Composites as candidate materials for photovoltaic cells

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Abstract

Composites are two or more materials with different properties joined together to manufacture a new material. The resulting physical and chemical properties of each constituent new materials which remain distinct with enhanced properties when compared to the individual constituent materials.With this background, Photovoltaic cells (PV) are very important source of energy in recent years falling under Renewable Energy Resources (RES) meaning that it is abundant in nature, and also environmentally friendly in producing electricity. PV cells contains tiny different types of silicon layers which when the sun shines through it causes reaction between the electrons. In this way, the movement of the electrons through itself and around the circuit generate electricity. Subsequently, the solar cell keeps generating electricity as long as the sun is shining on it. A lot of research has been done and still on-gong on the enhancement of the PV cells to optimize their application. Therefore, the objective of this study is to review and compare the current state-of-the-art articles on different types of composites, which have been used for the PV cells enhancement, especially some two-dimensional (2D) materials. Therefore, graphene and MoS used as nanocomposites are considered in this review to support appropriate and informed decisions that are made available to researchers and industries to know the best materials to use going forward in the manufacture of PV cells for better enhancement. Summary of these and more have been presented and prospected in this article.

Keywords: Composites, graphene, PV cells, RES.

1. Introduction

Globally extensive initiatives have been taken to produce efficient and lightweight equipment's for use. Especially for the production of electricity using PV cells. Therefore, this cause for research into more scientific and advanced engineering ways of production and fabrication which replaces metals and their alloys, hence delivering superior mechanical properties and lightweight. Consequently, most of these advanced engineering has been achieved through composites materials. Composites offers great advantage over the traditional materials [1]. Composite materials are needed in today's material science engineering because of their uniqueness in matching them to a particular application. By carefully selecting the reinforcement, the matrix and the process that brings them together, the properties of composites can be custom-made to meet a particular requirement. They have the advantage of been able to be molded into complex shapes. Which is a great advantage when manufacturing goods such as surfboards, boat hulls or bike frames.

Composites are combination of two or more materials either by joining two bulk materials or gradually introduced as a Functional Graded Material (FGMs) [2]. The later was introduced in the 1980s in Japan. It is also known as advanced engineering materials due to their ability to withstand harsh environmental conditions without deviating from their physical and chemical properties. FGMs is the process of depositing one material into another, which in traditional composites will not be able to retain its properties of constituent materials in the homogeneous combinations [3]. For example, the glass fiber cloth, this is fused together with a synthetic plastic to make the composite material referred to as fiberglass. The primary mechanical advantage of FGMs over the traditional composites is their resistance to failure due to sharp interfaces since they were eliminated by the inclusion of secondary material into the existing material gradually. Due to its nature, it has gained a landmark trajectory in fields such as biomedicals, aerospace, mineral processing industry, space and defense applications, among others [4].

2. Excerpt from the Literature

There are diverse types of composites, this is formed according to their specific need. Authors in [5] carried out experiment relating to Dental Resin Composites (DRC). Nanoclay technology was used with materials such as PMMA/MMT in 0.5 wt% which according to authors is a promising nanofiller for resin composite that significantly enhanced flexural strength and micro-hardness without compromising DC and color. Also, research conducted in [6] uses semiconductor/relaxor 0-3 type composites comprising a relaxor ferroelectric 0.6Ba(Zr0.2Ti0.8)O3-0.4(Ba0.7Ca0.3)TiO3 and ZnO nanoparticles to improve the strength of dielectric capacitors components of energy storage. Their results prove that the formation of semiconductor/relaxor 0-3 type composites can be another good way to improve the energy storage performance of RFE-based capacitors of an energy storage system.

Another study was carried out by [7] to investigate the impact of honeycomb composite structure of light weight photovoltaic in stratospheric capsule. With absolute consideration for varying core of honeycomb thicknesses, the mechanical properties were studied for improved solar flexibility. It was observed that the most significant overall result in terms of improved thermal insulation and mechanical performance was gotten with the 5mm honeycomb layer thickness.

The work done in [8] presented an innovative and efficient hybrid silicon solar cell with high efficiency device fabricated based on two carrier-selective composites of heterojunction and an nc-SiOx(n) with SiO2. Results shown that the hybrid solar cell of nc-SiOx(n) and of heterojunction layers respectively performs well due to high selectivity, and efficient charge transport.

According to [9] copper (Cu) and MAPbI3 was added to the perovskite solar cells. The aim of their work is to replace Pb with Cu to see the potential of a Pb-free solar cells. The replacement generates MACuxI3 employed for carbon-based perovskite solar cells. Surprisingly, Copper amalgamation increase speed of the near-infrared (NIR) absorption, implying a complete solar spectrum absorbance. Results shows that Integration of Cu as MAPb1−xCuxI3 results in the maximum PCE of ~12.85%, whereas using 1:1 cocktail perovskite solution of MAPbI3 and MACuxI3 exhibits an average PCE of ~12.43%. Notably, Cu-in-corporation enables a reasonably steeper and reduced PCE degradation rate than Pb-based Cells. Because Cu offers advantages like environmentally friendly, good quality warm and aqueous stability. The results will be quite useful with lots of potential in the application of a Pb-free base solar cells, which shows the opportunities in the area of near-infrared absorption with an improved device firmness.

Authors in [10] exploited the use of 0-dimensional (0D) carbon quantum dots (C QDs), 1-dimensional (1D) silver nanowires (Ag NWs), and 2-dimensional (2D) ultrathin Ag films to overcome the problems of photoelectric imbalance of rear transparent conductive electrodes (TCEs) which limit the photovoltaic performance of bifacial planar heterojunction perovskite solar cells (PH–PSCs). They took the advantage of the better electrical performance of the composite and developed a new rear TCE with ideal photoelectric balance, i.e., Ag NW + C QD/Ag NW/molybdenum oxide (MoOx)/ultrathin Ag (denoted as A + C/A/M/A) rear TCE with a 0D/ 1D/2D composite structure. Their results demonstrated that C QDs fully fill the voids within the Ag NW network, can successfully accelerates the charge transfer and collection, which significantly improves PV performance thus increasing the PV output.

Another research in [11] was based on the enhancement of the Solar backsheet. Backsheet is the protective layer of the PV module. The backsheet has properties such as, electrical, optical, mechanical, and chemical which are essential to look into in order to improve the life's span and performance of the PV module. Hence, a novel PVDF/nano-mica nanocomposite (PVDF-MX) films were invented through the film casting method. It was discovered that the addition of nano-mica increased the γ-phase of PVD, the level of crystallinity reduced, increased tensile strength, wettability, good thermal conductivity, improved opacity with excellent stability in high temperatures and dielectric was constant. Also, the exposure of hydrophobicity of PVDF-MX films was showed to be resistant to moisture absorption. From the various results, it can be established that the Improved properties of PVDF-MX films could be a potential material as a single-layered solar backsheet application and revealed a pleasing property for long-term stability with an enhanced PV cells for better outputs.

A simulation by [12] was based on PV temperature reduction. Temperature reduction in PV module can effectively improve the efficiency of the photovoltaic module. A composite phase change material was developed through a thermal heat transfer method to cooled down the temperature of the PV module. According to their findings, it was discovered that using the composite phase change material the thermal resistance between the PV module was reduce as well as the temperature. The experimental analysis of the efficiency and temperature of the PV module with composite phase change material stands at optimal thickness of 2.5 cm yielded 14.75% and 47.81 C correspondingly and simulation results were precise at an average of 0.4 C.

This study also discusses the current developments in nanocomposite materials, as well as the optimal combinations for improving panel efficiency.

3. Photovoltaic system

The electricity engineering and generating arm is experiencing a time of speedy and unprecedented transformation in the deployment of Renewable Energy Resources (RES) technologies. Over two decades now, renewable energy resources have generated more than half of the new energy generation capacity worldwide. In 2018, the total renewable energy generation was accounted for to exceeded 2000 GW, doubling the quantity in the space of ten years. Most significantly the use of PV system, this is due to its environmentally friendly, less cost and ample in nature [13]. Solar energy from the sun can be converted into electrical energy and produce electric power that can be used in diverse ways. Because of the technological advancements, deploying solar energy has provided many advantages to mankind through Photovoltaic (PV) by consuming the sunlight [14]. Photovoltaic (PV) system has the ability to convert solar energy into electrical energy also can be defined as the process of converting light energy into electricity energy**.** "In 2017, cumulative solar PV capacity reached almost 398 GW and generated over 460 TWh, representing around 2% of global power output. Utility-scale projects account for just over 60% of total PV installed capacity, with the rest in distributed applications (residential, commercial and off-grid). Over the next five years, solar PV is expected to lead renewable electricity capacity growth, expanding by almost 580 GW under the Renewables 2018 main case" [15]. Figure 1 depicts the solar PV generation and capacity between 2017-2023.

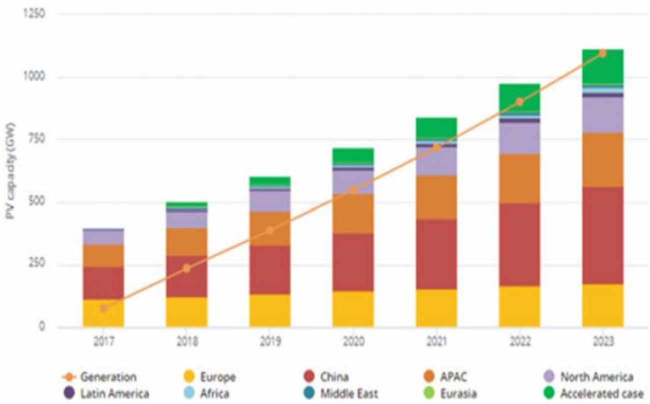

Fig. 1. Solar PV generation and capacity, 2017-2023 [16].

3.1 Types Photovoltaic cells

Photovoltaic cell is the smallest unit of the PV system. One or more cells are joined together to form a module and modules come together to form a panel. Figure 2 shows the illustrations of a simple PV system.

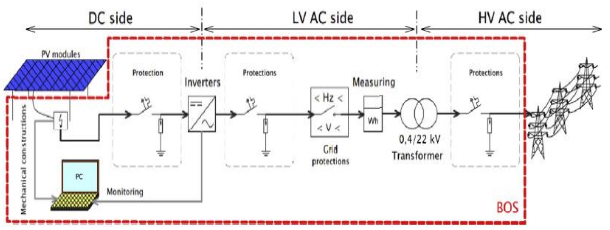

Fig. 2. A simple representation of a PV system [17].

Photovoltaic cells (PVCs) are devices used to conver t solar energy into electrical energy. This is achieved through the photovoltaic force. i.e., The coming together of two semiconductor areas with different electron absorption as seen in Figure 2. There are different material types either type- n with different electron absorption possessing excess electrons or type-p with excess of positive charge referred to as holes. Therefore, when both regions are in contact with each other, there will be a flow of holes from region p and electron from region n through the p-n junction [18].

As the light strikes the cell, the energy from photons will be absorbed by the electrons, which consequently break the bonds, constructing a hole-electron pairs. These charge carriers are pushed by the electric field and conducted through the p-n junction. Figure 3 depicts representation of PV cell.

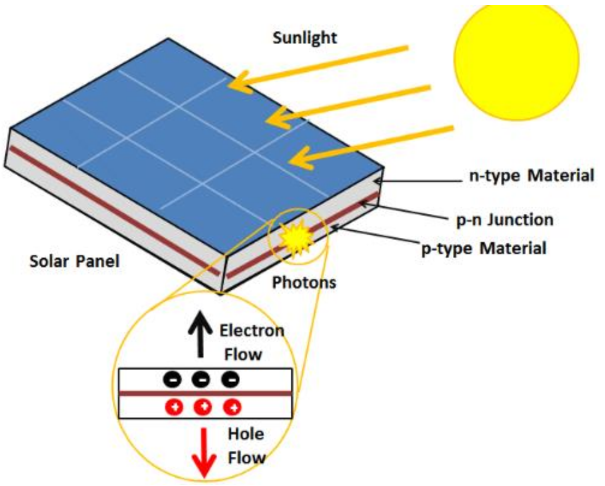

Fig. 3. Diagrammatical representation of a Photovoltaic cell [18].

The different types of PVCs that have been established up to date can be categorized into four major headings, these are referred to as generations. We therefore have first generation, second generation, third generation and fourth generation. The first and second generations of solar cells were centered around solid-state junction devices, for which silicon is highly the common material and mostly used for commercial purposes. In these generations, solar cells process the light engagement, charge generation, departure, and transport all utilized by the same material. Consequently, the emerging technology for solar cells achieves new models for sun harvesting and charge collection [19].The third and fourth generations approaches deeply rely on the development of a new grade of polycrystalline nanostructured materials. The generation of different PVCs basically defines the phases in which they have metamorphosed till date. [20].

3.1.1 First-generation

The first generation of photovoltaic cells are based on monocrystalline and polycrystalline silicon solar cells with that of gallium arsenide. Examples like (GaAs) are the PV cell technologies encompassed in this group. So, this generation is only constrained to ‘‘crystalline silicon-based technologies”. They are moderately efficient, but costly and therefore not too promising. Mono-crystalline silicon wafer-based technology has a record lab cell efficiency of 26.7%, while multi-crystalline silicon wafer-based technology has a record efficiency of 24.4%. CIGS solar cells have a lab efficiency of 23.4%, while CdTe solar cells have a lab efficiency of 21.0%. Perovskite has a record lab cell efficiency of 25.5% [21].

In 2020, Si-wafer-based PV technology will account for around 95% of overall production. Mono-crystalline technology currently accounts for around 84% of overall c-Si output (up from 66 %in 2019). There is a lot of research going on in the field of solar energy systems; this article reflects on the evolution of solar cells and which types of solar cells are more effective and efficient in terms of power conversion efficiency, manufacturing cost, and market availability.

The highest performing modules in the lab have a 24.4% efficiency and are made of mono-crystalline silicon. The Record efficiencies are an indication that there is still room for improvement at the production level. Figure 4 presents the efficiency comparison of technologies between the Best Lab Modules and the Best Lab Cells.

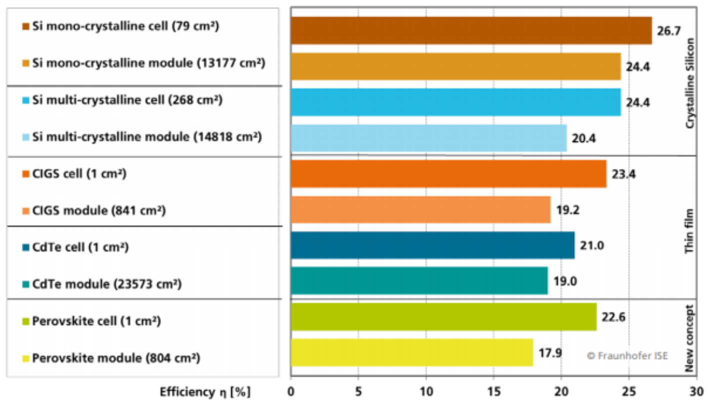

Fig. 4. Technology Efficiency Comparison: Best Lab Modules vs. Best Lab Cells [16].

Due to increasing efficiencies, thinner wafers, diamond wire cutting, and bigger ingots, material use for silicon cells has decreased considerably over the previous 16 years, from about 16 g/Wp to less than 3 g/Wp [22].

3.1.2 Second-generation

The second generation comes with the advance in the first generation of PVCs. These comprises of "thin film solar cell, amorphous silicon solar cell (a-Si), cadmium telluride/cadmium sulfide (CdTe/CdS) solar cell, and Concentrated PV solar cell (CPV)" all been covered in this generation. This generation was slightly less efficient, but considerably cheaper and hence more appropriate for large scale applications. "The efficiency of the first and second-generation cells cannot go beyond the Shockley-Queisser limit for single absorber material device".

3.1.3 Third- generation

The third generation PVCs technologies is centered around newer composites devices with a potential efficiency above the "Shockley-Queisser" limit. These technologies are based on ''dyed-sensitized solar cells, Multijunction solar cell nanocrystalline films, GaAs/GaInP (active quantum dots), organic polymer based solar cells" etc.

3.1.4 Fourth- generation

The fourth generation is generally referred to as ''inorganics-in-organics". Because of its low cost and low flexibility of the thin film polymers. This falls under the fourth generation with the firmness of ''innovative inorganic nanostructures such as nanoparticles or organic based nanomaterials metal oxides such as graphene, carbon nanotubes and derivatives of graphene".

Figure 5 depicts an equivalent circuit of a solar cell.

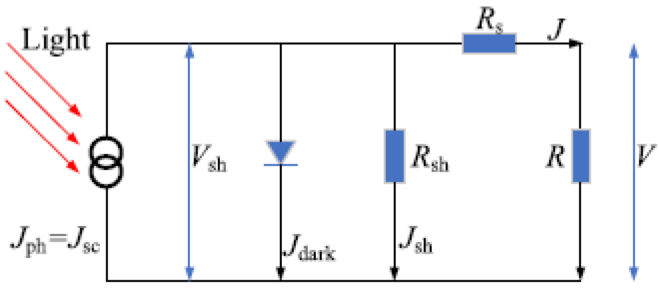

Fig. 5. A solar cell's equivalent circuit [23].

4. Recent PV technologies

Because renewable energy technology has increased efficiency while also lowering costs, the integration is very vast recently especially the PV system. PV system stands out among all the other renewables because of its major breakthrough in energy production as compared to other counterparts [43]. The availability of sun and the cost of panels which has drastically dropped makes this distinction.

4.1 Multijunction cells

Multijunction solar cells equally referred to as the next generation solar device, has the potential to attain higher efficiencies than the Shockley-Queisser limit for single junction cells owing to the fact that a broad range of the solar spectrum will be absorbed while minimizing thermal losses [24].

MJ solar cell is a method of piling sub-cells with different bandgaps, joining two or more solar cells can efficiently reduce the lattice thermal losses to achieve higher Power Conversion Efficiency (PCE). Additionally, multijunction solar cells are mainly apt for space applications because they have excellent reliability, high power-to-mass ratio (W/m2·kg) and outstanding radiation hardness. "In most cases, sub-cells at the upper part with wider bandgaps are made of group-III arsenide or phosphide (III–V) compound semiconductors (CSs) [25]. Narrower-bandgap III–V or group IV semiconductors such as Ge and Si are used for the lower-part or bottom sub-cells. MJ cells with various combinations of sub-cells such as InGaP/(In)GaAs/Ge, In-GaP/GaAs/InGaAs InGaP/(Al)GaAs/Si and In(Al)GaP/GaAs/InGaAsP/InGaAs were fabricated and excellent characteristics results was achieved" [26]. Figure 6 is the schematic of a multijunction PVCs with cell through contact architecture. Today, high concentration multi-junction solar cells in the laboratory reach efficiencies of up to 47.1%. Module efficiencies as high as 38.9% have been achieved using concentrator technology [27].

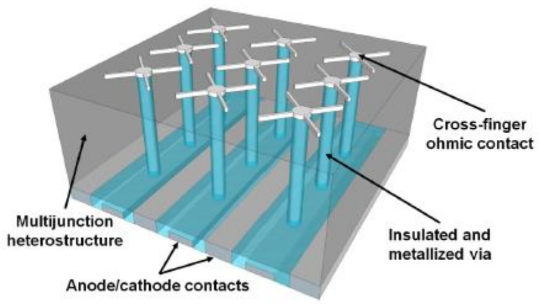

Fig. 6. Representation of a multijunction PVCs with cell through contact architecture [28].

4.2 Single-junction gallium arsenide cells

The single-junction solar cell has some drawbacks, such as the inability to absorb low-energy photons, resulting in a cell with a low conversion efficiency. Multi-junction solar cells, such as double and triple-junction solar cells, are advised to circumvent this constraint. Aside from having a high cell efficiency, the stacked multi-junction solar cell exhibits good consistency, as the issue of photodegradation associated with amorphous silicon solar cells is reduced. In1984, the National Renewable Energy Laboratory (NREL) invented the double-junction GaInP/GaAs cell [19].

4.3 Crystalline silicon cells

Solar cells are generally classified into crystalline silicon solar cells, amorphous silicon thin-film cells, GaAs solar cells, and the newly developed third-generation solar cells, which primarily refer to new concept solar resulting in a high conversion efficiency, such as dye-sensitized solar cells, quantum dot solar cells, and organic solar cells [29]. The crystalline silicon solar cell is one of them, and it has been extensively explored and used. Aside from this, many new technologies are still in the research and development stage. Crystalline silicon solar cells are less expensive and more mature than GaAs solar cells [23]. Though, the conversion efficiency of all PV crystalline silicon cells with texture does not rise in proportion with absorbance, due to problems such as; the effect of the surface optical functional microstructure on the uniformity of the PN junction depth of the crystalline silicon cells, During high-temperature diffusion, the top and bottom of the surface microstructure develop thermal stress-derived dislocation defects and lastly, The crystalline silicon cells' electrode contact resistance is increased by the surface microstructure [30]. As a result, the work done in [31] used an optical functional film with a triangular pyramidal texture to reduce the reflection loss of crystalline silicon cells. The results show that by using the triangular pyramid textured film, the reflection loss of smooth surface crystalline silicon cells decreases from 22.3 percent to 7.2 percent, and the photovoltaic conversion efficiency increases from 18.30 percent to 22.30 percent.

4.4 Thin-film solar cells technologies

Thin-film solar cells are appealing due to their low material consumption, low-cost synthesis procedures, and an upward trend in efficiency. The five major varieties of Thin Film Solar Cells (TFSC) are amorphous silicon (a-Si) solar cell, copper indium gallium selenide (CIGS) solar cell, copper zinc tin sulphide (CZTS) solar cell, and cadmium telluride (CdTe) solar cell-have made significant progress [32]. Figure 7 present the world record for PV/ thin-film production from the year 2010 to year 2020.

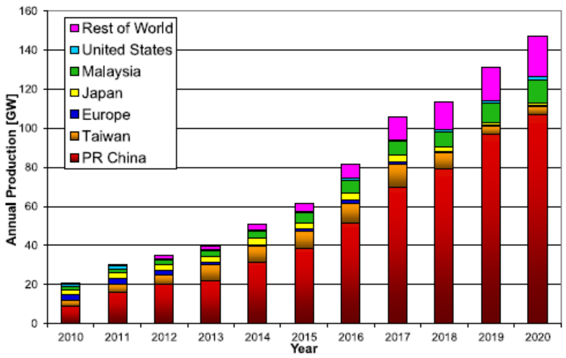

Fig. 7. Production of PV cells/thin film modules in the world from 2010 to 2020 [22].

Literature has looked into a variety of substrate and thin film materials. Such as Wood, gauze, paper, polystyrene foam, carbon fabric, cotton fabric, ceramic fiber wool, aerogel, nanoporous nickel, nanoporous anodic aluminum oxide, thin sheet of copper, and stainless-steel mesh are the most common substrate materials. Moreover, a variety of photothermal materials have been used as absorbents, as seen in Figure 8 including metal-based nanoparticles (aluminum, silver, and gold), metal-based oxides (ferroferric oxide, black titanium deoxide), carbon-based materials (graphite, graphene, graphene oxide, carbon black, carbon nanotubes), polymers (polydiacetylene and polypyrrole), and other materials such as cermet, titanium nitride, and copper sulfide [33].

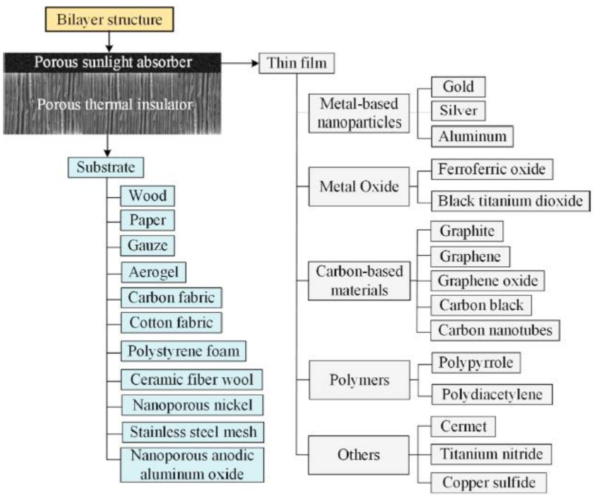

Fig. 8. Thin film and it's substrate materials [33].

The thin film materials can be classified as follows:

4.4.1 *Metal-based nanoparticles*

Metal-based nanoparticles such as gold, silver, and Aluminium, have become a widely accepted technology in various ways especially in fabrication because of its ease of use, excellent thermal conductivity, great electrical conductivity, great efficiency improvement, and low energy consumption [34].

4.4.2 *Metal Oxide*

Metal oxides, particularly transition metal oxides, have gained attention due to their magnetic, optical, electrical, and catalytic capabilities, as well as their prospective application in a variety of fields. Metal oxides have lately been used as a catalyst in the development of composite solid propellants, which yield reduced decomposition temperature and activation energy [35]. Metal oxide comprises of Ferroferric oxide, and black titanium oxide.

4.4.3 *Carbon-based materials*

Carbon-based materials includes Graphite, Graphene, graphene-oxide, carbon black and carbon nanotubes. Due to their distinctive structures and qualities, graphene (GE) and carbon nanotubes (CNT) have recently been widely explored in the field of rubber composite research. Large aspect ratios in CB, CNT, and GE promote bridging in the development of filler networks, disperse stress, and slow fracture formation. The elastic modulus and stiffness of a material can be significantly increased by addition of GE or CNT [36]. Also, [37] reported how the carbon-based materials could deliver an excellent capacitance performance. In their experiment to increase the performance of Electrochemical double layer capacitors EDLCs, composites containing several types of carbons, such as carbon nanodots (CD), carbon nanotubes (CNT), and graphene oxide (GO), with varied structural dimensions and porous architectures, have been created. They've been shown to have exceptional capacitance qualities.

4.4.4 *Polymers*

Polymers are organic materials such as polypyrrole, and polydiacetylene. Polymer composites are widely employed in industry, and are used in a variety of disciplines such as the airplane, automobile, electrical, and packaging industries, among others, because of their vast flexibility like, low cost, light weight, and excellent chemical consistency [38].

Figure 9: Shows the best-researched-PVCs with efficiency from 1975 to 2020.

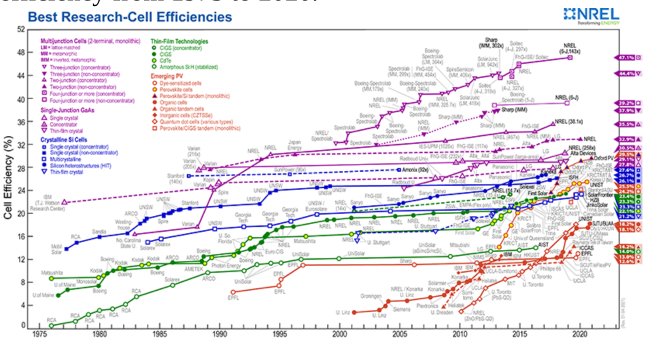

Figure 9: Best research- PVCs with efficiency from 1975-2020 [39].

4.5 Sustainability of PV as a renewable energy

Sustainable of solar energy has progressively gained ground as a significant energy source for the entire world [40] alongside other renewable power supplies, for instance, wind, hydro energy, and biomass [41]. In view of the free nature of the sun's energy, photovoltaics is among the essential forms of renewable power. Generally, solar PV techniques remain dependable, verified, also of minor upkeep. In addition to being reliable than several renewable power options, solar photovoltaic power can meet a wide range of electrical needs based on the design. It is more cost-effective to run a solar electric system off-grid instead of laying power lines in locations without an existing power supply. Solar panels generate electricity in proportion to the amount of sunlight they receive [42], up to their maximum capacity. In order to operate effectively, solar electric systems require unobstructed sunlight most of the day.

Furthermore, solar panels work best when sunlight hits them at 90° (optimum tilt angle). Therefore, the photovoltaic panels' orientation advantage will help increase energy production [43]. An issue with solar energy systems is the high temperature of the panels, which reduces their efficiency of electricity production. Due to the inefficiency of solar panels at night or during periods of dense cloud cover, solar electric systems require batteries for storing electricity or backup sources [44]. While the initial cost of PV systems is high [45], ongoing research into the materials and manufacturing methods might ultimately decrease costs in the future. Solar power is variable in common with several other renewable energy sources [46]. The investigation has also led to the development of concentrated solar collectors, thereby increasing the electrical energy generated quantity by the photovoltaic panels. Technology development in solar energy has several possible routes currently available. Among the possibilities is using high-efficiency photovoltaic cells [47] for building photovoltaic panels incorporated with a heat-exchange system. Another way to enhance the volume of energy given by photovoltaic panels is to increase their active area [48] as a solution to the adverse effects listed above. By implementing the highlighted improvements, solar energy generation can become a more sustainable source of renewable energy. Therefore, the PV systems must be sustainable in their deployment. The cells and the PV systems both must be sustainable with low-cost, high efficiency, have a long service life, and have the potential for further cost reduction. Incorporating PV sustainability into decentralized energy generating make sure that energy projects' long-term success is achieved [49]. The price of semiconductor silicon dropped rapidly during this period, from 500 USD/kg in 2007 to 55 USD/kg in 2010, and below 20 USD/kg since 2014 (the current price is under 10 USD/kg) [50].

5. Different materials used as Composites in Photovoltaic cell

Renewable energy sources have emerged as viable options for achieving fossil-fuel independence[51]. There are several renewable energy types used in many part of the world today, of note and widely available is the photovoltaic energy systems. Photovoltaic cells are made of silicon, which is the second most common substance on the earth's surface and has a high surface reflection characteristic. Because of its narrow bandgap, availability, affordability, nontoxicity, and well-established processing processes, silicon (Si) has become the most common semiconductor in solar-cell design out of the numerous semiconductors used for photovoltaics[52]. The efficiency of solar energy conversion into electricity, and the cost per watt of power generated, are perhaps the two most important variables in the success of silicon-based photovoltaics as a renewable energy technology. However, about 30% of sunlight reflects once it strikes the PV panel, significantly lowering the conversion efficiency[53]. To address silicon's reflecting property, a lot of research is being done on coatings for PV panels. According to recent developments, either micro coating or nanocoating of antireflection compounds on the PV panel improves solar energy conversion efficiency. When more research was done, it was discovered that nanocomposite materials are widely employed as antireflection materials [53].

Composite materials are made up of more than one type of material that are not really held together by chemical bonds. They were created with the goal of enhancing chemical and physical characteristics and expanding application options [54].

5.1 2D Materials

Due to their remarkable optical and electrical characteristics, 2D materials have received much interest, and they show a lot of promise for next-generation solar cells and other optoelectronic devices. With photovoltaic scaling trends heading toward smaller and thinner active materials, the atomically thin bodies and high flexibility of 2D materials make them the natural choice for integration with next-generation solar technology[52]. In the quest to lower cost per watt and increase watt per gram usage, silicon active absorber thickness must be reduced.

Thinner absorbers use less silicon but have a lower photon-absorption efficiency.
Several important properties of 2D materials stand out in this respect—excellent transparency, extraordinary flexibility, and high conductivity. Moreover, the outstanding features of scalability, modularity, and roll-to-roll fabrication enable 2D materials to play a key role in the future ultralight photovoltaic technology [55].

5.2 Graphene

With a high Young's modulus (1.1 TPa), a high thermal conductivity (3 X 10^3 W m^{-1} K^{-1} at room temperature), and an exceptional specific surface area (2630 m^2 g^{-1}), graphene, a zero-bandgap semi-metal with ambipolar electrical properties, also has remarkable mechanical properties [52]. The combination of G-based materials with polymers leads to new nanocomposites with enhanced structural and functional properties due to synergistic effects [56].

Nanocarbon materials are now being employed in PV solar systems due to their electrical and optical qualities that may be adjusted. These excellent properties are sufficient to meet the requirements of PVs and address charge carrier mobility and wide bandgap energy, as well as recombination center reduction, sheet resistance reduction, corrosion rate and degradation reduction, and thus an improve in the lifespan of PV cells modules [57].

Many authors have successfully investigated a variety of carbon nanomaterials, including fullerene's zero-dimensional (0D) material, carbon nanotubes' one-dimensional (1D) material, graphene's 2D material, and diamond or graphite's 3D material, which is widely used as a catalyst agent in every single PV cell. Graphene, a two-dimensional compound, will eventually become a flexible graphitic building block for other dimensional patterns. Graphene, on the other hand, performs poorly in PV cells when it comes to collecting electric field. Hence, PV-based graphene containing metal oxides with large band gaps, such as ZnO, TiO_2, Cu_2O, Al_2O_3, SnO_2,WO_3, NiO, In_2O_3, and others, is required. The following sections highlights the various types of 2D graphene-based for PV cells enhancement, as presented in Table 1 [58].

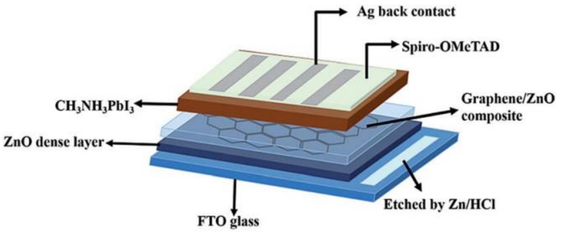

Fig.10. Schematic of the perovskite solar cell architecture fabricated using G/ZnO nanocomposite as an electron transporting layer [59].

Tables 1: Types of 2D graphene-based for PV cells enhancement

Materials	Composite	Technology type	Current density ($mA\ cm^{-2}$	% Performance	Reference
Graphene	Graphene/Zn	Perovskite	19.97	10.34	[59]
Graphene/Tandem solar cells	Graphene oxide (GO)	Schottky junction	19.1	10.6	[57]
Graphene/silicon-based Schottky junction solar cell	Silicon	Antireflecting coating	21.2	15.6	[58]
Organic-inorganic hybrid graphene solar cell	Silicon wafer	Schottky/graphene thickness control	21.1	15.48	[60]
Graphene electrode	Polybutylene	solid-state solar cells, electrochemical solar cells, QDSCs, and polymer solar cells.	19.0	10.5	[61]
Graphene-conducting polymer	Polybutylene/ TiO2	Transparent cathode	18.26	12.5	[62]
Graphene	Polyaniline (PANi)- and polyaniline-graphene/TiO2	(XRD), Scanning	26.3	8.63	[63]

		Electron Microscope (SEM), Raman Spectroscopy and Ultraviolet–Visible (UV–Vis) Spectroscopy			
Halogenated graphene	iodine and chlorine	HTL	18.1	11.1	[64]
Graphene	glass/ITO/Graphene/CH3NH3PbI3/Spiro-OMeTAD	ETL	21.24	20.95	[65]
graphene pre-illumination	GC6.3	Screen printed graphene coating (GC)	11	12.0	[66]

In Figure 11, a schematic diagram of graphene catalytic material integration of different types of PV applications is shown.

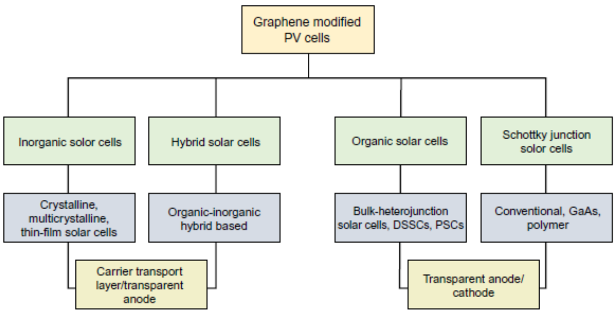

Fig. 11. A schematic diagram of graphene catalytic material types for PV applications [26].

5.3 MoS2

Two-dimensional (2D) materials, such as graphene and MoS_2, have stood out in the past decade due to their extraordinary properties. Because of the atomic thickness, mechanical strength, scalability, and large surface area, MoS_2 and other 2D materials are promising candidates for such applications[67], [68].

The monolayer MoS_2 experimental in-plane Young modulus is 270 ± 100 GPa [69], [70]. It also has band gaps of 1.2–1.8 eV, and this makes MoS_2 be promising 2D material [71]–[74]

Authors in [75] demonstrated that a high-quality monolayer n-type MoS_2 on a p-Si substrate with efficiency of 5.23% monolayer-based solar cells. The creation of a type-II heterojunction with p-Si, which creates a built-in electric field near the inter-face between MoS_2 and p-Si to enable photogenerated c, results in excellent photovoltaic operation in large-scale MoS_2 monolayers.

Figure 12 depicts the structure of MoS2. (a) is a three-dimensional representation of the MoS2 structure with interlayer and free spacing (b) is the 2H phase with trigonal prismatic coordination (c) is the 1T octahedral coordination phase.

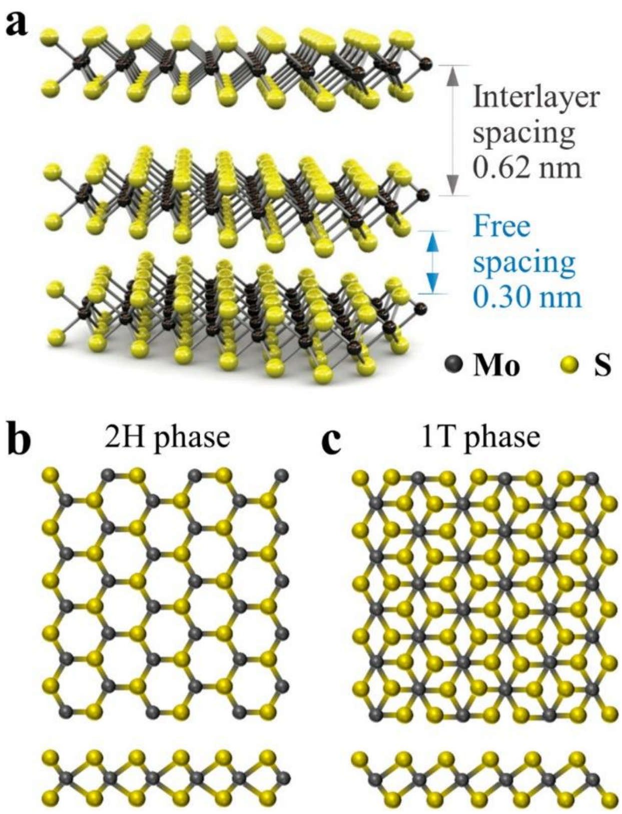

Fig. 12. (a) is a three-dimensional representation of the MoS2 structure with interlayer and free spacing (b) is the 2H phase with trigonal prismatic coordination (c) is the 1T octahedral coordination phase [59].

6. Conclusion

This paper has reviewed some recent developments in efficiency PV cell through different types of composites. The reviewed covered the various generation of PV cell technologies as it is generally termed under generations from first generation to the fourth generation. The first generation was basically centered around silicon-based materials, and it has gained more ground among others as it is more prevalent in industrial use. Although it is a good material but because of the high cost an alternative production and fabrication has to come in place which gave rise to the other categories under generation two to four. Even though there are still some recent developments at the laboratory stage and various research about these are still ongoing. Different composites such as (copper (Cu) and MAPbI3, Ag NWs, and ultrathin Ag films, nano-mica nanocomposite and composite phase change material) have come to a good use in trying to improve the efficiency of the solar cell. With these different composites' materials, we have seen in literature that the solar cell efficiency has been greatly improved in recent years. However, there is a need for more sustainable approaches in a bid to improve on the existing photovoltaic technologies which should inform the need for future research in this field.

References

[1] S. Safaee and R. K. Chen, "Development of a design and characterization framework for fabrication of functionally graded materials using magnetic field-assisted digital light processing stereolithography," *J. Manuf. Process.*, vol. 67, no. February, pp. 314–324, 2021.

[2] S. Joyson *et al.*, "Microstructural Characterization and Tensile Behavior of Rutile (TiO 2) - Reinforced AA6063 Aluminum Matrix Composites Prepared by Friction Stir Processing," vol. 5, pp. 52–62, 2019.

[3] M. Gautam and M. Chaturvedi, "Materials Today : Proceedings Optimization of functionally graded material under thermal stresses," *Mater. Today Proc.*, vol. 44, pp. 1520–1523, 2021.

[4] V. Boggarapu, R. Gujjala, S. Ojha, S. Acharya, P. Venkateswara, and S. Chowdary, "State of the art in functionally graded materials," *Compos. Struct.*, vol. 262, no. December 2020, p. 113596, 2021.

[5] F. Hassan, M. Salah, O. M. El-borady, M. Mabrouk, and D. I. El-korashy, "Physical and mechanical evaluation of dental resin composite after modification with two different types of Montmorillonite nanoclay," *J. Dent.*, vol. 112, no. January, p. 103731, 2021.

[6] A. R. Jayakrishnan, J. P. B. Silva, K. Kamakshi, V. Annapureddy, I. F. Mercioniu, and K. C. Sekhar, "Journal of Science : Advanced Materials and Devices Semiconductor / relaxor 0 e 3 type composites : A novel strategy for energy storage capacitors," *J. Sci. Adv. Mater. Devices*, vol. 6, no. 1, pp. 19–26, 2021.

[7] X. Zhang, K. Sun, D. Xu, and S. Guo, "Lightweight Photovoltaic Composite Structure on Stratospheric Airships," vol. 2018, 2018.

[8] M. Quddamah *et al.*, "High-efficiency hybrid solar cell with a nano-crystalline silicon oxide layer as an electron-selective contact," *Energy Convers. Manag.*, vol. 252, no. November 2021, p. 115033, 2022.

[9] M. Khalid, A. Roy, S. Bhandari, P. Selvaraj, S. Sundaram, and T. K. Mallick, "Opportunities of copper addition in CH3NH3PbI3 perovskite and their photovoltaic performance evaluation," *J. Alloys Compd.*, vol. 895, p. 162626, 2022.

[10] W. Lü *et al.*, "Photoelectric balance of rear electrode in bifacial perovskite solar cells : Construction of 0D / 1D / 2D composite electrode based on silver nanowires to boost photovoltaic output," *J. Power Sources*, vol. 520, no. November 2021, p. 230815, 2022.

[11] M. Khalifa, G. Wuzella, A. Hussain, and H. Lammer, "Poly (vinylidene fluoride)/ Mica nanocomposite : A potential material for photovoltaic backsheet application," *Mater. Chem. Phys.*, vol. 277, no. December 2021, p. 125551, 2022.

[12] V. Karthikeyan, C. Sirisamphanwong, S. Sukchai, and S. Kumar, "Reducing PV module temperature with radiation based PV module incorporating composite phase change material," *J. Energy Storage*, vol. 29, no. March, p. 101346, 2020.

[13] T. R. Olorunfemi and N. Nwulu, "Optimal Grid-Connected Microgrid Scheduling Incorporating an Incentive-Based Demand Response Program."

[14] K. R. T. Kumar and M. R. G. D. Sukumar, "A review on PV cells and nanocomposite - coated PV systems," no. November 2017, pp. 2305–2319, 2018.

[15] T. R. Olorunfemi and N. Nwulu, "Optimization Applications in Distributed Energy resources : Review and Limitations," *2018 Int. Conf. Comput. Tech. Electron. Mech. Syst.*, pp. 446–450, 2018.

[16] T. R. Olorunfemi and N. Nwulu, "A Review of Mathematical Optimization Applications in Renewable Energy-Powered Microgrids," pp. 603–613.

[17] L. Cern, "Heliyon Review article PV cells and modules – State of the art , limits and trends Vít," vol. 6, no. September, 2020.

[18] A. Luceño-s and A. Mar, "Materials for Photovoltaics : State of Art and Recent Developments," 2019.

[19] C. Outline and P. Cell, *Nanostructured Semiconductor Composites for Solar Cells*. 2018.

[20] B. Pratap, S. Kumar, and P. Kumar, "Materials Today : Proceedings Solar PV cell materials and technologies : Analyzing the recent developments," *Mater. Today Proc.*, vol. 43, pp. 2843–2849, 2021.

[21] R. Rajan, F. M. Fernandez, and Y. Yang, "Primary frequency control techniques for large-scale PV-integrated power systems : A review," *Renew. Sustain. Energy Rev.*, vol. 144, no. March, p. 110998, 2021.

[22] A. Jäger-waldau, "Snapshot of photovoltaics À March 2021," vol. 2, pp. 1–7, 2021.

[23] K. Liang, D. Ai, H. Zhang, Y. Zhao, Y. Zhang, and H. Chen, "Experimental performance analysis of the concentrated crystalline silicon solar cell —— slicing cell," *Sol. Energy*, vol. 224, no. July, pp. 1008–1016, 2021.

[24] G. Michael *et al.*, "Nano Energy High-performance piezo-phototronic multijunction solar cells based on single-type two-dimensional materials," *Nano Energy*, vol. 76, no. May, p. 105091, 2020.

[25] I. Rey-stolle and G. Hou, "High-low refractive index stacks for broadband antireflection coatings for multijunction solar cells," vol. 217, no. February, pp. 29–39, 2021.

[26] N. Shigekawa, R. Kozono, S. Yoon, T. Hara, J. Liang, and A. Yasui, "Solar Energy Materials and Solar Cells Effects of post bonding annealing on GaAs // Si bonding interfaces and its application for sacrificial-layer-etching based multijunction solar cells," *Sol. Energy Mater. Sol. Cells*, vol. 210, no. January, p. 110501, 2020.

[27] M. Azadinia, M. Ameri, R. T. Ghahrizjani, and M. Fathollahi, "Maximizing the performance of single and multijunction MA and lead-free perovskite solar cell," *Mater. Today Energy*, vol. 20, p. 100647, 2021.

[28] M. De Lafontaine *et al.*, "Micro and Nano Engineering Anisotropic and low damage III-V / Ge heterostructure etching for multijunction solar cell fabrication with passivated sidewalls," vol. 11, no. February, pp. 1–13, 2021.

[29] L. C. Andreani *et al.*, "Advances in Physics : X Silicon solar cells : toward the efficiency limits Silicon solar cells : toward the e ffi ciency limits," *Adv. Phys. X*, vol. 4, no. 1, 2019.

[30] Z. Zhang *et al.*, "Solar Energy Materials and Solar Cells Optimization of indium recovery from waste crystalline silicon heterojunction solar cells by acid leaching," *Sol. Energy Mater. Sol. Cells*, vol. 230, no. April, p. 111218, 2021.

[31] Z. Xu, X. Xu, and C. Cui, "Optical functional fi lm with triangular pyramidal texture for Crystalline silicon solar cells," *Sol. Energy*, vol. 201, no. February, pp. 45–54, 2020.

[32] A. Kowsar, M. Rahaman, S. Islam, A. Y. Imam, and S. Chandra, "Progress in Major Thin-film Solar Cells : Growth Technologies , Layer Materials and Efficiencies," no. June, 2019.

[33] A. H. Elsheikh, S. W. Sharshir, M. Kamal, A. Ali, and J. Shaibo, "Thin film technology for solar steam generation : A new dawn," *Sol. Energy*, vol. 177, no. November 2018, pp. 561–575, 2019.

[34] W. Yang, M. Pan, C. Huang, Z. Zhao, J. Wang, and H. Zeng, "Graphene oxide-based noble-metal nanoparticles composites for environmental application," *Compos. Commun.*, vol. 24, no. January, p. 100645, 2021.

[35] J. A. Vara and P. N. Dave, "Metal oxide nanoparticles as catalyst for thermal behavior of AN based composite solid propellant," *Chem. Phys. Lett.*, vol. 730, no. June, pp. 600–607, 2019.

[36] H. Guo, S. Jerrams, Z. Xu, Y. Zhou, and L. Jiang, "Enhanced fatigue and durability of carbon black / natural rubber composites reinforced with graphene oxide and carbon nanotubes," *Eng. Fract. Mech.*, vol. 223, no. August 2019, p. 106764, 2020.

[37] Y. Hu, H. Quan, J. Cui, W. Luo, W. Zeng, and D. Chen, "Journal of Alloys and Compounds," vol. 877, 2021.

[38] F. Gao, K. Zhang, Y. Guo, and J. Xu, "Progress in Materials Science (Ba , Sr) TiO 3 / polymer dielectric composites – progress and perspective," vol. 121, no. March, pp. 1–39, 2021.

[39] "best-research-cell-efficiencies.20200104.pdf." .

[40] R. Blaga, A. Sabadus, N. Stefu, C. Dughir, and M. Paulescu, "A current perspective on the accuracy of incoming solar energy forecasting," *Prog. Energy Combust. Sci.*, vol. 70, pp. 119–144, 2019.

[41] J. Liu, "China ' s renewable energy law and policy : A critical review," *Renew. Sustain. Energy Rev.*, vol. 99, no. August 2018, pp. 212–219, 2019.

[42] K. E. Khujamatov, "Modeling and Research of Automatic Sun Tracking System on the bases of IoT and Arduino UNO."

[43] C. S. Schuster and D. Ph, "The quest for the optimum angular-tilt of terrestrial solar panels or their angle-resolved annual insolation," *Renew. Energy*, vol. 152, pp. 1186–1191, 2020.

[44] C. Duan *et al.*, "A Solar Power-Assisted Battery Balancing System for Electric Vehicles," vol. 4, no. 2, pp. 432–443, 2018.

[45] T. M. Qureshi, K. Ullah, and M. J. Arentsen, "Factors responsible for solar PV adoption at household level : A case of," *Renew. Sustain. Energy Rev.*, vol. 78, no. December 2016, pp. 754–763, 2017.

[46] E. Du *et al.*, "The Role of Concentrating Solar Power Toward High Renewable Energy Penetrated Power Systems," vol. 33, no. 6, pp. 6630–6641, 2018.

[47] "Recently developed high-efficiency organic photoactive materials for printable photovoltaic cells a mini review.pdf." .

[48] F. Enrichi, A. Quandt, and G. C. Righini, "Plasmonic enhanced solar cells : Summary of possible strategies and recent results," *Renew. Sustain. Energy Rev.*, vol. 82, no. September 2017, pp. 2433–2439, 2018.

[49] B. Emmanuel *et al.*, "Optimization and sustainability analysis of PV / wind / diesel hybrid energy system for decentralized energy

generation," *Energy Strateg. Rev.*, vol. 32, p. 100570, 2020.

[50] C. Schenone and I. Delponte, "Renewable energy sources in local sustainable energy action PLANs (SEAPs): analysis and outcomes," *Energy Policy*, vol. 156, no. March, p. 112475, 2021.

[51] S. P. Lim, A. Pandikumar, H. N. Lim, R. Ramaraj, and N. M. Huang, "Boosting photovoltaic performance of dye-sensitized solar cells using silver nanoparticle-decorated N,S-Co-doped-TiO2 photoanode," *Sci. Rep.*, vol. 5, 2015.

[52] S. Das, D. Pandey, J. Thomas, and T. Roy, "The Role of Graphene and Other 2D Materials in Solar Photovoltaics," *Advanced Materials*, vol. 31, no. 1. 2019.

[53] K. Rakesh Tej Kumar, M. Ramakrishna, and G. Durga Sukumar, "A review on PV cells and nanocomposite-coated PV systems," *International Journal of Energy Research*, vol. 42, no. 7. 2018.

[54] M. C. C. de Oliveira, L. G. Soares, M. M. Viana, A. S. A. C. Diniz, and V. de F. C. Lins, "Development of ethylene-vinyl acetate copolymer/graphene oxide nanocomposites for crystalline silicon photovoltaic modules," *Int. J. Adhes. Adhes.*, vol. 100, 2020.

[55] N. Petrone, J. Hone, and D. Akinwande, "Two-dimensional flexible nanoelectronics," *Nat. Commun.*, vol. 2, 2015.

[56] A. M. Díez-Pascual, J. A. L. Sánchez, R. P. Capilla, and P. G. Díaz, "Recent developments in graphene/polymer nanocomposites for application in polymer solar cells," *Polymers*, vol. 10, no. 2. 2018.

[57] F. Wah, C. Wei, N. Asma, and Y. Yusoff, *Graphene and its derivatives , synthesis route , and mechanism for photovoltaic solar cell applications*. Elsevier Inc., 2021.

[58] J. Ma, Y. Yuan, and P. Sun, "Performances enhancement of graphene/n-Si Schottky junction solar cells with dual-functional MoS2 interfacial layers," *J. Alloys Compd.*, vol. 883, p. 160898, 2021.

[59] P. S. Chandrasekhar and V. K. Komarala, "Graphene/ZnO nanocomposite as an electron transport layer for perovskite solar cells; The effect of graphene concentration on photovoltaic performance," *RSC Adv.*, vol. 7, no. 46, 2017.

[60] A. Yi *et al.*, "Nano Energy Roll-transferred graphene encapsulant for robust perovskite solar cells," *Nano Energy*, vol. 77, no. June, p. 105182, 2020.

[61] T. Mahmoudi, Y. Wang, and Y. Hahn, "Nano Energy Graphene and its derivatives for solar cells application," *Nano Energy*, vol. 47, no. February, pp. 51–65, 2018.

[62] H. A. Chaliyawala, S. Vemuri, K. Lellala, and I. Mukhopadhyay, "Materials Today : Proceedings Role of surface passivation on the development of camphor based Graphene / SiNWAs schottky diode," *Mater. Today Proc.*, vol. 45, pp. 3789–3794, 2021.

[63] K. Nemade, P. Dudhe, and P. Tekade, "Enhancement of photovoltaic performance of polyaniline / graphene composite-based dye-sensitized solar cells by adding TiO 2 nanoparticles," *Solid State Sci.*, vol. 83, no. May, pp. 99–106, 2018.

[64] K. Ibrahim *et al.*, "Humidity-resistant perovskite solar cells via the incorporation of halogenated graphene particles," *Sol. Energy*, vol. 224, no. June, pp. 787–797, 2021.

[65] A. Daraie and A. Fattah, "Performance improvement of perovskite heterojunction solar cell using graphene," *Opt. Mater. (Amst).*, vol. 109, no. May, p. 110254, 2020.

[66] M. Alzahrani, A. Roy, K. Shanks, S. Sundaram, and T. K. Mallick, "Solar Energy Materials and Solar Cells Graphene as a pre-illumination cooling approach for a concentrator photovoltaic (CPV) system," *Sol. Energy Mater. Sol. Cells*, vol. 222, no. December 2020, p. 110922, 2021.

[67] P. O. Oviroh, T.-C. Jen, J. Ren, L. M. Mohlala, R. Warmbier, and S. Karimzadeh, "Nanoporous MoS2 Membrane for Water Desalination: A Molecular Dynamics Study," *Langmuir*, vol. 37, no. 23, pp. 7127–7137, Jun. 2021.

[68] J. S. Lim and G. Kim, "First-principles modeling of water permeation through periodically porous graphene derivatives," *J. Colloid Interface Sci.*, vol. 538, pp. 367–376, 2019.

[69] S. Deng, A. V. Sumant, and V. Berry, "Strain engineering in two-dimensional nanomaterials beyond graphene," *Nano Today*. 2018.

[70] S. Bertolazzi, J. Brivio, and A. Kis, "Stretching and breaking of ultrathin MoS 2," *ACS Nano*, 2011.

[71] H. J. Conley, B. Wang, J. I. Ziegler, R. F. Haglund, S. T. Pantelides, and K. I. Bolotin, "Bandgap engineering of strained monolayer and bilayer MoS2," *Nano Lett.*, 2013.

[72] J. W. Jiang and H. S. Park, "Mechanical properties of MoS2/graphene heterostructures," *Appl. Phys. Lett.*, 2014.

[73] T. Eknapakul *et al.*, "Electronic structure of a quasi-freestanding MoS2 monolayer," *Nano Lett.*, 2014.

[74] A. Fang, K. Kroenlein, and A. Smolyanitsky, "Mechanosensitive Ion Permeation across Subnanoporous MoS 2 Monolayers," *J. Phys. Chem. C*, 2019.

[75] M. L. Tsai *et al.*, "Monolayer MoS2 heterojunction solar cells," *ACS Nano*, vol. 8, no. 8, 2014.