Uttaranchal Journal of Applied and Life Sciences
U. J. App. Life. Sci. Vol: 3 (1): 14-25 **Dec 2022**

Graphene based Solar cells and superior energy conversion

Gözde Koşarsoy Ağçeli[1*], Kanika Dulta[2], Ayushi Khattri[2], Ram Subhash Yarramsett[2]
[1]Hacettepe University, Department of Biology, Ankara, Turkey
[2]Department of Food Technology, School of Applied and Life Sciences, Uttaranchal University, Dehradun-248007, Uttarakhand, India.
***Corresponding author:** gozdekosarsoy@hacettepe.edu.tr

Received: (15 Aug 2022) Revised: (25 Sept 2022) Accepted: (11 Dec 2022)

Abstract: Among the renewable energy generation methods, the most interesting one is the photovoltaic energy technology, which has unlimited usage potential and generates electricity by using renewable sunlight. Solar cells are a secure and viable photoelectric technology that could substitute existing fossil fuel systems. Graphene, with its outstanding electrical and optical properties, mechanical flexibility, adjustable working function, attracts great interest among scientific research groups in many fields. It has been identified as an exceptional material for upcoming energy storage devices. This review examines a few features of graphenes and evaluates whether it is a feasible alternative to the traditional materials used in photovoltaic cells.

Key words: Photovoltaic system, graphene, solar cell, electrode, energy

RENEWABLE SOLAR ENERGY AND SOLAR CELL: AN OVERVİEW

The energy crisis is one of the biggest serious issues impacting the planet. Global fuel consumption is increasing, while major energy sources such as fossil fuels are steadily declining. By using fossil fuels, natural resources are consumed and CO_2 emission increases at the same time. As a result of all this, global warming occurs (Hosenuzzaman et al., 2015). Therefore, finding and using new energy sources for renewable and sustainable energy technologies is gaining importance day by day.

Renewable energy is characterised as a organic and boundless energy source that is an unlimited fuel for the globe. A major advantage of renewable power is that it minimises long-term foreign dependency while also minimizing pollution and other risks (Nfaoui & El-Hami, 2018). They can be categorised into eight types of energy; Biomass, solar, ocean power, electric, wind, geothermal and hydroelectric. Solar energy has extreme environmental advantages in comparison to other sources. With solar energy, natural resources are not consumed, solid or liquid wastes are not produced and CO_2 emission is not realized . Various countries prefer solar energy as the most suitable energy source for environment-friendly and sustainable energy (Mekhilef et al., 2011). Among renewable energy sources, solar photovoltaics (PVs) are the fastest growing energy source for electric power generation and also have the highest power density with a global average of 170 Watt / m^2 (Jordehi, 2016).

The sun is a massive energy source that has been burning for over 4 billion years. It emits 95% of its total energy as light. Photovoltaic (PV) cells or solar cells are created to directly convert the sun energy into electrical energy (Karim et al., 2019). Solar cells are simple solar devices that use photons to drive electrons away from atoms and generate energy. Research and development studies began in 1954 for the industrial use of solar cells in electricity generation. However, the concentration on this area at the desired level started with the "1st Oil Crisis" in 1973 (Covi, 2015).

In 1839, French physicist Alexandre Edmond Becquerel was the first to describe photovoltaic phenomenon. Around 1880, Charles Fritts achieved the first photovoltaic of selenium (Se) resulting in 1% efficiency (Blandford & Watkins, 2009). The National Renewable Energy Laboratory(NREL) boosted the ability to deliver products to 30% in 1994 using a cell comprised of gallium arsenide (GaAs) and gallium indium phosphide (GaInP). With the expanding need for renewable energy, researchers around the world are working to develop more functional and cost-effective photovoltaics.

One of the features that make photovoltaic systems important is their application areas that are increasing day by day. Photovoltaic systems, which find a wide range of applications from rural areas where electricity lines have not yet reached to communication satellites where energy transmission is impossible, can be used in every application where electrical energy is required (Tsoutsos et al., 2005). A photovoltaic system has many advantages. High work opportunities in every nation offer a substantial benefit for photovoltaic systems. It outperforms comparable energy sources in terms of energy generation, which adds to an individual's energy independence and the dismantling of the energy monopoly. The photovoltaic system also has disadvantages. This system is generally fueled by sunlight , which, in some situations, is inadequately efficient, as a result of which power generation is reduced. For example, in the winter, half as much energy may be produced as in the summer, and no energy is produced at night (Nal, 2020). Furthermore, the construction of solar or photovoltaic effect modules is too expensive.

One of the essential parameters in solar cells is efficiency. The efficiency of the incident light beam is also determined by how much energy is converted into electricity as a percentage. Research on solar cells continues intensively. Various categories of solar cells (dye sensitized solar cells, organic hybrid solar cells, multijuction solar cells and organic solar cells and so on.) have been studied at the present time to bring about maximum throughput of the cells (Amiri et al., 2019; Enrichi & Righini, 2019; Green et al., 2020; "Solar Cells - New Approaches and Reviews," 2015). Organic solar cell structures are basically named according to the state and form of the active layer placed between the electrodes. The active layer in between can consist of a single layer, or it can be in two layers, or in a mixture of donor and acceptor. In the single layer battery structure, there is a semiconductor polymer coated between two electrodes with different work functions. In the structure of two-layered organic solar cells, the donor and acceptor layers are placed on top of each other between the electrodes. Electron-gap transfers between these two surfaces create the current. The biggest problem here is that exciton diffusion has a distance of at most 10 nm. Considering that the exciton must reach the interface to decompose, a large proportion of excitons cannot provide charge transfer (Tamai et al., 2015). In a mixed solar cell structure, donor and acceptor materials are prepared as a mixture and placed between the electrodes. Currently, the highest efficiency among organic solar cells is 13.2% in this solar type. The biggest advantage is that the interfaces that their excitons can reach are much more, so that the load transfers are realized more (Ganesamoorthy et al., 2017). Layers can be organic, inorganic or solar cells containing both can be produced (Ameri et al., 2013).

Most commonly used metal oxides in organic solar cell structures can be listed as aluminum doped oxide (AZO), indium oxide (ITO) and fluorine doped tin oxide (FTO). The conductivity of these structures is on average 100-200 μΩ. ITO is very advantageous compared to the roughness values, which is an important issue in organic solar cells. However, ITO is much more expensive than the other metal oxides mentioned and its production is quite laborious. Besides these disadvantages, ITO electrodes are not suitable for producing flexible solar cell structures because they are very fragile (Bedeloglu et al., 2010). For these reasons, the use of ITO in flexible solar cell production is limited. Unlike many other polymers, conductive polymers are polymers with special molecular structures that can transmit electric current. These polymers, also known as synthetic metals, are known as polymers with the conductivity properties of metals and the easy processability of polymers. Conductivity of these polymers comes from conjugated pi bonds in their molecular structure (Balint et al., 2014). Poly 3,4-ethylenedioxythiophene:polystyrene sulfonate (PEDOT:PSS) is frequently used conductive polymer as electrode in organic solar cell structures. High conductivity, flexibility and the capacity to generate transparent structures are the main reasons for this preference. Metals exhibit an absorbing or reflective character in the UV and IR region, which is important for solar cells. On the other hand, thin films with nanometric thickness can show a certain amount of permeability. When the high conductivity of metal films is combined with its permeability, ideal electrode structures can be formed. Silver and aluminum are the most preferred metals used as electrodes in organic solar cells, but their use is limited because they require high technology and can be produced with expensive methods (Lee et al., 2013).

Silver nanowires are electrode materials that stand out with their optical properties that can compete with ITO for organic solar cells thanks to their ability to be produced from solution by simple methods, high conductivity, and flexibility . There are two disadvantages in the use of silver nanowires as electrodes. The first of these is that silver is a metal that can be oxidized easily and loses its conductivity at a high rate when oxidized. Solar cells produced to eliminate this disadvantage can be encapsulated. The second and critical disadvantage is the high roughness of electrode structures produced from silver nanowires.

Apart from the mentioned materials, especially recently carbon-based nanomaterials are used as electrodes in organic solar cell structures with their superior properties. Various nanocarbon materials, especially carbon nanotubes and graphene, have been the focus of 3rd generation solar cells (Liu et al., 2008).

Graphene is a 2-dimensional carbon allotrope that stands out especially after the Nobel Prize given by Geim and Novosolev and is the subject of research from almost every sector. Carbon nanotubes are among the most studied nanomaterials in the last 25 years and can be defined as the form of graphene nanomaterial that has been brought into cylindrical form and accepted as one-dimensional (Hong et al., 2015). The low permeability and high roughness of the electrode structures obtained with carbon nanotubes limits its use. Apart from that, it is quite laborious and costly to produce carbon nanotubes in high quantities and purity. On the other hand, graphene has a great advantage in terms of production method variety. Chemical vapor deposition , mechanical exfoliation and chemical oxidation are just a few of the methods that have emerged for creating graphenes. The quality of graphene produced according to the production method varies and the resistance and permeability values that can be reached can vary considerably. Compared to carbon nanotube electrodes, higher permeability and much lower resistance values can be achieved. In addition, the rare characteristics of them such as the quantum gap effect are also remarkable for electrode applications (Allen et al., 2010).

GRAPHENE AND İTS USE İN SOLAR CELLS

The band gap can be physiologically altered, since intrinsic graphene is a zero barrier semiconductor. Due to this excellent property, graphene and graphene derivative materials attract great attention in many different fields such as biosensors, drug delivery, membrane nanoelectronics and Li-ion batteries (Lonkar et al., 2015). It is used in a variety of investigations owing to its multiple unique attributes such as a high internal mobility (200,000 $cm^2 V^{-1}s^{-1}$), large theoretical specific surface area (2630 $m^2 g^{-1}$), (Das et al., 2015), chemical properties and thermal conductivity (~ 5000 $Wm^{-1} K^{-1}$) (Balandin et al., 2008) and high young modulus value (~ 1.0 TPa) (Bolotin et al., 2008). Graphene can also endure high optical permeability (97.7%), high conductivity, and a density of 108 Å / cm^2. Apart from its exceptional electrical characteristics, graphene has excellent mechanical and optical properties (Tkachev et al., 2011). Graphene can be achieved by various manufacturing techniques. The best production methods for obtaining graphene are oxidation of graphite by chemical reduction or heat treatment and conversion of graphene oxide to graphene by exfoliation (Yang et al., 2011). Recently, Because of their large surface area, high electrical conductivity and strong adsorption. Functionalized graphene-based semiconductor photocatalysts have gained a lot of interest.

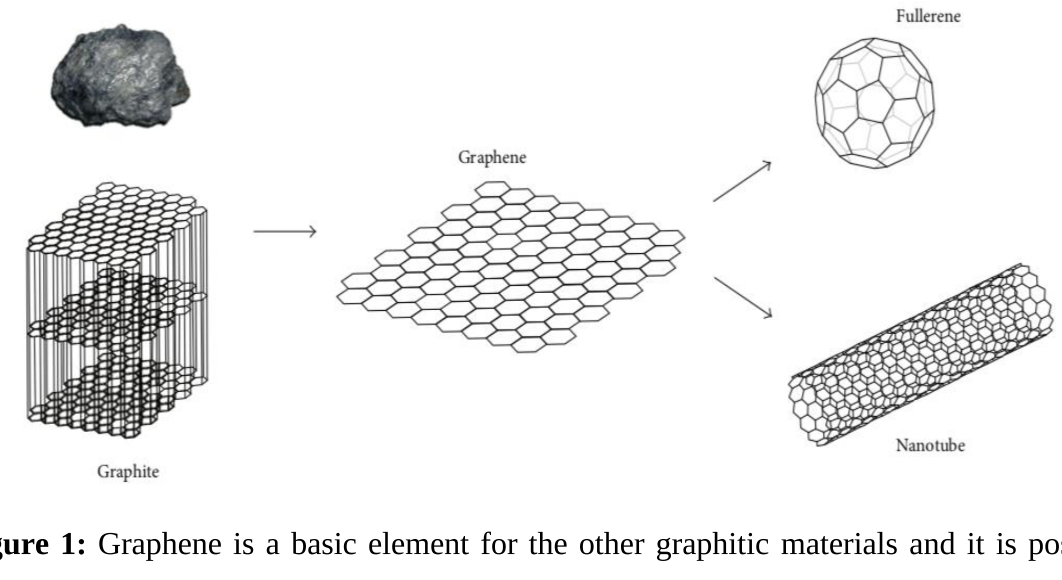

Figure 1: Graphene is a basic element for the other graphitic materials and it is possible to transform one structure to another in appropriate conditions

GRAPHENE AS AN ELECTRODE FOR SOLAR CELLS

PSCs achieve superior efficiency due to their exceptional optical and electrical features, which include a low rates of excitation binding energy, significant absorption coefficient and a configurable bandgap (Jung & Park, 2015). Furthermore, one appealing benefit of PSCs over traditional silicon for device manufacturing is the potential for low-temperature processing, which presents opportunities for solar cell improvement like flexibility,transparency and customizable shapes (Bailie et al., 2015). Transparent electrodes are a necessary component for many devices such as cellular phones, light emitting diodes(LEDs), liquid crystal displays(LCDs), photovoltaic devices(PVs) and so on . Accordingly, different bendable transparent electrodes like graphene, CNTs, metal nanowires and conductive polymer deposited onto polymer substrates have been studied for application in flexible solar cells. Fluorine-doped tin oxide (FTO) or indium tin oxide (ITO) are extensively used as clear materials in photovoltaic devices (Sachse et al., 2014). However, the element indium is extremely limited and costly. Graphene provides all the properties of a suitable electode with its high clarity , high electrical conductivity and high flexibility (N. Liu et al., 2017). The usage of them as upper and lower electrodes in solar cell structures has been the subject of many studies since 2008. Wang et al. created the first graphene electrode for DSSC (X. Wang, Zhi, & Müllen, 2008). In this investigation, because of the errors in the graphene layer, the DSSC with graphene performed poorly in comparison to the gold electrode (X. Wang, Zhi, & Müllen, 2008). In 2008, Wu et al. obtained a oxide of graphene (GO) film by coating the graphene oxide, which they obtained by the Hummers method, on glass with a rotational coating method, and then converted it to the reduced graphene oxide form by thermal annealing at 1100 ° C (Wu et al., 2008). It was observed that at the end of thermal annealing, the film achieved 80 % transparency and a conductivity between 5 k Ω and 1 M Ω.

GRAPHENE IN ORGANIC SOLAR CELLS

Graphene is hydrophobic which insoluble both in polar as well as in biological solvents. Their application in Organic Solar Cells (OSCs) eliminates the expense of the devices required. (Nanda et al., 2015). Obtaining graphene oxide (GO) by functionalizing graphene with oxygen can increase the efficiency of OSCs. Additionally, owing to the solubility requirement of Organic Solar Cells materials, graphene oxide and its derivatives outperform pristine graphene, they are widely utilized. Graphene oxide is hydrophilic due to functional groups of oxygen such as hydroxyl and epoxy groups. GO's poor dispersion in organic solvents, on the other hand, hinders its use in OSCs. Graphene's functionality, in contrast, can be improved by providing nucleation sites with oxygen functional groups. Thus, GO can be more homogeneously dispersed in organic solvents by functionalization both non-covalently and covalently (Zheng et al., 2017).

GRAPHENE IN DYE-SENSİTİZED SOLAR CELLS (DSSC)

Graphene and its materials have been employed in organic, dye sensitive, quantum dot sensitive, hybrid and Schottky junction solar cells. It has been used for applications such as transparent anode, clear cathode, light collecting layer, catalytic counter electrode and charge transmission layer. Graphene has received substantial research as a functional electrode material in DSSCs. Hasin et al. was the one to report graphene's capacity to decrease triiodide in 2010. Thus, they demonstrated the wide possibilities of graphene for counter electrode applications used in DSSCs. It has also been reported in this study that functionalization of graphene with a cationic polymer to increase its electrocatalytic activity is a promising way (Hasin et al., 2010).

GRAPHENE IN PEROVSKİTE SOLAR CELLS (PSCS)

PSCs received a great attention in solar research with an efficiency increase of 23.7% for ten years as a result of researches (Jena et al., 2019). When chlorobenzene solvent is employed, the efficiency of perovskite solar cells may be reduced due to large number of tiny holes on Spiro-OMeTAD surface coatings. Furthermore, these coatings are held at high temperatures prior to production. Graphene perovskite improves the reliability of solar cell products and extends their life. According to Ramli et al., graphene diffusion sheets finally closed over 90% of the perovskite solar cell film within 60 hours and increased stability. Perovskite solar cells are therefore resistant to oxidation, humidity, and toxins. Stability of perovskite solar cells could be increased with graphene dispersion. However, it was revealed that the work on spin coating should continue for a better coating and film formation (Ramli et al., 2021). Jin et al successfully produced perovskite solar cells that are all carbon electrode-based flexible bore conductor-free perovskite solar cells with PET/ graphene-Ag NWs as the front transparent anode and paste of carbon as the back electrode. It was oberved that performance was significantly better/PET flexible conductive substrate. With their work, they have provided a new way to produce productive long-term stable, flexible and low-cost PSCs (Jin et al., 2021).

GRAPHENE IN QUANTUM DOT SOLAR CELLS

Quantum dots (QDs) sensitised solar cells have sparked the interest of researchers as low-cost alternatives for third-generation solar cells by increasing potential power conversion efficiency (Chen et al., 2020). Researchers are interested in graphene-based quantum dot material solar cells due to their a great energy effectiveness. In the study quantum dot solar cells sensitized with CdS, nanocomposite graphene-TiO_2 photoanodes were produced and characterized to boost conversion and adsorption efficiency. In addition, they employed graphene's carrier-carrier association and/or dispersion characteristic to increase H value and decrease Joule losses (Mnasri et al., 2020). The results obtained demonstrate the ability of graphene and the amount of graphene in the light conversion process in cells of solar.

CONCLUSİON

In summary, this chapter covers the applications of graphene in solar cells and developments on photovoltaic efficiencies. Today, materials produced using graphene are considered to be used as an alternative to existing components in solar cells, based on the results obtained. Materials based on graphenes act as a semiconductor layers in solar cells, transparent conductive electrodes, sensitizersThere are some constraints to fully exploiting graphene nano-composites. First of all, graphene should be synthesized under regulated conditions. Several procedures for graphene synthesis have been established, and its use in different components of the next solar cells has been shown. Optimizing graphene shapes, employing functionalization, and regulating fault density, in particular, are more beneficial for attaining high graphene catalytic behavior.

REFERENCES

Allen, M. J., Tung, V. C., & Kaner, R. B. (2010). Honeycomb carbon: A review of graphene. Chemical Reviews. https://doi.org/10.1021/cr900070d

Ameri, T., Li, N., & Brabec, C. J. (2013). Highly efficient organic tandem solar cells: A follow up review. In Energy and Environmental Science. https://doi.org/10.1039/c3ee40388b

1. Amiri, I. S., Yupapin, P., Suseendran, G., & Palai, G. (2019). The realization of the intermediate layer (IML) in a tandem solar cell using silicon-based photonic ribbon structure. Optik. https://doi.org/10.1016/j.ijleo.2019.05.101

2. Bailie, C. D., Christoforo, M. G., Mailoa, J. P., Bowring, A. R., Unger, E. L., Nguyen, W. H., Burschka, J., Pellet, N., Lee, J. Z., Grätzel, M., Noufi, R., Buonassisi, T., Salleo, A., & McGehee, M. D. (2015). Semi-transparent perovskite solar cells for tandems with silicon and CIGS. Energy and Environmental Science. https://doi.org/10.1039/c4ee03322a
3. Balandin, A. A., Ghosh, S., Bao, W., Calizo, I., Teweldebrhan, D., Miao, F., & Lau, C. N. (2008). Superior thermal conductivity of single-layer graphene. Nano Letters. https://doi.org/10.1021/nl0731872
4. Balint, R., Cassidy, N. J., & Cartmell, S. H. (2014). Conductive polymers: Towards a smart biomaterial for tissue engineering. Acta Biomaterialia, 10(6), 2341–2353. https://doi.org/10.1016/j.actbio.2014.02.015
5. Bedeloglu, A., Demir, A., Bozkurt, Y., & Sariciftci, N. S. (2010). A Photovoltaic Fiber Design for Smart Textiles. Textile Research Journal. https://doi.org/10.1177/0040517509352520
6. Blandford, R., & Watkins, M. (2009). This Month in Physics History: April 25, 1954: Bell Labs Demonstrates the First Practical Silicon Solar Cell. APS News.
7. Bolotin, K. I., Sikes, K. J., Jiang, Z., Klima, M., Fudenberg, G., Hone, J., Kim, P., & Stormer, H. L. (2008). Ultrahigh electron mobility in suspended graphene. Solid State Communications. https://doi.org/10.1016/j.ssc.2008.02.024
8. Chen, K., Jin, W., Zhang, Y., Yang, T., Reiss, P., Zhong, Q., Bach, U., Li, Q., Wang, Y., Zhang, H., Bao, Q., & Liu, Y. (2020). High Efficiency Mesoscopic Solar Cells Using CsPbI3 Perovskite Quantum Dots Enabled by Chemical Interface Engineering. Journal of the American Chemical Society. https://doi.org/10.1021/jacs.9b10700
9. Covi, G. (2015). Puzzling Out The First Oil Shock. History, Politics and the Macroeconomy in a Forty-Year Retrospective. HISTORY OF ECONOMIC THOUGHT AND POLICY. https://doi.org/10.3280/spe2015-002004
10. Das, S., Sudhagar, P., Kang, Y. S., & Choi, W. (2015). Synthesis and Characterization of Graphene. In Carbon Nanomaterials for Advanced Energy Systems: Advances in Materials Synthesis and Device Applications. https://doi.org/10.1002/9781118980989.ch3
11. Enrichi, F., & Righini, G. C. (2019). Solar cells and light management: Materials, strategies and sustainability. In Solar Cells and Light Management: Materials, Strategies and Sustainability. https://doi.org/10.1016/C2017-0-04229-5

12. Ganesamoorthy, R., Sathiyan, G., & Sakthivel, P. (2017). Review: Fullerene based acceptors for efficient bulk heterojunction organic solar cell applications. Solar Energy Materials and Solar Cells. https://doi.org/10.1016/j.solmat.2016.11.024
13. Green, M. A., Dunlop, E. D., Hohl-Ebinger, J., Yoshita, M., Kopidakis, N., & Ho-Baillie, A. W. Y. (2020). Solar cell efficiency tables (Version 55). Progress in Photovoltaics: Research and Applications. https://doi.org/10.1002/pip.3228
14. Hasin, P., Alpuche-Aviles, M. A., & Wu, Y. (2010). Electrocatalytic activity of graphene multilayers toward I -/I3-: Effect of preparation conditions and polyelectrolyte modification. Journal of Physical Chemistry C. https://doi.org/10.1021/jp106130v
15. ong, G., Diao, S., Antaris, A. L., & Dai, H. (2015). Carbon Nanomaterials for Biological Imaging and Nanomedicinal Therapy. In Chemical Reviews. https://doi.org/10.1021/acs.chemrev.5b00008
16. Hosenuzzaman, M., Rahim, N. A., Selvaraj, J., Hasanuzzaman, M., Malek, A. B. M. A., & Nahar, A. (2015). Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation. In Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/j.rser.2014.08.046
17. İnalı, M. (2020). THE PROCESS OF CONVERTING SOLAR POWER TO ELECTRICITY USING SOLAR CELLS AND IMPROVING PRODUCTIVITY OF PHOTOVOLTAIC SOLAR POWER SYSTEMS VIA SOLAR CELLS. Gaziantep University.
18. Jena, A. K., Kulkarni, A., & Miyasaka, T. (2019). Halide Perovskite Photovoltaics: Background, Status, and Future Prospects. Chemical Reviews. https://doi.org/10.1021/acs.chemrev.8b00539
19. Jin, J. J., Li, J., Tai, Q., Chen, Y., Mishra, D. D., Deng, W., Xin, J., Guo, S., Xiao, B., & Wang, X. (2021). Efficient and stable flexible perovskite solar cells based on graphene-AgNWs substrate and carbon electrode without hole transport materials. Journal of Power Sources. https://doi.org/10.1016/j.jpowsour.2020.228953
20. Jordehi, A. R. (2016). Parameter estimation of solar photovoltaic (PV) cells: A review. In Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/j.rser.2016.03.049
21. Jung, H. S., & Park, N. G. (2015). Perovskite solar cells: From materials to devices. In Small. https://doi.org/10.1002/smll.201402767

22. Karim, N. A., Mehmood, U., Zahid, H. F., & Asif, T. (2019). Nanostructured photoanode and counter electrode materials for efficient Dye-Sensitized Solar Cells (DSSCs). In Solar Energy. https://doi.org/10.1016/j.solener.2019.04.057
23. Lee, K. S., Kim, I., Yeon, C. B., Lim, J. W., Yun, S. J., & Jabbour, G. E. (2013). Thin metal electrodes for semitransparent organic photovoltaics. ETRI Journal. https://doi.org/10.4218/etrij.13.1912.0025
24. Liu, N., Chortos, A., Lei, T., Jin, L., Kim, T. R., Bae, W. G., Zhu, C., Wang, S., Pfattner, R., Chen, X., Sinclair, R., & Bao, Z. (2017). Ultratransparent and stretchable graphene electrodes. Science Advances. https://doi.org/10.1126/sciadv.1700159
25. Liu, Z., Liu, Q., Huang, Y., Ma, Y., Yin, S., Zhang, X., Sun, W., & Chen, Y. (2008). Organic photovoltaic devices based on a novel acceptor material: Graphene. Advanced Materials. https://doi.org/10.1002/adma.200800366
26. Lonkar, S. P., Deshmukh, Y. S., & Abdala, A. A. (2015). Recent advances in chemical modifications of graphene. In Nano Research. https://doi.org/10.1007/s12274-014-0622-9
27. Mekhilef, S., Saidur, R., & Safari, A. (2011). A review on solar energy use in industries. In Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/j.rser.2010.12.018
28. Mnasri, G., Mansouri, S., Yalçin, M., El Mir, L., Al-Ghamdi, A. A., & Yakuphanoglu, F. (2020). Characterization and study of CdS quantum dots solar cells based on Graphene-TiO2 nanocomposite photoanode. Results in Physics. https://doi.org/10.1016/j.rinp.2020.103253
29. Nanda, S. S., Papaefthymiou, G. C., & Yi, D. K. (2015). Functionalization of Graphene Oxide and its Biomedical Applications. In Critical Reviews in Solid State and Materials Sciences. https://doi.org/10.1080/10408436.2014.1002604
30. Nfaoui, M., & El-Hami, K. (2018). Extracting the maximum energy from solar panels. Energy Reports. https://doi.org/10.1016/j.egyr.2018.05.002
31. Parida, B., Iniyan, S., & Goic, R. (2011). A review of solar photovoltaic technologies. In Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/j.rser.2010.11.032
32. Ramli, N. F., Fahsyar, P. N. A., Ludin, N. A., Teridi, M. A. M., Ibrahim, M. A., & Sepeai, S. (2021). Graphene dispersion as a passivation layer for the enhancement

of perovskite solar cell stability. Materials Chemistry and Physics. https://doi.org/10.1016/j.matchemphys.2020.123798

33. Sachse, C., Weiß, N., Gaponik, N., Müller-Meskamp, L., Eychmüller, A., & Leo, K. (2014). ITO-Free, small-molecule organic solar cells on spray-coated copper-nanowire-based transparent electrodes. Advanced Energy Materials. https://doi.org/10.1002/aenm.201300737
34. Solar Cells - New Approaches and Reviews. (2015). In Solar Cells - New Approaches and Reviews. https://doi.org/10.5772/58490
35. Tamai, Y., Ohkita, H., Benten, H., & Ito, S. (2015). Exciton Diffusion in Conjugated Polymers: From Fundamental Understanding to Improvement in Photovoltaic Conversion Efficiency. Journal of Physical Chemistry Letters. https://doi.org/10.1021/acs.jpclett.5b01147
36. Tsoutsos, T., Frantzeskaki, N., & Gekas, V. (2005). Environmental impacts from the solar energy technologies. Energy Policy. https://doi.org/10.1016/S0301-4215(03)00241-6
37. Wang, X., Zhi, L., & Müllen, K. (2008). Transparent, conductive graphene electrodes for dye-sensitized solar cells. Nano Letters. https://doi.org/10.1021/nl072838r
38. Wu, J., Becerril, H. A., Bao, Z., Liu, Z., Chen, Y., & Peumans, P. (2008). Organic solar cells with solution-processed graphene transparent electrodes. Applied Physics Letters. https://doi.org/10.1063/1.2924771
39. Yang, Y., Ren, L., Zhang, C., Huang, S., & Liu, T. (2011). Facile fabrication of functionalized graphene sheets (FGS)/ZnO nanocomposites with photocatalytic property. ACS Applied Materials and Interfaces. https://doi.org/10.1021/am200561k
40. Zheng, F., Yang, X. Y., Bi, P. Q., Niu, M. S., Lv, C. K., Feng, L., Qin, W., Wang, Y. Z., Hao, X. T., & Ghiggino, K. P. (2017). Poly(3-hexylthiophene) coated graphene oxide for improved performance of bulk heterojunction polymer solar cells. Organic Electronics. https://doi.org/10.1016/j.orgel.2017.02.021