.
[11] S. Sharma, K.K. Jain, A. Sharma, Solar cells: in research and applications—a review, Materials Sciences and Applications 06 (12) (2015) 1145–1155.
[12] M. Bernardi, M. Palummo, J.C. Grossman, Extraordinary sunlight absorption and one nanometer thick photovoltaics using two-dimensional monolayer materials, Nano Lett. 13 (8) (2013) 3664–3670.
[13] Y. Wei, C. Xu, S. Xu, C. Li, W. Wu, Z.L. Wang, Planar waveguide– nanowire integrated three-dimensional dye-sensitized solar cells, Nano Lett. 10 (6) (2010) 2092–2096.
[14] Chu, Yinghao, Peter Meisen, Review and comparison of different solar energy technologies, Global Energy Network Institute (GENI), San Diego, CA (2011).

[15] Y.T. Chae, J. Kim, H. Park, B. Shin, Building energy performance evaluation of building integrated photovoltaic (BIPV) window with semi-transparent solar cells, Appl. Energy 129 (2014) 217–227.
[16] A.E. Shalan, T. Oshikiri, S. Narra, M.M. Elshanawany, K. Ueno, H.-P. Wu, K. Nakamura, X.u. Shi, E.-G. Diau, H. Misawa, Cobalt oxide (CoO x) as an efficient hole-extracting layer for high-performance inverted planar perovskite solar cells, ACS Appl. Mater. Interfaces 8 (49) (2016) 33592–33600.
[17] A. McEvoy, L. Castaner, T. Markvart, Solar Cells: Materials, Manufacture and Operation, second ed., Elsevier Ltd., Oxford, 2012, pp. 3–25.
[18] A.L. Fahrenbruch, R.H. Bube, Fundamentals of Solar Cells, Academic Press Inc., New York, 1983.
[19] A. Yadav, P. Kumar, Enhancement in efficiency of PV cell through P&O algorithm, Int. J. Technol. Res. Eng. 2 (2015) 2642–2644.
[20] B. Srinivas, S. Balaji, M. NagendraBabu, Y.S. Reddy, Review on present and advance materials for solar cells, Int. J. Eng. Res.-Online 3 (2015) 178–182.
[21] P. Wurfel, U. Wurfel, Physics of Solar Cells: From Basic Principles to Advanced Concepts, John Wiley & Sons, Hoboken, 2009.
[22] S. Dmitrijev, Principles of Semiconductor Devices, Oxford University Press, Oxford, 2006.
[23] M. Bertolli, Solar Cell Materials, Solid State II. Department of Physics, University of Tennessee, Knoxville, Course, 2008.
[24] T. Saga, Advances in crystalline silicon solar cell technology for industrial mass production, NPG Asia Mater. 2 (3) (2010) 96–102, https://doi.org/10.1038/asiamat.2010.82.
[25] P. Jayakumar, Solar Energy Resource Assessment Handbook. Renewable Energy Corporation Network for the Asia Pacific, 2009.
[26] M. Imamzai, M. Aghaei, Y. HanumMdThayoob, M. Forouzanfar, A review on comparison between traditional silicon solar cells and thin-film CdTe solar cells., in: Proceedings of National Graduate Conference (NatGrad 2012), TenagaNasionalUniversiti, Putrajaya Campus, 8-10 November 2012, 2012, pp. 1–5.
[27] M.A. Maehlum, Energy Informative The Homeowner's Guide To Solar Panels, Best Thin Film Solar Panels— Amorphous, Cadmium Telluride or CIGS? Last updated 6 April 2015, (2015).
[28] D. Yogi Goswami, F. Kreith, Handbook of Energy Efficiency and Renewable Energy, CRC Press, Boca Raton, 2007.
[29] A. Luque, S. Hegedus, Handbook of Photovoltaic Science and Engineering, second ed., John Wiley & Sons, Ltd, Hoboken, 2003.
[30] K.M. Elsabawy W.F. El-Hawary M.S. Refat, Advanced Synthesis of Titanium-Doped-Tellerium-Camium Mixtures for High Performance Solar Cell Applications as, (2012).
[31] One of Renewable Source of Energy, Int. J. Chem. Sci., 10, 1869–1879.
[32] W.A. Badawy, A review on solar cells from si-single crystals to porous materials and quantum dots, J. Adv. Res. 6 (2) (2015) 123–132, https://doi.org/10.1016/j.jare.2013.10.001.
[33] A.M. Bagher, M.M.A. Vahid, M. Mohsen, Types of solar cells and application, Am. J. Opt. Photon. 3 (2015) 94–113.
[34] V.K. Sethi, M. Pandey, P. Shukla, Use of nanotechnology in solar PV cell, Int. J. Chem. Eng. Appl. 2 (2011) 77–80.
[35] F. Andorka, CIGS Solar Cells Simplified. Solar Power World. http://www.solarpowerworldonline.com/2014/01/cig s-solar-cells-simplified/, 2014.
[36] T.M. Razykov, C.S. Ferekides, D. Morel, E. Stefanakos, H.S. Ullal, H.M. Upadhyaya, Solar photovoltaic electricity: current status and future prospects, Sol. Energy 85 (8) (2011) 1580–1608, https://doi.org/10.1016/j.solener.2010.12.002.
[37] H. Hoppe, N.S. Sariciftci, Polymer solar cells, Adv. Polym. Sci. 214 (2008) 1.
[38] P.C. Choubey, A. Oudhia, R. Dewangan, A review: solar cell current scenario and future trends, Recent Res. Sci. Technol. 4 (2012) 99–101.
[39] S. Dubey, J.N. Sarvaiya, B. Seshadri, Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world: a review, Energy Procedia 33 (2013) 311–321, https://doi.org/10.1016/j.egypro.2013.05.072.
[40] Clarke, Chris (19 April 2011) San Jose Solar Company Breaks Efficiency Record for PV. Optics.org. Retrieved 19 January 2011
[41] Konarka Power Plastic reaches 8.3% efficiency. pv-tech.org. Retrieved 7 May 2011.
[42] R.R. Lunt, V. Bulovic, Transparent, near-infrared organic photovoltaic solar cells for window and energy- scavenging applications, Appl. Phys. Lett. 98 (11) (2011) 113305, https://doi.org/10.1063/1.35 67516.
[43] Rudolf, John Collins (20 April 2011). "Transparent Photovoltaic Cells Turn Windows Into Solar Panels". green.blogs.nytimes.com.
[44] UCLA Scientists Develop Transparent Solar Cell". EnviroNews.com. 24 July 2012. Archived from the original on 27 July 2012.
[45] R.R. Lunt, T.P. Osedach, P.R. Brown, J.A. Rowehl, V. Bulović, Practical roadmap and limits to nanostructured photovoltaics, Adv. Mater. 23 (48) (2011) 5712–5727.
[46] R.R. Lunt, Theoretical limits for visibly transparent photovoltaics, Appl. Phys. Lett. 101 (4) (2012) 043902, https://doi.org/10.1063/1.47 38896.
[47] G. Li, R. Zhu, Y. Yang, Polymer solar cells, Nat. Photon. 6 (3) (2012) 153–161, https://doi.org/10.1038/nphoton.2012.11.
[48] C.J. Brabec, S.E. Shaheen, C. Winder, N.S. Sariciftci, P. Denk, Effect of LiF/metal electrodes on the performance of plastic solar cells, Appl. Phys. Lett. 80 (7) (2002) 1288–1290, https://doi.org/10.1063/1.1446988.
[49] R. Zhu, A. Kumar, Y. Yang, Polarizing organic photovoltaics, Adv. Mater. 23 (36) (2011) 4193–4198.
[50] S. Suhaimi, M.M. Shahimin, Z.A. Alahmed, J. Chyský, A.H. Reshak, Materials for enhanced dye-Sen- sitized solar cell performance: electrochemical application, Int. J. Electrochem. Sci. 10 (2015) 28–59.
[51] B. Li, L. Wang, B. Kang, P. Wang, Y. Qiu, Review of recent progress in solid-state dye-sensitized solar cells, Sol. Energy Mater. Sol. Cells 90 (5) (2006) 549–573, https://doi.org/10.1016/j.solmat.2005.04.039.
[52] J. Zhan, P. Sun, S. Jiang, X. Sun, T. Lund, An Investigation of the Performance of Dye-Sensitized Nanocrytsalline Solar Cell with Anthocyanin Dye and Ruthenium Dye as the Sensitizers, Roskilde University, Roskilde, 2006.
[53] M. Graetzel, R.A.J. Janssen, D.B. Mitzi, E.H. Sargent, Materials interface engineering for solution- processed photovoltaics, Nature 488 (7411) (2012) 304–312, https://doi.org/10.1038/nature11476.
[54] A.J. Nozik, Nanoscience and nanostructures for photovoltaics and solar fuels, Nano Lett. 10 (2010) 2735–2741, https://doi.org/10.1021/nl102122.