International Advance Journal of Engineering, Science and Management (IAJESM)
ISSN -2393-8048, January-June 2018, Submitted in May 2018, iajesm2014@gmail.com

PCE Historical Development: An Overview

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INTRODUCTION

Solar cells are an essential component in the process of transitioning the energy systems of the globe away from the use of fossil fuels and toward the use of renewable technologies. This movement is being driven by the goal of reducing the world's reliance on nonrenewable sources of energy. This shift is currently under way and will be completed over the course of the following several decades. The overall amount of energy that comes from the sun is many thousands of times greater than the amount of energy that is required to meet the demands of the population of the whole globe. This means that the sun is the primary source of energy for the planet. The sun is responsible for the direct production of solar energy, as well as the indirect production of other types of renewable energy, such as wind, wave, hydroelectricity, and biomass. In addition, the sun is directly responsible for the creation of solar energy. One example of this type of technology is photovoltaics, which stands out due to its capacity to transform sunlight into an electric current in a straightforward manner. There are a number of various methods in which the technology that underpins solar cells can be put into practice. Because they can be manufactured on flexible substrates from solutions and at low temperatures with the help of roll-to-roll manufacturing processes that are reasonably inexpensive, organic solar cells represent an alternative to the more typical silicon sun cells. Because of this, organic solar cells are an appealing alternative to the more conventional silicon solar cells. In addition to this, not only are they simple to carry, but they can also be manufactured without the use of any raw materials that may pose a risk to the environment. Organic solar cells have a shorter lifetime and a poorer power conversion efficiency (PCE) compared to silicon solar cells. Organic solar cells also degrade more quickly. This is due to the fact that organic solar cells are constructed using a distinct kind of material. In contrast, organic solar cells have a power conversion efficiency (PCE) of around 5% and a lifetime of approximately 5 years, whereas typical silicon photovoltaic panels have a PCE of approximately 17% and a lifetime of nearly 25 years.

Because of the multiple benefits that they offer, organic solar cells (OSCs) with the bulk heterojunction (BHJ) active layer have caught the curiosity of a substantial number of people. This is due to the fact that organic sun cells (OSCs) are relatively new. A low weight, a low degree of opaqueness in appearance, and a high degree of mechanical flexibility are only some of the advantages that come with this material. It is now possible for organic solar cells, also known as OSCs, to attain power conversion efficiencies (PCEs) of more than 18 percent because to the fast advancement of organic photovoltaic materials and device engineering. The fact that OSCs have been able to attain such high levels of power conversion efficiency is what made this accomplishment conceivable. Despite the significant advancements that have been achieved in PCE development, the low operational stability of OSCs restricts the scope of the practical applications that may be carried out with them. This is the situation in spite of the substantial effort that has been made in bettering PCE. It is important to take note of the fact that the morphology of the photoactive layer degrades with prolonged exposure to a variety of environmental components (such as light, oxygen, and heat), since this continues to be a primary barrier in the path toward the commercialization of OSC technology.

History

It is necessary to perfect the morphology of the BHJ in order for OSCs to perform to the best of their abilities. For exciton dissociation to operate effectively, this morphology has to have a lot of electron donor/electron acceptor (D/A) connections, and it also needs to have bicontinuous D and A domains so that charge may travel between the two. On the other hand, the inherent instability of the composite photoactive layer often becomes apparent when the material is exposed to light for an extended period of time or when it is allowed to age thermally. Both of these scenarios are referred to as photoaging. In particular, the transition of the blend morphology from the kinetically trapped state to the thermodynamically stable state, such as the aggregation and/or the D/A interface recession, would result in a severe deterioration of charge dissociation or transfer as well as an inadequate lifespan for OSCs. This would be the case because the D/A interface recession and/or the aggregation are both examples of transitions. Because the D/A interface recession and/or the aggregation are both examples of transitions, this may be the case. For example, Martorell and McGehee discovered that exposure to UV radiation produced disordering in the D and A domains, whereas the Brabec group34 discovered that the fundamental mechanism responsible for a loss in lifespan was caused by a lack of miscibility between the D and A domains. Both of these groups came to this conclusion independently of one another. 2004 was the year that saw the completion of each of these studies' respective study projects. In addition, Lidzey proved that it is possible to accelerate the device's deterioration by the utilization of thermal annealing at temperatures higher than the temperature at which the photoactive layers' glass transition occurs. This was accomplished by heating the device to a higher temperature than the temperature at which the glass transition happens. As a direct result of this, the development of efficient techniques to generate stable ideal BHJ morphology and, as a direct result of this, to enhance the device's stability, is an essential requirement. As a consequence of this, the development of effective methods to produce stable ideal BHJ morphology and, as a direct result of this, to raise thet.

Development

SOLAR-CELL

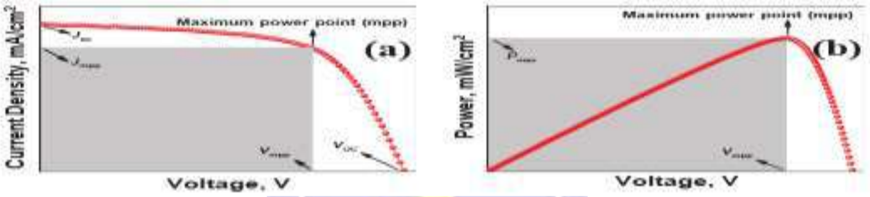
When treated to hard circumstances, their all-polymer BHJ blends, on the other hand, were hampered by thermodynamically unfavorable miscibility and large-scale phase separation 46. To this purpose, a few studies have indicated that the stability difficulties might be resolved by utilizing well-tailored dual functional single-component photovoltaic materials. This was done in order to achieve the aforementioned goal. These materials are characterized by the presence of two or more D and A components that are covalently bound in a single material. Examples of these materials include molecular dyads, conjugated block copolymers consisting of D and A as blocks, and double-cable type polymers. The D and A components of these materials are laid out in a block format throughout. The formation of phase-separated domains with the necessary length scales that are thermodynamically stable is possible with these materials thanks to their unique properties.

In this respect, block copolymers are regarded to be one of the most promising alternatives as the PCEs of their related OSCs have been growing at an alarming rate. In this regard, block copolymers are thought to be one of the most promising alternatives. However, the free volumes in the block copolymer networks will lead to the chain segment motion49, which will make it difficult to overcome the trade-off between initial solar performance and long-term operating stability for OSCs. This motion will make it difficult to overcome the trade-off between initial photovoltaic performance and long-term operating stability. This is due to the fact that the chain segment motion will be caused by the free volumes. Even more importantly, single-component photovoltaic materials are afflicted by tough synthetic challenges or intricate purification procedures. Both of these issues are quite important.

The integration of additional electron-deficient building blocks, also known as a units, into the polymer backbones enabled OSCs produced from S11 to give a substantially greater performance, with an ideal PCE nearing 12%. This was made possible by the incorporation of more electron-deficient building blocks into the polymer backbones. This is in contrast to its equivalent S9, which had a dominating structure that was of the typical block polymer type d1-a1-d2-a2 as its predominant structure. In parallel with this, the devices that were based on S11 demonstrated much superior light and thermal stabilities (maintaining > 80% of their original PCEs after more than 1000 h) in comparison to the devices that were based on single-component and two-component photoactive layers, respectively. We have a working hypothesis that suggests that the block copolymer interlaced networks with backbone entanglements permitted by block polymer PM6-b-L15 were formed in the S11 multicomponent system as a consequence of the painstaking analysis of the opto-electrical and morphological aspects. Block polymer PM6-b-L15 was utilized in order to accomplish this goal successfully. Because of the minimal amount of PM6 and L15 polymers present in the S11 matrix, the nanovoids of the interlaced nanostructures will be filled in, which will inhibit the chain motion of block copolymers. During this period of time, the networks that are being generated by PM6-b-L15 blocks have the ability to minimize the excessive aggregates of PM6 and L15 polymers that are present in the multi-component system. As a result of this, the favorable frozen film shape of the networks, which enables well-balanced charge transfer, makes it feasible to achieve high device performance while also increasing the lifetime of the OSCs. This is because the shape permits well-balanced charge transfer. As a consequence of this, the work that is being discussed here gives a feasible synthetic approach using one-pot polymerization for the synthesis of the multicomponent photoactive layers in the OSCs. These layers have both excellent device efficiency and operational stability, which is essential for their use.

J-V Characterization

The performance of a typical solar cell device is first assessed in the presence of illumination (AM 1.5G, 1Sun) by the exploitation of the current density-voltage (J-V) measurement, which enables the PCE19 to be determined. This evaluation takes place in the presence of a single sun. The current density is recorded by linearly sweeping the voltage across the electrodes in order to generate the J-V curve that can be seen in Figure 1.1a. This is done in order to acquire the J-V curve. The graph is the result of this. The voltage can be swept in either the forward direction (from a state of open circuit to a condition of short circuit) or the reverse direction (from a condition of short circuit to a condition of open circuit) depending on whatever direction is desired. Estimation of the following parameters is made possible by the use of the J-V curve:



Generations of Solar Cell

It is possible to distinguishably divide the development of solar technology into four separate generations (Figure 1.3). The advancement of this field took place over the period of several decades. Wafers of crystalline silicon measuring hundreds of micrometers in thickness were the principal substrate for solar cells during the first generation of these devices. These wafers were used as the primary substrate for solar cells. In order to manufacture these solar cells, a process known as diffusion is performed on wafers of crystalline silicon. Crystalline silicon has made it possible to achieve a power conversion efficiency (PCE) that is 27.6 percent higher in single junction devices and 47.1 percent higher in four junction devices. At the moment, solar cells built from silicon wafers hold the majority of the market share and are the product that has the economic upper hand in the field of terrestrial sun cells. The reason for such a powerful grip is the prolonged payback duration, which can run anywhere from 25 to 30 years. The production of solar-grade silicon wafer is a process that is not only very costly but also takes a large amount of time and consumes a significant quantity of energy. Despite the fact that this solar cell technology is the most economically practical of its kind, there is still a problem. In addition, the solar modules were heavier than they might have been due of the thickness of the wafers, which prevented their employment in applications that took place in space. In addition to this, the amount of waste that they generate is on the order of hundreds of tons of metric weight, and it is continuously increasing year by year..

ORGANIC SOLAR CELL (OSC)

These third-generation solar cells have an additional layer that serves as the light-absorbing photo-active layer. This layer is composed of organic semiconductors, which can be polymers or tiny molecules. OSCs are a type of solar cell that were developed in the third generation. In general, the organic molecules associated with the production of OSC may be easily synthesized at very low prices, and there is a large variety of materials to choose from. This is because OSC can be manufactured from a variety of substances. This is due to the fact that OSC may be produced using a wide number of different components. The majority of the time, the solution-processing method is used in the production of OSCs. Because of this, the product creation process is made even more efficient, which is especially helpful for large numbers and expansive locations. Solar cells of this sort may be manufactured on flexible substrates, which results in a considerable reduction in their overall weight when compared to their silicon-based counterparts. Since the materials that are used in inorganic solar cells can be easily disposed of, it is highly possible that widespread commercialization of inorganic solar cells would result in a reduction in the pollution that is caused by the use of inorganic solar cells. This would be a positive development for the environment.

In OSCs, the active layer can be made up of either a donor material (of the p-type) or an acceptor material (of the n-type), or both, in a wide number of different combinations. It is also possible for the active layer to be made up of both types of materials. A single layer organic semiconductor capacitor, also known as an OSC, is constructed using an organic semiconductor that is positioned between two contacts, one of which possesses a higher work function than the other contact, while the other contact possesses a work function that is somewhat lower. These two contacts, working in tandem, provide the built-in potential that enables photo-generated charges to rapidly diffuse and be collected at the electrodes. This potential is provided by the fact that these two contacts function in tandem. Recombination of photo-generated excitons, which are confined holes and electrons, is a challenge for the single layer OSC due to the fact that it only has one layer. Due to the fact that these excitons have a relatively short diffusion length, the charges have the opportunity to recombine before they reach the electrode. Single-layer organic semiconductor capacitors (OSCs) are capable of producing exceptionally low PCEs of 1% or less by virtue of the fact that the inherent potential is inadequate to attract the charges in the direction of the electrodes.49, 50 In order to remedy this deficiency, manufacturers began producing bilayer OSCs, which are also referred to as planar heterojunction OSCs. These OSCs were built with two layers: a donor layer and an acceptor layer, which were positioned between two electrodes and sandwiched between the electrodes. An electrostatic force was able to be produced at the interface between the donor material and the acceptor material as a result of the lower electron affinity of the donor material and the greater ionization energy of the acceptor material, respectively. The photo-generated excitons that are found in close proximity to the interface are able to be segregated from one another and collected at the electrodes in a very straightforward manner. The fact that the excitons that were formed away from the interface still recombined was the flaw in this system's design, and it caused a loss in the photovoltaic devices as a consequence. As a direct consequence of this, the thickness of each layer began to play a part in the process of producing planar heterojunction devices that was of an exceedingly major significance. The PCE was limited in bilayer OSCs at the beginning; however, as new donor and acceptor materials have been created, the PCE has grown to be greater than 14%.51-53 As a solution to the problems caused by these two different kinds of junctions, bulk heterojunction (BHJ) OSCs were created. Before being employed to cover the active layer in these organic solar cells (OSCs), the donor and acceptor materials are mixed together in a solution at a ratio that has previously been determined.54-56 This method was used to create in the film a nanoscale domain consisting of the donor and acceptor components. Due to the fact that this made it feasible for the excitons to immediately divide at each contact, the quantity of loss that occurred was significantly reduced. It has been demonstrated that it is feasible to get PCEs of more than 18% when using the most frequent type of junction, which is the BHJ.

Engineering Organic Solar Cells

Since the discovery of conducting polymers in 1977, the field of organic solar cells has demonstrated the capacity to lower the cost of photovoltaic technology as well as the amount of trash generated by inorganic solar panels. OSCs are able to be manufactured using a solution-processable approach at a cheap cost, and they are also able to be readily incorporated into flexible substrates. One further significant benefit offered by OSC is a short payback lifespan. Because to careful engineering of materials and devices, the power conversion efficiency (PCE) now exceeds 18%. Changing the proportion of donor material to acceptor material in the mix solution used to deposit the BHJ active layer is the method that is utilized most frequently when attempting to improve the performance of an OSC device. By varying the proportion of donor to acceptor materials, one may achieve the optimal domain size on the nanoscale for the diffusion and transport of photo-generated charges in a smooth manner.63, 64 Fabricating a ternary OSC by adding a third component (either a donor or an acceptor) that has complementary absorption not only enhances the performance of the device but also allows the morphology of the active layer to be tuned to a more optimal state.

If it is necessary, further annealing of the active layer is performed in order to remove any surplus solvent from the film. Another method that has enhanced the morphology of the active layer even more and boosted the solar cell's power conversion efficiency is called solvent vapor annealing. It has also been noted that annealing can sometimes result in degradation of the active layer, which in turn leads to a reduction in the performance of the device. In these kinds of situations, the annealing method is substituted with a treatment of the active layer that is carried out in a high vacuum in order to remove excess solvent from the film.6It has also been necessary to make adjustments to the transport materials in order to locate an appropriate band alignment that would allow for the seamless collection of charges at the electrodes.69 In addition, the pollution and health problems caused by halogenated solvents have been mitigated as a result of the processing of blend solutions with a variety of environmentally friendly solvents. It has also been accomplished to produce the ideal nanoscale shape of the active layer processed using environmentally friendly solvents, and the performance of the solar cell device has not been impaired in any way. The use of additives has been shown to modify the morphology of the solar cells, and a tiny fraction of these additions have also enhanced and stabilized the performance of the solar cells.

Because annealing may sometimes slow down the charge transport process by messing with the morphology, researchers have experimented with a variety of alternative methodologies in an effort to boost device performance, particularly in PTB7 and PTB7-Th based OSCs. As was said before, this is because annealing can sometimes hinder the morphology. Cooling a hot ink approach is one way that is highly successful. In this procedure, the blend solution is heated to ensure that the donor and acceptor are adequately mixed, and then the solution is cooled to a lower temperature before coating at ambient temperature. The annealing treatment resulted in an improvement in the PCE of the device as compared to its previous state. A second method is the hot-casting technique, which involves coating the mixture on a substrate that has already been heated. This method does not require additional annealing for the removal of surplus solvent in order to obtain PCE levels of more than 9%. Changing the temperature at which the casting was done allowed for the modulation of the material's thickness as well as its shape. It has also been noticed that annealing the active layer after hot-casting the device may also result in a minor improvement in the performance of the device.

Tandem Organic Solar Cells

As was mentioned earlier, the spectral range that may be spanned by the topologies of organic solar cells is limited. This limitation is due to the fact that organic sun cells are not photovoltaic. When it comes to light absorption, certain organic cells are able to do so in the region of short wavelengths, while others are able to do so in the region of long wavelengths. Solar cell structures should be constructed in such a way that they can collect energy from as much of the sun's spectrum as is physically possible, with a particular emphasis on the wavelength range of 400–900 nm. This is the most important region for solar cells to collect energy from. Because of this, we will be able to take in the most quantity of sunshine possible. A major portion of this wavelength range may be created with the highest level of efficiency by employing a tandem design that is comparable to the one that is seen in Figure 8a. Organic tandem solar cells are constructed from two subcells that are kept physically distinct from one another by an interlayer. Expanding the number of subcells in a design like this one has the potential to extend the spectrum of light that is absorbed; however, doing so would raise both the complexity and the cost of the fabrication process. Each subcell was developed with the express purpose of operating in a particular region of the electromagnetic spectrum emitted by the sun. Figure 8b provides an explanation of the fundamental concept that supports the tandem cell, in which the front cell (PV1) is responsible for carrying out its functions within the wavelength range of 300–600 nm and the back cell (PV2) absorbs between 450 and 750 nm. Because they were based on multilayer manufacturing processes, the early attempts to build tandem cells did not achieve the expected rise in PCE. This was because of the nature of the manufacturing techniques. This is due to the fact that the two subcells were layered on top of each other without a buffer layer being placed in between them. The lowest current that can be produced by any one of the subcells places a ceiling on the maximum current that can be extracted from these multilayer devices. This ceiling limits the maximum current that can be extracted. Due to the fact that each subcell functions independently, this is the situation.

When an interlayer is placed in between two subcells, it makes it much simpler to collect all of the photocurrent that is produced by both of the subcells. In relation to this architecture, results have been acquired over the course of the previous few years that are extremely encouraging in their scope and potential. Combining a poly[2-methoxy-5-(20-ethyl-hexyloxy)-1,4-phenylene vinylene] (MEH-PPV):PCBM subcell with a P3HT:PCBM subcell and using TiOx as the buffer layer allowed for the production of 6% polychlorinated biphenyls (PCE). Work on tandem devices has revealed PCEs greater than 7%, and more recently, an 8.6% PCE has been attained by Yang's group (Dou et al. 2012), which moves OPVs closer to the 10% efficiency milestone than they were previously.

Plasmonics in Organic Solar Cells

Because the exciton diffusion length in organic solar cells is between 10 and 40 nm, the active layer needs to be relatively ultra-thin in order to be effective. It is important that the thicknesses be in the order of the absorption length of the materials that are used as the active layer. Even though a relatively high PCE calls for a high absorption efficiency, this will not be the case since the absorption efficiency will not be high enough due to the reason stated above. It is possible to increase the amount of incident light that is absorbed by the active layer without increasing its thickness by making use of plasmonic materials and structures, which are capable of entrapping light inside the active layer. This may be accomplished by increasing the amount of incident light that is absorbed by the active layer. By utilizing this strategy, it is feasible to increase the possibility of photon absorption in even the extremely thin layers being considered.

CONCLUSION

PCE based working in never stoppable and development in this field is high and conclude that it never be finalized as end.

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