

# Technical characteristics and development trend of third generation solar cells

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**Abstract.** The future of global sustainable energy systems is anticipated to heavily rely on photovoltaic solar energy (PV). This paper provides an analysis of third-generation solar cells, exploring their underlying working mechanisms, evaluating their performance metrics, and discussing both their advantages and disadvantages. Third-generation solar cells, which include perovskites, dye-sensitized cells, and organic photovoltaics, offer promising advancements over traditional silicon-based cells, such as higher efficiencies and potential for lower production costs. However, challenges like material stability, scalability, and long-term reliability hinder their widespread adoption. In offering a comprehensive examination of these advanced solar technologies, the paper aims to contribute to the understanding and progress of renewable energy solutions. It underscores the importance of continued research and innovation in overcoming the existing limitations of third-generation solar cells. The transition towards a future that relies more heavily on sustainable energy sources hinges on the ability to develop and implement efficient, reliable, and cost-effective solar technologies. The paper identifies these bottleneck issues and suggests pathways for overcoming them.

**Keywords:** third generation solar cells; technical characteristics; development trend.

## 1. Introduction

The initial generation of solar cells, primarily founded on crystalline Si, set the foundation with high efficiency but at a high production cost and material usage. Thin-film technologies such as copper indium gallium selenide (CIGS) and cadmium telluride (CdTe) comprise the second generation, offered reduced material costs and greater flexibility but at the expense of lower efficiencies. Today, we stand at the brink of a new era with the solar cells of third-generation, which promises to address the constraints of previous generations by utilizing advanced materials and novel mechanisms to achieve higher efficiencies and lower production costs. The primary research objective in this domain is to address these challenges head-on, with a focus on developing non-toxic, stable materials that can be produced at scale without compromising efficiency.

The aim of this paper is to enhance comprehension and advancement in renewable energy solutions, emphasizing the promise and obstacles of third-generation solar cells in the shift toward a more sustainable energy landscape.

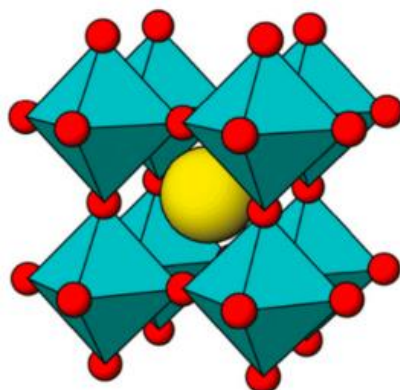
## 2. Working mechanism

The main components of perovskite solar cells include light-absorbing materials, hole transport layers, electron transport layers and electrodes, as shown in fig.1. In 2009, a solar cell based on perovskite structure has attracted worldwide attention. There are many kinds of compounds satisfying the structure of perovskite, and hybrid metal halide perovskite materials are emerging in the field of solar cells. A typical three-dimensional perovskite is composed of three main ions, the chemical formula is  $ABX_3$ , where the A site is A monovalent cation with A large radius, such as inorganic metal ions  $Cs^+$ ,  $Rb^+$ , and organic ammonium ions  $CH_3NH_3^+$  (MA). The B site is usually composed of divalent metal cations of smaller radius, and X is the halogen anion.

In perovskite materials, after photon energy is absorbed, electrons are excited to the conduction band while leaving a hole in the valence band. Due to the high dielectric constant of the perovskite

material, these excitons can quickly separate into free electrons and holes at room temperature. This kind of exciton separation efficiency is very high, which helps to improve the photoelectric conversion efficiency of the battery.

The separated electrons and holes are transported to the battery electrode through the electron transport layer (ETL) and hole transport layer (HTL) respectively. Common electron transport materials include  $\text{TiO}_2$  and  $\text{SnO}_2$ , while hole transport materials usually use Spiro-OMeTAD or PEDOT. These transmission layer materials need to have good conductivity and matching energy levels to reduce the recombination loss of carriers during transmission [1].



**Fig 1.** Crystal structure of perovskite [2]

After electrons and holes reach the electrode through their respective transport layers, the charges are collected and an electric current is generated. Electrodes are usually composed of transparent conductive oxides (such as ITO or FTO) and metal electrodes (such as silver or gold). Transparent conductive oxide electrodes are used to let in sunlight, while metal electrodes are used to collect and transmit electrical current.

### 3. Performance

The third generation of solar cells shows many advantages in the research and application of solar energy technology, especially in terms of energy density, life cycle and cost. These properties give them great potential in future energy markets.

Energy density is one of the important indicators for evaluating solar cell performance. The third-generation solar cells have excellent performance in terms of energy density, far exceeding the first- and second-generation solar cells. Traditional silicon-based solar cells (first generation) have relatively low energy density due to limitations in materials and technology. Despite technological improvements in second-generation thin-film solar cells, their energy density has still not reached ideal levels. However, third-generation solar cells have greatly improved energy conversion efficiency by using new materials and advanced technologies, such as perovskite materials, quantum dot technology and multi-junction solar cells.

Specifically, the energy conversion efficiency of perovskite solar cells has exceeded 25%, which is close to or even exceeds the limit of traditional silicon-based cells [2, 3]. This high efficiency is due to the excellent optoelectronic properties of the perovskite material, including its high light absorption coefficient and tunable band gap. In addition, the preparation process of perovskite materials is relatively simple and low-cost, giving it significant advantages in large-scale production.

Multi-junction solar cells form a multi-layer structure by stacking materials with different band gaps together. Each layer of material can absorb photons of a specific wavelength. This design maximizes the use of different parts of the solar spectrum and improves overall energy conversion efficiency. The theoretical efficiency limit of multi-junction solar cells is much higher than that of single-junction solar cells, so they also perform well in terms of energy density.

In addition to these new materials and technologies, third-generation solar cells also benefit from advanced manufacturing processes and materials engineering. For example, by using nanomaterials

and advanced thin film deposition technology, the photoelectric performance and stability of cells can be further optimized. These technologies not only improve energy conversion efficiency, but also enhance the long-term reliability and environmental adaptability of batteries.

The life cycle of a solar cell is an important indicator of its long-term use value. Third-generation solar cells also perform well in this regard. In comparison, first- and second-generation solar cells typically have a life cycle of between 20 and 25 years. Although the practical application of third-generation solar cells is not long ago, preliminary research and testing show that their life cycle is expected to reach or even exceed this level. For example, perovskite solar cells have shown good stability and durability through optimized packaging and material modification [4].

Cost is one of the important factors affecting the large-scale application of solar cells. Traditional silicon-based solar cells cost more, mainly due to high temperatures and high purity requirements during the manufacturing process. In contrast, third-generation solar cells have obvious advantages in reducing costs. New solar cells such as perovskite solar cells, dye-sensitized solar cells (DSSC) and organic solar cells (OPV) use low-temperature preparation processes and cheap materials, significantly reducing manufacturing costs. For example, perovskite materials have low raw material costs, simple manufacturing processes, and can be prepared at low temperatures, thus significantly reducing production costs [5].

#### 4. Advantage and disadvantage

The third generation of solar cells is a hot topic in current solar technology research. Its main materials include perovskite, quantum dots and organic materials. These new materials and technologies bring great potential and challenges to the development of solar cells. These cells use new materials and advanced structural designs, which significantly improve energy conversion efficiency. For example, the energy conversion efficiency of perovskite solar cells has exceeded 25%, approaching or even exceeding the limits of traditional silicon-based solar cells [2]. In addition, multi-junction solar cells can more effectively utilize the solar spectrum by stacking materials with different band gaps, thereby further improving efficiency [6]. The diversity of third-generation solar cell materials allows them to be prepared in flexible and lightweight forms. Flexible solar cells can be used in building integration, wearable devices and other fields, expanding the application scope of solar cells [7].

Third-generation solar cells can more effectively capture and utilize sunlight of different wavelengths by optimizing material and structural design. For example, quantum dot solar cells control their absorption spectrum by adjusting the size of quantum dots, thereby improving the utilization of sunlight [8]. Specifically, quantum dots are nanometer-sized semiconductor particles whose unique quantum size effect enables them to absorb and convert photons of specific wavelengths. By precisely tuning the size of quantum dots, researchers can make them absorb different wavelengths of light, maximizing the use of energy in the solar spectrum.

This ability to tune the absorption spectrum gives quantum dot solar cells significant advantages. Traditional silicon-based solar cells can only efficiently absorb part of the solar spectrum, while the rest of the energy is wasted. However, quantum dot solar cells can cover a wider spectral range by using quantum dots of different sizes, thereby significantly improving photoelectric conversion efficiency. For example, small-sized quantum dots can absorb high-energy short-wavelength photons, while large-sized quantum dots can absorb low-energy long-wavelength photons. This multi-wavelength absorption property gives quantum dot solar cells greater flexibility and efficiency in capturing and utilizing sunlight.

In addition, quantum dot solar cells can also be combined with other types of solar cell materials to form multi-junction structures. This structure utilizes the absorption characteristics of different materials for light of different wavelengths to further improve the photoelectric conversion efficiency. For example, quantum dot layers can be stacked on top of perovskite layers or organic solar cell layers

to create a multi-layered absorption structure, allowing each layer of material to absorb and convert photons of specific wavelengths, resulting in higher overall efficiency.

For the disadvantages, although third-generation solar cells offer significant advantages in terms of efficiency and cost, their long-term stability remains an important challenge. Perovskite solar cells are easily affected by environmental factors such as humidity and oxygen, leading to rapid performance degradation [4]. Therefore, how to improve the stability of third-generation solar cells is the focus of current research.

Compared with the first- and second-generation solar cells, the production process of the third-generation solar cells is not yet fully mature. Although the research results in the laboratory are exciting, there are still many technical bottlenecks in large-scale production. For example, perovskite solar cells are prone to defects during the preparation process, affecting cell performance [9]. Some third-generation solar cell materials contain harmful substances, such as lead in perovskite solar cells, which may pose potential threats to the environment and human health [10]. Therefore, developing lead-free or low-lead alternative materials is an important direction for future research.

The third-generation solar cells also have complex packaging requirements. To improve the stability of the third-generation solar cells, complex packaging processing is required. This not only increases production costs, but may also affect the flexibility and lightweight characteristics of the battery [11].

## 5. Bottleneck issues

Stability is one of the main issues facing third-generation solar cells. Perovskite solar cells have shown high efficiency in the laboratory, but their long-term stability is poor. Perovskite materials are very sensitive to environmental factors such as humidity, temperature and oxygen, and are prone to decomposition or performance degradation [12]. For example, the perovskite layer undergoes a hydrolysis reaction under the influence of moisture, causing battery performance to rapidly decline. In order to improve stability, researchers have tried a variety of encapsulation methods and material modifications, but they still have not been able to completely solve this problem [13].

The production process of third-generation solar cells is not yet fully mature. Although the research results in the laboratory are exciting, there are still many technical bottlenecks in large-scale production. Perovskite solar cells are prone to defects during the preparation process, such as the uniformity of the perovskite crystal and the quality of interface bonding. These problems will affect the overall performance of the battery [14]. In addition, quantum dot solar cells and organic solar cells also have many challenges in material preparation and device assembly, and the production process needs to be further optimized to improve product stability and consistency [15].

Worryingly, some third-generation solar cell materials contain harmful substances, such as lead in perovskite solar cells. This may pose potential threats to the environment and human health [16]. Lead is a heavy metal whose toxicity is well known and can cause serious damage to vital organs such as the nervous system, blood system, and kidneys. At the same time, the environmental pollution problem of lead cannot be ignored. Once it enters soil and water sources, the removal process of lead will be very difficult. Therefore, perovskite solar cells require special attention during manufacturing, use and disposal to prevent the spread of lead contamination.

Although researchers are actively looking for lead-free or low-lead alternative materials, to date, the ideal material that combines performance and stability has not been found. Currently, many alternative materials have not yet achieved ideal results in terms of energy conversion efficiency and long-term environmental stability. For example, tin-based perovskites are considered a potential lead-free alternative, but their photoelectric conversion efficiency and long-term stability still need to be improved. In addition, there are other perovskite materials such as copper-bismuth-based and germanium-based perovskite materials that have also shown some promise in research, but they also face problems such as low efficiency and poor environmental stability.

In addition, certain organic semiconductor materials in organic solar cells may also produce harmful chemicals during production and use [17]. These organic materials easily decompose at high temperatures and release volatile organic compounds (VOCs), which are harmful to human health and may cause respiratory diseases and other health problems. At the same time, these organic compounds also have potential pollution risks to the environment. For example, materials such as benzoxazines and polystyrene may produce toxic decomposition products when exposed to high temperatures and ultraviolet radiation. Therefore, in the production and application of organic solar cells, strict control measures need to be taken to reduce the generation and release of harmful chemicals.

In order to solve these problems, scientists are exploring various technological paths. For example, developing new non-toxic materials, improving battery packaging technology to reduce the leakage of harmful substances, and optimizing production processes to reduce the generation of harmful by-products. At the same time, strengthening the environmental performance evaluation of existing materials and formulating more stringent environmental standards and waste disposal specifications are also considered important measures to reduce the impact of third-generation solar cells on the environment and health. Through these efforts, third-generation solar cells are expected to achieve safer and more environmentally friendly development directions in the future.

## 6. Further trends

With the improvement of environmental awareness, the third generation of solar cells in the future will pay more attention to the development and application of environmentally friendly materials. These environmentally friendly materials not only have efficient photoelectric properties, but can also reduce the release of harmful substances during production and use, promoting the development of green energy. Improving the long-term stability and durability of third-generation solar cells is the focus of future research. Although current perovskite solar cells perform well in the laboratory, they still need to overcome long-term stability issues in practical applications. By optimizing packaging technology and interface engineering, the impact of environmental factors on battery performance can be effectively prevented and its service life extended. In addition, the stability improvement of quantum dots and organic solar cells also needs to be achieved through material modification and process optimization.

## 7. Conclusion

Third-generation solar cells utilize advanced materials and novel mechanisms to overcome the limitations of the first two generations, achieving higher efficiency and lower production costs. Its working mechanism mainly includes light-absorbing materials, hole transport layers, electron transport layers and electrodes. Perovskite materials excel due to their high light absorption properties and high carrier mobility. The third generation of solar cells has excellent performance in terms of energy density, life cycle and cost. In particular, the photoelectric conversion efficiency of perovskite solar cells has exceeded 25%. However, there are also some challenges and bottlenecks, including long-term stability issues, technical bottlenecks in the production process, and environmental and health risks of certain materials.

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