# Graphene Modified Perovskite Solar Cells: Structure, Properties and Applications

Zili Wei *

Department of Material Science, Shanghaitech University, Shanghai, China

* Corresponding Author Email: weizl2022@shanghaitech.edu.cn

**Abstract.** With the increasing severity of energy issues, solar cells have been considered as one of the best solutions in recent years. There are various types of solar cells. Among these, perovskite solar cells (PSCs) have attracted the attention of researchers because of their high energy conversion efficiency, which is much better than conventional solar cells. What's more, PSCs are lightweight, flexible, and cost-effective. Graphene, as a novel nanomaterial, exhibit great optical, electrical, and mechanical properties. It has been employed as a new functional material for PSC modification in recent years. The integration of graphene and its derivatives in PCSs is considered to have an positive impact the performance and stability of PSCs. Therefore, this work focus on graphene modified PCSs. Firstly, the structure and properties of graphene materials were introduced. In addition, the different applications of graphene in PCSs are highlighted. This work will contribute to the in-depth study of graphene in PCSs.

**Keywords:** Solar cells; graphene-based material; applications.

## 1. Introduction

Due to the energy crisis, solar cells have become a ray of hope in recent years, which provides a viable way to deal with urgent energy issues. Perovskite solar cells (PSCs) are one of the solar cells that have garnered a lot of interest. Their exceptional power conversion efficiency, which outperforms that of conventional solar cells, including amorphous silicon, gallium arsenide, and cadmium telluride, is the reason for this spike in interest. PSCs also have many other benefits, such as flexbility, lightweight, and low-cost, which adds to its allure as a promising way to solve energy issue.

The use of graphene in PSC applications has gained significant attention in recent years due to its remarkable optical, electrical, and mechanical characteristics. Graphene, a two-dimensional material with a hexagonal lattice structure made up of closely spaced $sp^2$ hybridized carbon atoms. Graphene is reported to have exceptional properties such excellent optical transparency, a huge specific surface area, an ultrahigh Young's modulus, and amazing thermal conductivity. Because of these characteristics, graphene can be used in a wide range of industries, including surface-enhanced Raman spectroscopy (SERS), wearable sensors, catalysts, and optical modulators. Additionally, compounds derived from graphene, such as reduced graphene oxide and graphene quantum dots (GQDs), are promising materials due to their improved conductivity, capacity for surface modification, and quantum size effects. Graphene has shown promise in enhancing stability, efficiency, and charge extraction, whether it is utilized as an electrode, charge transport layer, or stabilizer. This article attempts to shed light on the disruptive potential of graphene in advancing the area of renewable energy by offering an in-depth exploration of its structural features and its numerous uses in PSCs.

## 2. Graphene-based Material

Novoselov et al. [1] used the Scotch tape method to discover graphene in 2004. Graphene is a two-dimensional material that resembles a sheet made of closely packed $sp^2$ hybridized carbon atoms in a hexagonal lattice. Graphene also can be furled to form a one-dimensional nanotube and be stacked to form three-dimensional graphite. According to the research, graphene shows a high optical transparency of 97.8% from infrared to ultraviolet regions, a large specific surface area of 2632 $m^2/g$, an ultrahigh Young's modulus of approximately 1 TPa, good mechanical flexibility, and a high thermal conductivity of approximately $5\times10^3$ W/(m·K) at indoor temperature. Consequently, graphene can be used in optoelectronic disciplines, such as light-emitting diodes, commercial solar cells (especially in PCS), LEDs, and screens. In addition, it can also be used as wearable sensors, catalysts, optical modulators, and SERS.

Common graphene derivatives include reduced graphene oxide (RGO) and graphene oxide (GO). Graphene precursors, or GO, are a mixture of $sp^2$ and $sp^3$ hybridized carbon atoms covalently bonded to oxygen functional groups at the basal plane. GO can be modified by these functional groups to achieve high water solubility and hydrophilicity. This provides a pathway for graphene to bind with different biomolecules through covalent bonds. A controlled reduction of GO to graphene can be achieved simultaneously by varying the duration of exposure to hydrazine vapor. High conductivity, water dispersibility, chemical active defect sites, adaptable surface modification, and photoluminescence could be obtained in RGO by this means.

Single-layer, bilayer, or few-layer graphene sheets greater than 10 nm in size are known as graphene quantum dots, or GQDs. The GQDs combine the best features of both graphene and quantum dots, showing strong conductivity, good photoluminescence, and quantum size effects. Furthermore, the hydrophilic groups known as dangling bonds (-OH, -C=O, and -COOH) on GQDs promote advantageous interactions with perovskite materials, resulting in denser perovskite grains and lowering defects. It is projected that the addition of GQDs to PSCs will greatly enhance the ability of charge transmission.

## 3. Applications in Perovskite Solar Cells (PSC)

### 3.1. Graphene as Electrode in PSC

It should satisfy the needs of excellent chemical stability, low sheet resistance, high transparency, and low cost to make the perfect electrode for solar cells. Nowadays, the most commonly used material is indium tin oxide (ITO), which is deposited with liquid or vapor deposition methods to form the hole transport layer (HTL). However, ITO has a number of disadvantages, such as brittleness, expensive preparation costs because of indium resource limitations, sensitivity to high or low pH levels, and challenges with patterning. It indicates that new candidates with excellent transparency, high conductivity, chemical stability, and flexibility are urgently needed. Graphene is considered as the best transparent conductive materials for solar cells because of its amazing transparency, excellent conductivity, and minimal surface roughness.

You et al. used several layers of graphene as the upper transparent electrode to create semi-transparent perovskite solar panels [2]. With the number of layers increasing, the sheet resistance of CVD-prepared graphene electrodes decreases. A thin film of poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate) (PEDOT: PSS) is employed, with a thickness of around 20 nm. The visible region transmittance of double-layer graphene doped with PEDOT: PSS is 90%, and its sheet resistance is $140\pm36$ $\Omega sq^{-1}$. The transmittance falls to less than 90% and the sheet resistance further declines for graphene electrodes with additional layers. When devices are lighted from the top (graphene side) and bottom (FTO side) electrodes, PSCs based on graphene electrodes show average PCEs of 11.65% and 12.02%, respectively.

Roel et al. [3] developed flexible PSCs with an all-carbon electrode, where graphene and cross-stacked carbon nanotubes (CSCNT) serve as the front and back electrode. Flexible PSCs with and without spiro-OMeTAD hole conductors obtained PCEs of 11.8% and 8.3%, based on the all-carbon electrode. In cyclic bending testing, the PSCs with the all-carbon electrode kept 85% of their starting value after 2000 bending cycles. This was mostly because the fill factor (FF) lost 6% and the short-circuit current density ($J_{sc}$) decreased by 11%. When enslaved to heat treatment at 62°C, flexible PSCs with the all-carbon electrode still show excellent thermal stability. It maintained around 89% of the initial PCE after 1570 hours, showing great thermal stability and better performance retention.

### 3.2. Graphene as Layers for Electron Transport in PSCs

It has also been shown that graphene function as ETL in PSCs, improving PSC performance. Graphene/zinc oxide nanocomposites (G/ZnO NC) were sprayed by Qian et al. [4] as an ETL in PSC devices. The best graphene concentration in the G/ZnO NC film was determined to be 0.75 weight percent. This led to better PSC performance, with $J_{sc}$ rising from 15.50 mA/cm$^2$ to 19.90 mA/cm$^2$. Besides, the PCE also enhanced from 7.0% to 10.3%. The photovoltaic performance of the nanocomposites is improved by the graphene network, which also improve the surface shape and crystallinity of the film.

GQDs, which was added between $SnO_2$ and perovskite, can dramatically improve electron extraction and reduce charge recombination in PSCs [5]. Perovskite films on $SnO_2$: GQD substrates quench photoluminescence (PL) more effectively. This suggests a decreased defect density and improved electron extraction capabilities. As ultrafast electron tunnels, GQDs can inhibit carrier recombination and reduce the quenching of perovskite absorbers. Due to advancements in the perovskite/ETL interface and perovskite film, devices based on $SnO_2$: GQDs ETL exhibit improved stability, maintaining 81% of their initial mass after a month of storage in ambient air. Moreover, under the identical storage settings, devices that use $SnO_2$ ETL show a 65% decrease in PCE over their baseline values.

### 3.3. Graphene in Perovskite Active Layers

The exist of graphene derivatives in perovskite active layers has been verified that it can increase the size of perovskite grains, thereby improving PSC performance. Nitrogen-doped RGO was added to mixed organic-inorganic halide perovskites by Hadadian et al. [6]. In contrast to a reference cell PCE of 17.3%, these devices showed practically hysteresis-free PCE of 18.7%. In order to enhance charge transfer, decrease boundary impedance in perovskite films, and increase size of the perovskite crystals, Shi et al. [7] recently incorporated rGO-cysteine/gold nanoparticles (rGO-CysAu) hybrid material to PSC devices. The addition of 0.040 mg/mL rGO-CysAu resulted in the maximum device performance, with FF of 79.50%, PCE of 20.50%, $J_{sc}$ of 23.80 mA/cm$^2$, and open-circuit voltage of 1.08 V. Additionally, rGO-CysAu has outstanding intrinsic stability and can shield perovskite against deterioration.

## 4. Conclusion

In this review, the applications of graphene and its derivatives in perovskite solar cells are summarized, providing detailed insights into its structure, properties, and applications. With solar cells emerging as a crucial solution to energy challenges, PSCs have attracted a lot of interest since their energy conversion efficiency is equivalent to conventional solar cells, along with their lightweight, flexible, and cost-effective nature. Graphene, renowned for its exceptional optical, electrical, and mechanical properties, has applications in PSCs, demonstrating a positive impact on the performance and device stability. In-depth discussion concerning with the properties of graphene is provided in this paper. The contributions of the derivatives to enhanced charge transport and perovskite grain formation are also highlighted, including graphene oxide, reduced graphene oxide (RGO), and graphene quantum dots (GQDs). Furthermore, this work also analyzes the applications of graphene in PSCs. Graphene act as an electrode, charge transport layer, and stabilizer are discussed respectively. Various studies cited in this review indicate the potential value of integrating graphene into PSCs. The significant effect of enhanced charge extraction, reduced recombination, and better stability are achieved in graphene modified PSCs. Overall, this review underscores the significant potential of graphene in advancing the efficiency and reliability of perovskite solar cells, thereby promoting the development of sustainable renewable energy technologies.

## References

[1] Novoselov K S, Geim A K, Morozov S V, et al. Electric field effect in atomically thin carbon films. science, 2004, 306(5696): 666-669.

[2] You P, Liu Z, Tai Q, et al. Efficient semitransparent perovskite solar cells with graphene electrodes. Advanced Materials, 2015, 27(24): 3632-3638.

[3] Luo Q, Ma H, Hou Q, et al. All-carbon-electrode-based endurable flexible perovskite solar cells. Advanced Functional Materials, 2018, 28(11): 1706777.

[4] Chandrasekhar P S, Komarala V K. Graphene/ZnO nanocomposite as an electron transport layer for perovskite solar cells; the effect of graphene concentration on photovoltaic performance. RSC advances, 2017, 7(46): 28610-28615.

[5] Pang S, Zhang C, Zhang H, et al. Boosting performance of perovskite solar cells with Graphene quantum dots decorated SnO2 electron transport layers. Applied Surface Science, 2020, 507: 145099.

[6] Hadadian M, Correa-Baena J P, Goharshadi E K, et al. Enhancing efficiency of perovskite solar cells via N-doped graphene: crystal modification and surface passivation. Advanced materials, 2016, 28(39): 8681-8686.

[7] Shi Z E, Liu S H, Tsai C H, et al. Enhancing charge transport performance of perovskite solar cells by using reduced graphene oxide-cysteine/nanogold hybrid material in the active layer. FlatChem, 2021, 28: 100254.