International Journal of Thin Films Science and Technology

http://dx.doi.org/10.18576/ijtfst/150101

Recent Advances and Challenges in Power Conversion Efficiency of Organic, Dye-Sensitized, Thin-Film, and Perovskite Solar Cells: A Comprehensive Review

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Received: 2 May 2025, Revised: 13 Jul. 2025, Accepted: 22 Aug. 2025
Published online: 1 Jan. 2026

Abstract: This review focused on the most recent developments, which include solar cells regarding their features and applications. Characteristic designed solar cells were also presented and special properties like band gaps and carrier mobility were highlighted. The band gap is one of the most fundamental properties of a semiconductor material in a solar cell, where it determines the quality in terms of what light in the spectrum can be absorbed and utilized to make electricity. A perfect band gap is not too large to absorb photons across the solar spectrum and at the same time it minimizes energy losses. A band gap of 1.5 eV is generally considered ideal for solar cell materials since it allows efficient absorption of a significant fraction of the solar spectrum, particularly in the visible portion. Carrier mobility is an important solar cell performance parameter, which governs the speed with which electron, hole pairs move under an electric field through the material. High carrier mobility is also important for efficient charge collection at the electrodes, which minimizes recombination losses and ultimately increases the power conversion efficiency. Dye-sensitized solar cells (DSSC) based on natural dyes have several advantages in energy utilization. Natural dye-sensitized solar cells have been favored by multiple advantages, while the efficiency of DSSCs is much lower than that of silicon-based solar cells. A significant impact of the plant-part selection on the performance of such devices can be observed. Therefore, the compounds in the plant have been thoroughly investigated, which are responsible for the increase of efficiency of the device. The power conversion efficiency of organic solar cells increased dramatically over the past decade, approximately 10 years when the high-performance organic electron donor and acceptor is used as the photoactive layer. The molecular design principles of different organic solar cells are presented and some of the most promising research directions are reviewed. The performance of perovskite solar cells has already surpassed 25% efficiency, based on the possibilities to fabricate high-quality films using low-temperature synthesized methods, as well as the progress in establishing proper interface and electrode materials. As for the thin film solar cells, the power conversion efficiency, the fill factor, the open circuit voltage, and the short circuit current density also depend sensitively on the experimental conditions.

Keywords: band gap, dye sensitized solar cells, energy efficiency, organic solar cells, photovoltaic, thin films.

1. Introduction

Energy makes the world go in the modern world today, and traditional sources of energy lead to severe environmental pollution, low efficiency, and not too sustainable. There is therefore a pressing requirement for alternative clean and sustainable energy options. The increasing worldwide demand for clean and sustainable power has driven extensive research activities on renewable energy applications [1], where solar power is one of the most attractive candidates. Key among them are the solar cells (or photovoltaic cells), which convert the solar energy into electricity in the form of the photovoltaic effect, and hence, have contributed the most in decreasing the greenhouse gas emissions and mitigating the environmental damage.

The solar cell has experienced an impressive evolution since the discovery of the first silicon solar cell in the 1950s, and has made significant progress in efficiency, as well as in different materials, stability, and price. So far, silicon type solar cells have been greatly used owing to the high efficiency and reliability [2]. Nevertheless, because of the growing demand for renewable energy sources worldwide, the photovoltaic sector is still seeking other, more efficient solutions than traditional silicon-based solar cells. This exploration has expanded to the development of thin-film semiconductor-based solar cells and preliminary concept of the research was proposed in early 1970s during the oil crisis, because our reliance on alternative energy sources was becoming critical by the day. The thin-film semiconductors are a type of semiconducting materials, which are positioned in the form of a thin layer, usually

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between a few nanometers to a few micrometers, on a substrate like glass, plastic or metal [3]. Such materials including amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium gallium selenide (CIGS) showed required semiconducting functionality such as light absorption, generation of charge carriers, and electrical conduction, and could be used for devices such as solar cells and other optoelectronic devices.

CdTe is less toxic than cadmium (Cd). The main situation of concern would be the liberation of cadmium from CdTe including leaching. There is no amount of cadmium exposure that is healthy. It has also been associated with neurotoxicity and carcinogenicity, and with harm to the kidneys and bones. Indium is a rare and expensive element, and the cost of technologies that rely on it can tend to be more expensive. Indium has some drawbacks, especially with respect to health and environmental issues and technological limitations. There are also potential health risks to the lungs from inhalation and to the skin from physical contact, with greater exposure levels increasing the risk of more severe organ damage. Environmentally, indium is a scarce element that poses challenges to recycle from e-waste, which may be a driving factor behind e-waste pollution.

Indeed, their specific features render them ideal for niche and emerging fields other than conventional solar cells, such as those featured in flexible electronics and lightweight power systems [4]. The first commercial thin-film solar modules, known from 1983 as AQT 1, were produced in 1981 and look like the Apollo Telescope Mount, using amorphous silicon (a-Si) cells. The 1990s also brought up cadmium telluride and copper indium gallium selenide thin film cells, which provided higher efficiencies and better stability. Thin-film solar cells as opposed to the traditional silicon cells, have some advantages such as low material usage requirement, compatible flexible substrate, and ease of manufacturing process scalability, which make them a desirable candidate for applications in which rigid, heavy silicon panels cannot be used. First Solar and Siemens Solar were the ones who started to commercialize large-area CdTe modules in the 1990's.

Third generation solar cells take one more step forward in photovoltaic technology to overcome the disadvantages of their precursors and it is desired to break the so-called theoretical Cartesian efficiency limits. It is the advanced one based on new materials and technical workers power conversion in high-performance, low-cost new materials and production process. This type of solar cell employs all manners of low light-to high-efficiency technologies, ranging from cheap dye-sensitized or organic cells, to the more expensive (III-V multi-junction device). These are solar cells with several p-n junctions' series-connected with each other by a variety semiconductor material [5]. At each junction an electric current is generated by a light of different wavelengths. This increases the conversion of the incident sunlight to electricity and the efficiency of the device. Tandem solar cells have we are on target for making devices that can be used as much also been proposed to harvest as much light as possible of the light as possible than it can over different materials (with different band gaps). It will be appreciated that a full cell (including active and counter electrodes) may be constructed in differing configurations which contain same or different material types. Fourth generation photovoltaics (that produce significantly lower cost of production) such as polymer & thin films enable the potential for terawatt peak level power generation (especially due to the ease of the production technique). Graphene based photovoltaic cells, it is conceived that particularly clear benefits are realized in the domain of solar energy technology with graphene based photovoltaic cells providing flexible solar cells, as well as transparent and high-efficiency solar cells [6]. Graphene has unique properties like high carrier mobility, high mechanical strength and optical transparency to malignant parts in photovoltaic structure. Because the graphene sheet is so thin, graphene solar cells need only a small amount of raw material, which means extremely low manufacturing costs can be achieved. Its natural adaptability has allowed researchers to make a wide variety of solar cells using it that would simply be impossible with silicon. It has a variety of superior physical and electrical properties and provides many opportunities for tuning solar cell applications, which are very attractive for power-hungry people.

In this context we will analyze solar cells with diverse architectures and working principles, challenges and high-performance materials. The review concentrates on organic solar cells, thin film solar cells, perovskite solar cells and dye sensitized solar cells. At the same time photovoltaic characterizations, such as power conversion efficiency, will be obtained on the dedicated cells.

2. Experimental

A comprehensive literature search was carried out across seven electronic databases such as Google Scholar, Taylor & Francis, ACS, Scopus, Wiley Online Library, Science Direct, and MDPI. The search was performed for the research papers published from 1979 until 1st July 2025. The main keywords included "organic solar cells", "absorption properties", "silicon based solar cells", "thin film based solar cells", "chalcogenide thin films", "perovskite solar cells", "dye-sensitized solar cells", "band gap", "semiconductor materials", and "photovoltaic parameters".

3. Photovoltaic parameters on the performance of organic solar cells

Organic solar cells have been intensively studied and reported by many researchers (Table 1). For the most part they were polymers or small molecules. To incorporate an

organic material into organic electronics [7], it needs to be a semiconductor, for which a high degree of conjugation is essential. This conjugative system of the organic compound causes the bonding electrons in the double bonds to spread all over the entire system. These electrons are higher in energy than other electrons of the molecule and are analogous to valence electrons in inorganic semiconductors. Like other solar cell types, the organic solar cell aims to produce electricity from sunlight. This occurs through the absorption [8] and excitation of one electron from HOMO to LUMO, as the energy of light is the same as or greater than the energy gap that is formed.

This is formed by the fact that the surrounding atoms are all short of one electron and so they will attract the wandering electrons and form something called a "hole" or a "missing electron". Because of the contrary charges of the electron and hole, they are attracted, and they create an electron–hole pair, called an “exciton”. To eliminate the charged particles in the solar cell, which is the extraneous electrons and holes, the researcher must separate the electron-hole, so called “exciton dissociation”.

As a rule, for inorganic semiconductors, the strength of the electron [9] and hole interaction (exciton binding energy) is so small that this can be compensated by thermal energy at room temperature (typically 2 meV). The high dielectric constant reduces electron-hole binding due to stronger screening effects.

Resulting from the type-II structure, the electron and hole are readily separated. Conversely, for organic semiconductors, the low dielectric constant results in large binding energies of 0.3–0.5 eV. For inorganic semiconductor materials, exciton dissociation by thermal energy is impossible. At least two different organic semiconductors are required to counteract this in organic photovoltaics. The energy amounts of the two organic solar cells are staggered and are much higher than the binding energy level, so that active layer can be dissociated at the interface of organic solar cell.

Especially for the discipline of organic solar cell technology, until now, continued efforts are being made to increase the photovoltaic properties [10] of donor-acceptor material to achieve higher power conversion efficiencies. Such kind of amendment contributes to the advanced conduction-band and electrochemical properties. And, via its combination of BTD-OMe and eight other (benzothiadiazole-based and other) donor-acceptor materials, the group developed compound BT05, one of its nine new compounds found to be of interest in organic photovoltaics, that (at 25%) outperformed BTD-OMe's 18% power conversion efficiency. Higher values of the open circuit voltage can be observed, which increasing binding energy in 1.99 eV, large maximum wavelength (470–476 nm) and decreasing in the energy gap (4.25–4.65 eV) also justify the power conversion efficiency and confirmed the successful synthesis of molecules BT01–BT09. The experimental results indicated that BT01-BT09 were efficient to enhance the properties of organic solar cells and were reasoned as a promising motive for the technology in the field of renewable energy application. BT05 shows the highest open circuit voltage of 2.26 V, the fill factor of 87%, and the efficiency of 25% among the compounds.

Fullerene derivatives have been used in indoor organic solar cells as electron acceptors for their spectral complementarity and photodimerization was controllable. An interesting observation for such a fullerene material is observed in the overlap region between the absorbance with the artificial light sources and the active layer. Furthermore, since the incident light level is low, photodimerization is minimized and the morphological instability of fullerene is suppressed. The devices [11] were also characterized for operation under indoor illumination, with fullerene PC61BM based cells mixing with three different donor polymers. Devices showed far enhanced power conversion efficiencies under sun illumination compared to low-light efficiencies. The optimized PM6:PC61BM standard organic solar cells showed the maximum efficiency of 7.94% under AM 1.5G test and 23.27% under LED illumination. In contrast to the inorganic solar cells, the organic solar cells work in the region of the photovoltaic characteristic when they are illuminated with sunlight. Although, the organic absorbers with high absorbance in the visible light range (380 nm-760nm) might have very promising for indoor applications; indoor use are the artificial light sources used, such as LED, fluorescent lamps, filament lamps and obviously all lamps with this range.

Introduction of a new non-fullerene acceptor material for organic solar cells. A high filling factor (> 95%) and power conversion efficiency of 30.34% for D2APH1 was also obtained. Red shift and energy band gap smaller than the reference molecule cause Shannel of the absorption spectra of D2APH1-D2APH4. In addition, the engineered molecules exhibited a high open circuit voltage with high electron and hole mobility over-metal electrode. The simple exciton in a higher excited state can easily form, because the excitation energy is relatively low and the oscillator strength is strong.

Conjugation was similarly important in other classes of light absorbing materials such as the electron acceptor of the active layer. Meanwhile, owing to the conjugation effect, the charge carrier transfers from the bottom and the top of valence band and the band gap could reduce the size, meanwhile the chargers can be quickly transferred forward and back and forth.

Heteroatoms and long conjugation rings also act to facilitate the transfer of charge over long distances from one part of the active layer material to another by the sunlight when photons interact with the material. The theoretical energetic efficiency work values and the D2APH1−D2APH4 were 30.64% (D2APH1), 29.21% (D2APH2), 30.1% (D2APH3), and 29.39% (D2APH4), respectively. After a thorough survey and discussion, the

altered species are found promising candidates with improved power conversion efficiency offering with the existing efficiency increment that can be further extended to the future solar cells. Such molecules with small reorganizational energies (indicating high mobility of both electrons and holes) and red shifted absorption will be suitable for obtaining high efficiencies in organic solar cells in future. Further, a band gap in a narrow energy is to easily transfer a charge between two molecular orbitals. Smaller binding and excitation energies facilitate excitation and state dissociation of exciton.

More broadly, both tandem solar cell efficiency and efficiency per unit cost is typically maximized by selecting active layers with complementary absorption, but efficiency may be further boosted by balancing photocurrent between them rather than sub-cells. Mismatched photocurrents may lead to carrier accumulation of the sub-cells and thereby reduce the fill factor of the tandem cell. In general, ideal sub-cell thickness in tandems is not the same as the single junction case [12]. To obtain the actual balance in a tandem configuration, however, it is necessary to carefully adjust the thickness of each sub-cell. In that sense it is necessary to control the introduction of the optical field in the tandem device in the best way so that in addition to having a balanced photocurrent very high performance and fill factor is obtained. Balanced photocurrents in the sub-cells may also be realized by appropriately designing the donor/acceptor ratio in the sub-cells.

The interconnecting layer (ICL) of tandem devices is also an important constituent to the performance. For one, the ICL must provide equal (ohmic) contacts to combine the open circuit voltage of the sub-cells without any loss. It also must be cleaned as clean can be, aesthetically. From a mechanical standpoint, the ICL is rigid enough to resist the solution being penetrated while the back cell is processed.

The two terminal tandem organic solar cells would increase the energy limits still more and is a potential route to high efficiency organic solar cells. In this work, we described the preparation [13] of an all-solution process interconnecting layer comprising ZnO:PEI/PEI/PEDOT:PSS/2PACz for tandem solar cells. The donor: acceptor ratio and film thickness of the PM6:BTPeC9 active layer material were optimized for both the front and rear sub-cells. Mechanical, electrical and optical properties of the ICL were determined. Enhancement of heterojunction front- and rear-sub-cells by multi-dimensional modulation for high efficiency homojunction tandem solar cells The configuration of tandem solar cells was ITO/PEDOT:PSS/2PACz/active layer/ICL/active layer/PNDIT-F3N/Ag. The optimized device achieved a power conversion efficiency of 19.9%, which is the highest among all reported homojunction tandem solar cells. It was shown that careful design of layer-to-layer interconnections in a homojunction tandem cell structure (even donor-to-acceptor ratio) could lead to a breakthrough increase in the efficiency of photovoltaic conversion.

In the present, as new trends of material science, big data and AI have been introduced to construct quantitative structure activity relationships. Machine Learning (ML) is now mature for the rational design of photoelectric material (efficiency, band gap, stability). Therefore, ML is suitable for organic solar cells, and it can mine out any possible underlying relationships between the features and the labels.

ML reduces the trial-and-error cost through data analysis and predictive modeling to find the best solution and a trend, which minimizes extensive and expensive experiments. ML models can predict outcomes, optimize processes, and recommend next-best solutions using historical data that could have taken much longer if it was set in a traditional approach.

For example, a case study in the context of the design and testing of materials for organic solar cells employed molecular dynamics simulations synergistically with machine learning methods and identified new materials. The procedure began with assembling information about different molecular structures and their properties. ML models could then learn to predict the performance of such configurations, thereby optimizing the selection process by reducing the number of candidates that may need to be tested experimentally. This approach not only accelerated the research process, but also reduced costs with other time-consuming, trial-and-error experiments.

The efficiency of organic solar cells now surpasses 19% with non-fullerene acceptors [14]. To this end, machine learning models based on combined input features (molecular descriptors and fingerprints) are explored for various algorithms to aid the non-fullerene acceptor study. While the model with fingerprints performed slightly less well, it can be computed faster and on denser grids and has much better generalization due to its lower complexity that hinders overfitting.

The exciton diffusion lengths were calculated to be 26 nm for ITIC and 34 nm for IT4F. This red shift [15] ofIT4F with respect to ITIC at the onset of absorption. The exciton diffusion in ITIC and IT4F was investigated quantitatively using singlet-singlet exciton annihilation. The exciton annihilation in organic semiconductors is thought to proceed when two singlets come close to a critical separation.

In the annihilation event, one exciton is annihilating transferring its energy to another with higher energy. The single-singlet annihilation crucially depends on the exciton concentration as well as on the exciton diffusion constant. Exciton splitting in this non-fullerene electron acceptor (NFA) was characterized using transient absorption (TA) measurements at the planar heterojunction interfaces of acceptor/donor.

Transient absorption spectroscopy is a powerful tool to

study exciton splitting in non-fullerene electron acceptors for understanding excited state dynamics. With TA measurements, one can monitor the dynamics of bright and dark states, including singlet excitons and charge transfer states, on the ultrafast time scale. This is indispensable to understanding the exciton dissociation processes to free charges, which is a crucial step for improving the efficiency of organic solar cells.

At last, the authors further fabricated the planar heterojunction solar cells of PM6/NFA device. The efficiency of PM6/IT4F bi-layer exceeded 7% was concluded. It is noteworthy that the spin-coating process of upper-layer NFA should not affect the morphology of PM6 layer, which suggests the existence of a fully developed bi-layer interface, but not a quasi-bilayer or partially configuration. The findings indicate that high exciton diffusion length and efficient exciton dissociation and charge generation may play an important role in achieving a high efficiency.

A possible material for organic solar cells is PTB7:PC71BM and thus has high electrical conductivity and has good solubility in many solvents and can be deposited on the large area at low temperatures in each low-cost process. For high quantum efficiency, all the photogenerated excitons must be separated at the interface between the donor and acceptor materials. Furthermore, the induced charges should subsequently be gathered at their corresponding electrodes.

Graphene oxide is the HTL in PTB7:PC71BM solar cells, and the impact of graphene oxide to the PTB7:PC71BM cells was studied [16]. Organic solar cells were also modelled using SCAPA-1D. An optimal absorber layer thickness of 40 nm has been chosen. Devices with the graphene-oxide doped showed higher conversion efficiency than the control devices, suggesting that graphene-oxide promotes exciton dissociation, as well as the charge transport. Graphene oxide (GO) is certainly one of the promising candidates as a hole transport layer for solar cells because of its outstanding features. The 3D architecture and conductive nature of GO facilitates the rapid transport of holes of solar cells. Graphene oxide may enhance stability and long-term service life in the solar cell in the meanwhile.

Graphene oxide can be prepared by a simple [17] and low-cost method that is easily up scaled for mass production. The ITO/ZnO/P3HT:PCBM/MoO3/Ag architecture is used, and performance is enhanced by incorporating various loadings of the gold (Au) nanoparticles to the ZnO electron transporting layer. It was noticed that doping of ZnO with 10 w% Au enhanced the power conversion efficiency from 2.94 to 3.48% in agreement with the optimized simulation. Thus, an improvement in efficiency of 20% was realized. The increase in the current density from the gold NPs through the plasmonic effects eventually reflects the most important source for the increased efficiency. The current density of the GNPs-free device was 8.14 mA/cm^2, and the value was raised to 8.58 mA/cm^2 in the 10% GNPs scenario.

Nanoparticles have considerable importance for technological advances, this is based on their tunable physicochemical characteristics, which includes melting point, wettability, electrical and thermal conductivity, catalytic activity, light absorption, ad scattering, to show higher performance behavior with respect to their bulk materials. In addition, their fluorescence, adjustable size and strong extinction make them desirable for various application fields including electronic devices, nanomedicine and solar cells. Zinc oxide can be considered as one of electron transport layers for organic solar cells. That is, it is possible that the power conversion efficiency is increased by gathering and performing electronic carriers in zinc oxide and shielding a hole carrier potentially contained therein. Moreover, the ZnO is used as an optical spacer and an oxygen blockade in solar cells to stabilize and prolong the lifetime of the solar cells and to enhance the performance of the solar cells. Moreover, the ZnO absorption can be improved by doping some dopants into ZnO in the proper doping content to absorb more UV/vis light. One benefit of using it is that the band gap of zinc oxide is reduced.

It is an efficient strategy to enhance photo-voltaic performance by preparing a suitable ternary constituent. Another efficient quinoxaline-core non-fullerene acceptor (BQ)has been synthesized [18]. The quinoxaline moiety as an electron-withdrawing unit can maintain the high energy level of LUMO for BQ. As a result, a high Voc of 0.959 V is achieved when the molecule is blended with D18. The open-circuit voltage became broader with a value of 0.846 V and it decreased the non-radiative recombination via a cascade-like recombination by increasing the exciton distance (23 nm), fast exciton diffusion, and easy separation of charge carriers and their transfer in an ordered interface The champion ternary solar cells showing high power conversion efficiency of 18.9% is due to complete optical property absorption, fast exciton transportation and dissociation, efficient carrier transportation and collection, proper phase separation (dominant D18:N3), low energy loss, and high phase purity. In connection with the above, another common effective approach towards improved total photovoltaic performance and stability of devices has been to add an absorber or an acceptor phase to a binary system, such as for instance ternary systems for organic solar cells, where a performance boost in the device can often be obtained beyond that for a binary device.

Porphyrins have also been included in organic solar cells, when they were used in molecular donor acceptors (DA) dyads in combination with appropriate acceptors. Among the non-fullerene acceptors, Perylenebisimides have been identified as crucial acceptors [19] and several derivatives of Perylenebisimides have been used in acceptor-donor motifs as an acceptor. A N-benzannulated Perylenebisimide-porphyrin dyad and its Zn(II) complex:

design and photovoltaic application.

X-ray single crystal diffraction studies show that the free base dyad has the non-coplanar conformation of the chromophores. The Perylenebisimide and porphyrin chromophoric units all display π-π stacking interactions between head-to-tail associated chromophoric units and a donor-acceptor separation distance of 3.4 Å. Solution processed bulk heterojunction organic solar cells were made with the compounds as donor and PC71BM as acceptor. The power conversion efficiency of the devices is 7.25% and 9.1%, respectively.

Rylene diimides belong to the class of compounds which have been extensively scrutinized and researched due to its numerous practical applications in the modern organic material-based devices. They have a stiff polyaromatic backbone with two imide moieties at the ends along their long axis. The imide groups increase solubility of these compounds and, in general, do not contribute to the electronic properties because of nodes through the N-N bond. Accordingly, this type of molecule has been extensively studied as a multi-redox system in modern optoelectronic devices.

One group of such substances are perylenebisimides, which due to their stability, both chemically and photochemically, are of a special interest. Their photophysical characteristics render them attractive for organic photovoltaic and organic light emitting devices. It has been shown that the fluorination methods bring significant performance enhancement in the non-fullerene acceptor (NFA) device. The fluorine (F) substitution effects can be studied from three facets, that is, modulation of the physicochemical properties, enhancement of donor- acceptor (D–A) characteristics, as well as the tuning of the molecular arrangement behaviours. Currently, fluorination is classified into direct fluorination and indirect fluorination including the trifluoromethylation.

Central unit fluorination in NFAs is less widely studied, as there are no reaction sites in Y-system acceptors that are common in general cases. These non-fullerene acceptors [20] are characterized by a central unit, with fluoro- (CH-F), trifluoromethyl- (CH-CF) and fluoro- and trifluoromethyl- (CH-FCF) substituents, respectively. Among them, the CH–FC mixture composite films showed enhanced intermolecular interaction and the crystallinity and the fibrillar network were more superior for the CH–FCF composites films and hence the better the charge generation/transfer ability. Thus, the binary type of organic solar cells using CH-FCF outperformed the efficiency of the derivatives (CH-F: 17.34% and CH-CF: 17.62%). Overall, our findings highlighted the importance and demand for synergistically regulating the core unit of small molecule acceptors with multiple fluorination strategies to adjust their molecular packing, eventually promoting the photovoltaic efficiency of the devices.

Novel energy sources, such as organic solar cells, can also supply electric power that captures and converts sun light energy. Partial incident light is selected using the ST-OSCs for colorful display. Hence, for the semi-transparent organic solar cells, the light absorption is less, which will inevitably cause the poor performance of the solar cells.

Low-temperature Semi-transparent organic solar cell (STOSC) in the form of colored photovoltaic glass such as windows and glass furniture, building integrated photovoltaics and many issues were proposed and investigated as the simplest and industrially most feasible application of green energy harvesting research field. Also, we should consider that an MgF_2 type microcavity for semitransparent organic solar cells which is Au/Ag/MgF_2/Ag structure for high peak transmittance can be ignored for power-conversion-efficiency [21]. The device configuration of ST-OSC was also ITO/glass. ZnO/PTB7-Th:IEICO-4F/MoO_3/Au/Ag/MgF_2/Ag. A transparent bright organic solar cell with high transmittance of MgF_2 microcavities and low absorbance of IEICO-4F at the blue light region is demonstrated. The absorptance of the active layer in the IEICO-4F was high in the near IR region and low in the visible region. Its maximum transmittance exceeded, at 440 nm, 48%, and the power conversion efficiency was 10.4%. The excellent high peak transmittance is realized at power conversion efficiency loss of only 5% with respect to the reference opaque device. The loss of power conversion efficiency at each peak transmission of the semitransparent organic solar cells is the lowest among all reported. By tuning thickness of the MgF_2 films, semitransparent organic solar cells with various colors are fabricated, and a peak transmittance of over 32% and the efficiency loss ratio less than 7.25% are demonstrated.

An efficient electron transport layer (ETL) was developed for inverted structure organic solar cells [22] by the modification of commercial SnO_2 nanoparticles with a simple molecule NMA. Tin oxide has become a focus of research as an ETL because of its improved electron mobility, photo resistance, photocatalytic activity and chemical stability compared with ZnO. The light-soaking problem of those uncoated SnO_2-based devices is also eliminated by the surface modification. It also significantly improved the performance and stability of the solar power equipment. While the PM6:L8-BO device with the hybrid ETL demonstrates an excellent efficiency of 18.33% with a fill factor of 78.62%, Voc of 0.882 V and Jsc of 26.4 mA/cm^2. Of even more significance, the winning device demonstrates superior shelves, thermal and photo stabilities. Good efficiency at 99.7% was also held in the condition at room (nitrogen gas) and thermal (65 ºC, 1000 h) test; 87.1%. MPPT under continuous light over a period of 800 h resulted in 86.6% retention of efficiency. The NMA device exhibited improved EQE response over almost the entire absorption range. The integrated short circuit density obtained from the EQE curve was 25.12, 24.65 and 26.74 mA/cm^2 to the un-coated SnO_2 layer

before and after light-soaking, and to the NMA-modified devices, respectively.

Table 1: Properties of organic solar cells

Researchers	Highlighted results
Zhang and co-workers	The hole transport layer will be eliminated by using cold N plasma jet to the PET/ITO surface [23]. The efficiency is significantly improved with 12 W (4.25%) and 15 W (4.55%) plasma treatment
Wael and co-workers	BP-DTS showed the lowest excitation energy [24], and highest maximum absorption wavelength (945 nm) Open circuit voltage and fill factor were 0.73 V and 87%, respectively.
Cunha and co-workers	When the active layer [25] was PCDTBT:PC71BM, short circuit current=8.31mA/cm^2, open circuit voltage=0.91V, fill factor=61.9%, efficiency=4.7% When the active layer was PTB7-Th:PC71BM, short circuit current=13.5 mA/cm^2, open circuit voltage=0.8 V, fill factor=64.2 %, efficiency=6.9 %
Liu and co-workers	organic binary PM6:Y6 solar cells achieved efficiencies of 17.15%, fill factor of 73%, open circuit voltage of 0.87 V, short circuit current of 26.87 mA/cm^2. Specific solar cell structure [26] was ITO/PEDOT:PSS with Cu(II)@OMN /PM6:Y6/PDINO/Ag.
Wei and co-workers	chloroprene rubber (CR) was used in D18:L8BO organic solar cells. CR can improve stretchability and durability [27]. efficiency of 19.25% and 16.9% were observed for rigid solar cells and ultra-flexible solar cells, respectively.
Alam and co-workers	Photovoltaic parameters were studied based on PM2:CETIC (efficiency=7.93 %, V_{oc}= 0.88 V, J_{sc}=15.52 mAcm^2, fill factor=58 %). CETIC was observed to be highly soluble in chloroform and chlorobenzene, could be used to improve visible transparency [28]
Asma and co-workers	Donor, acceptor, HTL and ETL are PBDB-T, ITIC-OE, Cu_2O and TiO_2, respectively. The highest efficiency [29] reached 12%.
Nour and co-workers	It was noted that fill factor, efficiency and open circuit voltage will be enhanced when gap energy was reduced [30]. The highest efficiency was 18.68% in AZ3 structures.
Li and co-workers	It was noted that devices exhibited open circuit voltage loss when the temperature was increased [31] In PBDB-TF-T1:BTP-4F−12 devices, open circuit voltage=0.8 V, fill factor=67%, efficiency=11.49 %, short circuit current=21.8 mA/cm^2 In PBDBTCl-DTBT:BTP-4F−12 devices, open circuit voltage=0.86 V, fill factor=61%, efficiency=10.62%, short circuit current=20.33 mA/cm^2
Cisem and Tok	Short circuit current [32] has been enhanced (8.96 mA/cm^2 to 10.85 mA/cm^2) by adding $CsPbBr_3$ due to light harvesting. Efficiency was enhanced (1.75 % to 2.88 %) because of improved current density.
Or and co-workers	Efficiency was 0.18%, and the thickness was 309 nm–400nm. Organic solar cells have been prepared using PVD method, using PC61BM (fullerene) and PCPDTBT (polymer) [33].
Alqurashy and co-workers	Band gap [34] was found to be 1.35 eV and 1.43 eV for DTPBT1F and DTPBT2F, respectively [34]. Power conversion efficacy was observed in the range of 17.23 % and 11.25 %.
Ma and co-workers	Solar cells were fabricated using PBDB-T, electron donor (fluorinated derivative PM6) and Y-series small molecules [35].

	It was noticed that low re-organization energy could be observed in specific designed donor and acceptor materials, can enhance efficiency of devices.

4. Photovoltaic parameters on the performance of dye sensitized solar cells

Dye sensitized solar cells have been developed and described by many scientists (Table 2). Compared with p-n junction photovoltaics, dye sensitized solar cell (DSSC) is a competitor that can cast light on new throughputs in today. In the late 1960s it was discovered that electrochemical cells could produce electricity when photoexcited organic dyes were used as the light harvester. Four major parts [36] were described: the working electrode, the sensitizer, the redox mediator and the counter electrode. The DSSC consists of a working electrode plus a counter electrode, the counter electrode (CE) is dipped in the sensitizer solution, these two are separated by a thin layer of electrolyte, and where they connect is sealed with hot melt tape.

The working electrode is fabricated by spin coating with an oxide semiconductor material on the transparent conducting glass such as fluorine doped tin oxide (FTO) slide, and indium tin oxide (ITO) coated one. These oxides themselves had large band gap energy, hence 3 eV–3.2 eV oxides are widely used. Titanium dioxide shows two large phases: anatase (3.2 eV) and rutile (3.0eV). TiO_2 had an edge over others including plastics, since it did not need to be doped. As a semiconductor, however, it is classified as such a small amount of TiO_2 absorbing some light especially in UV region.

When a specific solution is poured onto the film and permitted to evaporate afterwards, the dye molecules will bond to the TiO_2 surface covalently in this adatom-like state. It is for that great number of dye molecule to adhere to the TiO_2 nanocrystalline structure, because of its large surface area and high developed porosity. This dye should absorb at least in the ultraviolet visible and near infrared range. The HOMO is far from the TiO_2 conduction band surface. Also, LUMO must be very close to titanium oxide. It is higher compared to the potential of TiO_2 conduction band. The highest point of the dye should be hydrophobic. Then the cells last longer. This is because the dye reduces the direct interaction between the electrolyte and the anode.

The natural dyes are dyes derived from plants, invertebrates, or minerals. While dye sensitized solar cells with natural dyes as dyes offer many advantages, the drawbacks of low efficiency compared to silicon-based solar cells are also encountered. Moreover, it is still challenging to convert these cells into practical devices to power our everyday life. Natural dyes are environmentally friendly and easily available, but they generally exhibit lower efficiency for DSSCs, compared with synthetic dyes. Also, natural dyes can be effectively degraded by environmental conditions like pH, temperature, moisture, and light and oxygen exposure. This intrinsic instability reduces the radiation life of DSSCs and efficiency. These solar cells can also suffer from physical instabilities, such as evaporation of electrolyte or bleaching of dye, and chemical instability due to degradation of the dye, electrolyte and counter electrode as the devices operate. In addition, natural dyes generally have a lower light absorption as compared to synthetic dyes, due to which lesser numbers of photons are captured and thus the photocurrent generation is decreased.

Artificial dyes are widespread applied as sensitizers in DSSCs which have a broad range of light absorption and high conversion efficiency. But due to their high cost and adverse environmental impact, natural dyes have reemerged as alternative colorants. Artificial dyes are a large group of chemically prepared substances for which the function is to provide the products brilliant, stable colors. Many of these dyes come from non-renewable sources like coal tar or petrochemicals that have been shown to include known carcinogens and can function as eye, skin, and lung irritants.

An electrolyte is made up of several different components. A redox pair must effectively regenerate the oxidized dyes with long-term chemical stability. The redox pair should not be corrosive to DSSC components when in contact; charge carriers must be able to transport it contact characteristics, information content of measuring quantities introduced or removed by ion and electron transport between working electrode counter electrode (and capacitance between them). For an efficacious connection between semiconductor film absorbed and such areas of contact, the redox absorption spectrophotometer spectra should not overlap with the absorbance spectra of the dye [37]. The counter electrode is made of platinum or carbon. Researchers have found that the electrodes connect (silk-screened) as close as possible in all experiments. An electrolyte was then added via a syringe.

The counter electrode is also charged with reducing triiodide/iodide and receiving “holes.” Platinum was chosen as the counter electrode to make sure it has higher effectiveness. But platinum will soon bear replacement as it is unsuitable for use in the counter electrode due to its high cost and as it is unenforceable. Some of the replacements for the platinum counter electrode in DSSC are carbon, carbonyl sulfide, iron selenide, or cobalt nickel. The function of the electron transport layer (ETL) is such that, it improves the electron transport and slows the electron recombination in the photoelectric process by accumulating the electron in this layer.

Magnesium (Mg)-doped titanium dioxide thin film can be successfully prepared using a modified sol-gel technique. The photoanodes [38] were then immersed in a N719 solution in absolute ethanol and left for 1 day at room

temperature to sensitize them. After that, the dye-covered photoanode was washed with ethanol to remove those dye molecules which had been physically adsorbed on its surface. A platinum coated ITO counter electrode was made using magnetron sputtering technique. The sensitized photoanode, which had already been described in the previous step above, sandwiched between these Pt counter electrodes.

The molar ratio of magnesium to titanium was changed and in addition, also used to adjust the light transmittance, band gap and photoelectric properties of TiO_2 film. Mg-doped TiO_2 film was used as the compact layer in a DSSC. This makes it clear that the decreased amount of non-lattice O_2 and the modified energy band significantly promote the photoelectron production and inhibit recombination losses in solar cells.

In addition, the results of the electrochemical impedance spectra show that photovoltaic device using 15% magnesium doped TiO_2 had smallest electron transport impediment / most electron lifetime. Finally, the DSSCs based on a 15% Mg doped TiO_2 layer gave the highest photoelectric conversion efficiency of 7.84% by far and which is 17.66% greater than that from pure TiO_2 compact layers.

Gamma irradiation [39] can also be utilized to enhance the apparatus efficiency of such a low-cost counter electrode (CE) without platinum to increase its number of active sites and thus improve its catalytic activity in solar cells. In this work, a series of novel chitosan@polyvinyl alcohol@Titanium dioxide (CPT) hybrid films were prepared as catalytic counter electrode using different in-situ gamma irradiations to enhance the microstructural and physicochemical characteristics of the electrodes. The surface properties of the modified composites were found to improve with increasing dose of gamma radiation and were maximum at 30 kGy of gamma dose (apparent porosity equal to 72.2%, average roughness- 5.3 A) as compared to the composites of the unmodified counter electrode materials.

The long gamma irradiation improved the DSSC performance and efficiency up to 6.45% (10 KGy) and 7.14% (0 KGy), respectively. The movement of the charge carriers in the CPT compounds was initiated due to high energy gamma photons and recombination was prohibited by facilities of space charge separation. Thus, lesser mobility and Resistive losses, give rise to longer life and higher charge transfer in solar cell. Under such circumstances, the maximal efficiency and ISC were 8.57% and 19.1mA/cm2 for CPT catalytic counter electrode treated by surface modification of 30 KGy. Efficacy compared with native samples increased 41.2%. The improved photovoltaic performance was related to the large amount of oxygen free radicals that doped in the CPT that created percolation paths for fast e- transport.

TiO_2/eggshell composite material [40] with different ratios prepared by solgel method was also found in literature for the photoanode preparation in DSSC. The absorption profile showed that as the concentration of the eggshell increase there is an increase in absorption and this selection was good for the application of the solar cells. The eggshell is beneficial to the electrochemical property for photoanode. It was confirmed by electrochemical impedance spectroscopy that adding eggshell has the effect of inhibiting the charge transfer resistance and increasing efficiency to 2.95% based on natural dye sensitizer of TiO_2/eggshell composite of 3:10.

Machine learning method was employed by the k-Nearest Neighbors(kNN) to forecast the highest maximum efficiency optimum for the different survey samples of the EIS study. The kNN analysis predicted the highest efficiency of DSSC with TE 3:10to be 90%. Counter electrode (CE) is an indispensable conductor in the DSSC, it collects the electrons from the external circuit and catalyzes the redox paraphrase in the electrolytes. It's a massive driver of the efficiency of photovoltaics, their longevity, and even their price. Platinum-coated FTO glass substrates are one of promising and popular CE candidates due to their superior electrical conductivity and electrocatalytic activity towards the reduction of redox species in the electrolyte, such as iodide/triiodide-based electrolyte systems. Nevertheless, platinum is known to corrode and is therefore not widely used as counter electrode for solar cells. To resolve these issues, it has been studied widely to seek other counter materials. Other materials, including carbon materials, conducting polymers, such as PANI, PEDOT, PEDOT:PSS and PPy and inorganic materials, such as transition metal compounds, such as sulfides, nitrides and carbides, have been effectively employed as counter electrodes.

PEDOT:PSS is a co-polymer whereby the electrical charge carriers are supported in the PEDOT and the PSS serves as a counter ion to maintain the charge. Polystyrene sulfonate Polystyrene sulfonate generally includes a1:1 mixture of R and S enantiomers of atropisomers off-polystyrene sulphonate, a negatively charged polymer. Some of the sulfonyls were effectively located and deprotonated to bear a negative charge. These other parts PEDOT a positive charged conducting polymer polythiophene based, the salt is generated by reacting the charged macromolecules. In term of the efficiency, photovoltaic with SnSe–rGO/PEDOT:PSS CE [41] has reached a highest efficiency of 8.78%, greater than the one (8.13%) with the Pt CE modified device. These results indicate that SnSe-rGO/PEDOT can serve as a low-cost and high-efficiency candidate for a potassium-ion anode of solar cells.

Erdi et al. built a functional nanoparticle composite [42] to enhance the performance of the Cu_2S film. SLG was synthesized by chemical vapor deposition and its use as counter electrode (CE) combined with the CdSe/ZnS core/shell QDs for highly efficient and stability quantum dot sensitized solar cells (QDSSCs). Even a Cu_2S film is

made from the electrode positioned upon the Single layer graphene (SLG) target. High efficiency of 3.93% with the nanocomposite as the counter electrode was achieved. This high performance could be ascribed to the large surface area afforded by the nanoflower shapes, lower charge transfer resistance, and the superior catalytic activity and surface smoothness along with good adhesion. More importantly, no color variation or stripping from the surface could be seen for the Cu_2S@SLG assembly, the result implies that the SLG matrix can protect Cu_2S from the attack of the sulfur ions in the electrolyte and enhance the adhesion of Cu2S to the substrate, preventing the degradation of Cu_2S from happening. Therefore, the Cu_2S@SLG nanocomposite might be considered as a promising candidate to enhance the solar cells performance.

Recently, new quinary composites [43] such as PEDOT:PSS functionalized multiwalled carbon nanotube (f-MWCNT), nitrogen doped reduced graphene oxide (Nr-GO) and TiO_2 has been developed as a cost-effective counter electrode in DSSC. The MWCNT has been doped with PEDOT: PSS to tailor its electrical property and microstructure. A modest (25%) level of conductive polymer loading has also been added to reduce the degree of agglomeration and to enhance the solution dispersion of MWCNTs, which are restricted, to van der Waals interactions and stacking interaction amongst the primary tubes. Reduced agglomeration is found in the efficient electron transfer pathways according to EIS and electron imaging analysis. Of the 3 quaternary composites explored, f-MWCNT /Nr- GO/TiO_2 (2:1:1) exhibits the best performance with a charge- transfer resistance value of 7.27 Ωcm^2, and the cathodic peak current density is 17.08m A/cm^2. The as-prepared cell has a high photo-conversion efficiency of 4.25%, and the redox pair can sustain chemical stability after 500 cycles of photoelectrochemical operation.

Low-cost DSSC of TiO_2/ZnS heterostructure were reported via vacuum annealing of the TiO_2/ZnS to enhance the cell efficiency [44]. TiO_2 nanoparticles were deposited onto FTO glass substrates by the doctor's blade technique. Best sensitization of TiO_2 with N719 sensitizers was achieved by soaking for 20 h in 0.2 mM of the dye and was 1.91%. A ZnS layer was deposited onto the TiO_2 layer by the SILAR method at 20 °C, then the heterostructure was vacuum annealed at 200 °C for 2 h. Devices employing vacuum annealed TiO_2/ZnS as photoanode significantly enhance the EQE in the UV-visible region. The champion device showed an efficiency of 2.27% with an open circuit voltage of 0.67 V, Jsc of 7.59 mA/cm^2 and a fill factor of 44.79%.

The conductivities of transition metal oxides are lower than those of metals, they behave as a semiconductor [45]. Therefore, the addition of a conductive polymer such as polyaniline (PANI) into the composites can greatly enhance conductivity. The advantageous composite phase constructs conductive pathways, fastens the charge transfer and enhances the electrochemical system, and thus has great prospect/host for the counter electrode. The coral reef-like structure appeared slightly while the second component of composite is PMMA, so the $FeCo_2O_4$ (CFO) has a nanosheet of the flower type. A petal-scale flower morphology is observed in the FCO/PANI composite as well. And the surface of the composite is rough and porous, which benefits the contact of electrode to electrolyte as seen from the contact angle measurement. Electrocatalytic activity and charge transfer resistance are the maximum takes place with the FCO/PANI composite, minimum with the PANI, the second lowest with FCO and the platinum electrode, respectively. The photoelectric conversion efficiencies of the solar cells based on the films of FCO, PANI, FCO/PANI, and platinum counter electrodes are 4.22%, 5.58%, 6.38% and 3.58%, respectively.

Polymers have been continually used [46] as a possible alternate approach to improve the catalytic performances of molybdenum diselenides. Good choices may result in potential everlasting exfoliation and tend to be the surface and flexible improvement of the dichalcogenide. To minimize the trade-off, the researchers used two conductive polymers, namely poly (3,4-ethylenedioxythiophene) (PD) and polyaniline (Pn), to improve the overall performance of $MoSe_2$ in solar cells. However, an optimized percentage is also required to form each well-disturbed and -separated system, thereby, good electrocatalytic sites and conductive behaviors based on the present system with flexibility provided by PD. Another consideration is that PD is deposited alone (in the absence of a second polymer). The great electrocatalytic performance, including superior electrocatalytic activity, fast electron transfer and improved current density, have been demonstrated by electrochemical measurement as compared to pristine materials. The electrochemical measurements of the prepared-hybrid device showed excellent performance with an electrocatalyst of large amount, and the conversion efficiency of as high as 8.65%.

Pristine (Zn_2SnO_4), Zn_2SnO_4-SnO_2 and Zn_2SnO_4-ZnO composites were synthesized via an easy and simple solid-state calcination method [47]. XRD patterns indicate the existence of various phases depending on stoichiometric ratio of the synchronization precursor. Surface morphological studies indicate that the composites of Zn_2SnO_4-SnO_2, and Zn_2SnO_4-ZnO exhibit micro-sheet and micro-rodlike structures, respectively. Dye loading capabilities of the composite materials are higher as compared to the untreated Zn_2SnO_4 as prepared samples result in better performance. The composite photoanodes possessed higher efficiencies compared to pristine Zn_2SnO_4 photoanode (3.7%), such as 6.26% for Zn_2SnO_4-SnO_2 and 4.48% for Zn_2SnO_4-ZnO.

The harvesting nanostructured material for solar cells showed potential in Zn_2SnO_4 nanoparticles was developed by Yang et al. [48]. Efficiency of the light to electric conversion up to (3.8 %; Fill factor=0.66; Voc=0.62 V;

Jsc=9.3 mA/cm^2) have been achieved. Compared to zinc oxide or SnO_2 individually as the component oxide, the Zn_2SnO_4 cell is more stable in acidic dyes than the zinc oxide cell, and much more stable than the SnO_2 cell. It is also reported that the multi-cation oxides of various compositions and tune able properties exhibit very promising potency as new electrode materials in the field of solar cells. Its mobility (1 cm^2/V.s) is very low and thus can impede electron collection at the front electrode. These losses should be minimized as these devices, due to being focused on semi-transparent solar cells, require the highest possible photocurrent. In this point, Zn_2SnO_4 can be used as an electron collector material for the electron collector layer instead of the TiO_2.

High bandgap zinc-based oxide such as Zn_2SnO_4 offer advantages over both TiO_2 and SnO_2 with both higher band gap and higher electron mobility (3.6–3.7 eV, and 10–15 cm/V.s, respectively). Furthermore, the electron affinity level of Zn_2SnO_4 is approximately 0.1 eV higher than that of TiO_2, accelerating the collection of photoelectrons from the dye. It has been reported that solvothermal synthesis of zinc stannate nanoparticles. The as-prepared samples are fcc spinel phase as indicated by the X-ray diffraction (XRD) measurement [49]. The size of prepared nanoparticles is 20 nm, which is observed in the TEM image of nanoparticles. In the fabrication of photoanodes for semi-transparent dye sensitized solar cells, a slurry of the formed nanoparticles is made. Efficiency of 0.86% was obtained for fabricated dye adsorbed Zn_2SnO_4 photoanode.

The materials used were cubic spinel Zn_2SnO_4 and zeolite imidazole framework-8 (ZIF-8) nanoparticles as photoanode materials. The Zn_2SnO_4 employed here was synthesized via a facile and cheap hydrothermal method. Nanocomposite Zn_2SnO_4/ZIF-8 was coated onto TiO_2 compact layer to mitigate charge recombination [50] at muscovite-TCO interface. The results show that the introduction of ZIF-8 into Zn_2SnO_4 can greatly improve the photovoltaic performance of the resultant cells. In addition to this, the open circuit voltage and short current density were also increased with comparison to pure Zn_2SnO_4 from 0.64 V to 0.77 V and 6.89 to 11.27 mA/cm^2, respectively. Power conversion efficiency of ZIF-8-doped Zn_2SnO_4+15% increased by 195% (2.02% to 3.94%) relative to the pure Zn_2SnO_4 photoanode. The Zn_2SnO_4+15% ZIF-8 nanoparticles have the highest electron transport rate, best electron collection efficiency and the largest charge recombination resistance, which greatly enhance the performance of the device.

The rGO-modified Ce-doped Zn_2SnO_4 photoanodes [51] are prepared via an ultrasonic assisted hydrothermal method. Ce -doped composted was prepared successfully, the spinel cubic structure was held, and the strong combination of rGO was preserved. In addition, the BET analysis showed the surface area (124.7 m^2/g) of the rGO/Ce-doped-Zn_2SnO_4 hybrid photoanodes. The Ce-dopedZn_2SnO_4/rGO photoanodes possess superior photovoltaic characteristics (efficiency of 7.19%, fill factor of 0.74, open circuit voltage of 0.85 V, short circuit current of 15.86 mA/cm^2) among the solar cells. The work demonstrated that coordinated utilization of rGO and cerium dopant in the Zn_2SnO_4 photoanode can substantially improve the PCEs, offering an efficacious means to achieve high photovoltaic performance via the material engineering pathway.

Table 2: Properties of dye sensitized solar cells

Researchers	Highlighted results
Wang and co-workers	Zn_2SnO_4 sphere/broccoli-like array films were prepared using specific substrates such as FTO glass slides [52]. Efficiency was 0.83% and 0.69% in sphere photoanode and broccoli like array, respectively.
Gholamrezaei and co-workers	$SrTiO_3$ nanostructures were synthesized through sol gel method [53]. V_{oc}=0.62 V, J_{sc}=1.6 mA/cm^2, fill factor=59%, efficiency= 0.58 %.
Praveen and co-workers	$SrTiO_3$ films were heated at 1000 °C, exhibited lower band gap value, higher crystalline properties and spherical morphology [54]. Short circuit current=3.36 mA/cm^2, open-circuit voltage=0.63 V, efficiency=1.12%.
Qiong and co-workers	$SrTiO_3$-TiO_2 nanotube arrays were synthesized on FTO glass, via hydrothermal reaction [55]. Short circuit current=15.3 mA/cm^2, open-circuit voltage=0.82 V, efficiency=5.42%, fill factor=43%.
Enyan and co-workers	$SrTiO_3$/TiO_2 nanosheet heterostructure were prepared through hydrothermal techniques [56]. Short-circuit current density=12.55 mA/cm^2 and efficiency=7.42% under one sun illumination.
Rui and co-workers	Sr-doped TiO_2/$SrTiO_3$ nanorod were produced through two-step hydrothermal process [57]. Efficiency of 4.7% and 3.1% could be observed in TiO_2/$SrTiO_3$ and bare rutile TiO_2 photoanode, respectively.
Prabhu and co-workers	Solar cells were made using TiO_2/$SrTiO_3$ as photo-anodes [58]. Efficiency of 0.69 %, 0.84 % and 0.37 % for *Terminalia catappa*, Azadirachta indica and Clitoria

	ternatea, respectively.
Chen and co-workers	Nanoporous electrodes [59] were fabricated using TiO_2 matrix with Nb_2O_5. Efficiency has significantly increased (3.6 to 5%).
Ueno and co-workers	Zinc oxide was coated using niobium oxide (served as energy barrier) to make solar cells [60]. Efficiency was 5.19%, and a high short circuit current could be observed.
Suresh and co-workers	Nb_2O_5 served as blocking layer [61] could reduce charge recombination rates, and showed efficacy of 7.3%, fill factor of 65.07%, open circuit voltage of0.776 V, and short circuit current of 14.5 mA/cm^2. SEM studies confirmed that dense, smooth morphologies could be observed when the anneal temperatures were 600 °C and 700 °C.
Hyuk and co-workers	Efficiency was 7.23% in devices (Nb_2O_5-coated TiO_2, three-dimensional ordered porous electrodes). Nb_2O_5 should be controlled strictly, due to improved short-circuit current density [62].
Cho and co-workers	Preparation of Nb_2O_5 blocking layer through sol–gel method to prevent electrons transferred to the electrolyte again [63]. In the optimized conditions, efficiency=6.185%, short circuit current=13.2 mA/cm^2, open circuit voltage=0.672 V, fill factor= 69%.
Riccardo and co-workers	Solar cells have been fabricated using iodide-based electrolyte and N719 dye solution [64]. Efficiency of 3.4%, could be observed under sun illumination, using 2-propanol as solvent.
Yen and co-workers	Nb_2O_5 thin film was deposited on FTO photoanode via dip-coating method [65], which could enhance performance of solar cells. Efficiency could be improved by 10% to 53% in specific conditions such as low-intensity illumination in the presence of blocking layer.
Sunil and co-workers	Sn-doped TiO_2 samples were prepared using sol gel method, successfully exhibited anatase and rutile phases [66]. Power conversion efficacy was 5.4%, and Sn-doped TiO_2 films are superior, can improve short circuit current in devices.
Antunes and co-workers	Solar cells were prepared using bixin dye (carotenoid pigment), bismuth vanadate (band gap=2.37 eV) and lithium perchloride [67]. Short circuit current could be enhanced using $LiClO_4$.
Sebajk and co-workers	Gamma irradiation improves efficiency, surface morphology, and porosity [68]. The highest efficiency was 8.25%, with fill factor of 61%, open circuit voltage of 0.749 V, and short circuit current of 18.06 mA/cm^2.
Sabari and co-workers	Pure and Ni-doped Bi_2O_3 films have been prepared through wet chemical method [69]. The highest efficiency was 0.4%, with fill factor of 47%, open circuit voltage of 0.8 V, and short circuit current of 0.1 mA/cm^2.

5. Photovoltaic parameters on the performance of thin film based solar cells

Thin films based solar cells have been investigated by many researchers (Table 3). Based on technology, the market is categorized into monocrystalline, polycrystalline, CdTe, amorphous silicon and CIGS. In 2024 monocrystalline segment was the largest contributor by value to the market, with an estimated 80.2% share, as relative efficiency is high for solar cell monocrystalline which varies in efficiency from 18 percent to more than 22 percent as it is a silicon based solar cell. The advent of new technologies, such as the Passivated Emitter and Rear Cell technology, heterojunction technology, and N-type silicon, have helped to enhance the efficiency and efficiency of the technology also.

Monocrystalline Silicon solar panels are generally better than polycrystalline silicon solar panels. This efficiency benefit originates from monocrystalline silicon made up by just one, uniform crystal structure promoting free electron mobility for better electricity generation. Monocrystalline silicon is manufactured using the Czochralski process, which produces extremely pure and homogeneous crystal. The homogeneous layer ensures that imperfections that would hinder the free movement of electrons are minimized, and the panel's performance potential is

maximized.

The polycrystalline segment, on the other hand, will grow at a CAGR of more than 6% through 2034, as these are a cost-effective option and are gaining traction in the developing markets. When cables are engineered for large deployments, these cells may offer the possibility of high-power output at lower cost. Additionally, the switchover to hybrid solar cells or bifacial modules will boost the market demand.

CdTe is a technology that is especially at home in the wild frontier of large-scale solar farms. Utility providers have made large installations of the systems due to it being more cost-effective and efficient; enabling them to offer lower cost renewable energy that complements their business landscape. For example, First Solar brought its $1.1 billion next-generation, vertically integrated solar manufacturing factory to the U.S. in 2024.

The properties such as flexibility and light weight along with low manufacturing cost are the main features that will contribute towards the growth of amorphous silicon market [70]. Continual merging of amorphous silicon with materials such as crystalline silicon, to achieve higher efficiencies and yet preserve the cost attractiveness, will shape the business environment.

CIGS film is expected to grow in the market share as thin film technology advances to improve the efficiency of BIPV systems [71], making them increasingly attractive for commercial and residential applications. In addition, laboratory efficiencies for these cells have now surpassed 23%, challenging silicon solar cells and leading the market demand.

While bulk wafer based solar cells dominate in the market in terms of performance, thin films based photovoltaic technology entered as an alternate with certain salient features such as lower production cost, flexibility, combined materials combination of different bandgaps to absorb different wavelength, light weight, and enhanced energy absorption via the formation of multi-junction [72]. All such parameters intrigued researchers to consider thin films of various semiconductors as major photo-active material candidates in solar cells for optical absorption. However, certain unavoidable issues in thin film semiconductors play a crucial role in determining photovoltaic parameters in the resulting solar cells. For example, absorption loss, amorphous nature, grain-grain boundary distribution, defects, interfacial recombination loss are a few major dominant factors that seriously limit the photovoltaic parameters in a solar cell.

In general, short circuit density, a parameter which will directly get affected by absorption loss due to thickness and the usage of inappropriate optical bandgap of the semiconductors. Open circuit voltage, a parameter determined by the band structure (quasi-Fermi level split). Fill factor and efficiency all play a direct role in determining the photovoltaic performance solar cells and all such parameters are greatly influenced by the micro-structural, optical, and electrical properties of thin film semiconductors employed in the solar cells [73]. Physical vapor depositions such as electron beam evaporation, sputtering, pulsed laser deposition and chemical vapor deposition based thin films are highly preferred for efficient energy absorption in solar cells.

Thin films offer unique opportunities to engineer microstructural properties through which all other properties also shall be controlled, for example charge transport in a solar cell [74]. Process temperature, thickness, deposition rates, precursor quality and post-annealing treatment are few important parameters deciding the photovoltaic parameters of thin film solar cells. It is well known that single crystalline semiconductor thin film coating is not possible and most of the cases result in poly, nano and multi-crystalline thin film semiconductors which critically exhibit charge transport through grain-grain boundary distribution where recombination loss dominates and limits the performance of the resulting solar cells.

The thin film based solar cells offer a variety of choices to choose materials for optical absorption in solar cells. For example, silicon based thin film solar cells employ polycrystalline silicon with an optical bandgap of 1.1 eV, amorphous silicon with 1.7 eV-1.8 eV, and microcrystalline or nanocrystalline Si with 1.4 eV – 2.0 eV. The wider range of optical bandgaps shows that the potential competitiveness of silicon as an indirect bandgap thin film semiconductor suitable for multijunction solar cell application for wider range of energy absorption [75].

Further, silicon thin film structure facilitates fabrication process in terms of formation of heterostructures with the best possible band structure alignment to achieve efficient charge transport. On the other hand, III-V thin film based solar cells employing gallium arsenide (E_g=1.42 eV), gallium indium phosphide (E_g=1.85 eV), indium phosphide (E_g=1.32 eV), gallium antimonide (E_g=0.73 eV), gallium phosphide (Eg=2.25 eV) are few well known direct bandgap semiconductors that are effectively being used in thin film solar cells to achieve high efficiency [76].

Chalcopyrite based thin film solar cells also offer decent performance due to their optimum optical bandgap values as determined by the Shockley-Queisser limit [77]. Copper indium diselenide (E_g=1.0 eV), copper indium disulfide (E_g=1.5 eV) and copper gallium diselenide (E_g=1.7 eV) exhibit remarkable photovoltaic parameters such as open circuit voltage, short circuit current and efficiency. Heterojunction solar cells such as cadmium telluride (CdTe) and cadmium sulfide (CdS) have shown promising photovoltaic performance.

In this case, CdTe (E_g=1.45 eV) is used as the major photo-absorber layer while CdS (E_g=2.5) is considered for window layer just to form the heterojunction in which not much energy absorption is expected [78]. Recent studies have shown that thin film photovoltaic devices have shown

remarkable open circuit voltage values, such as 900 mV, which ensures that efficient bandgap engineering achieved in the device structure [79].

CdTe or cadmium telluride, is the world's record in photovoltaic thin films and the best-selling thin film technology. By 2018, First Solar produced over 17 GW of CdTe modules. To elucidate the cause of this efficiency loss in CdTe solar cells, the photoexcitation microscopy and scanning probe microscopy were employed to observe the characteristic properties of nanoscale charge movement combined with the grain boundary of CdTe. Grain size, grain boundary passivation and previous heat treatment history of $CdCl_2$ play a vital role in charge transport through this film. The light-sensitive mechanical property of CdTe crystal was verified as a big difference on the value of yield stress of CdTe crystal determined from the stress-strain hysteresis loop between its dark and under-illumination mechanical tests. Furthermore, the mechanical properties examined with nanoindentation analysis, the elastic modulus of the film may also be controlled by the substrate temperature during deposition.

As for the flexible device, it should be noted that CdTe is a soft semiconductor and it has a big lattice mismatch with the window layer of CdS, which is a bad issue for reliable flexible CdTe-based solar cells. There would be a huge irreversible deformation for a lot of dislocations and stacking faults in the CdTe film. The nanoscale mechanics of the CdTe films during the operation of solar modules are also poorly understood, and the built-in electric field across the CdTe films may have implications on the device failure, besides the known failure due to the ion electromigration-induced degradation.

Binary antimony selenide (Sb_2Se_3) thin films are emerging as absorbers for the inorganic chalcogenide compound photovoltaics due to the appealing anisotropy of optoelectronic behaviors. But Sb_2Se_3 solar cells present a particular and complex induced effects situation originating from the low symmetry of quasi-one-dimensional crystalline structure, this induces large voltage loss, greatly restriction on the power conversion efficiency. Compact films have been reported to have a strong (001) orientation, high crystalline [80], fewer trap states and little non-radiative Recombination loss by the anodic vapor deposit method. This deposition then gives improved films in comparison with close-spaced sublimation or co-evaporation. By virtue of the suppressed recombination of carriers and the efficient carrier transport and extraction, the based film yielded of 10.12%. Therefore, it offers a new promising way to prepare good films and other advanced chalcogenide semiconductors with good performance.

Because of its advantages for absorption coefficient, conversion efficiency, and the inexpensive materials fabricating process, ZnTe is an important material for potential photovoltaic applications. The cell performance was analyzed by SCAPS-1D. All the spin coated ZnTe films are cubic phase from XRD [81]. Optical band gaps value was between 1.77eV–2.18 eV. SEM images indicated that the surface of the 400 °C annealed films exhibited improved surface coverage and more homogeneous and uniform films compared with the other annealed films, and less vacant. The energy-dispersive X-ray (EDS) analysis shows that the films are Te-rich samples. The highest power conversion efficiency of 17.45% is reported with the open circuit voltage of 1.41 V, the short circuit current of 14.01 mA/cm^2 and the fill factor of 88.53% for the best ZnTe thickness is 1184 nm annealed at 400 °C. The composition stack of the device is described as: ZnS/ITO/Pt/Al/ZnTe/P/back metal, and the P is denoting the back metal, the transparent conducting oxide, the back metal and so forth.

ZnS thin films were prepared by thermal evaporation, and their morphologies, optical properties, and compositions were studied [82]. Theas deposited ZnS films were highly smooth and exhibited (111) preferred orientation. XPS confirmed the atomic % of Zn=49.98% and sulphur=50.02%. The band gap of 3.72 eV was obtained based on optical transmittance spectra. The maximum conversion efficiency of the hydrogen-doped AZO/ZnS/textured p-Si heterojunction solar cell reached 8.83%. It was found that the unencapsulated solar cell showed no decay>2400 h, implying that our device has good stability. Undoped [83] and sodium doped ZnS films of 1, 5, 10 and 15 % concentrations were deposited on to the glass and silicon substrate through the spray pyrolysis method. Photovoltage I-V curves were taken on ZnS/Si hetero junction cells at different illumination conditions to study the photovoltaic behavior. The band gap energy of ZnS films decreased from 3.66 eV to 3.42 eV and resistivity of film transmission was reduced from $5.17x10^5$ Ω. cm to $2x10^5$ Ω. cm with the sodium doping concentration increased. The photovoltaic performance of the ZnS/Si heterojunction cell was enhanced, and the efficiency was enhanced to 5.06%, up from 2.2%.

CdS/Cu_2S thin film [84] solar cells have been developed for >9% conversion efficiency. Certain cell geometries are produced by considering the optical and electronic losses that occur in the cells. The structure and materials of fabrication engineering are then tailored to suppress the conversion of energy losses. The current cell feature comprises of 5 film layers that are deposited on a 35 µm thick copper substrate. It is not only a material control challenge for each respective component layer, but electrical, chemical, mechanical, and morphological compatibility at the interfaces of all corresponding adjacent layers is necessary to achieve the desired cell performance. A solar cell which was optimized for 100% utilization of received sunlight was shown to have a practical efficiency of 11% with CdS/Cu_2S junction. Conversion efficiencies of approximately 13-15% are expected to be attainable on an actual device with a CdZnS/Cu_2S junction configured to yield the best possible open circuit voltage for Cu_2S as the

absorber.

Cadmium sulphide (CdS) is one of the group II-VI, who is inherently sulfur deficient with sulfur vacancies and with a high affinity towards the electrons. This means the CdS is free to pick up electrons, so the Cds are n-type [85]. It has been the most extensively investigated nanocrystalline semiconductors as a photoanode in photoelectrochemical (PEC) cell due to its appropriate band gap, long lifetimes, good optical properties, excellent chemical stability, convenient preparation and various device applications.

This research is concerned with the preparation of nanocrystalline CdS films by rf sputtering using a ribbon-type CdS target. This method is suitable for preparing thin film transistors and other structures whose device layers are based on thin film technology. A doctor's blade was used to prepare nano-crystalline CdS films on indium doped tin oxide glass substrates. The initial powder of CdS was synthesized as material by a hydrothermal route and then it was further ball milled. To screen print it was made into paste, adding ethyl cellulose as binder and terpineol as solvent. Photocurrent of 3.5mA/Cm^2, fill factor 0.44, open circuit voltage 0.5 V and a conversion efficiency of 2.2% was obtained under simulated solar light when the films were annealed at 380 °C in air for 30 minutes. The maximum quantum efficiency of 5.5 % was obtained at an incident wavelength 500 nm. From the results [86], it appears that the CdS/CdTe solar cell has a notable series resistance, which is detrimental to the efficiency of solar cells. Both active layers (CdS and CdTe) were deposited through the thermal evaporation process, and then each of them was measured separately. Specifically, absorber layer (5-7 micron) not only conducted light more than 90 % of the incident at this low series resistance but also showed perfectly oriented crystalline lumps. It was noticed that deposited cells which had not been heat-treated tended to show a reduced increase in short circuit current with increasing light intensity. This type of deposited cell has low conversion efficiency.

The selenium doping concentration was raised to n+ level in the rear of the cell, and heat treatment was utilized to enhance energy conversation efficiency while contact resistance became as low as p- or n-type silicon whose resistivity is no greater than 1mΩcm^2.Energy conversion efficiency increased by over 7%. This test was an indication that transmittance was quite sensitive in small increments of CdS thickness. The thicker the CdS layer, the worse the quality of the layer gets. At the same time, the resistivity of this thicker CdS layer increased more than that for a thinner one.

CdTe film (59 nm thick) is highly transparent for short wavelength light (500 nm), while the transparency becomes much more apparent at longer wavelengths above 800 nm. The absorption edge shifted to shorter wavelengths as the annealing temperature rose to higher levels. It was clear that the higher resistivity of the CdS-coated glass prepared at 250°C would result in bigger increments of photocurrent generated. CdTe is considered as n-type semiconductor. Because the under layer which contains excess cadmium upsets the balance, and the deposit itself either becomes contaminated somewhat through grain boundaries or because of impurities.

Copper indium telluride is an important I-III-VI$_2$ semiconductor material whose optical, electrical and thermal properties are attractive for use in electronic devices. The 0.91-1.02 eV direct bad gap of $CuInTe_2$ lies within the range between CdS and $CuInSe_2$ (1.5 eV and 1.04 eV respectively). Quantum confinement effect and Bohr radius for $CuInTe_2$ are larger than those of $CuInS_2$ and $CuInSe_2$ owing to tellurium forming strong covalent bonds. taking these two materials, it can only be attributed to energy transfer between them due to physical change.

Guanwei and colleagues have shown that stearic acid can greatly determine the shapes of $CuInTe_2$ nanocrystals and thus provide a very simple way to synthesize them [87]. The XRD results demonstrated nanocrystal as a sphalerite phase. Average compositions of the film were determined to be 0.24:0.28:0.48 by analysis, which is close to our target composition of 0.25:0.25:0.5. The band gap of energy was found to be 1eV by measuring optical absorption spectra for the colloids of nanocrystals. $CuInTe_2$ is essentially p-type, and the device structure used in this trial is Au/$CuInTe_2$/CdS/ZnO and ITO (indium-tin oxide).

$CuInTe_2$ nanocrystals were prepared from a toluene derivative. Using spray-coating technique the nanocrystal layer does not require annealing. The photovoltaic characteristics for a typical device under AM 1.5 illumination are open circuit voltage of 342 mV, short circuit current density 10.651 mA/cm^2, fill factor 0.335 and the power conversion efficiency 1.22 %. Incident photon to current conversion efficiency (IPCE) were obtained. It complied with the absorbance spectra. The high response of the cadmium sulfide film in IPCE between 400-500 nm could be due to its photovoltaic nature. The measured incident photon to current efficiency in the shorter wavelength and longer wavelength ranges were lower at 400-500 nm, respectively. The high photovoltage response of the IPCE at 400-500 nm may be due to the cadmium sulfide film. The cutoff wavelength in the long wavelength range of up to 1250 nm corresponds to the optical bandgap energy=1.02 eV in this type of material. The rapid dropping of the IPCE at less than 400 nm is a result of light being absorbed by ZnO.

$CuIn_3Te_5$ films (1.8 to 4μm) were grown on uncoated and Mo-coated soda lime glass substrates [88] at the substrate temperatures of 250 to 400 °C by single step co-evaporation using a molecular beam epitaxy system. Raising the film thickness, which was deposited at a substrate temperature of 250 °C, achieved perfectly (112) oriented grains with a Hall mobility of 450 cm^2/V.sec. At higher film temperatures, cathodoluminescent analyses and temperature dependent Hall measurements showed that there are shallow defect levels in the film. A μmax solar

cell (temperature=250 °C and film thickness=4 μm) obtained a total area (0.504 cm^2) of 6.28%. Based on temperature dependences of the electrical properties of the films and the solar cells, the recombination mechanisms of the CdS/$CuIn_3Te_5$ films are analyzed.

Nanocrystalline $CuInS_2$ thin films can be deposited using a solution-based, two-step growth sequence [89] under ambient atmosphere at ambient temperature (less than 350 ° C). The precursor solution, which is prepared by aqueous reaction method, consists of Cu_2O and $In(OH)_3$ and organic solvents like butyldithiocarbamate acid and ethanol. Of the films fabricated in this manner, the as-deposited films were identified as a copper deficient composition with a band gap in the range of 1.53-1.58 eV. By using a planar heterojunction solar cell structure (FTO/CdS/$CuInS_2$/Spiro-OMeTAD/Au), scientists have got the following results the best solar cell when $CuInS_2$ films annealed at 350 °C were used has an average efficiency of 1.79% and demonstrated excellent performance over twenty days of stability test. Based on the XRD patterns, three diffraction peaks at 28°, 46.5° and 54.7° are observed in all the films and they can be well matched to the (112), (204)/(220) and (112)/(316) crystal planes of cha1copyrites, respectively. According to the diffraction peak (112), the average grain size of the annealed films is about 4.3, 6.9 and 8.1 nm at different annealing temperatures.

With lower temperature and an ink-based application, [90] we used $CuInS_2$-based materials. Researchers dissolved metal chlorides and thiourea that are used to make the molecular ink in methanol, which serves as a solvent for this material. The so-made molecular ink was spun onto soda lime glass. Then the samples were placed in a pot for heating purposes. The solid state photovoltage characteristic of the proposed structure was examined by photoelectrochemical measurements (without the platinum catalyst). The cell has a relatively high open circuit voltage of 0.82 V, as well as a photocurrent density 7.4 m/A cm^2. Nevertheless, the relatively low value of fill factor (34.84%) limits the power conversion efficiency of the cell to only 2.11%, due to bulk recombination within $CuInS_2$ films.

As-prepared [91] $CuInS_2$-based solar cells were prepared using rapid-thermal-process (RTP) technique. Copper and indium as the layers in the second group of elements are subsequently sputtered on glass/Mo substrate by DC magnetron sputtering. A team of researchers uses a stepwise procedure in which copper and indium films are quickly heated and subjected to sulfur vapor. All samples were synthesized with a slight copper excess [Cu]/[In]=1.8. The sample is rapidly heated to approximately 600 °C by direct radiation from the front. SEM of an absorber layer of a rapid thermal process post-cyanide etch. The grain size is approximately 1-2 μm as of the layers using heat treatment. The cross-section shows an etched layer on the back contact whereas this layer is quite rough. As such, uniform growth of an absorber layer cannot be assured according to the above observation. Seems like the absorber does not bond well to the molybdenum back contact. The XRD demonstrates that the absorber layers fabricated by this method possess good quality crystallinity. To investigate the defect chemistry in more detail, PL and admittance spectroscopy are performed. The solar cells using these RTP absorbers achieved a total area efficiency of 11.4% (A=0.5 cm^2).

The p-type absorber with higher copper concentration is thermally co-evaporated [92]. For the ratio 1:1 of the components relative to copper and indium smaller losses in solar-to-electric conversion might be afforded by a decrease to the ratio 1:1.8 in the ratio of copper to indium. The sharp rise in current collection at 1.5eV is indicative of a sufficiently long minority carrier diffusion length in the absorbing $CuInS_2$ layers. A quantum yield of 83% at 560 nm is achieved. The reduction of quantum yield at 500 nm relates to light absorption in thin layers of band gap 2.42 eV. Since majority carriers produced suffer from high efficiency interface recombination compared to the deposited layer electrons, the current is decreased. The wide difference in molecularity, clearly existing even in the as-deposited state, vanishes after cyanide treatment. Therefore, any variation in composition was permissible because of a chemical modification of the film composition. This new method could enable the upscaling of such types of solar cells in the future. Cu-In precursors [93] were deposited electrochemically. Acid behind hydrochloric acid adjusted the pH of the solution, which varied from 3.22to 1.74. For CuInS2 preparation, Cu-In precursor films were prepared by evaporating and annealing the as-prepared precursor in sulphur vapor at 500 ºC for 60 min. During the samples annealing, grain coarsening was detected, and it was relatively enhanced for the Cu rich films. A thin layer of Cu-In was electrodeposited and then sulfurized to form corresponding CIS films. The morphology optimization enabled us to prepare solar cells by depositing/finishing their high-purity Cu_xIn precursors. Morphology studies show that a film of good morphology and a grain size of 1 μm can be obtained without HCl. The composition of the films was to some extent processed also by hydrochloric acid. And They grew a photovoltaic with 1.3% efficiency.

$CuInSe_2$ absorber layers were also directly derived from selenization [94] of the amorphous Cu-In-S nanoparticles, which were synthesized without external heating by means of a low-temperature prepared colloidal process. There were two approaches adopted in this work to prepare the cold-pressed high density absorbed films. These involved two approaches; one involved surface complexation of a chelate complex of ethanolamine onto the inorganic nanoparticles, while the second version relied on the lattice expansion that occurred on introduction of selenium in place of sulphur when Se particles were synthesized. In this way, the as-prepared film exhibits nearly dense status and

the corresponding devices based on the absorbed films demonstrated a power conversion efficiency of 7.94% under illumination without anti-reflection coating. A simple low-cost and eco-friendly source dip-coating fabrication method [95] for $CuInSe_2$ film has been reported. The feed solution consists of a blend of metal acetate, ethanol and ethanolamine. Rather, the precursor solution is prepared, without necessarily having to have performed particles, making preparation quite rapid and simple. The as-formed solution in air is an additional benefit for the precursor preparation and film deposition in ambient condition without any glove box. A solar cell made of the absorber film obtained by this method showed 7.72% for the initial conversion efficiency.

Zhi and colleagues utilize the one step Co-evaporation technique for CZTS (Cu_2ZnSnS_4) solar cells on soda-lime substrates [96]. In the first place the reduction in series resistance by eliminating ZnS blocking improves efficiency. The more densified tin-containing CZTS films with reduced purities were achieved under the restriction of the re-evaporation of the volatile phases, resulting in a significant enhancement of the photovoltaic parameters. The decrease in efficiency at a high Sn vapor concentration level shows that saturation of tin composition is key factor on the CZTS formation during decomposition process. Compared to post-annealing starting from the surface, a superior level of in-plane homogeneity can be achieved due to direct- on-site deposition and reaction control throughout the film-growth process, and the better quality and integrity of the film. It can be easily operated because of one step co-generation. A power conversion efficiency of 4.3% is obtained with a relatively high open circuit voltage at 608 mV originating from the rapid carrier transfer.

In a recent study, it was reported that a certified 11% efficient thin film solar cell with 730 mV open circuit voltage and 54 mA/cm^2 short circuit current was obtained through an annealing process to minimize the heterojunction recombination [97]. Consequently, higher temperature annealing induces elemental inter-diffusion: direct doping of cadmium into the zinc or copper lattice and accumulation of sodium in conjunction with a local cyst depletion in the region of the heterojunction. To allow new phases to grow at the hetero interface for achieving better conduction band alignment. In addition, researchers exhibit a certified scale (1.11 cm^2) photovoltaic device with efficiency. It is the first efficiency of 10% kesterite cell on the standard cm scale.

Cu_2ZnSnS_4 solar cell with efficiency of 8.4% was made by Shin et al. [98]. According to the literature, the optimal solution is copper deficient and zinc rich (even if secondary phases of ZnS are present). This was the case even at a very low an absorber thickness (600 nm) which even resulted in a reasonable short-circuit current. The films were deposited on Mo-coated soda lime glass substrate by thermal evaporation in a high vacuum system with Knudsen type sources. The growth was maintained at a low substrate temperature˜ 150 °C to prevent the secondary phase at CZTS/Mo interface. After depositing layer E and before evaporation, the devices underwent a short (5 min) anneal at 570 °C under atmospheric pressure. The device structure below the CdTe layer is 90-100 nm of CdS grown by chemical bath, 80 nm of intrinsic ZnO and 450 nm of aluminum doped ZnO grown by sputtering, Ni-Al contacts, and a 100 nm MgF_2 for anti-reflection.

The influence of post-annealing temperature and film thickness after CdS deposition on the photovoltaic performance was investigated for CZTS based two layers configuration solar cell to enhance device efficiency. Short circuit current density [99] was greatly increased by the introduction of CdS (film thickness=40 nm) and high temperature annealing of 603 K due to an increase of the external quantum efficiency at a light wavelength between 400 and 800nm. The best reported cell efficiency for the CZTS absorber was 9.4 % active area (9.1 % aperture).

It was also reported that a CZTS cell with an open circuit volage of 0.8 V was obtained by precisely tuning the composition of CZTS films. The procedure for the manufacture of the CZTS cell is described. Mo electrodes with a thickness of 0.7 μm were first deposited on alkali glass substrates by sputter deposition. The CZTS absorber films were deposited by a two-step process approximately 1200 nm thick. The first CZTS layers were deposited by electron beam and RF magnetron sputtering of Cu,Sn,Zns on a Cu/Sn/Zns/Mo/Alkali-glass reticule and sulfurized at 853 K for 20 minutes in H_2S and nitrogen atmosphere at atmospheric pressure. The temperature of heating and cooling was 5 and 10 K/min, respectively. The second CZTS layers were fabricated in a similar manner by coating another precursor on the pre-prepared one forming ZnS/Sn/Cu/CZTS/Mo/alkali glass, and then sulfurating them in H_2S-N_2 gas at 773K for 1h. The XRD patterns of the single or bilayers of the CZTS do not show any impurity phases. The Raman spectroscopy identified as the layer is CZTS. Nevertheless, the 287 and 373 cm^{-1} Raman peaks are weak, indicating that CZTS has some degree of disorder. The MoS layer is located at the CZTS/Mo and ZnS interface of the CZTS layer, and the CZTS layer possesses a porous structure as confirmed by STEM-EDX.

The evaporation was carried out at a pressure of 10^5 mbar, with molybdenum as the back contact direct deposition of CZTS on the substrate without any atmosphere sulfurization could also be studied, such as the multi-stage co-evaporation process [100]. Homogeneous films were formed by an in-situ film growth monitoring technique, which is based on the measurement of the apparent substrate temperature by pyrometer. These data give convincing evidence of the formation of the CZTS phase; first, by virtue of the re-evaporation of SnS containing compounds, at the first stage, and secondly, in the way of major diffraction lines associated with the (CuS + ZnS) phase present with a slight proportion of CZTS. (CuS+ZnS) precursor developed CZTS phase to the copper-rich region

and such development was reflected significant substrate temperature variation for the subsequent process, while the slightly segregated CuS phase has been nearly exhausted under (Zn+Sn+S). A glass/Mo/CZTS (Cu/Sn+ZnS/Zn = 0.71; Zn/Sn = 1.6)/CdS/ZnO:Ga solar cell fabricated with an NaF precursor layer yielded the best performing (active area) cell efficiency of 3.83% (fill factor=0.603, Jsc=11.3 mA/cm^2, Voc=567 mV).

Table 3: Properties of thin film based solar cells

Researchers	Highlighted results
Jeon and co-workers	Copper zinc tin selenide films were deposited onto substrate using electrodeposition method [101]. Films at 550 °C show the best device quality, with an active efficiency as high as 8%.
Cha and co-workers	Nano-ink solution method [102] was employed for the production of $Cu(In,Ga)Se_2$. Efficiency of thin film solar cells reached 5.17%.
Vahid and co-workers	Selenization of oleylamine-capped $Cu(In, Ga)Se_2$ nano crystals sintered at high temperature with selenium vapor [103]. The maximum power conversion efficiency achieved was 5.1% for [Ga]/[In+Ga]=0.32.
Liu and co-workers	Direct formation of large-area $Cu(In,Ga)Se_2$ nanotip arrays by a one-step Ar+ milling [104]. Open circuit voltage and short circuit current were 0.39 V and 22.56 mA/cm^2, correspondingly, with a fill factor and efficiency of 59% and 5.2%, respectively.
Yuuki and co-workers	Deposition of a new $In(OH)_3$:Zn^{2+} buffer layer for fabricating high efficiency CIGS solar cells [105]. With buffer layers, a 14% (V_{oc}=0.575 V, I_{sc}=32.1 mA/cm^2, fill factor=0.758) cell was realized without resorting to the light soaking effect.
Gour and co-workers	$Cu_2ZnSn(S,Se)_4$ kesterite absorber material [106] has been attracted much attention. An existing large band gap (1.4 eV) with the maximum efficiency of 13%.
Vijay and co-workers	In multi components of CZTSSe films [107], the tri-layer stacked metal precursors (Cu/Sn/Zn) were deposited on a Mo-coated soda lime glass substrate by the DC sputtering method at ambient temperature. The metallic precursors were also softened annealed in argon following with annealing in a chamber type RTA system with graphite box in a chalcogen vapor atmosphere.
Cheng and co-workers	In devices such as ($FTO/NiO_x/Sb_2Se_3/CdS/i$-$ZnO/ITO/Al$), short circuit current of 29.93 mA/cm^2, open circuit voltage of 0.414 V, efficiency of 6.72 % NiO_x serves as hole transport layer, contact sides were FTO and aluminium [108]
Kang and co-workers	Two-step selenization of CZTSSe film [109] for improved efficiency. An overall efficiency of 12.5% is obtained by synergistically high temperature selenization.
Priscilla and co-workers	solar cells with high sulfur content [110] having a maximum efficiency of 11.89% and open circuit voltages as large as 0.67 V.
Khan and co-workers	CZTSSe film was fabricated by an electrochemical deposition method [111] and annealed. Solar cells exhibit a power conversion efficiency of 9.9 %.
Elarbi and co-workers	Cu_2SnS_3 films have been deposited using SILAR method [112]. Efficiency of 9.85 % and open-circuit voltage of 0.739 V.
Dong and co-workers	The treated $Cu_2ZnSn(S,Se)_4$ solar cells [113] reached efficiency of 6.39 % (if compared to untreated devices (3.65 %). sodium treatment method improves properties of films and performance of devices.
Li and co-workers	Vapor-assisted solution process was used to prepare high crystallinity $AgBiS_2$ films [114]. Higher efficiency (10.2%) could be observed in small active area (0.06 cm^2), while large active area (1 cm^2) yielded efficiency of 9.53 %.
Huang and co-workers	Close spaced-sublimation method was used to prepare Li doped

	$Sb_2(S,Se)_3$ thin-films [115]. ITO/CdS/Li-$Sb_2(S,Se)_3$/PbS/Carbon solar cell produced efficiency of 6.18%.

6. Photovoltaic parameters on the performance of perovskite solar cells

This class of the new age semiconductor materials used in perovskite solar cells is being employed as a crystalline material for electricity generation due to the generation of electricity. These provide opportunities for achieving high efficiency, low-cost processing and flexible or lightweight design, and thus are suitable for various applications including building-integrated photovoltaics [116]. Properties of this type of solar cell were reported by many researchers (Table 4). Although perovskite solar cells have been underdeveloped, there has been little data on the efficiency improvement that exceeds the efficiency limit of silicon solar cells, which has become the society dependent on carbon neutrality to accelerate.

BIPV (building integrated photovoltaic) is the integration of photovoltaic [117] into building elements that are normally produced by the same factory as the building such as roof tiles, skylights for electricity production. These types of photovoltaic are also a part of the overall design of the building, it is not an applied, latter device. Perovskite solar cell has a perovskite structure material (material with an organic small molecule inorganic & $CH_3NH_3PbX_3$ as the light-active layer in the form of a thin film. Thin films, as the material making up the devices were grown in vacuum or printed, which are coated or deposited on a substrate [118]. The high-performing perovskite solar cells have been rapidly developed, achieving over 25% in the laboratory [119]. A few researchers also examined cell thin film perovskite with a platinum polycrystalline silicon tandem solar bypassing in Mentor Ohio. Compact perovskite cells have already reported efficiencies of 32.5%. The high flexibility [120] and versatility of perovskite solar cells makes it possible to use them not only at a flexible solar panel scope but also in the case of tandem solar cells combined with silicon.

Unfortunately, the organic charge transport materials are not stable, and the resist is very expensive for the wide commercialization of the perovskite solar cells in practical application. Under this line of thinking solar cells based on carbon perovskites aiming at low-cost carbon materials [121] with natural moisture blockage rate as one of the serious candidates that might be able rank around large-scaled applications. The studies of carbon-based perovskite solar cells have been mainly concentrated on carbon-based materials in hole transport materials and counter electrodes. The carbon coating may also be a simple blade coating or screen printing. There is no longer a requirement for metal electrode preparation equipment for high vacuum. Accordingly, a device and process for manufacture may be simplified. Generally, carbon-based perovskite solar cells are prepared after the perovskite film is generated and hole transport material (PTAA or Spiro-OMeTAD) is spin-coated. Carbon behaves like Ag or Au in case of back contact. The carbon-based PSCs are processed without additional hole transfer materials. The hole transporting layers can be a carbon material which is formed before or after forming the perovskite layer.

Carbon-based perovskite solar cells without hole transfer layer materials have their own set of advantages. First, they can be synthesized at low temperatures, and secondly, carbon materials have natural hydrophobicity. The layer made from carbon layers may also prevent migration of efficacy in perovskite solar cells [122], which accounts for a large part of the decline in efficiency at 70% optical fluorescence for a perovskite solar cell (as compared to the 20–60% that exists in any good commercial product). However, the poor quality of the interface between the carbon film and hole transfer materials has been the bottleneck for carbon-based perovskite solar cells. In contrast, for the preparation of carbon-based perovskite solar cells that do not contain any hole transfer layer materials, since the photosensitive absorption edges for electrons and holes in YBAMz have already been widely split due to such high work function values of carbon.

Spiro-OMeTAD is the most widely used [123] hole transport layer materials for MAPbI3 solar cells due to its relatively higher conduction band position and lower valence band position compared to perovskites. With band edges position, hole transfer from MAPbI3 to spiro-OMeTAD is possible [124], also it keeps a kinetic barrier to the reverse of electron transfer. But spiro-OMeTAD will fruit with low conductivity and lower intrinsic charge carrier mobility.

Silver nanowire transparent conductors and coordinated mechanisms for applications in planar and framed lines. Nevertheless, it is quite prone to corrosion in the practical use of perovskite solar cell on account of lead halide-based hybrid perovskite [125]. The nature of the transparent conductor is altered by nickel electroplated thereby to solve a problem. Nickel electro-deposition may enhance the conductance and promote the corrosion and oxidation resistance of the transparent conductor. Furthermore, the SnO_2 quantum dots' compound can downward adjust the conductor surface and sputtering of ITO can enhance the conductive film once more. Then the modified TCOs are employed to materials the PSCs. The optimal cell showed an efficiency of 18.37% under the AM1.5G simulated light intensity. Transmission and EIS results indicate that the honeycomb-like Ni TCs facilitate the effective carrier extraction and inhibits the recombination process. The storage stability of the device is recorded to retain 80% of their initial performances when kept in the dark for 432 h.

Thepoly(bis(4-phenyl)(2,4,6-trimethylphenyl)amine) (PTAA) was used as the carrier transport layer, polymethyl methacrylate (PMMA) was employed as the interface

modification layer. The ultralow-temperature behavior of PC61BM-PTAA-based MAPbI3 device was different from that of the TiO_2-spiro-MeOTAD based ones. Open circuit voltage and short circuit density were also rising without PMMA, a was enhanced first, then decreased sharply towards the temperature falls. Therefore, the reduction of fill factor is the reason why the power conversion efficiency is decreased appreciably at and below phase transition temperature. The introduction of the PMMA interlayer significantly improved the open-circuit voltage, effectively suppressed the decline of the fill factor, and declined $MAPbI_3$ crystal phase transition temperature from almost 170 to130 K and then resulted in an excellent photovoltaic performance of $MAPbI_3$ solar cells at low temperature [126]. Therefore, the best efficiency up to 22.4%at 90 K was achieved, and it is superior to the peak efficiency of 21.1% at 170 K of reference device, which is the record efficiency based on the whole p-i-n structured $MAPbI_3$ solar cells at low temperature.

Dopant-free hole-transporting layers [127] have been reported. For this present design, we prepared triphenylene derivatives possessing triphenylamine groups grafted on them. In T-6 TPA with extended π-conjugation, a high hole mobility of 2.06×10^{-3} $cm^2/V.s$ was obtained and when these molecules infiltrated into the perovskite layer before hole transport layers were deposited then hole extraction at the interface was significantly improved. By means of the infiltration method power conversion efficiency increased from 18.5% to 20.2%. The effectiveness of anti-solvent installation lies in set up a uniform, smooth track for hole transport. The initial power conversion efficiency remains 80% after 60 days of exposure to air, or 600 hours for devices stored at 60 °C.

An inorganic halide perovskite, $RbGeBr_3$ in its cubic phase, presents a band gap of 1.49 eV. Carbon 60 (Fullerene), or "Buckyball," has been widely used as the electron transporting layer in perovskite solar cells. This work on the fullerene system as an electron transport layer (ETL) material is crucial for efficient electron transfer in photovoltaic devices. Its inherent spherical shape consists of 60 bonded carbon atoms arranged in a conjugated π-electron system. This not only possesses good electron mobility to suppress charge recombination losses but also greatly increases the effectiveness of resulting devices. Comparison on the publication order of sourced materials shows that C60 and some organic & inorganic HTMs [128] and admired inorganic $RbGeBr_3$ perovskite have been applied to ordinary solar cells. Among them, the FTO/C60/RbGeBr3/NiO/Au-based HTM got the highest efficiency of 16.48%. (Open circuit voltage=0.92 V, short circuit current=22.25 mA/cm^2). At the same time as replacing the nickel electrode with gold, the resulting increase in efficiency is nearly identical.

When mixed halide perovskites are irradiated, the migration of halide ions may lead to a phase separation that is difficult to overcome from the industrial standpoint. A simple [129] and effective method to prevent phase separation photoinduced in the mixed halide-film FA0. Cs0.17Pb(I0.6Br0.4)3 is to add tetra-octyl-amonyl-amine chloride (TOAC). The results show that by using TOAC, halide ion migration is effectively suppressed and the perovskite phase stabilized, and phase segregation inhibited in additive passivation coupled devices. Mixed-halide perovskite solar cells produced using dual TOACs could, however, reach an efficiency of 15.8 % while showing superior stability under long light soaking and reduce hysteresis. Moreover, TOAC, with its larger organic cation framework and extended alkyl chain systems, may have other potential benefits. Those longer organic tails, for example, may provide improved hydrophobicity and hence better protection to protect against moisture induced degradation than shorter chain members. This would also mean they might behave in a different manner with respect to the passivation of perovskite crystallization and grain boundaries than these shorter chain members can.

By giving TOAC a shorter organic tail, the number of perfect is reduced to a level that there is an extremely less chance leakage, ion migration or charge recombination occurs—so leading to a markedly reduction in defect density and increased recombination resistance, longer lifetime of carriers. Notably, these improvements have been observed in both iodine-only and mixed-halide perovskite solar cells. The instability of the inorganic perovskite-based solar cells arises from the fact that inorganic perovskites show poor surface sensitivity. For $CsPbI_2Br$ perovskite [130], a three-dimensional/zero-dimensional inorganic perovskite single-layer comprising a surface reconfiguration applied to 0D Cs_4PbI_5Br and higher efficiency can be realized simultaneously on all inorganic perovskite solar cells. It involves creating a 0D Cs_4PbI_5Br capping layer in-situ to effectively enhance the stability of $CsPbI_2Br$ perovskite and to construct energy level structures for charge extractions that are advantageous. Simultaneously, the surface reconstruction leads to the secondary crystallization of perovskite, and markedly improves perovskite morphology, reduces perovskite defect, and enhances perovskite quality.

Table 4: Properties of perovskite solar cells

Researchers	Highlighted results
Shen and co-workers	2-(2,2,2-Trifluoroethoxy)aniline was added in devices to improve efficacy (22.72 % to 24.1 %). The presence of specific groups such as fluorine and NH_2 groups to cement their intrinsic properties [131]
Jing and co-workers	Organic additives could be observed to produce ionic bonds, coordination bonds, and hydrogen bonds. The highest efficiency (11.34%) could be found in 3,4-dibromo-1H-pyrrole-2,5(2H,5H)-

	dione organic additives [132].
Fadwa and co-workers	Improve efficacy (23.34%) and minimize defects by adding thiosemicarbazide-functionalized carbon nanotubes in devices. Finding revealed that this device could maintain 91.3 % efficiency after 800 hours [133]
Manasvi and co-workers	Lead-free perovskite solar cell was made such as FTO/AZnO/$Cs_2CuSbCl_6$/MoO_3 Photovoltaic parameters [134] were studied using CAPS-1D simulations (open circuit voltage=1.58 V, short-circuit current density=21.82 mA/cm^2, fill factor=91.12 %, efficiency=31.5 %.
Yuan and co-workers	Lithium acetate served as crystal growth regulator, will be added in electron transport layer/perovskite interface [135]. These dual interfaces modified devices reached an efficiency of 25.48 %, maintaining 90 % of initial performance for 1200 hours.
Liu and co-workers	High quality of $CsPbI_3$ could be observed using proper amount of excess PbI_2 (1.0 mol%). Power conversion efficiency [136] was found in the range of 12.57 % to 14.39 %.
Revathy and co-workers	$CH_3NH_3SnI_3$ was used because of non-toxicity materials and lower band gap [137]. In FTO/TiO_2/IDL/$CH_3NH_3SnI_3$/Carbon devices, efficiency=22.23 %, open circuit voltage=0.886 V, short circuit current=30.68 mA/cm^2, fill factor=81.58 %.
Hannah and co-workers	Device (active area=0.5 cm^2) showed specific photovoltaic properties such as efficiency=7.04 %, fill factor=70.4 %, open circuit voltage=1 V, short circuit current=9.9 mA/cm^2. Multi-layered hole transport layer was prepared by using selenium and copper selenide [138].
Malik and co-workers	Specific device FTO/WS_2/$(FA)_2BiCuI_6$/CBTS/Au was made [139]. Photovoltaic characteristics were reported (efficiency= 30.23%, short circuit current density= 29.63 mA/cm², fill factor= 84.32%, open circuit voltage=1.21 V.
Navdeep and co-workers	Stacked absorber layer will be added into solar cells to enhance power conversion efficiency [140]. Results confirmed that efficiency will be increased (28.5%-30.4%) when the thickness of stacked absorber layer was increased.
Mondal and co-workers	TiO_2/WO_3, Cu-based served as ETL and HTL, respectively [141]. MoOx/Au/MoOx electrode will be employed to reduce sheet resistance.
	$CsPbIBr_2$ could be utilized as absorber material for semi-transparent perovskite solar cells, with efficacy of 10.4%.
Vijay and co-workers	The highest efficacy (20.03%) could be observed in petri-plate assisted vapor annealing perovskite films if compared to conventional thermal annealing (19.02%). In XRD and SEM studies, smaller grain size could be found in the samples prepared through conventional annealing [142].
George and co-workers	Lead-free solar cell [143] was fabricated (ITO/$PC_{61}BM$/$CH_3NH_3SnI_3$/PEDOT:PSS/Mo). Photovoltaic parameters were studied (short circuit current density= 34.84 mA/cm², open circuit voltage= 1.52 V, Fill factor= 71.04%, efficiency=37.66%.

Encapsulation is very important to avoid undesired ingress and escape phenomena, as all solar cells must be properly encapsulated before their use in practice. The option of encapsulants and an encapsulation strategy is required to achieve adequate lifespan. Hermetical encapsulation creates a pressure resistant environment to prohibit volatile gaseous decomposition products to release and to retard perovskite solar cell degradation. An ideal encapsulant would also exhibit a low water vapor transmission rate to minimize the effects of moisture penetration.

Perovskite solar cells can degrade by a number of mechanisms with moisture, temperature, light and electrical bias known to be the main causes of degradation. On treatment with the above stressors, numerous degradation pathways can be set in motion, including hydrolysis, grain boundary degradation, phase separation, ion migration etc. Water molecules first condense on the perovskite material, selectively over the organic cation and halide anions. This leads to the creation of hydrated intermediates with downloads the generation of decomposition products such as lead iodide, methylammonium iodide and other water-soluble species. The grain boundaries, which are high-energy and reactive regions in the polycrystalline perovskite films, will be more susceptible to moisture penetration. When moisture intrudes these limits, it creates structural changes that result in defects and more degradation products.

7. Outlook of the photovoltaic industry

In addition to power conversion efficiency, further research is needed to raise the endurance times of these organic solar cells, that may become useful in real-time applications. Most testing in the laboratory takes place under the severe environmental conditions of solar simulators. Yet these devices should be tested under other conditions as well, such as low indoor lighting, illumination underwater, or in any atmosphere.

The dye sensitized solar cell industry is growing and offers

low production costs, flexibility, and is readily responsive to low light conditions. Further research on materials-natural dyes, advanced nanostructures, and so on is crucial if these devices are ever to reach their full potential.

During the past three years, rapid development of perovskite solar cells has made this photovoltaic technology a promising candidate for potential large-scale deployment on the terawatt scale in the photovoltaic market. How to design and fabricate modules is another critical issue for high-performance operation of perovskite solar modules in various applications. There are two main schemes employed in module construction: monolithic and grid-connection. The resistance in interconnections areas must be reduced.

Thin film solar cells have a bright outlook, expected to grow through technological advancements, more extensive adoption in diverse applications and as costs come down. Although currently a smaller share of the overall solar market, thin film solar is expected to expand significantly in the future. With improving efficiency and wider use in novel applications like building-integrated photovoltaics or wearable tech, thin film solar cells are set to become a keystone of tomorrow's energy picture.

8. Conclusions

Currently, different types of solar cells which include organic solar cells, dye sensitized solar cells, perovskite solar cells and thin film based solar cells are making great strides in performance. Higher efficiencies of these solar cells are achieved by a combination of multiple production methods and new semiconductor materials. However, further development such as increasing efficiency and ensuring stability of a device, improving the competitiveness for solar technology requires a reduction in material and production costs. Thin film solar cells have the added advantage of low material consumption and high efficiency. Thin film technology is a long-term investment in time and energy, so there needs to be much more experienced building partnership with thin film technology before building integrated photovoltaic can become feasible in both engineering cost terms. Graphene solar cells have attracted much interest but they also face numerous challenges Because the graphene sheet is so thin, graphene solar cells need only a small amount of raw material, which means extremely low manufacturing costs can be achieved. Its natural adaptability has allowed researchers to make a wide variety of solar cells using it that would simply be impossible with silicon. It has a variety of superior physical and electrical properties and provides many opportunities for tuning solar cell applications, which are very attractive for consumers. Perovskite solar cells offer several substantial benefits over conventional silicon-based solar cells. They also tend to have lower production costs, so there could also be more affordable options in a renewable energy market. They are also more efficient, meaning more energy can be converted. Moreover, perovskite-cell design and fabrication are much more flexible and allow for more novel types of application. Their interesting characteristics also make them good candidates for tandem solar cells, where they can actively contribute to improving the performance of silicon-based technologies. Dye sensitized solar cells will require soon-to-be-developed theoretical model that shows quantitatively which combinations of semiconductor, dye, and electrolyte are most promising, as well as how to put them together. A model of this kind will make those researches much easier to share instead of lots of time and trouble. Light harvesting and electron losses can both be improved via guided optimization as experiment on various heterostructure devices. It was the discovery of efficient organic electron-donor and electron-acceptor molecules and compounds: polymers, small molecules and fullerenes as the photoactive layer has resulted, in the past several decades, in a large improvement in the power conversion efficiencies of organic solar cells. Heterojunction organic solar cells may be classified into a number of categories in terms of both donor and acceptor materials.

Acknowledgement

The author (Ho SM) is grateful to the INTI International University for providing the financial assistance to carry out this work.

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