Proceedings of CONF-MCEE 2026 Symposium: Geomaterials and Environmental Engineering
DOI: 10.54254/2755-2721/2026.MH31348

Applications of Graphene in Solar Energy

Zixuan Teng

Keystone Academy, Beijing, China
876179191@qq.com

Abstract. Graphene as a material is becoming more and more prevalent recently due to its conductivity and its economical price compared to metal, causing it to become competitive in the field of solar energy. This article aims to discuss graphene's typical traits and its specific applications in the field of solar energy to enable readers to recognize the practical values of graphene through the lens of literature analysis and literature review, which serves as the foundation and opportunities for future development in mitigating the issues such as water scarcity and environmental pollution, as graphene can enhance product performance when combining with other materials through improving conversion efficiency while ensuring the sustainability. It is realized that even though graphene's use in the field of solar energy may encounter challenges and risks, its potential still provides people with valuable insights into what future solar energy industries should be aware of or even investigate further on.

Keywords: Graphene, Solar Energy, Material Science, Renewable Energy

1. Introduction

The rising demand for sustainable and renewable energy has hastened developments and innovations in solar energy technologies, causing solar energy to become a crucial element for the future [1].

As solar energy is available and clean, it is an unparalleled alternative to traditional unrenewable energy sources. Recently, the majority of solar cells are composed of silicon, which is costly and requires a complex fabrication process. Consequently, nanostructure materials and thin-film materials emerged to help to overcome the limits, leading to the possibility of using graphene in the field of solar energy [2].

This article is different than other pertinent papers because of the angle. According to research, there are reviews focusing on the broad progress of graphene or carbon-based materials, however, these valuable reviews concentrated on the broad applications instead of diving into the specific field of solar energy. There are many research papers focusing on specific innovations using graphene for improving the performance in the field of solar energy, but a review has not emerged yet to combine these precious investigations together with a main thread. Therefore, this article aims to fill the gap and serves as a reference for readers who are looking forward to gaining the future vision of solar energy industries.

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2026.MH31348

2. Graphene basic traits

Graphene is an allotrope of carbon that has a covalent network structure, also known as a giant covalent. In covalent network structures, the atoms are connected in a continuous lattice by covalent bonds. Graphene is unique among the allotropes; it has a single atomic layer structure with carbon atoms arranging in a honeycomb lattice, which is two-dimensional. It fulfills sp^2 hybridization. The delocalized large π is the extra bond that can emerge in any of the single bonds, thus it has high electron mobility, causing it to become similar to metals. Multiple layers of graphene become graphite [3].

There are multiple ways that people can obtain graphene. Two general categories are the top-down approaches and the bottom-up approaches. The Top-down approaches encompass mechanic exfoliation, nanotube slicing, ion implantation, supersonic spray, and plasma-enhanced exfoliation. The Bottom-up approaches involve liquid phase exfoliation, fullerene splitting, graphite oxide reduction, chemical vapor deposition, microwave irradiation, electrochemical synthesis, hydrothermal self-assembly, sodium ethoxide pyrolysis, epitaxy graphene growth on silicon carbide, solvent interface exfoliation, and graphene synthesis from graphite using thermal treatment [4].

3. Conversion efficiency – a trait that can be used for general applications in solar energy

Graphene can enhance the performance of solar cells due to its ability to improve the absorption of light, the ability to help efficient charge transport within the solar cell, and have high electrical and thermal conductivity, causing greater conversion efficiencies and greater power output. The following result is based on an experiment with dye-sensitized solar cells under low-light conditions/low irradiation in 2024. It has high diffusion lengths(7.1μm) and high charge carrier recombination lifetime(3.22mS).

Specifically, the solar cell with graphene indicates higher PCE, ff, VOC, JSC.

PCE (Power Conversion Efficiency) = $\frac{Pmax}{I}$, where Pmax is the maximum power output of the cell, and I is the irradiance of the incident light.

ff (Fill factor)= $\frac{Pmax}{VOC\ JSC}$, where VOC is the open-circuit volage, and JSC is the short-current density.

Firstly, graphene can reduce resistance. To elaborate, it can reduce the charge transport resistance between two interfaces of Titanium dioxide (TiO_2) and the charge transport resistance of the photoelectrode, as evidenced by the high ff.

Secondly, as proved by the increase in ff and VOC, it can be observed that graphene can improve charge transfer, which decreases the recombination losses, enhancing the efficient conversion of light energy to electricity.

Thirdly, graphene-added interlayer leads to rapid electron extraction, increasing the VOC value. Graphene possesses a massive surface area and competent carrier mobility, which can help to distribute TiO_2 and improve electron injection from the excited dye molecules to move across layers, improving the efficiency of dye-to-photoelectron conversion, diminishing energy loss.

DOI: 10.54254/2755-2721/2026.MH31348

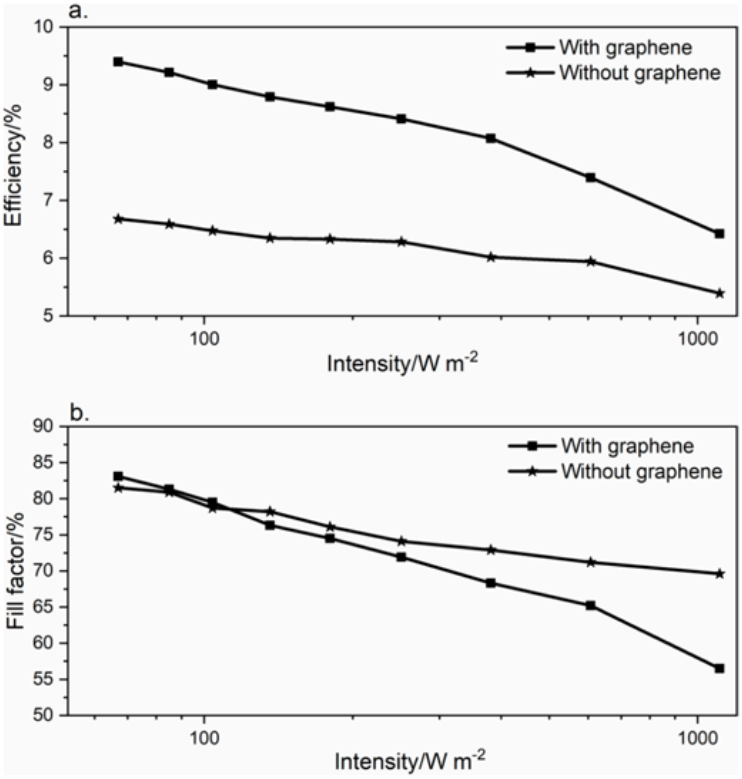


Figure 1. a) The relationship between efficiency of the cells and light intensity with legends of graphene & without graphene. b) The relationship between the fill factor of the cells and light intensity with legends of graphene & without graphene [5]

Overall, the addition of 1% of graphene to the 4th TiO_2 layer of the photoanode improves 1.32% of the efficiency, revealing the significance of adding the graphene [5]. As indicated in Figure 1a, although the difference between the efficiency of the cells with graphene and the cells without graphene gradually becomes smaller as the intensity of light increases, the difference always exists, suggesting the massive impact that graphene causes. As depicted in Figure 1b, the difference between the fill factor of the cells with graphene and the cells without graphene is gradually becoming larger and larger, indicating cells with graphene have noticeably less energy losses.

For another instance, there is a simulation in 2016 suggesting the same idea that graphene can help to enhance conversion efficiency, which is also based on dye-sensitized solar cells due to its affordability. By comparing TiO_2 -graphene composite and TiO_2 – ZnO composite, it can be deduced that with the use of graphene, the electron transfer rate rises, leading to a decline in the recombination of electrons, triggering more carriers and thus increasing the open circuit voltage. As a result, TiO_2 -graphene composite is 2.7% more efficient relative to TiO_2 – ZnO composite [6].

For another instance, there is an experiment conducted in 2020 differentiating the performance of TiO_2 and TiO_2 – graphene composite using as a photoanode. In this case, graphene can improve efficiency by about 6.97% compared to TiO_2 [2].

4. Other applications

To elaborate, there are specific practical cases of how graphene can bring changes to the field of solar energy, which is categorized into two types: Cold energy storage system related, and water

DOI: 10.54254/2755-2721/2026.MH31348

purification related. These are both water-based. Cold energy storage system is based on the principle of water cycling with the help of condensation and sorption/desorption.

4.1. Cold energy storage system

Solar driven cold energy storage system is economical, efficient, and relatively simple, which can help to tackle the issue of high energy consumption of traditional cold energy storage systems.

Wang and other researchers conducted an experiment based on a graphene-based composite sorbent that was created by embedding strontium chloride ($SrCl_2$) into an interconnected graphene, which can indicate the potential of using graphene in the field of cold energy storage systems.

The result is that Strontium Chloride ($SrCl_2$)-graphene composite sorbent performs superior compared to $SrCl_2$ / Expanded sulfurized graphite (ENG-TSA) / Carbon coated thermal conductive aluminum powder (AI@C) sorbent, speaking of the stable ability to absorb and desorb ammonia fluid. Under the condition of 263.15 kelvin for the evaporation temperature, the sorption and desorption capacity for $SrCl_2$-graphene composite sorbent reaches 0.577g/g, while $SrCl_2$ /ENG-TSA/AI@C sorbent only approaches 0.537g/g, emphasizing graphene's advantage. Under the condition of 0.62 MPa as the condensation pressure, $SrCl_2$-graphene composite sorbent has 0.034 g/g more sorption/desorption capacity compared to $SrCl_2$ /ENG-TSA/AI@C sorbent. The difference between the two sorbents can be attributed to the reason that the $SrCl_2$-graphene composite sorbent interconnected graphene structure can help to improve the transfer way for heat. These two statistics demonstrate that $SrCl_2$-graphene composite sorbent has a relatively good adaptability and stability. Furthermore, in the simulation of solar energy driven desorption under constant pressure, under 4 hours of stable sunlight, systems with $SrCl_2$-graphene composite sorbent achieve more than 90% cold energy storage, implying the future usage of maintaining a healthy cycle of daytime storing cold energy and nighttime cooling release. The ability of this sorbent to help to store cold energy is 1.9 times that of the traditional way of storing cold energy.

The use of graphene can help to enhance cycling stability and effectiveness, which can serve as the foundation for future sustainable development in the field of solar thermal-driven cold energy storage [7].

4.2. Water purification

Freshwater scarcity is a crisis that can be mitigated through solar-driven water purification.

Desalination driven by solar energy is based on solar thermal conversion, which can heat the water by converting the heat energy, ultimately leading to evaporation or vaporization. Graphene can be a kind of photothermal material.

All the carbon-based materials have a rough surface with a pore structure, which allow lights to scatter for multiple times to reduce reflectivity, enabling the absorption to improve. Additionally, carbon-based materials are not poisonous and adjustable [8].

Yu conducted an experiment based on a nano-structured leaf-like graphene layer on a wood substrate (HLG/Wood), which is a photothermal material that can be used in desalination for seawater. This material demonstrates exceptional ability to absorb light with low heat energy loss, which can be implied by the statistics of the ability to absorb more than 87.2% of light between 200-2500nm. This effectively contributes to the desalination of seawater; the evaporation efficiency is stable under a high-salt environment with the interception rate of over 99.7% of ions such as Na^+ [9].

DOI: 10.54254/2755-2721/2026.MH31348

Chang suggested that Polyaniline/Graphene nanocomposite materials can be used in solar energy-driven evaporation and seawater desalination due to the broadband absorption of the solar spectrum through the process of mixing graphene with acidified polyaniline membrane [10].

Li and other researchers proposed that under the condition of 1kW/m2 of sunlight, the evaporation efficiency of graded graphene foam (h-G) exceeds 90%, as visualized in Figure 2a. While the long-range vertically aligned 3D graphene sheet film (VA-GSM) under the identical condition, the evaporation efficiency can reach 86.5%, as illustrated in Figure 2b [11].

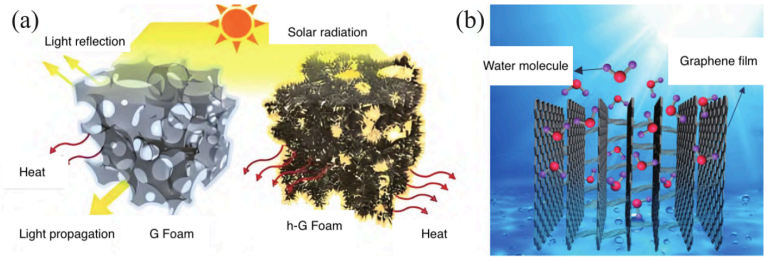


Figure 2. a) Structure for different graphene foams. b) vertically aligned 3D graphene sheet film [11]

Li and other researchers have conducted an experiment based on another photothermal material, which is the combination of graphene and gold particles from electronic waste in a melamine sponge, termed as Graphene-Recycled Au-Melamine Sponge, referred as “GRAMS”. It is reusable, washable, and stable. The water purified through this achieves WHO drinking water standards [12].

5. Conclusion

In conclusion, graphene’s unique traits have enabled it to have excellent performance in the aspect of conversion efficiency, leading to feasible usages in the field of solar energy such as cold energy storage or water purification. This paper has not yet delved into every single aspect in depth, for instance, there are more cases that graphene can be used in the field of solar energy. Overall, graphene can be incorporated with various other materials to create salient contributions in the field of solar energy. Future investigations may focus on more possible combinations of graphene and other materials that can be used in the solar energy field to enhance efficiency, further promoting human wellbeing.

References

[1] Chen, Q., Kim, J., Choi, M., & Jeon, S. (2025). Advancing solar energy applications with graphene: the potential of minimally oxidized graphene. Nano Convergence, 12(1). https: //doi.org/10.1186/s40580-025-00498-x

[2] Fattah, A., Abbasi, A., Bavir, M., & Orouji, A. A. (2021). Anode resistance reduction of dye-sensitized solar cells using graphene for efficiency improvement. Optical and Quantum Electronics, 53(5). https: //doi.org/10.1007/s11082-021-02859-2

[3] Bylikin, S., Horner, G., Grant, E. J., & Tarcy, D. (2023). Oxford Resources for IB DP Chemistry: Course Book (p. 135). Oxford University Press.

[4] Ramezani, M. J., & Rahmani, O. (2025). A review of recent progress in the graphene syntheses and its applications. Mechanics of Advanced Materials and Structures, 32(21), 5256–5288. https: //doi.org/10.1080/15376494.2024.2420911

[5] Bandara, T. M. W. J., Gunathilake, S. M. S., Gamachchi, G. G. D. M. G., Pemasiri, B. M. K., Ajith DeSilva, L., Dissanayake, M. A. K. L., & Kumara, G. R. A. (2024). Strategic graphene integration in multilayer photoanodes for enhanced quasi-solid-state dye-sensitized solar cells and performance under variable irradiance. Journal of Applied Electrochemistry, 55(3), 691–707. https: //doi.org/10.1007/s10800-024-02204-x

DOI: 10.54254/2755-2721/2026.MH31348

[6] Bavir, M., & Fattah, A. (2016). An investigation and simulation of the graphene performance in dye-sensitized solar cell. Optical and Quantum Electronics, 48(12). https: //doi.org/10.1007/s11082-016-0821-6

[7] Wang, K., Fu, S., Gao, P., Wu, W., & Wang, L. (2025). Solar Thermal-Driven Cold Energy Storage Based on a Novel Graphene-Based Composite Sorbent. Journal of Refrigeration, 1–9. https: //doi.org/10.12465/issn.0253-4339.20250726001

[8] Chen, J., Hu, X., Cai, Y., Liu, X., & Yang, Y. (2025). Research progress on carbon-based materials for solar-driven interfacial water evaporation. New Chemical Materials, 1–6. https: //doi.org/10.19817/j.cnki.issn1006-3536.2026.02.041

[9] Yu, Z. (2025). Fabrication and Property Investigation of Wood/Graphene Photothermal Conversion Composites [PhD Thesis]. https: //kns.cnki.net/kcms2/article/abstract?v=1UNTTfPTmO-i1_-EJ4VQfSaUJDZDlaqdQOOBn-OezWGKxwcbvwKnxx-sTcUJOvgBfRDB6-UVtxZpx9R79QFQcSBQ0b132LDJ0iBbx8KWlkaPk-7n2_Tn558WxeMw-O94sCAtIBhewYVJ_ZCV-znmU2DM2VcxjVkcSzcwrPoygPVzyFMVHyr4t_A2FSZJyS_A&uniplatform=NZKPT& language=CHS

[10] Chang, Y. (2025). Research progress on polyaniline/graphene nanocomposites. Chemical Fiber & Textile Technology, 54(07), 14–16. https: //kns.cnki.net/kcms2/article/abstract?v=1UNTTfPTmO9uKf1OgG9VeiVOL5OYZuslpxGTFROofIvQ-fazxTr-39ttjGk6CmBgcwPxbYhz1me7f28Lj_MckVMaLxLRyB0o1zBxE4R3uBkmvqnaH3vERW52IbZ1spPzeMjFSElIE9n-HyDY7wsMAdkJ59h2ejLW2lV4B-kDt3kgKaycxNQLSw==& uniplatform=NZKPT& language=CHS

[11] Li, X., Yang, R., Liao, Y., Zhou, L., & Jing, D. (2025). Carbon-based materials in solar-driven interfacial evaporation: Carbon emission reduction mechanisms and application prospects. Low-Carbon Chemistry and Chemical Engineering, 1–14. https: //doi.org/10.12434/j.issn.2097-2547.20250066

[12] Li, F., Huang, J., Xu, D., Wang, C., Zhao, L., Gong, X., Li, H., Zhang, C. Y., Song, Q., Su, Y., & Cheng, H.-M. (2024). A portable and washable solar steam evaporator based on graphene and recycled gold for efficient point-of-use water purification. Science China Materials, 67(11), 3700–3709. https: //doi.org/10.1007/s40843-024-3089-2