

**Review****Research Progress of Perovskite Solar Cells**Zhiyin Liu<sup>1,\*</sup>

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can be used commercially. Perovskite solar cells are outlined in this overview along with some research findings on stability augmentation, defect passivation, and fabrication process improvements.

**Abstract:** Countries all around the world have long depended on fossil fuels to power industrial development and economic expansion since the Industrial Revolution. However, the global political and economic landscape has grown more complex in recent years as the world entered the post-pandemic age. An unstable energy supply-demand pattern has resulted from a number of factors, including the pandemic, natural disasters, diplomacy, and conflict. The ability of nations all around the world to buffer against energy emergencies is being put to the test by the shrinking supply of fossil fuels. As a result, a growing number of perceptive people are focusing on solar energy, which is a new form of sustainable energy. Perovskite solar cells' experimental photovoltaic efficiency is currently getting close to the 30% theoretical limit, but a number of problems need to be fixed before they

**Keywords:** Perovskite solar cells; stability; defect passivation; preparation process

## **1. Introduction**

Solar cells are machines that transform light energy into electrical energy; they will immediately produce current and voltage as long as they are illuminated and have the necessary external circuit.

Monocrystalline silicon cells, which represent the first generation of solar cells, must be heated to high temperatures in order to produce high-purity silicon for the creation of high-efficiency devices, which results in expensive and time-consuming procedures. This problem led to the development of the second generation of solar cells, which use diverse compound thin-film batteries and are represented by copper indium gallium selenide.

These batteries' raw components are costly, hazardous, and in short supply. The third generation of solar cells—represented by PSCs, which are inexpensive thin-film batteries with the benefits of straightforward procedures and a wealth of materials—arose in response to the problems with the first and second generations. These cells have advanced quickly in a matter of years. According to more and more publications, PSCs will be the next solar cells used in commercial and personal applications.

## **2. Perovskite solar cell**

### **2.1. The Development of Perovskite Solar Cells**

One kind of solar cell that has garnered a lot of interest recently is perovskite solar cells. This is mostly because of their inexpensive cost and remarkably straightforward production method, as well as the fact that power conversion efficiency has rapidly increased over the last ten years. The first perovskite solar cell was created in 2009 by Kojima and colleagues in Japan; however, because volatile liquid electrolytes were used, the cell's stability was very poor, and its efficiency was just 3.81% (Niu et al., 2014). Numerous research teams from around the world carried out in-depth, methodical studies on perovskite solar cells in the ensuing years. A research team in South Korea under the direction of Seok successfully created solar



cells with an efficiency of 20.1% in 2015 by combining various perovskite materials with various organic groups and halide anions (Noh et al., 2013).

In the following years, research related to perovskite increased rapidly. Some researchers conducted studies on preparation processes, providing new technical solutions for the fabrication of perovskite solar cells, such as spraying methods, anti-solvent techniques, and so on (Meng, 2017). Some researchers have focused on the components of the light-absorbing layer, developing various perovskite solar cells such as lead-free (or low-lead) perovskite, inorganic perovskite, and two-dimensional perovskite.

## **2.2. Working principle of perovskite solar cells**

The working principle of perovskite solar cells is based on the photovoltage effect, starting with the perovskite light-absorbing layer capturing incident photons. When the photon energy exceeds the material's bandgap, electrons in the valence band are excited to the conduction band, forming electron-hole pairs. Subsequently, thanks to the excellent carrier diffusion properties of the perovskite material, the photogenerated carriers separate and diffuse toward both sides of the cell: electrons are selectively extracted by the electron transport layer, while holes are efficiently collected by the hole transport layer. This selective transport mechanism effectively prevents the direct recombination of carriers. Ultimately, the separated charges are conducted through the respective electrodes to the external circuit, generating a continuous current. However, the presence of bulk defects, interface states, or pinholes in the perovskite layer in actual devices can lead to non-radiative recombination (including bulk recombination, interface recombination, and recombination between transport layers), resulting in the loss of some photogenerated carriers, which poses a key challenge to improving battery efficiency.

## **3. Current Research Status of Perovskite Solar Cells**

### **3.1. Defect Passivation**

The fundamental principle of defect passivation in perovskite solar cells lies in filling or shielding the defect states in the perovskite material through chemical,



physical, or structural means, thereby reducing non-radiative recombination, lowering the defect-state density, optimizing carrier transport characteristics, and ultimately enhancing the device's photoelectric performance and stability. By introducing molecules or materials with specific functional groups, stable chemical bonds or coordination structures can be formed with deep-level defects in the perovskite, directly filling the defect sites (Hameiri, 2017). Using low-dimensional perovskites or quantum dots to construct a passivation layer that covers the perovskite surface or grain boundaries can reduce the exposure of defect states, while also optimizing interface energy level alignment (Bishop et al., 2018). In addition, through ion diffusion or interface modification, the interactions between the perovskite layer and the transport layer can be regulated, passivating the defects at the interface and improving the carrier extraction efficiency (Song et al., 2023). The above mechanisms work together on the perovskite material, achieving effective defect passivation and significantly enhancing the performance and stability of perovskite solar cells.

Liu investigated a straightforward technique for increasing the efficiency of carbon-based all-inorganic perovskite solar cells by treating CsPbI<sub>3</sub> perovskite films with an OAI solution. Freshly made CsPbI<sub>3</sub> perovskite films were found to react in situ with PbI<sub>2</sub> to form OA<sub>2</sub>PbI<sub>4</sub> 2D perovskite after being placed in an IPA solution of OAI for a while and then annealed. This reduces the PbI<sub>2</sub> phase, which is detrimental to stability, and the passivation effect of OAI also improves the energy level alignment at the CsPbI<sub>3</sub>/Carbon interface and lowers the density of defect states on the perovskite film surface. In addition, the reduction of PbI<sub>2</sub> at the grain boundaries and the hydrophobic nature of the long-chain alkyl groups in OAI enable unencapsulated CsPbI<sub>3</sub> C-PSCs to exhibit excellent long-term storage stability, with unencapsulated devices retaining 91% of their initial efficiency after being kept in the environment for 30 days (Ma et al., 2023). Zhang investigated ways to modify the cation-anion interaction in order to enhance battery performance. It was discovered that K in K<sub>2</sub>SO<sub>4</sub> can diffuse into the perovskite layer, preventing the creation of halide vacancies inside the film, by embedding the functional potassium sulfate (K<sub>2</sub>SO<sub>4</sub>) inorganic salt at the SnO<sub>2</sub>/perovskite interface. K<sub>2</sub>SO<sub>4</sub> can simultaneously passivate oxygen vacancy flaws in the SnO<sub>2</sub> film and successfully enhance the perovskite film's shape. By optimizing the energy band alignment between the perovskite film and the electron transport layer, this cation-anion modification technique improves the perovskite film's crystallinity and accomplishes defect



passivation at the grain borders and interfaces. The photoelectric conversion efficiency (PCE) of devices modified with K<sub>2</sub>SO<sub>4</sub> increased from 19.45% to 21.18%, and after being stored for 1000 hours in an air environment with a relative humidity of about 25%, they still retained 85% of their initial efficiency (Li, 2024).

### **3.2. Stability Improvement**

Synergistic application of multiple strategies to optimize interface characteristics, decrease the density of defect states within the device, improve material environmental adaptability, and increase structural stability is the fundamental principle for improving the stability of perovskite solar cells. Building low-dimensional/high-dimensional perovskite structures or using a “lattice-to-lattice” doping effect can improve the lattice stability of perovskites, increasing their resistance to humidity and thermal stress; passivating intrinsic defects in perovskites can suppress non-radiative recombination while also achieving energy storage and photon down conversion to improve light stability; A stable network structure is formed between the perovskite grains, further enhancing the mechanical and chemical stability of the device. In addition, regulating the interface energy level alignment (Liu et al., 2023) and preventing the penetration of external environmental factors (Zhang et al., 2023) can effectively reduce charge recombination and chemical corrosion at the interface, thereby extending the device’s service life.

Zhuang investigated ways to improve perovskite solar cells’ performance by adding perovskite quantum dots and long afterglow materials. It was discovered that adding Y<sub>2</sub>O<sub>2</sub>S: Eu<sup>3+</sup>, Ti<sup>4+</sup>, and Mg<sup>2+</sup> long afterglow materials as a photon energy conversion layer can enhance light stability and produce an energy storage effect. A ‘lattice-to-lattice’ doping effect is made possible by employing CsPbBrCl<sub>2</sub>: Ln<sup>3+</sup> perovskite quantum dots to passivate inherent flaws in perovskite, which greatly improves the lattice stability, humidity stability, and temperature stability of the material (Zhang et al., 2023). Sheng studied methods to enhance the performance of perovskite solar cells by constructing cross-linked systems through the introduction of organic and inorganic crosslinkers. It was found that introducing triallyl is cyanurate (TAIC) as an additive into the perovskite precursor solution could form an in-situ cross-linked three-dimensional polymer network. On this basis, the inorganic crosslinker sodium tetraborate (Na<sub>2</sub>B<sub>4</sub>O<sub>7</sub>) was introduced to synergistically crosslink the perovskite grains with TAIC, constructing a stable organic/inorganic crosslinking



system, achieving crosslinking and passivation of the perovskite grains, and ultimately fabricating high-efficiency and stable inverted planar FAPbI<sub>3</sub>-based perovskite solar cells (Zhuang et al., 2023).

### **3.3. Improvement of the Preparation Process**

The improvement of perovskite solar cell fabrication processes mainly focuses on key aspects such as crystallinity regulation, interface optimization, low-dimensional/high-dimensional structure design, nucleation and crystallization acceleration, electrochemical deposition, and interface modification. In order to create a high-conductivity electron transport layer and increase electron transport efficiency while decreasing interfacial charge recombination, the solvent-assisted technique (Liu, et al., 2024) creates high-crystallinity nanomaterials and adjusts the annealing temperature. By building a double-layer electron transport (Sheng et al., 2024) or adding an interfacial modification (Zhang et al., 2023), interface defects may be successfully passivated, electron transport characteristics can be improved, charge traps can be decreased, and device performance and stability are subsequently increased. To efficiently passivate defect sites in perovskite films, minimize defect state density, maximize interface energy level alignment, and inhibit non-radiative recombination, design 2D/3D perovskite architectures (Zhou et al., 2022). To speed up the nucleation process, shorten the crystal development cycle, create high-quality perovskite films, improve film crystallinity, decrease defects at grain boundaries, and increase light absorption efficiency and carrier mobility, add homologous nuclei to the precursor solution. A low-voltage, room-temperature electrochemical deposition technique is used to prepare perovskite films (Zou et al., 2021). Post-doping is used to further improve battery stability, achieve uniform perovskite layer deposition, and maximize film quality and device performance. By modifying the interface and regulating the energy levels, the energy level alignment between the electron transport layer and the perovskite layer is optimized, reducing charge recombination at the interface and improving the extraction efficiency of charge carriers (Yang et al., 2022).

Wu studied methods to improve the performance of novel photovoltaic devices, perovskite solar cells (Pero-SCs), and found that introducing homogeneous nuclei into the precursor solution can accelerate the nucleation process and shorten the crystal growth cycle, thereby producing high-quality perovskite films. In addition, by



introducing bifunctional small molecules as an interfacial modification layer, the electron transport issues at the interface between the electron transport layer (ETL) and the perovskite were improved, further enhancing the performance and stability of Pero-SCs (Ren, 2023). Liu investigated a low-voltage, room-temperature electrochemical deposition method for perovskite films, and improved the stability of electrochemically deposited perovskite solar cells through post-doping. It was found that using mesoporous  $\text{TiO}_2$  (mp- $\text{TiO}_2$ ) as the electron transport layer and a platinum sheet as the counter electrode, and depositing the Pb layer and MAI layer in two steps, allows for uniform deposition of a  $\text{MAPbI}_3$  perovskite layer on mesoporous  $\text{TiO}_2$  under room temperature conditions. By controlling the deposition process parameters, the effects of Pb and MAI deposition conditions on the preparation of the perovskite layer and cell performance were analyzed, providing important reference for room-temperature electrochemical deposition of perovskite films (Liu, 2024).

#### **4. Conclusion**

Perovskite solar cells (PSCs), as a highly promising third-generation solar cell technology, have made significant progress in recent years in areas such as material modification, defect passivation, stability enhancement, and fabrication process improvement. Introducing defect passivation strategies, such as star-shaped polymers, OAI solution treatment, and cation-anion interface modification, can significantly reduce the defect state density of perovskite films and improve the photoelectric conversion efficiency and stability of devices. Stability enhancement strategies, including long-persistent phosphorescent materials, rare-earth-based quantum dots, and in-situ three-dimensional cross-linking, can effectively strengthen the PSCs' ability to maintain performance under light, humidity, and thermal conditions. Improvements in fabrication processes, such as low-temperature preparation of electron transport layers, nucleation management, interface modification, and electrochemical deposition, further optimize the quality of perovskite films and device performance.

Perovskite solar cells still need to overcome a few obstacles, though. Large-scale use of lead-based perovskites is restricted by their toxicity, hence lead-free or low-lead perovskite materials must be developed further and their photovoltaic conversion efficiency increased. Even while perovskite solar cells' efficiency in lab



settings has gotten close to the 30% theoretical limit, sustaining high efficiency in large-scale manufacturing is still a major problem for real-world applications. Furthermore, more research is still needed to confirm the long-term durability of perovskite solar cells, particularly in complicated environmental settings including high humidity, high temperatures, and light exposure. Perovskite solar cells are anticipated to emerge as a key technology for meeting the world's energy needs and environmental concerns as a result of ongoing developments in materials research, interface engineering, and device fabrication.

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**References**

- [1] Bishop, J. E., Read, C. D., Smith, J. A., & Ramadan, A. J. (2018). Advances in spray-cast perovskite solar cells. *The Journal of Physical Chemistry Letters*, 9(8), 1977–1984. <https://doi.org/10.1021/acs.jpcllett.8b00311>
- [2] Hameiri, Z. (2017). Photovoltaics literature survey (No. 138). *Progress in Photovoltaics: Research and Applications*, 25(12), 1077–1083. <https://doi.org/10.1002/pip.2967>
- [3] Li, X. Y. (2024). Study on the strategy of defect passivation in perovskite solar cells using star-shaped polymers [Master's thesis, Beijing University of Chemical Technology]. <https://doi.org/10.26939/d.cnki.gbhgu.2024.000934>
- [4] Liu, D. Y. (2023). Study on the preparation of perovskite solar cell films and device performance [Doctoral dissertation, Jilin University]. <https://doi.org/10.27162/d.cnki.gjlin.2023.008004>
- [5] Liu, J. Y. (2024). Low-temperature preparation of SnO<sub>2</sub> electron transport layer and study on the stability of perovskite solar cells [Doctoral dissertation, Harbin Institute of Technology]. <https://doi.org/10.27061/d.cnki.ghgdu.2024.000370>
- [6] Liu, S. N., Wang, X., & Chen, L. (2024). Research on improving the performance of perovskite solar cells through additive engineering [Doctoral dissertation, Jilin University]. <https://doi.org/10.27162/d.cnki.gjlin.2024.000353>
- [7] Liu, W. F., Zhang, Y., & Li, H. (2023). Research on crystallization regulation and defect passivation of carbon-based all-inorganic perovskite solar cells [Master's thesis, Qingdao University of Science and Technology].
- [8] Long, B. Y., Zhou, M., & Wu, X. (2022). Study on the performance and encapsulation of PVK-modified perovskite solar cells doped with antioxidants [Master's thesis, East China Normal University]. <https://doi.org/10.27149/d.cnki.ghdsu.2022.004221>
- [9] Ma, X. H., Liu, J., & Wang, S. (2023). Effect of ethyl carbamate interface modification on the performance of perovskite solar cells. *Electronic Components and Materials*, 42(8), 982–987. <https://doi.org/10.14106/j.cnki.1001-2028.2023.0187>
- [10] Meng, L. (2017). Interface engineering and morphology study of thin film



- organic-inorganic halide perovskite optoelectronic devices [Doctoral dissertation, University of California, Los Angeles]. <https://escholarship.org/content/qt9kt895bs/qt9kt895bs.pdf>
- [11] Niu, G., Guo, X., & Wang, L. (2014). Review of recent progress in chemical stability of perovskite solar cells. *Journal of Materials Chemistry A*, 3(17), 8970–8980. <https://doi.org/10.1039/c4ta04994b>
- [12] Noh, J. H., Im, S. H., Heo, J. H., Mandal, T. N., & Seok, S. I. (2013). Nanostructured TiO<sub>2</sub>/CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub> heterojunction solar cells employing spiro-OMeTAD/Co-complex as hole-transporting material. *Journal of Materials Chemistry A*, 1(38), 11842–11847. <https://doi.org/10.1039/c3ta12681a>
- [13] Ren, G. H. (2023). Research on the optimization of functional layers in perovskite solar cells [Doctoral dissertation, Jilin University].
- [14] Sheng, X., Li, Y., & Wang, J. (2024). Construction of efficient and stable perovskite solar cells based on an in-situ three-dimensional crosslinking strategy [Master's thesis, Nanchang University]. <https://doi.org/10.27232/d.cnki.gnchu.2024.000863>
- [15] Song, J., Wang, H., & Liu, Y. (2023). High-performance perovskite solar cells passivated with multifunctional amino acid derivatives. *Chinese Journal of Inorganic Chemistry*, 39(2), 327–336.
- [16] Wu, T. (2023). Achieving high-performance perovskite solar cells by regulating perovskite crystallization based on nucleation management and interface modification [Master's thesis, Soochow University]. <https://doi.org/10.27351/d.cnki.gszhu.2023.003707>
- [17] Yang, X. Y., Zhang, L., & Wang, R. (2022). 2D/3D perovskite solar cells based on chlorobenzylamine. *Journal of Inorganic Materials*, 37(1), 72–80.
- [18] Zhang, C., Li, X., & Wang, H. (2023). High-efficiency perovskite solar cells based on crystallization control and defect passivation [Doctoral dissertation, Chongqing University]. <https://doi.org/10.27670/d.cnki.gcqdu.2023.002859>
- [19] Zhang, L., Wang, S., & Liu, Y. (2023). Research progress on Cs<sub>2</sub>AgBiBr<sub>6</sub> perovskite solar cells. *Journal of Inorganic Materials*, 38(9), 1044–1054.
- [20] Zhang, Z. F., Yang, J., & Li, W. (2023). Research on the optimization of



- anti-solvent and electron transport layer of perovskite solar cells [Master's thesis, Henan Normal University]. <https://doi.org/10.27118/d.cnki.ghesu.2023.000585>
- [21] Zhou, Z., Liu, Y., & Wang, X. (2022). Physical mechanisms of perovskite solar cells based on dual-layer electron transport layers. *Acta Physica Sinica*, 71(20), 369–376.
- [22] Zhu, L. Q., Zhang, H., & Wang, Y. (2022). Research on the regulation of perovskite solar cell performance by small organic molecule additives containing C=O or F atoms [Master's thesis, Yunnan University]. <https://doi.org/10.27456/d.cnki.gyndu.2022.003438>
- [23] Zhuang, X. M., Li, J., & Wang, S. (2023). Research on high-efficiency and stable perovskite solar cells [Doctoral dissertation, Jilin University].
- [24] Zou, Y., Wang, X., & Liu, H. (2021). Effect of NaTFSI interface modification on planar TiO<sub>2</sub>-based perovskite solar cells. *Acta Photonica Sinica*, 42(5), 682–690.