Graphene And Its Derivatives for Organic Solar Cells

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Abstract. Organic solar cells (OSCs) have attracted extensive research interest due to the low-cost, flexibility, customizability, environmental friendly, and broad spectral response. Electrode materials are one of the key factors affecting the chemical performance of OSCs. Finding electrode materials with high photoelectric conversion and stable structure is crucial to promote the development of OSCs. Graphene is a two-dimensional material with special structure and excellent properties. It can be used as an electrode material or conductive additive for OSCs. The integrating of graphene derivatives has been proved to be an effective strategy to improve the performance of OSCs. Graphene oxide, reduced graphene oxide, and functionalized graphene are contribute to increase the photovoltaic conversion efficiency, enhance light absorption, and improve the carrier transport. In this paper, OSCs and graphene are introduced firstly. The latest progresses in the research of OSCs and graphene are summarized respectively. In addtion, applications of graphene and its derivatives are discussed in OSCs. The preparation methods of electrodes are discussed. The photoelectric conversion rate and electrode stability of these OSCs are enhanced significantly. Finally, the challenges and future directions of graphene in OSCs are summarized. The current problems of graphene, such as the integrity of graphene, scalability, and cost-effectiveness, are presented. Developing novel graphene derivatives, exploring applications of graphene hybird with other materials, and improving the preparation process of graphene will help to promote the development of this field.

Keywords: Organic Solar Cell; graphene derivatives; photovoltaic.

1. Introduction

Organic solar cells (OSCs) are devices that use organic semiconductors to achieve photoelectric conversion. These cells are clean and environmentally friendly compared to traditional silicon-based solar cells. They also have the advantages of low preparation cost, flexible and have a wide spectrum absorption range. Although organic solar cells have been commercializated, the low photoelectric conversion efficiency still limit their further application. On the one hand, due to the structure of organic material, electrons and holes tend to recombine, result in the effective separation of charge. On the other hand, the migration rate of electrons in organic materials is generally low. The collection efficiency and transmission rate of electrons are not satisfied.

Graphene has a unique honeycomb lattice arrangement in a single two-dimensional crystal, which gives it high conductivity. At room temperature, its electron migration rate is more than 15,000 square centimeters per volt-second. Additionally, it is ultra-thin, flexible, and chemically stable, with a long service life. The properties of graphene are complementary to organic solar cells. Graphene, as a two-dimensional nanomaterial, can be used as a medium for electron transport for OSCs or as a substrate for electrode materials. It is of great significance to study graphene and its derived products in improving the properties of OSCs.

This work initially provides an overview of OSCs and graphene. Subsequently, it concentrates on the enhancement of graphene to OSCs. Finally, the promising prospects and challenges are discussed.

2. The Latest Progress of Organic Solar Cells

Organic solar cells cover a wide range, belonging to chemistry, physics, engineering, material chemistry and other fields. In-depth study of the advantages of organic solar cells, would contribute to optimizing the shortcomings and developing its potential advantages.

It is acknowledged that active nanoscsale morphology can affect the properties of devices. The interface materials, donors and acceptors of organic solar cells were investigated [1]. The ideal bicontinuous interpenetration network morphology of active nanoscale layers has significantly improved the efficiency of charge transport and collection. This was achieved through additive treatment, heat treatment, and other methods. This has changed the phase separation to a significant degree. Moreover, studying physical properties such as the electronic structure of the interface and energy loss is significiant for understanding how OSCs work, which in turn can help to find new ways to improve photovoltaic performance.

Due to the renewability of organic solar energy, a lot of research concerning with organic solar cells were carried out and the technology of translucent organic photovoltaic (ST-OPVs) was reported. The biggest advantage of ST-OPVs is the tunable electronic energy level and selective absorption spectrum of its active layer material. ST-OPVs can achieve both high transmittance and high photoelectrical conversion efficiency by utilizing the solar spectrum selectively. The photoelectric conversion efficiency of organic photovoltaic is not as high as that of inorganic photovoltaic. Therefore, it still has great potential for improvement.

Some scholars introduce industrial quality factor (i-FOM) to ensure that OSCs are both efficient and stable while also being cost-effective, which can more precisely assess the application prospect of emerging photovoltaic materials [2]. In addition, traditional OSCs have been criticized for poor instrument stability. Other researchers have conducted studies on the stability of OSCs, analyzing the factors that may affect its stability, such as water, oxygen, heat, mechanical stress and other factors. To solve this problem, researchers have adopted the latest measures, such as material design, active layer device engineering, the use of inverted geometry, optimization of buffer layers, the use of stable electrodes and packaging materials. However, OSCs can still be affected by natural forces (such as light, heat, electric field) that degrade their performance. In the future, OSCs has the possibility to put into real life and commercial application, but it also faces the technical challenges.

3. The Ability of Graphene to Improve the Performance of OSCs

Graphene is considered to be a promising material which can enhance the performance of solar cells. Graphene, as a 2D nanomaterial, is composed of carbon elements which has abundant reserves.

Thermal and electrical conductivity of graphene are excellent. The structural hole allows phonon unimpeded, giving graphene significant thermal conductivity [3]. With a zero-band gap, the electrons in graphene can move freely freely, creating its ultra-high conductivity. In addition, graphene has excellent optical and mechanical properties. The study found that every layer of graphene absorbs up to 2. 3% of the white light, with a reflectivity less than 0. 1% [3]. Therefore, the pure graphene monolayer is transparent.

The optical properties of graphene contribute significantly to the enhancement of organic solar cell performance. Graphene can take in light that falls within the ultraviolet to near-infrared spectrum and has a wide spectral response. The band structure of graphene has a conical shape with no band gap. This means that it can achieve controllable light absorption and light emission over the entire range of the visible spectrum. Adding graphene nanosheets or quantum dots to the active layer of solar cells enhances the absorption of the solar spectrum and the generation of generating carriers [4]. This would raise the efficiency of photoelectric conversion. In solution-processed solar cells (SPSCs), graphene oxide (GO) and graphene-like transition metal disulfide (TMD) nanosheets were explored as extraction layers that transport holes or electrons [5]. Their goal is to improve the performance of OSCs by streamlining the process of charge-transporting. Graphene exhibits exceptional transparent electrical conductivity, whereas other transparent electrode materials have poor electrical conductivity and light absorption capability. The efficiency of solar cells can be enhanced by employing graphene as a transparent electrode material, because it can enhance light transmission.

4. Applications of Graphene and Derivative Materials in OSCs

4.1. Polyimide-Integrated Graphene Electrodes

At present, some scientists have integrated imide on graphene to obtain an electrode constructed with graphene that is both highly flexible and durable. By the use of polylactic acid, the electrode made of graphene has an extremely clean surface. The as-prepare electrode display 92% light transmittance and a high degree of thermal stability. Compared with the traditional polymethacrylate-assisted transfer (pmma) (PET/GR), PI-assisted graphene transparent electrode (PI@GR) [6] has a better overall sheet resistance. Thanks to the perfect contact of graphene with the substrate, no polymer residue on the surface of the graphene. There is no insulating residues for PI@GR, which could damage the chemical properties of the graphene electrode. Besides, this helps keep the surface flat and smooth.

The direct integration process of graphene can enhance the close contact between graphene and the substrate interface. The adhesive force obtained by this integration is similar to the adhesive force of PET@GR. However, PI@GR displayed a stronger adhesion, which means that PI@GR is less susceptible to mechanical bending. Due to the close contact between graphene and backing at the interface, the mechanical stability and integrity of PI@GR are also enhanced. Although graphene has excellent thermal stability, PET@GR will lose its electrical conductivity after 150ºC. PI@GR has negligible change in electrical resistivity at 400ºC. Thermal expansion may occur at high temperatures due to the low membrane temperature (70-80ºC) of PET@GR [6]. It may reduce the unique chemical characteristics of the graphene electrode. PI@GR has excellent optical and electrical properties, as well as strong thermal stability. It has substantial advantages in the production of flexible optoelectronic devices.

In addition, the scientists measured the photoelectric conversion rate of PI@GR (PCE=14. 3%), which is close to that of the indium tin oxide (ITO) based glass (PCE= 15. 7%). It is shown that its performance is competitive with that of ITO due to its high light transmission profile and higher current passing through PI@GR [6]. Although the PCE of PI@GR decreases slightly with the expansion of the active area, it is still possible to achieve large-scale production of organic solar cells.

4.2. Graphene Anode

It is reported that OSCs doped with graphene-based transparent anodes are very flexible. ITO, as the transparent anode, has the disadvantages of fragile texture and poor transparency in the near-infrared light area. Due to its flexibility, uniform light transmittance and high chemical stability, graphene is a promising material for creating new electrodes. A key step in the preparation of graphene transparent conductive electrode (TCE) is to make large, high-quality films through chemical vapor deposition growth and transfer it on a flexible polymer substrate [7]. Scholars used a mixture of methyl butyrate as a photoactive layer. In addition, graphene doped with benzimidazole (BI) are used as a transparent anode. The large square resistance of graphene TCE can affect the photoelectric conversion rate of large-area devices. The large square resistance increases with the area of the OSCs, resulting in a decrease in the current density of the device. The performance of OSCs is susceptible to the surface roughness of graphene, and the particles on the surface can easily lead to battery short circuit, especially for large areas of equipment. For graphene TCE, the doped layer can reduce the resistance value of large squares. It can also reduce the loss of photoelectric conversion rate. Surface roughness can be solved by increasing the thickness of the photosensitive material layer. The optimal number of layers is experimentally proved to be 3 layers. In this condition, the block resistance, light transmittance and surface roughness reach the optimal equilibrium. At this time, OSCs has the maximum photoelectric conversion efficiency of 6. 85% [8]. The research results confirm the feasibility of making large-area OSCs, and also ensure its high photoelectric conversion efficiency.

4.3. Graphene as a PEDOT: an Additive Inside the PSS

Kuary et al. stripped the graphite powder using stainless steel wire and platinum wire. The as-prepared stable suspension in OSCs was served as an additive to polystyrene (3,4-ethylene dioxythiophene) polystyrene sulfonate (PEDOT: PSS). Compared with chemical vapor deposition method [9] and redox method [10], electrochemical stripping method achieve product with complete structure without impurity. Li et al. optimized the composition ratio of PEDOT:PSS. The conductivity was enhanced, and the photoelectric conversion efficiency of photovoltaic devices were improved. After some proportions of the PEDOT: PSS were washed out, a smoother film was left. The ratio of PEDOT and PSS in the remaining film was higher than that of the untreated product. This improves the conductivity of the OSCs, and also reduces the damage of the electrode material. The study found that the photoelectric conversion rate of the washed-based PEDOT: PSS was improved to 16. 75% [11]. This research indicated that this method of preparing graphene is comparable to commercial methods.

5. Conclusion

In summary, the modification and application of graphene to OSCs are discussed in this work. Graphene was synthesized to the active layer of photovoltaic cells to improve the performance of OSCs. By this means, the photoelectric conversion efficiency of OSCs has been significantly improved. The problem that has plagued people for decades has been solved. With the help of graphene, the mechanical stability of OSCs has been improved. The ability which resistant to conflicts from external forces is improved. In other cases, the flexibility of OSCs has also been improved, which is of great importance for the future application of OSCs in wearable flexible devices. The process of making graphene solar cells still faces some difficulties. Although chemical vapor deposition method can produce pure graphene mixture, the cost of this preparation method is high. Electrochemical stripping method can obtain complete and excellent performance products, but the operation technology is complex. Therefore, further technical breakthroughs are still needed. The photoelectric conversion rate of OSCs ranges from 13% to 19%. Although some OSCs can achieve a photoelectric conversion rate of 15%, it is still lower than other types of photovoltaic cells. The photoelectric conversion efficiency of OSCs is urgently needed to be enhanced in the future. The large-scale manufacturing of OSCs is also a research direction which is worth of futher investigation.

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