Comparison of the practicality of organic solar cells of different materials

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Abstract. In today's world of rapid technological development, huge resource consumption and environmental protection are becoming major issues for human survival. It is generally believed that mankind needs more efficient and environmentally friendly ways of generating energy. Among the many ways to generate electricity, solar power is a very environmentally friendly and resourceful way to generate electricity as by converting a very small amount of solar energy received on earth into electrical energy, we can obtain a considerable amount of electric energy. Among the many materials used to produce solar cells, organic materials are the most popular research subject because of their low price, abundance, and bendability. Among the many materials used in solar cells, organic materials have received attentions because of their low price, abundance and excellent properties such as bendability, non-toxicity, and degradability. As one of the most popular power generation methods, numerous scientists have tried to commercialize it, but there are still some problems that prevent them from doing so, such as the lack of stability of organic materials. This article will collect information on various organic solar cell materials and compare them, trying to find the one with the most commercial potential or feasibility.

Keywords: Organic solar cells (OSC), practicality of OSC, future perspective of OSC.

1. Introduction

The solar cell, also known as the photovoltaic (PV) system, is the equipment used to convert sunlight energy to electricity. It is mainly composed of two semiconductor silicon layers, the n-type layer, and the p-type layer. Two electrodes are installed on the respectively two layers connected with a wire and finally, covered by an anti-reflective coating. It works in the following ways:

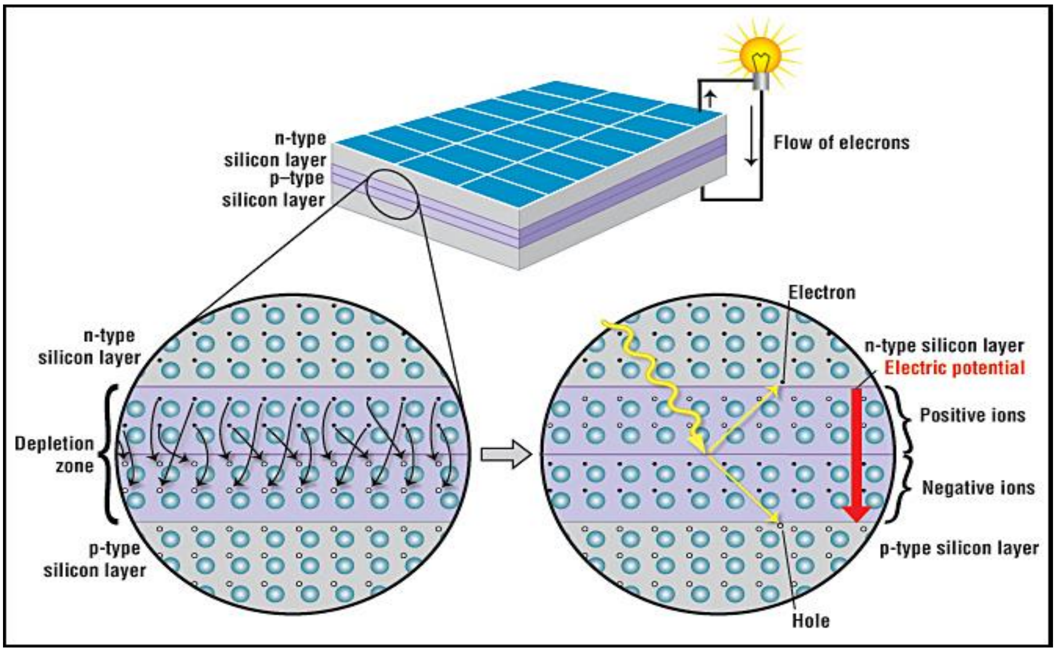

Figure 1. Schematic diagram of working principle of organic solar cell [1]

When the solar cell doesn't receive any sunlight, the n-type layer is filled with negatively charged particles with electrons while the p-type layer is dominant with positively charged particles (Fig 1). Electrons will move from the n-type layer to the p-type layer at their interface area, creating an area that is oppositely charged compared to its other part named depletion zone. The purpose of the zone is to maintain the balanced electric field within the solar cell, preventing electrons from filling the holes in the p-type layer. When the sunlight is absorbed by a PV system, the electrons will be activated by photons and move to the n-type layer side. As the electrons all move to one side, the balance is undermined, thus forming potential differences across the wire that attaches to the two electrodes. This article aims to make a comparison of the practicality of organometallics photovoltaic systems (OPV) from the aspects of commercial and technological advancement.

2. Organic solar cell materials

2.1. Small molecule materials

Starting with small molecule materials, which have characteristics of the followings. First, they have well-defined structures with no dependence on molecular weight. Second, they are low-weighted, easy to process, and low-cost, meaning a considerable potential for manufacturing. Third, their organized nanostructures bring better mobilities for higher charge carriers. Three typical small molecule materials will be included in the comparisons: phthalocyanine, porphyrin, and perylene [2].

Phthalocyanine (PLC) is a typical material used to produce small molecule solar cells. PLC PV has advantages as the following: 1.) Relative wider spectral range of 600-800nm. 2.) Better hole mobility. 3.) longer exciton diffusion lengths. These characteristics make PLC one of the most noticed directions of research and development. For the past decade, a considerable amount of research has been done to improve the efficiency of for its development and technological practicality. In 2016, Li et. al. discovered that building the PLC PV with polyoxometalate-modified TiO_2 photoanode is able to boost its PCE effectively. It can be explained by the increase in the reduced charge recombination and electron transport in the cell [3].

In 2020, Ghadaria and colleagues conducted extensive scientific experiments and found that adding 1.09949681 carbon dots to solar cells could greatly increase their PCE by 3-4%. Quantum dots (QDs) have been developed as light collectors in photosensitive solar cells owing to their special optical and electronic characteristics. Compared with the traditional quantum dots, carbon quantum dots have the advantages of high efficiency, high durability, and great stock in nature. On the other hand, the economic feasibility of PLC PV is porphyrin (PPR), another typical small molecule material used in the construction of PV system, has the following advantages: porphyrin sensitizer has strong absorption in the visible light region, it has a large number of reaction sites for structural modification, and its manufacture is relatively cheap. Similar to PLC, PPR is a PV material used to better absorb sunlight in the far-infrared spectral region. PPR is growing fast and its PCE is approaching that of conventional PV systems, reaching 11% in 2010. This PCE was achieved by co-sensitizing SONY nail dye N749 with Indoline organic dye D131. In 2021, Fang et al. Al. Nip-doped PSCs were designed with an efficiency of 22.1% for an effective area of 1.0 cm^2, and the improved open-circuit voltage and fill factor could be observed. By doping monoamine porphyrin into perovskite films, MPs self-assembles into supramolecules at grain boundaries [4].

Perylene has a strong ability to absorb visible light, and a large number of existing papers have shown that Perylene-based materials, such as Perylene diimide (PDI), which has high electron mobility, have significant advantages in the manufacture of solar cells. They show good photostability, thermal stability and chemical stability, and are easy to be chemically modified. Compared with PDI, PMI lags far behind diimines in organic solar cell applications due to its poor solubility and difficulty in synthesis and modification. Back in 2009, Foster et al. found that polyisocyanide and poly (3-hexylthiophene) (P3HT) nominal (1:1) blend weight ratio of the prototype structure poly (9,9 "-dioctylsolane-co-bis (N, N'(4-butylphenyl)) -bis (N, N' -phenyl)-1, 4-phenylenediamine) (PFB) can effectively improve the efficiency. Another study discussed how to solve this problem with the agglomerated PDI molecules, which hinders the transport of electrons and ultimately leads to the reduction of PCE. The researchers found some ways to overcome this problem. The most efficient way to do this is to control the the Π–Π stacking of molecules and maintain adequate level overlap for better electron transport. It is also effective to reduce the flatness of the molecule by introducing bridging groups [5].

2.2. Polymer materials

photoactive materials containing donor-acceptor (D-A) copolymer donors is typical kinds of organic solar cells (OSCs). It is well known that D-A copolymers have complex molecular structures and complicated synthesis processes, which bring serious cost problems and poor scalability to the large-scale application. Therefore, in order to develop its practicability, attention should focus on modify the polymer doners through engineering their chemical structures.

Polythiophene (PT) should be one of the simplest polymer donors, and in the past two years, some breakthroughs have been made in OSCs based on it. This paper briefly introduces the recent progress of OSCs based on PT derivatives as affordable polymers. The level regulation, preaggregation effect, and D/A hybrid OSCs have had good prospects in the past [6].

Polyp-styrene (PPV) has been extensively used in optical applications as well as promising materials for OSC. Inchoate studies of PPV focused on the doped materials, while the results are no as well as expected. However, people have again paid attention to PPV materials when friends and colleagues of Cam-Bridge discovered in 1990 that thin films undoped with PPV could serve as emission layers for organic electroluminescence (EL) devices (2). Since the solvent can significantly affect the Kerr effect of polymer solutions, it is important to obtain the exact value of the solvent Kerr constant. The electric dipole moment, vector, tensor and optical anisotropy are the most convenient and sensitive parameters to study the conformational dependence of polymer chains [7]. Therefore, the electro-optic Kerr constant is a commonly used parameter to study the conformational properties of small molecules and polymers in solution, and is related to polarity and polarizability (optical and electrical). In our earlier paper, it was shown that the permittivity and dipole moment of stereopoly (N-vinyl carbazole) (PVK) in solution are significantly affected by the polymer synthesis process. The earlier studies of Beevers and Mumby on the electro-optical properties of stereopoly PVK were confirmed. Because Molkel's constant often depends sensitively on the relative distribution of molecules which is determined by Proton NMR.

3. Comparisons between these types of organic solar cells

For the small molecule compounds, the class one compounds are the most valued and well-studied organic materials. In contrast, the advantages of class two compounds are that they have very good photothermal stability and are very easy to form complexes with their metal factors due to their chemical properties. The third category belongs to semiconductor materials, with high absorption efficiency for visible light, strong photoconductivity, and high solubility, but their stability is lower than other small molecule materials.

Regarding the big molecule compounds, polythiophene compounds have high photochemical stability matching the solar spectrum, so they are widely used. Especially after the 1980s, it developed rapidly. In addition, poly-p-styrene has very good optoelectronic properties, and now the main focus is on its synthesis and modification. And polyvinyl carbazole is easy to crystallize and is an insulator in the dark, and its conductivity can be greatly improved under ultraviolet irradiation. Its photon yield is more dependent on the device and the strength of the electric field.

In the aspect of technological performance and development, most advanced research has shown that the efficiency of non-fullerene electron acceptorsinorganometallic photovoltaic (OPV) cellsisable to reach over 18%. However, such decent performance is proved can't be achieved when manufacturing [8].

In 2020, Riede and coworkers have proposed that organic solar cells will likely be the cheapest way of getting electricity, even cheaper than traditional silicon PV. Although silicon PV is still dominating the market with more than 95% market share, OPV has more potential for its material, carbon-based semiconductor. Production of OPV consumes a relatively small amount of carbon-based semiconductor (1g per m2) which is cheap, abundant, and non-toxic. The manufacturing technologies used, mainly vacuum coating and solution treatment, enable low-cost and rapid large-area coating. Additionally, the environmental benefits brought by OPV could result in saving more capital which could have been used to deal with pollution caused by generating electricity [9].

As one of the major issues, the lifespan of OPV is solved by a group of scientists as well. They succeeded in prolonging that of OPV to over 10 years, which is sufficient for commercial use. In conclusion, OPV is considered the electricity generator with the most potential in the future, but its stability is impeding its commercialization.

In 1958, Kearns and Calvin prepared the first organic photoelectricity between two electrodes with different work functions. On this device, they observed a voltage of 200MV, higher than the voltage of a silicon-based solar cell. Little progress was made for more than 20 years until 1986, when the industry reached a milestone. Deng et al. of Keda Company used two organic semiconductor materials to simulate inorganic heterogeneous solar cells, and the photoelectric conversion efficiency reached 1%. Until now, the double layer heterojunction structure is still the focus of organic solar cell research. At present, this structure still maintains the highest conversion efficiency of organic solar cells. The organic optoelectronic Materials and Devices team led by GE and colleagues has made new progress in the field of all-small molecule organic solar cells. This study is the first to apply end-group asymmetry. Alternative strategies for small molecule donor materials. Sm-ca, SM-REH, SM-CA-REH, SM-ID and SM-CA-ID donor materials have been designed and synthesized by combining the end groups of cyanoacetate (CA), rhodamine (Reh) and SM-ID with different electron absorbing abilities. When mixed with the small molecule receptor N3, the SM-CA-REH: N3-based device combines the characteristics of SM-CA: N3 high fill factor and SM-REH: N3 high current, and the final device efficiency is significantly improved from 15.41% (SM-CA: N3) to 16.34%. [10]

4. Conclusion

In the long run, OPV has a great potential to replace crystalline silicon PV as one of the main tools for future power generation due to its low cost, flexibility, low weight, and transparency. Small molecule organic photovoltaic sensitizers, phthalocyanine and porphyrins, are two of the most encouraging materials for organic PV applications for their strong absorption of light in parts of the spectrum. In view of their shortcomings, such as poor electron transport, scientists have found relatively sound strategies to improve them. With the advancement of these specialized researches, these two materials have been better used in photovoltaic manufacturing. Organic photovoltaics of macromolecular materials such as polythiophene and polystyrene also have a decent prospect, and their disadvantages can be effectively overcome by incorporating other materials or improving methods. Finally, although organic photovoltaic technology is maturing, we still have a long way to go, and hope that our paper will help more researchers and contribute to the commercialization of organic photovoltaic.

References

[1] ACS chemistry of life. How a Solar Cell Works. December 6, 2021. Retrieved on September 7, 2022. Retrieved from: https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/past-issues/archive-2013-2014/how-a-solar-cell-works.html.

[2] Abby-Jo Payne, Gregory C. Welch, Development of Small Molecule Donors for Solution-Processed Organic Solar Cells. Retrieved on September 7, 2022. Retrieved from: https://www.sigmaaldrich.com/US/en/technical-documents/technical-article/materials-science-and-engineering/organic-electronics/development-of-small-molecule-donors.

[3] Li N, Sun Z, Liu R, et al. Enhanced power conversion efficiency in phthalocyanine-sensitized solar cells by modifying TiO2 photoanode with polyoxometalate. Solar Energy Materials and Solar Cells, 2016, 157: 853 - 860.

[4] Ghadari R, Saei P S, Sabri A, et al. Enhanced phthalocyanine-sensitized solar cell efficiency via cooperation of nitrogen-doped carbon dots. Journal of Cleaner Production, 2020, 268: 122236.

[5] Cao J, Yang S. Progress in perylene diimides for organic solar cell applications. RSC advances, 2022, 12 (12): 6966 - 6973.

[6] Yang C, Zhang S, Hou J. Low-cost and efficient organic solar cells based on polythiophene-and poly (thiophene vinylene)-related donors: Photovoltaics: Special Issue Dedicated to Professor Yongfang Li. Aggregate, 2022, 3 (3): e111.

[7] Zhang M, Guo X, Ma W, et al. A polythiophene derivative with superior properties for practical application in polymer solar cells. Advanced Materials, 2014, 26 (33): 5880 - 5885.

[8] Cui Y, Yao H, Hong L, et al. Organic photovoltaic cell with 17% efficiency and superior processability. National Science Review, 2020, 7 (7): 1239 - 1246.

[9] RiedeM,SpoltoreD, Leo K. Organic solar cells—the path to commercial success[J]. Advanced Energy Materials, 2021, 11(1): 2002653.

[10] Zhang Y, Wu B, He Y, et al. Layer-by-layer processed binary all-polymer solar cells with efficiency over 16% enabled by finely optimized morphology. Nano Energy, 2022, 93: 106858.