Comparison Between Perovskite and Silicon for Photovoltaic Cell Applications and Future Industrial Prospects

Wentao Ding *

School of Engineering, The University of Edinburgh, Edinburgh, EH9 3JU, United Kingdom

* Corresponding Author Email: s2345604@ed.ac.uk

Abstract. Environmental concerns have evolved into an essential focal point within contemporary human progress. An increasing number of individuals are recognizing the paramount significance of safeguarding our environment and are actively engaged in crafting a sustainable developmental framework. An integral facet of sustainable progress is the adoption of clean energy, representing a pivotal paradigm shift in the global energy landscape. One remarkable manifestation of this shift is the utilization of photovoltaic (PV) cells, which adeptly transmute radiant light energy into electrical power. This paper delves into an exploration of the prevailing silicon photovoltaic cells widely accessible in the market, while also delving into the realm of perovskite photovoltaic cells, an experimental yet highly promising avenue. It endeavors to juxtapose these two technologies across various dimensions, including energy conversion efficiency, overall cost implications, and environmental repercussions. Evidently, silicon and perovskite technologies manifest distinct advantages and drawbacks in different contexts. It is unequivocally established that both forms of photovoltaic cells hold profound implications for the future trajectory of energy consumption and the overarching ethos of sustainable development.

Keywords: Silicon; Perovskite; Photovoltaic cell; Sustainability.

1. Introduction

Human development, whether scientific and technological or cultural, cannot be separated from the natural environment, which is the basis of everything. The industrial revolution made people realize that the importance of the environment should not be neglected while developing technology, and that the establishment of a sustainable development system is the right direction of development. The use of energy is an important part of the concept of sustainable development. As early as 1981, Brown from the United States mentioned the development of renewable energy to achieve sustainable development in "Building a Sustainable Society" [1]. In 2015, the World Summit on Sustainable Development adopted 17 sustainable development goals, one of which is about clean energy [2]. The most representative use of clean energy is photovoltaic cells. Photovoltaic cells are power generation devices designed to convert solar energy into electricity, thereby reducing carbon emissions compared to conventional power generation such as thermal power. Photovoltaic cells on the market today are mainly made of silicon, but their conversion efficiency has never allowed them to become a mainstream power generation method. Because of this, scientists are looking for other materials to make photovoltaic cells, and one of the materials that has received a lot of attention is chalcogenide.

This paper provides an overview of the introduction and comparison of conventional silicon photovoltaic cells and perovskite photovoltaic cells, as well as future perspectives and challenges. In section 2, the working principle of these two materials in PV cells is described in detail. In section 3, the two materials are compared in different aspects, namely energy conversion efficiency, cost, and environmental impact of the materials. In the end, the respective shortcomings of silicon and perovskite photovoltaic cells are discussed, such as in terms of durability, stability, and performance in extreme environments. The future opportunities of PV cells are also discussed, such as future applications in more industries, material innovation, government policy support, and market demand.

2. Characterisation of photovoltaic cells and two materials

2.1. Basic introduction to photovoltaic cells

Photovoltaic cells, also known as solar cells, are devices capable of converting sunlight directly into electricity, mainly for clean energy generation. They work on the basis of the photovoltaic effect, which refers to the fact that when sunlight (photons) strikes a semiconductor material, electrons are excited to produce an electric current [3]. The specific workflow is that photons from sunlight are first absorbed by the semiconductor material in the photovoltaic cell, and the energy of the absorbed photons allows the electrons in the semiconductor to gain enough energy to jump from the valence band to the conduction band, forming free electrons and holes. The free electrons and holes are then separated by an electric field, causing the electrons to flow towards one side and the holes to flow towards the other, creating an electric current. Finally, electrodes inside the cell collect the flowing electrons and holes to produce usable electrical energy. These cells typically consist of multiple thin sheets or layers of semiconductor material used to capture and convert solar energy into usable electrical energy. Photovoltaic cells are widely used in solar power systems to provide clean energy. Different types of photovoltaic cells vary in efficiency, cost, and application areas. Different types of photovoltaic cells use different semiconductor materials and mechanisms of operation, including the silicon and perovskite solar cells I will discuss today. PV cells of these different materials differ in terms of solar energy conversion efficiency, cost, and applicable environments.

2.2. Properties of silicon and its application to photovoltaic cells

Silicon is a common semi-metallic, semiconducting material with a conductivity between that of a conductor and an insulator. In pure silicon crystals, silicon atoms are linked together in the form of tetrahedra to form a lattice structure with few free electrons and holes, but doping with impurities can create "p-n junctions" that can alter its conductivity [4]. Silicon absorbs photon energy, which produces electron-hole pairs that are then separated by an electric field to form an electric current, which is the basis of the photovoltaic effect. The photovoltaic cell is made of multilayer silicon material, when sunlight hits its surface, the silicon material in the cell absorbs photon energy and interacts with the silicon atoms, and the energy is transferred to the electrons in the silicon. The absorbed light energy excites the electrons in the silicon, causing them to jump to the conduction band, forming free electrons and leaving holes behind. This jump is called photogenerated carrier production. N-type silicon with added phosphorus and P-type silicon with added boron are joined together to form a p-n junction. At the p-n junction, an electric field is formed, under which free electrons move towards the P-type region on one side of the cell and holes move towards the N-type region on the other side of the cell. The separated electrons and holes generate an electric current that electrodes can collect inside the cell. This current is the electricity that is converted from sunlight [5]. In summary, silicon photovoltaic cells produce an electric current by creating a p-n junction in silicon and an electric field to separate and collect the electrons and holes produced.

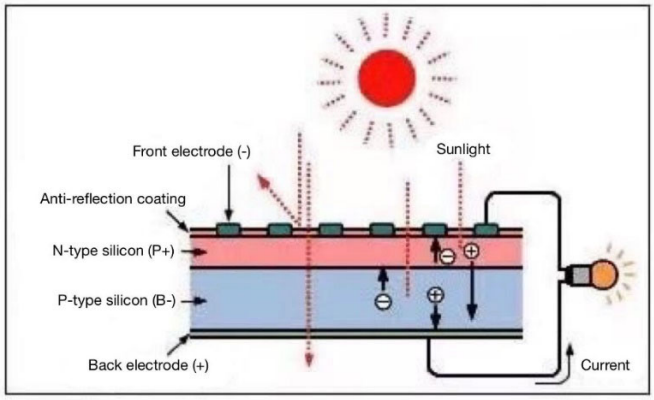


Fig. 1 Silicon photovoltaic cell structure [5]

2.3. Properties of perovskite and its application to photovoltaic cells

Perovskite is a material with a special crystal structure with the chemical structure ABX3, where A and B are cations and X is an anion [6]. It has excellent light absorption and photovoltaic conversion properties and is suitable for use in photovoltaic cells. The most common application of perovskite is in solar cells, where organometallic halide perovskite is used. This perovskite material efficiently absorbs light in the visible range, converting it into charge carriers that generate an electric current. The light absorption coefficient of the perovskite material in the visible range is very high, allowing it to effectively absorb sunlight [7]. The electron-hole pairs in perovskite materials have relatively long lifetimes, which helps to increase the efficiency of the separation of electrons and holes, thereby increasing the efficiency of the battery. The band gap width of perovskite materials can be adjusted by changing the components and structure, which makes them effective in absorbing light energy in different wavelength ranges.

The principle of using perovskite in photovoltaic cells is also based on the photovoltaic effect, but it is different from conventional silicon photovoltaic cells. Perovskite photovoltaic cells use perovskite as a light-absorbing layer, as shown in Figure 2. When light hits the perovskite layer, these materials efficiently absorb the energy in sunlight and convert it into charge carriers. The absorbed photons' energy causes the perovskite's electrons to jump from the valence band to the conduction band, forming electron-hole pairs. The electrons in the conduction band become free electrons, while the holes in the valence band are electron-deficient sites. In the structure of a perovskite solar cell, the electrons and holes can be separated into different polar regions of the cell, which helps to create a potential difference that drives the flow of electrons and holes in different directions. A p-n junction or p-i-n structure is commonly used to separate electrons and holes. The electrons will flow towards one polarity of the cell while the holes will flow towards the other polarity. The current formed through the separated electrons and holes can flow through an external circuit to generate electrical energy, enabling the conversion from light energy to electrical energy. In summary, perovskite solar cells use perovskite materials' light absorption and electron-hole separation properties to convert solar photons into electrical energy. Their high absorption, good energy conversion efficiency, long carrier lifetime, tunable bandgap width, and relatively low manufacturing cost make them an emerging photovoltaic technology of great interest.

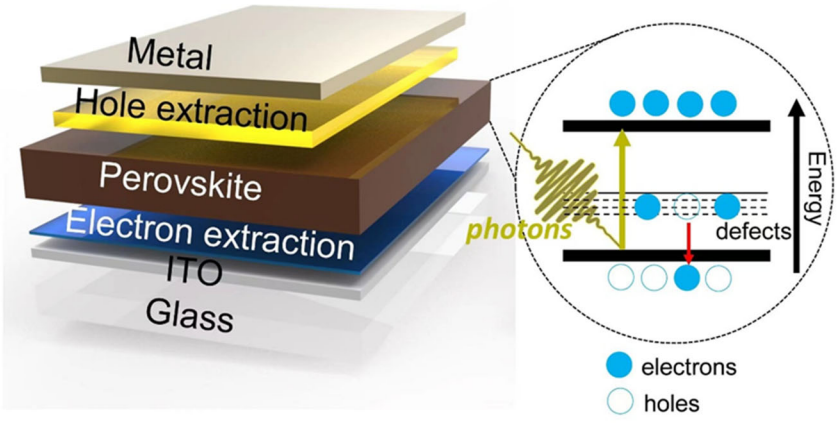


Fig. 2 Perovskite photovoltaic cell structure [8]

3. Comparison of the two materials

3.1. Comparison of the efficiency of the two materials

Silicon is one of the most used materials in photovoltaic cells, and its energy conversion efficiency varies depending on a number of factors. Monocrystalline and polycrystalline silicon solar cells typically have high conversion efficiencies, ranging from about 15 to 22 percent. Amorphous silicon

solar cells, on the other hand, typically have lower efficiencies, ranging from about 5 to 12 percent. Silicon solar cells' efficiency is affected by various factors, including material quality, cell structure, light intensity, temperature, etc. The manufacturing process is also an important factor affecting silicon photovoltaic cells. As a new type of solar cell technology, the perovskite solar cell has a higher energy conversion efficiency. Perovskite solar cells have achieved efficiencies of more than 20 to 25 percent in the laboratory, as illustrated in Table 1.

Table 1. Comparison of energy conversion efficiency of different photovoltaic cells

Materials	Minimum conversion efficiency (%)	Maximum conversion efficiency (%)
Monocrystalline/polycrystalline silicon	15	22
amorphous silicon	5	12
perovskite	20	25

Zhaolai Chen from King Abdullah University of Science and Technology (KAUST) and his team of researchers in 2019 studied monocrystalline perovskite photovoltaic cells with an energy conversion rate of around 21 percent [9]. However, the relative lack of stability and durability of perovskite solar cells means that they are still being researched and cannot be put into large-scale commercial use like silicon cells, so there will still be some errors in the conversion efficiency when they are actually used. The method proposed by Bhattacharya and the team at the University of Toronto in their 2019 paper allows for an energy conversion rate of over 30 percent for silicon photovoltaic cells [10]. However, this is not universal to the market, so overall the energy conversion efficiency of perovskite is still higher than silicon.

Overall, perovskite solar cells have potential in terms of efficiency, but silicon solar cells are more mature and stable in commercial applications. In the future, with further improvements in technology, perovskite solar cells may make greater breakthroughs in energy efficiency.

3.2. Comparison of the combined costs of the two types of batteries

When it comes to the cost of manufacturing photovoltaic cells, there are a number of factors that need to be taken into account. Firstly, there is the cost of materials. Although silicon is the second most abundant element in the earth's crust, the manufacture of PV cells (photovoltaic cells) requires high-purity silicon, whereas the cost and difficulty of obtaining the raw material for perovskite are lower than that of high-purity silicon. Secondly, the production process of perovskite PV cells is simpler than that of silicon PV cells, which results in lower energy costs, labor costs, and equipment costs than silicon cells. a 2022 article on the Solar Square website states that polycrystalline silicon and monocrystalline silicon PV cells cost about 25.5 rubles per watt and 31 rubles per watt, while perovskite PV cells cost 12-13 rubles per watt, refer to Table 2 [11].

Table 2. Manufacturing costs of different photovoltaic cells

Types of photovoltaic cells	Manufacturing costs (roubles/watt)
Monocrystalline silicon photovoltaic cells	31
Polycrystalline silicon photovoltaic cells	25.5
Perovskite photovoltaic cells	12-13

However, the cost of manufacturing photovoltaic cells is more specific, for example, the cost of labor varies from place to place, as well as the equipment and manufacturing process of different manufacturers for the same material, so it is not possible to make an absolute comparison between the two types of cell manufacturing costs. A comprehensive comparison of the cost of perovskite photovoltaic cells will be a little lower.

3.3. Comparison of the environmental impacts of bulk use and mining

The natural environment is an aspect that all engineers and scientists take into account, and the adoption of photovoltaic power generation is an effort to improve the environment and achieve sustainable development. Of course, the manufacture and use of photovoltaic cells does not mean that there is zero impact on the environment. The manufacturing process for silicon PV cells typically requires more power and energy from fossil fuels or other unsustainable fuels and involves multiple steps from the production of high-purity silicon to crystal growth, some of which may involve high temperatures or chemical processing. This can lead to energy consumption and some degree of greenhouse gas emissions. As I mentioned above, the manufacturing process for perovskite PV cells is usually relatively simple and does not require high-temperature processes, and therefore may be lower in terms of energy consumption. However, the process of mining and refining perovskite materials can also lead to pollution of soil and water resources. At the same time, a number of chemicals and solvents are used in the manufacturing process of both types of batteries, which may pose potential risks to the environment and workers' health.

During the use phase, both types of photovoltaic cells take up a larger land area and resources to receive the sun's rays because they are photovoltaic. Of course, both types of cells do not emit greenhouse gases or other environmentally unfavorable substances during operation and do not directly contribute to atmospheric pollution.

Overall, both types of photovoltaic cells are applications of renewable energy, reducing dependence on fossil fuels, environmental pollution, and climate change. At the same time, both materials of the battery in the process of making each have a certain adverse impact on the environment, both in the stage of manufacturing the environmental impact is similar. However, as technology develops in the future, the manufacture of photovoltaic cells will become more and more environmentally friendly.

4. Future Challenges and Outlook for Photovoltaic Cells

4.1. Deficiencies and challenges

Contemporary solar photovoltaic (PV) cells have many shortcomings that are waiting to be solved. Photovoltaic power generation systems on the earth's surface can only work during the daytime, and the efficiency of photovoltaic power generation is even more affected if it encounters cloudy, rainy, or foggy days. Photovoltaic cells may be affected by environmental factors, such as ultraviolet rays, temperature changes, etc., during long-term use, thus affecting their stability and lifespan. Its conversion efficiency is also not as good as other traditional power generation methods, which means that photovoltaic power generation is not yet able to completely replace other power generation and can only be used as a subsidiary power generation method in human daily life.

At the same time, different photovoltaic cell materials also have their own disadvantages. Silicon, the traditional semiconductor material mentioned in this paper, is abundantly produced, but to make silicon photovoltaic cells, expensive machines, and complex manufacturing processes are needed. The spectral range and energy conversion efficiency of silicon crystals are limited, preventing photovoltaic power generation from becoming a mainstream power generation method. As a new semiconductor material, perovskite has improved conversion efficiency, but its stability is far less than that of silicon. Perovskite photovoltaic cells may be degraded under high temperature, humidity, and other conditions, which greatly affects their service life. The lattice structure of the perovskite material may undergo volume changes under prolonged exposure to strong light, which may lead to device failure. Secondly, perovskite may contain toxic elements such as lead, which may pose potential risks to the natural environment and human health during manufacturing and disposal.

4.2. Future development

The future of photovoltaic cells as a sustainable power generation and storage device using clean energy is sure to be well-developed and full of opportunities. In the future, scientists will keep trying to improve the energy conversion efficiency of photovoltaic cells by adopting new materials, designs, and structures to achieve higher energy conversion rates. Photovoltaic technology can be applied to a wider range of fields. It may be integrated into a variety of applications such as building materials, vehicles, etc., to provide clean energy for various fields, to achieve overall sustainable development, and to bring a better living environment for human beings. Photovoltaic technology in terms of flexibility, if it can be developed, this technology can set the battery module in the daily clothing or wearable devices, to achieve better and faster human-computer interaction. Of course, the main thing is to find more effective light absorption materials, photovoltaic conversion materials, and materials that can adapt to extreme weather and still have stability, which is the carrier of photovoltaic technology, but also the core. Increasing energy conversion efficiencies will enable PV technology to provide stand-alone power to replace conventional power generation and improve energy supply. The environmental impact and cost control of the manufacturing and disposal phases also need to be continually reduced to drive PV technology in a more sustainable direction.

As mankind places greater emphasis on the environment and explores sustainable development, the future market demand for PV technology is increasing, which will inevitably usher in government support. In China, one of the world's largest PV markets, the government has developed a number of programs, such as the "PV Poverty Alleviation" program, which aims to build PV power plants in poor areas to provide electricity to the population and has also invested large sums of money in the PV technology industry [12]. The European Union's "Green Deal" plan to achieve carbon neutrality by 2050, which increases investment in renewable energy sources such as solar energy, provides more opportunities for the PV technology industry [13]. The U.S. states and the federal government have been vigorously developing solar PV research and development since the release of the National Energy Act in the 1970s, which not only includes investment but also the introduction of many related programs [14].

From a comprehensive point of view, photovoltaic technology is a technology that will inevitably need to be developed in the future, and it will inevitably have broad prospects and potential. With the advancement of science and technology and the promotion of innovation, photovoltaic technology is expected to bring about an energy revolution in the future and play an irreplaceable and important role in the global energy system.

5. Conclusion

Photovoltaic cells, whether made of silicon or perovskite, are an important part of the contemporary energy system. As a new material, perovskite naturally has many advantages, although there are also many issues that need to be taken into account. This paper draws the following conclusions from a comprehensive comparison of silicon photovoltaic cells and perovskite photovoltaic cells:

Firstly, perovskite photovoltaic cells have a higher conversion efficiency than silicon photovoltaic cells. Secondly, the overall fabrication cost of perovskite PV cells is relatively lower than that of monocrystalline and polycrystalline silicon PV cells, although the cost varies with the fabrication requirements of different manufacturers and different factors. Thirdly, both have some environmental and health impacts during remanufacturing, though the process of using them is beneficial to nature. Fourthly, the spectral range and energy conversion efficiency of silicon crystals are limited, and the longevity and stability of perovskite are far less than silicon. This prevents the photovoltaic cells made by both from becoming mainstream power generation at this time.

In conclusion, both types of photovoltaic cells are very promising, and in the future, they will need to be invested in both capital and manpower to make them even better when applied to photovoltaic

cells. At the same time, the research on photovoltaic cells is not only to alleviate the earth's energy problems but also a further exploration of mankind in the direction of sustainable development.

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