

Applications of Polymers in Perovskite Solar Cells: A Review

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Abstract

Emerging technology and recent research activity help perovskite solar cells to cross with a notable 22% efficiency. Rapid research and development in organic photovoltaics (OPVs) and light-emitting diodes (OLEDs) leads to optimize the efficiency further. Device efficiency and stability largely depend on components and the device structure of the solar cell. The aim of this report is to review the different strategies employed polymer as an electron transport material (ETM), hole transporting material (HTM) or as a templating agent to enhance the performance, stability, and durability of the perovskite solar cell.

Keywords: Perovskite; Polymers; Solar cells; Efficiency

Introduction

Modern technology has a growing interest in the application of polymer as a flexible substrate in Dye-sensitized solar cells (DSSC), film-forming agents of the working electrode, platinum-free counter electrodes, and semi solid-state electrolyte. Uses of polymer in perovskite material lead to crystallization processes and work as an additive to adjust the nucleation. These polymers are generally used as an electron transfer material, hole transfer material or interface layer and work like to reduce the recombination rate and improves the separation efficiency of the charge carriers [1]. Polymers are often used as buffer layers or donor layers in inorganic solar cells. Some polymer nanostructured are used to enhance device performance [2,3]. Some low bandgap polymer materials are used as a hole transporting material in perovskite solar cells (PSC) to optimize efficiency as well as prevent cell degradation. Researchers are using a polymer-perovskite composite material to fabricate hybrid structures that are widely used in perovskite-based light-emitting diode (LED). Polymers encapsulated perovskite solar cell has a comparative longer lifetime and less degradation of materials than without encapsulation [4]. The light absorption of Perovskite layer is less impacted by the polymer coating. Though polymers have a lot of advantages for uses in perovskite solar cell some issues like thermal stability in high temperature, water permeability through polymer layer and adhesive property of thin layer is challenging and lot of research work is going on to address the challenges [5]. Recent trends of polymers application in perovskite-based solar cells and its achievements are reviewed and discussed in this article. Moreover, the practical challenges of polymer layered perovskite solar cell and implementation techniques are addressed.

Different Applications of Polymer on Perovskite Solar Cells

- A. Polymer-based photovoltaic technology like Dye-sensitized solar cells (DSSC), perovskite solar cell (PSC), Organic Photovoltaic Solar Cells (OPV) are the key interest nowadays. In DSSC polymers work like a film-forming agent of photoanode and best suitable for the flexible substrate. The platinum-free counter electrode can be fabricated by conductive polymers as Conductive polymers exhibit high catalytic activity which can be ideal for perovskite solar cells [6]. Polymers are widely used in DSSC as a semi solid-state electrolyte.
- B. Polymers are widely used in PSC as it facilitates the nucleation process which regulates the crystallization of perovskite films and enhances cell performance and

stability. Polymers are often chosen as a hole transport material due to significant high hole mobility [7].

C. Light-harvesting efficiency and performances of devices are largely influenced by the polymer addition in OPV. Improvement of the efficiency of the OPV is possible by tuning with a novel polymer having narrow bandgap and appropriate energy level alignment [8]. Besides this, the application of polymer is well promising for the tandem OPV fabricated with a tunable spectrum absorption range.

D. Various OPV and Organic Light-Emitting Diodes (OLED) research facilitates in the perovskite research area and helped by adding polymers which were already been used in OPV or OLED. Previous researches have helped a lot in developing perovskite device as polymers provide a various solution like providing quality charge transport and absorber [9].

E. Despite having high-efficiency perovskite solar modules are still not commercialized. Instability is one of the major drawbacks. With more than 2 decades OPV cells have witnessed lots of improvements and evolution. Operational feasibility and environmental stability were thoroughly studied, however, PSC has very little statistical data to study and worked on. To overcome the instability problem, polymers could serve as a templating agent, acts as a barrier and resist the cell from moisture [10].

F. Heterojunction layer of P3HT: PCBM (poly(3-hexylthiophene): [6,6]-phenyl C61-butyric acid methyl ester) works as a control scheme for the past few years due to its predictable performance and characteristics in OPV. Adding polymers to lead-based halide perovskite leads to increase chemical stability; however, their stability mechanism is poorly understood especially for hybrid materials. Several perovskite hybrid models for solar cells have been compared for stability enhancement, structural and spectroscopic analysis and it was found that perovskite crystallite sizes decrease with the addition of polymers (polyethylene glycol, polyethyleneimine, poly(acrylic acid) and polyvinylpyrrolidone) [11].

Some Polymers used in Recent Research in Perovskite Solar Cell

Polyanilines (PANI)

PANI has high conductivity and used as a hole transporting material. PANI nanoparticles have between 20-60nm of size and can be produced via polymerization [12]. PANI increases the light absorption property of the perovskite layer by improving the surface of perovskite thin film introducing the nanoparticles into a thin film. Conductive hole transport material in OLED is layered with PANI.

Polytriarylamines (PTAAs)

An exceptional electron blocking capabilities and low ionization is the key importance for choosing PTAA as a hole transport material in perovskite and OLED research. Amorphous materials have low hole mobility and PTAA has high void space. The crystal

structure of PTAA can be improved by introducing planar moieties to transform it into more crystalline HTM material [13]. Hole mobility of the material can be enhanced by suitable doping with cobalt compounds. PTAA containing Hydrophobic alkyl chain has a higher tendency to show hysteresis rather than hydrophilic ones.

Polyfluorenes (PFO)

Polyfluorenes and polyfluorene doped products are used as hole-transporting materials due to efficient hole extraction in perovskite solar cells. Only PFO has low oxidation potential and low valence band compared to perovskite. Suitable doping and structure change is possible by introducing an electron-rich triarylamine monomer that improves the valence band of the perovskite [14]. After structure modification, it works better than polyfluorenes and better than spiro-OMeTAD in terms of hole extraction ability.

Carbazole

Due to desired electrical and tunable optical properties conjugated polymer based on Carbazole are now being used in perovskite-based solar cells. As an ideal hole transport material Carbazole based polymers are suitable in perovskite solar cells [15]. By copolymerization process with 3,4-ethylene di-oxythiophene (EDOT), the newly formed compound has more electron-donating ability. 2,7-Cbz-EDOT and 3,6-Cbz-EDOT are the most popular among carbazole based material which is used as a hole transport material in perovskite solar cells.

Polymer-based on sulfur-selenium materials

Recent research reveals that sulfur-selenium material-based polymer can be used in perovskite solar cells as a hole transport layer. Photoluminescence property and photoinduced absorption quality are ideal for transfer quality charges. Sulphur-selenium based polymeric material used in perovskite solar cell has achieved 10.21% efficiency [16]. The conductivity of this material is relatively good than other many polymeric materials. By introducing selenium material in the polymeric sulfur, it reduces the optical bandgap of the polymer. Selenium doped sulfur polymer has an impact on photoluminescence property of thin-film perovskite.

Low Band Gap Polymers Application in Perovskite Solar Cell

Low bandgap polymers are introduced in OPV as well as perovskite solar cells to improve the absorption of infrared or near-infrared region wavelengths of light [17]. Generally, lower bandgap polymer has higher hole transfer mobility than other HTM. Different variables like processing time, temperature, additives used has a high impact on the bandgap of the polymers. Low bandgap polymer HTM like, PCBTDP, PCDTBT or PCPDTBT has been tested by researchers but any significant improvement was not found from their observation and all these materials are belongs to thiophene based polymers [18]. PTB7 similar type thiophene based polymer works like hole transporting material has reported decent improvement in power output in perovskite solar cell. PTB7 has higher hole mobility than P3HT and even widely used spiro-OMeTAD [19]. PTB-DCB21 polymer has a dichlorobenzene

functional group exhibit higher power conversion efficiency [19]. It works as a bridge between perovskite and HTM layer. Lower the recombination rates and faster the electron transfer leads to higher efficiency.

A Polymer-perovskite Composite Material in Hybrid Perovskite Devices

The polymer-perovskite composite used in making perovskite-based LED is termed as heterostructure. This structure is a combination of perovskite components layered with an insulating polymer. Perovskite structure is made with 2D and 3D components. Charge carriers move from 2D to 3D regions and in the 3D regions charges are separated out that lead to recombination and light emission from the perovskite-based LED [20]. The perovskite material and polymers blend most prevent the charge carriers from recombination and prevent the device from non-emissive losses. This hybrid perovskite structure with LED when first developed was facing losses charge carriers from the perovskite layer due to the micro defects in the perovskite crystal structure which leads to lowering their light-emitting efficiency [21,22]. After a lot of development and research by adding polymer with the perovskite material it is now possible to transfer charge faster from 2D to 3D regions and charge extraction from 3D regions in an efficient way.

How Polymers Improve Perovskite Solar Cell Performance?

Solution processing followed by the heating method introduced defects at grain boundaries of the perovskite thin-film layer. A suitable number of additives adding not only changes the surface morphology of thin film but also increases the stability of the perovskite material in challenging ambient conditions. Suitable tuning in grain boundary morphology helps to improve the optoelectronic property of the solar cell as well as increases the stability of the cell [23]. When polymer additives (some specific polymer) are added to the perovskite material, polymer and perovskite molecules form a cross-linked polymer chain like substance. These cross-link's materials help the perovskite material to become more stable in humid ambience and protect from electrical decoupling between two adjacent grains [24].

Adding surfactants having a smaller molecule has a significant impact on the power conversion efficiency of the perovskite solar cell in solution processing methods. It was observed that suitable polymer addition with perovskite changes the carrier dynamics and the surface morphology. Recent research reveals that using 4-vinyl pyridine (PVP) with Methylammonium lead iodide (MAPbI₃) has a large improvement in the open-circuit voltage of the fabricated solar cell, consequently, the cell's performance-enhanced significantly [25]. PVP not only enhances the power output but also addressed the degradation issue of the cell. Perovskite solar cells coated with a thin-film plasma polymer layer become more stable in humid conditions. This encapsulation helps the cell to prevent degradation under moisture and humid weather. This thin-film polymer is deposited on the perovskite layer by the plasma vacuum deposition method and performed at room temperature [26]. The

absorbance quality of the perovskite layer does not have an impact after polymer film deposition and very less impact on power conversion efficiency.

Some Drawbacks of Polymers Used in Perovskite Solar Cell

The transparent polymer layer on perovskite provides better stability and passivation. Apart from the many advantages, polymers have a few drawbacks in perovskite solar cell applications. Thermal stability is one of the most important issues for polymers in the perovskite solar cell application, apart from this, the ability of water retention and adhesive forces characteristics of the polymer largely has an impact on the performance of the perovskite solar cell [27].

The thermal stability of a polymer encapsulated perovskite solar cell in high ambient temperature conditions is the main concern and opens new challenges for further research. A significant amount of thermal stress evolved in the solar cell during the high-temperature ambient condition and that leads to thermal instability and material degradation. Thermal stress and followed by thermal degradation can be encountered by introducing a lower bandgap donor polymer which is efficient in harvesting near-infrared region light [28].

The adhesive property of thin-film solar cells encapsulated with polymer substance highly depends on solution processing and thermal treatment during fabrication. The adhesive property of the substance largely influences the multi-layered device structure [29]. Adhesive property change may raise the strains in the perovskite solar cell layer which may be caused by many reasons like environmental conditions, handling the material wrongfully, inhomogeneous thermal expansion or shrinkage formation during the processing of solution [30].

Perovskite material is significantly affected by water molecules [31,32]. To improve the stability of perovskite solar cells we must prevent water penetration. NiO (Nickel oxide), Silicon dioxide (SiO₂), etc hydrophilic oxide molecules help the perovskite layer from water retention. Dual Parylene transparent polymer layer improved the passivation effects and helps from water retention by strong molecular binding of Parylene with SiO₂ [33].

Conclusion

Despite having high-performance efficiency in perovskite solar modules are still not commercialized. Instability is one of the reasons. Adding polymers to lead-based halide perovskite leads to increasing chemical stability. In another way, the addition of polymers in perovskite solar cells provides various solutions like quality charge transport and works as an absorber. Polymers are widely used in PSC which regulates the crystallization of perovskite films that leads to enhances cell performance and stability. Due to their high hole mobility, these polymers can be employed as the hole transfer materials also. Thermal stability in high ambient conditions, the ability of water retention, and adhesion property still an issue for polymer application in perovskite solar cells, and further research is going on to optimize the performances and counter the issues.

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