Research Journal of Chemical Sciences ISSN 2231-606X
Vol. **16(2),** 68-80, June **(2026)** *Res. J. Chem. Sci.*

Review Paper

Perovskite Solar cells as an advanced Solar Technology

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Available online at: www.isca.in, www.isca.me
Received 5th February 2026, revised 10th March 2026, accepted 26th April 2026

Abstract

Perovskite solar cells (PSCs) are one of the most promising new types of solar cells because they have great optoelectronic properties, low production costs, and their power conversion efficiencies are getting better quickly. Since they sent in their first report, PSCs have done very well. Over the course of a relatively short time, they were able to achieve a verified efficiency of more than 26 % for their development throughout the course of this paper. We will discuss the fundamental ideas that form the basis of PSCs, as well as the technological advancements that have been made in this field over the course of time. At the beginning of the event, there is a discussion about the problems that are occurring with the energy supply all over the world and how important it is to develop solar energy sources that are less harmful to the environment. People are talking about the ways in which PSCs have evolved and grown over the course of time, with a particular emphasis on the experiences that have been the most significant and the way in which they have become most effective. In particular, the characteristics that are inherent to perovskite materials are the focus of the research. This group has a lot of different traits. Some of these traits include a high absorption coefficient, a long charge-carrier diffusion length, the ability to change the bandgap, and the ability to fix mistakes. The report goes into more detail about the different materials that are used to make the different layers of solar cells. This material has electrodes, layers that move electrons, layers that move holes, and perovskite absorbers. Photovoltaic solar cells work by taking in light, making charges, separating them, moving them, and collecting them. This paper talks about the many ways that photovoltaic solar cells can be used.

Keywords: Perovskite Solar Cells, Energy, Solar Technology, Perovskite Materials, Optoelectronic properties.

Introduction

The amount of energy used around the world has never gone up this much in the 21st century, and this is a big problem for the world we live in today. The world's energy supply is under more and more pressure because of faster population growth, more industrialization, bigger cities, and ongoing technological progress. For a long time, people all over the world have mostly used coal, oil, and natural gas to get their energy. People like them mostly because they are easy to find, have a lot of energy, and are well-known. On the other hand, using fuels for a long time has many bad effects on both the company and the environment.

Some of these effects are more air pollution, more greenhouse gas emissions, climate change all over the world, and the slow loss of natural resources that can't be renewed. As the global cost of making energy from fossil fuels becomes clearer, people are getting more worried about the long-term safety and sustainability of energy[1]. Because of issues like smog, acid rain, ocean acidification, and rising temperatures around the world, we need to find new ways to use energy right now. Switching to clean and renewable energy sources is no longer just a choice; it is now a world need that must be met. Solar power is one of the most promising and convincing solutions to the world's energy problems, out of all the different types of renewable energy that are available right now. Solar power is the best way to meet the world's growing energy needs because it is plentiful, easy to get to, and almost limitless. People think that the sun can send enough solar energy to the Earth in just one hour to meet the basic energy needs of everyone on Earth for a whole year. This discovery blows my mind. Photovoltaics have a lot of potential, so scientists, engineers, and technology developers have done a lot of research on them. Over the past few decades, the photovoltaic industry has seen a lot of changes. Crystalline silicon solar cells are the most common type of solar cell sold on the commercial market. This is because they are very reliable, last a long time, and are very good at turning electricity into other forms of energy. These technologies have made it possible for solar power generation on a large scale to happen all over the world. Each new generation of photovoltaic technologies has its own materials, ways of making them, cost structures, and ways of measuring how well they work[2].

Figure-1 shows how photovoltaic technologies have changed over time. First-generation silicon solar cells are still the most prevalent type on the market. However, because they are expensive to make and need a lot of energy to process, new photovoltaic materials and methods for producing next-generation solar cells have been developed.

Historical Background

The world's energy needs have gone through the roof because of rapid population growth, urbanization, and industrialization. The majority of this demand continues to be for fossil fuels such as coal, oil, and natural gas. The main reasons for climate change, air pollution, and greenhouse gas emissions are the burning of these fuels. Because of this, both national and international policies now place a lot of importance on switching to clean and sustainable energy. Solar energy is one of the best renewable resources because it is abundant, easy to find, and works well with both centralized and decentralized systems. The most common type of solar cell right now is the crystalline silicon (c-Si) solar cell. This is because they are very efficient, reliable, and well-made. On the other hand, silicon is getting close to its practical efficiency limits and needs high-temperature wafer processing, stiff modules, and production costs that are relatively high. These limits drive the search for new thin-film photovoltaics. This limitation is why metal halide perovskite solar cells (PSCs) are now one of the best types of third-generation PV technology. In slightly over ten years, PSCs have gone from about 3.8% certified PCE (2009) to about 26.7%. Perovskite and silicon tandem cells are currently working more than 34% of the time. PSCs are excellent for optoelectronics and can be made in solution at low temperatures. They also have adjustable band gaps and work well with flexible structures that allow light to pass through. This makes them very useful for many solar projects.

The Generations of Solar Cells: The objective of solar cell innovation is to create a solar cell that is not only more efficient but also more cost-effective and that lasts for a longer period of time. It is also expected that this solar cell will be cost-effective. The main goal of photovoltaic technology has been to inspire research into new materials and creative ways to make solar cells. This will help us reach these three goals. This has been the goal all along. There are four different kinds of solar cells, and each one is named after the year it was originally sold.

First generation: Crystalline silicon solar cells: Most solar cells on the market are "Generation I" devices made of crystalline silicon (c-Si). Making devices out of c-Si is a well-known and well-developed technology. They are somewhat expensive to make because of the high processing costs needed to make silicon wafers with high purity and long-range order. Silicon solar cells are the most commonly used type of solar cell because they are very good at converting light into electricity, even when they are just one-junction photovoltaic devices. Also, the fact that silicon is so common makes it the most popular material in the PV field. Silicon has an indirect band gap of 1.12 eV, which means that it can absorb light in the visible and infrared parts of the spectrum. If an empty state in the conduction band has the same energy and momentum as an electron in the valence band with the addition of the incoming photon, the photon will be absorbed. In an indirect band gap semiconductor like silicon, the conduction band and the valence band are not directly above each other. In this case, the absorption process includes a phonon, an electron, and a photon[3,4]. The chances of these three particles interacting with each other are lower than the chances of an electron and a photon interacting with each other in a direct band gap semiconductor. So, it is clear that absorption is much higher in a material with a direct band gap. Also, making Silicon (Si)-based solar cells is expensive because it requires very advanced manufacturing methods and the cost of electronic-grade silicon wafers. Also, Si-based solar panels are heavy and stiff, which means that they need expensive mechanical support systems to be installed.

Second generation: Thin-film solar cells: Generation II materials are the least advanced as a PV technology. They are typically deposited using vacuum-assisted or chemical vapor deposition (CVD). Generation II materials include chalcopyrite-based compounds, like Cd Te and copper-indium-gallium-selenide (CIGS) technologies, as well as amorphous silicon thin-film solar cells. They are relatively inexpensive, but their performance is lower. But they are better because they can be made in much thinner and lighter formats than Si-based ones. This is why these solar cells are also called thin-film solar cells[5]. There are a few significant differences between first-generation and second-generation solar cells. The most significant distinction is that the semiconductor material in the first cell has a direct band gap, whereas the silicon semiconductor material in the second cell has an indirect band gap. This is the most critical difference. These thin-film solar cells are better to first-generation solar cells due to the fact that they are more economical; yet, they still have a few problems. There is an example of a substance that is difficult to obtain and expensive, and that is indium. A new generation of solar cells was developed as a result of these issues as well as the requirement for economies of scale.

Third generation: The third generation of photovoltaic technologies aims to address the deficiencies and constraints of preceding generations through a comprehensive array of innovations. Some of these are Quantum Dot Solar Cells (QDSCs), Perovskite Solar Cells (PSCs), Organic Photovoltaics (OPV), and Dye-Sensitized Solar Cells (DSSCs). Organic polymers are a key component of OPV technology that captures light. DSSCs have a photosensitive dye that helps them absorb sunlight. They are also light, flexible, and can be made cheaply. Still, their efficiencies are not as good as those of other photovoltaic technologies[6]. Generally, third-generation cells are known to work well in low light and come in a variety of configurations. Perovskite, a material that absorbs light, is used in PSCs; on the other hand. They are very popular because they quickly become more efficient, with improvements of more than 25% in a short amount of time in the lab. This makes them perfect for mass production at a low cost[7]. Quantum dots are used as light-absorbing parts in Quantum Dot-Sensitized Solar Cells. These are tiny crystals of semiconductors. They help in modifying the band gap, which increases their efficiency[8].

Fourth generation: This generation is at the forefront of photovoltaic research, coming up with new ideas and materials to make solar energy more useful, affordable, and efficient in a variety of situations. This generation includes multi-junction solar cells as one of its technologies. They use different semiconductor materials with different band gaps to catch more of the solar spectrum[9]. These cells may be able to work better than single-junction cells. Also, there is a type of solar cell that tries to catch the extra energy of charge carriers that photovoltaic cells make before it turns into heat. This kind of solar cell could work much better than others. Last but not least, there are plasmonic solar cells. These cells can make thin-film solar cells work better by making them absorb more light. These cells make use of plasmonic nanoparticles[10,11]. The first and second generations of solar energy; however, the third and fourth generations have a great deal of potential for the future. PSCs are now one of the most promising solar technologies in the third generation[12].

As a result of their employment of cost-effective procedures, such as solution-based approaches and vacuum deposition methods, PSCs consistently exhibit superior performance and cost-effectiveness. These can be manufactured at lower temperatures in comparison to silicon cells, which need methods that are more complicated and expensive. These processes include high-temperature crystallization and silicon purification. The simultaneous creation of a large number of PSCs is made possible by these technologies, meaning that they have the potential to be applied in the commercial sector. The band gap of PSCs may be adjusted; they have a high absorption coefficient, and they have long diffusion lengths for charge carriers[13,14]. These are only some of the intriguing characteristics that PSCs exhibit.

The PSCs are even more flexible because they can be made on flexible substrates. This means that they can be used on surfaces that aren't flat, worn, or in places other than where solar panels are usually found. Also, PSCs let you use tandem solar cells, which are solar cells that combine the perovskite absorber layer with other materials, like silicon, to make solar cells that work better than single-junction solar cells. Silicon solar cells, on the other hand, are mostly used in homes and large solar farms because they work well in many different kinds of weather and have been around for a long time. There are stilla lots of significant issues that need to be resolved before the PSC technology can be manufactured in large quantities, despite the fact that it has gone through a lot of improvements. One of the biggest difficulties that can happen when photovoltaic cells are exposed to high temperatures, high humidity, and UV light for a long time is that they stop working. Researchers have looked into a number of various ways to make them more stable. Some of these ways are changing the material and how they are packaged. Silicon solar cells, on the other hand, are well-known for their long life and durability because they are comprised of silicon[15-17]. They can last for more than 25 years with little wear and tear. There have been recent advancements in the fields of material science, device physics, and architecture that have led to the development of viable solutions for these issues. Numerous breakthroughs in compositional engineering, enhancements in interfaces, and encapsulation methods have contributed to an increase in the stability of the PSCs as well as an increase in their operational lifetimes. It is clear that research is being done to make photovoltaic solar cell (PSC) technology better for the environment. However, there are still a lot of lead-free solar cells that don't work very well.

Fundamental properties of perovskite solar cells: The elevated PCE and open-circuit voltage (Voc) result from various distinctive characteristics of perovskites (Figure-2), including a high absorption coefficient (>10 cm^{-1}), long carrier diffusion lengths, moderate carrier mobility, high defect tolerance, and slow carrier recombination. Research indicates that these extraordinary characteristics may arise from several factors, including intrinsic ferroelectricity, bulk photovoltaic effects, surface fields and diffusion, carrier-lattice interactions, and the formation of large polars[18,19]. It is important to look into the basic structure, chemical makeup, and material properties of the perovskite materials that make PSCs work so well. This will help us figure out why they act the way they do. The first part of the discussion is about the structural properties of perovskite materials and why these properties are important for photovoltaic applications. In the next parts of this study, we will talk about these things in more depth.

Materials used in PSCs: To get the most out of these appliances, you need to know a lot about the different materials that are used to make PSCs. The materials' properties mentioned above not only affect how stable and efficient the device is, but they also affect how it looks, how big it is, and how much it costs. To understand how the choice of materials affects the cell's overall performance and reliability over time, it is necessary to first look into each important layer of the PSCs. Below, you will find a more detailed breakdown of each of the materials that make up PSCs.

Charge Transport layers: Charge transport layers are a key part of perovskite solar cells (PSCs) because they make the cells work better and more reliably. These charge carriers help move the charge carriers that light makes from the active layer of perovskite to the electrodes. This step is finished. Charge transport layers (CTLs) have a big impact on how well perovskite solar cells work[20]. In order for CTLs to work with the perovskite structure, they must have some of the following characteristics: improved electrical conductivity, proper energy level alignment, excellent optical transparency, and the capacity to integrate all of these characteristics. ETLs (for electron transport layers) and HTLs (for hole transport layers) are the two main types of charge transport layers.

Electron Transport Layer (ETL): In photovoltaic solar cells (PSCs), the electron transport layer (ETL) plays a significant role because it assists in the elimination of electrons, the alignment of energy levels, the blocking of holes, and the reduction of recombination losses. Eliminating recombination and increasing the efficiency of charge transfer are two of the ways in which ETLs contribute to the stability of PCS[21]. In order to achieve the desired speed of electron movement, it is necessary to ensure that the conduction band minimum of the ETL and the perovskite layer are in perfect alignment. To make the device last longer, the ETL used must not dissolve in perovskite precursors and must be able to handle damage from moisture, oxygen, light, and heat. J-V hysteresis is a problem that PSCs have that can slow down their ability to make things. Some ETL materials can help with this. Electron transport layers make it easier for electrons to move by being thin, uniform, and compact. Additionally, they reduce the likelihood that recombination and short circuits will occur among the components. A wide variety of materials, including organic and inorganic semiconductors, have been investigated by researchers to determine whether or not they have the potential to be utilized as ETLs. These materials each have their own set of advantages and disadvantages. Figure-3 illustrates the energy level representation of a number of the ETLs that are utilized in perovskite solar cells, which are among the most common.

Types of Electron Transport Layer: Inorganic Electron Transport Layer: Inorganic materials, particularly metal oxides, have been widely employed as ETMs due to their high electron mobility and chemical stability.

TiO_2 is a common ETL in PSCs because it has a wide band gap (~3.2eV) and high electron mobility, which makes it good at picking out electrons. Due to the fact that it possesses a high level of chemical stability, it is an excellent material for the front contact in solar cells.TiO_2 is a common ETL in PSC, but it has a lot of surface trap states that can make electrons recombine and cause J-V hysteresis. This could make the device less stable and less efficient[22].

SnO_2 is becoming a more popular choice over TiO_2 because it has a high electron mobility and a wide band gap (3.6 eV). These two properties make it very clear in the visible spectrum. It is different from TiO_2 because it has a lower recombination rate and a smaller hysteresis. SnO_2 is a great material for flexible substrates and low-cost applications because it can be treated at lower temperatures[23].

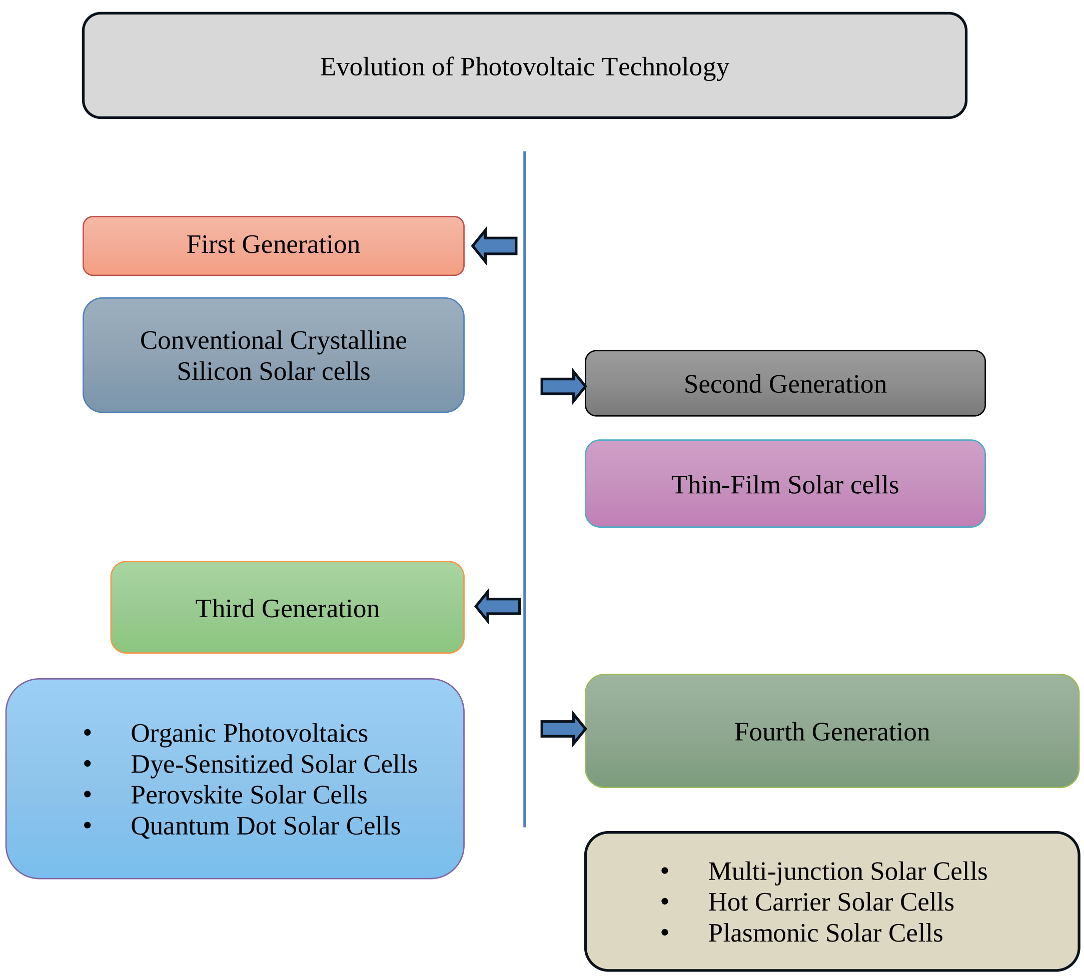

Figure-1: Different generations of photovoltaic technologie.

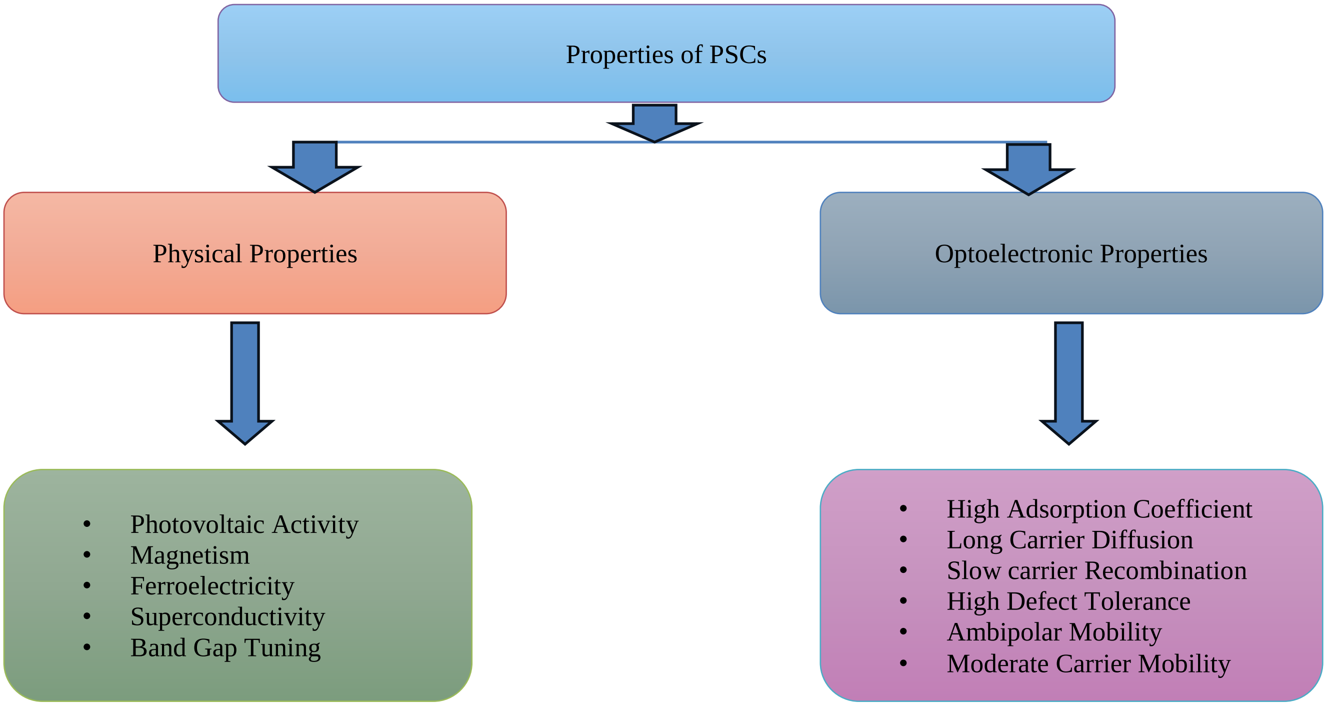

Figure-2: Fundamental properties of PSCs.

ZnO is good at moving electrons because it has a wide band gap (3.3 eV), and electrons can move through it easily. It needs to be treated on its surface to stay stable over time[23].

Nb_2O_5 is not used as much, but it has a lot of potential because it has a wide bandgap (3.4–3.6 eV) and good electron mobility. It is also very chemically stable and can reduce recombination losses in some PSC architectures[24]. The characteristics of ZnO are enhanced by the addition of magnesium, which causes the bandgap and electron mobility to increase. This results in the material becoming more stable and reducing the rates of recombination[24].

Nb-TiO_2 is superior to pure TiO_2 due to the fact that it facilitates the movement of electrons and reduces the number of defects that are present at the interface with the perovskite[25]. It may be seen from this that both Voc and Jsc are higher.

WO_3 has a broad bandgap (varying from 2.6 to 3 eV) and outstanding electron mobility, despite the fact that it is not utilized as frequently as other materials would be. It has the potential to serve as an alternate ETL for specialized PSC systems, given that it is chemically stable[25].

This is because of the fact that it is chemically stable. Because of its insulating qualities, Al_2O_3 can be utilized as a mesoporous scaffold. This is despite the fact that it is not a material that is generally used for transferring electrons. Moreover, it permits carriers to go greater distances within perovskite layers, which is in addition to making things more stable mechanically. However, while having a greater Voc, it has a lower fill factor[25]. This is because of the higher impedance that it contains.

Organic Electron Transport Layer: Organic electron transport materials, also known as ETMs, are attracting a lot of attention as a result of their ability to undergo transformation and processing at low temperatures. This is the reason why ETMs are so popular. Existing materials can be divided into two categories: those based on fullerene and those that do not contain fullerene[26].

Fullerene-Based Organic ETMs: Fullerene derivatives like C_{60}, C_{70}, and [6,6]-phenyl-C_{61} butyric acid methyl ester (PCBM) are popular due to the fact that they are able to quickly extract electrons, possess high electron mobility, and have the appropriate energy levels. On the other hand, they are not only pricey but also not very stable, and they do not disintegrate very well[27].

Non-Fullerene Organic ETMs: Organic electron transport materials (ETMs) that aren't fullerenes offer alternative options to fullerenes and give you more freedom when designing molecules. You can put them into these groups: Organic ETMs with a small molecular chain: These have simple, well-defined structures that make it easy to purify and characterize the substance. To enhance charge transfer, these outcomes lead to the creation of homogeneous and compact sheets on the perovskite layer. There are derivatives of pyrazine-azaacene, naphthalene diimide, and perylene-diimide, for example[28].

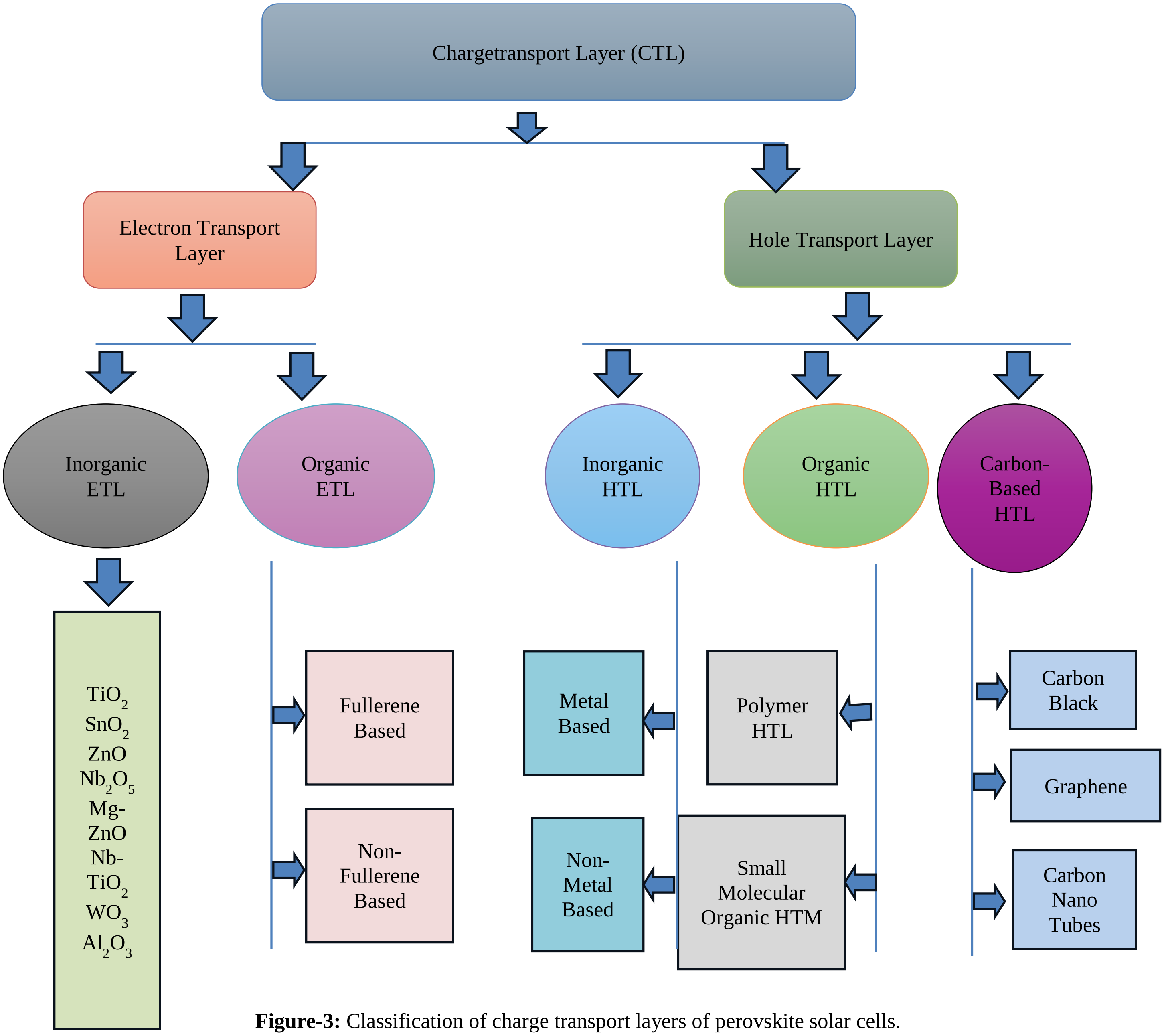

Figure-3: Classification of charge transport layers of perovskite solar cells.

Hole Transport Material: HTMs play a crucial role in connecting the perovskite layer to the anode in PSCs. Their main job is to gather holes that are made in the perovskite layer and send them to the anode. They also prevent electrons from passing through the recombination of holes. Types of HTMs

Organic HTMs: People often use organic HTMs in PSCs because their molecular structures can be changed, their energy levels can be changed, they work well with the perovskite layer, and they can be processed in solution at low temperatures[29]. There are two types of organic HTMs: small molecular organic HTMs and polymer HTMs. Each has its own merits and demerits.

Small Molecule Organic HTMs: The architectures of small molecular HTMs are straightforward to observe, which makes it less difficult to purify and identify these specific molecules. As a general rule, they produce films that are dense and homogeneous on the perovskite layer, which makes it simpler to transfer and remove charge. Spiro-OMe TAD and PTAA are two examples of small-molecule HTMs that are utilized on a regular basis throughout the world. These materials were selected since there is a possibility that they will improve the stability of the device as well as the shape of the film[30].

Polymeric HTMs: They are able to create networks that pass through the perovskite layer because polymeric HTMs, such as P3HT and PEDOT: PSS, have structures that are more complicated than those of typical HTMs. Because of this structural advantage, the device is more stable, and it also fixes interface problems, resulting in improved functionality at the device. It is also possible to modify polymer HTMs chemically, which makes them valuable for improving the functionality of devices and extending their lifespan.

In general, the electronic properties of organic HTMs, such as ionization potential and highest occupied molecular orbital (HOMO) levels, are determined by their molecular structure. It is necessary for a good HTM to have a high HOMO level that corresponds to the valence band (VB) of the perovskite layer and the work function of the anode. Because of this, energy losses and recombination will be reduced[31].

Inorganic HTMs: More and more people are interested in inorganic hybrid materials (HTMs) because they are more stable at high temperatures and could be used as protective barriers. These compounds keep the perovskite layers safe from the heat, light, moisture, and oxygen that are in the air around them. These materials protect the layers of perovskite transistors. It is now harder to add these materials to PSCs because of problems with making films and lining up energy levels. There are two types of inorganic hybrid materials: those that are based on metals and those that are not.

Metal-based inorganic HTMs: Some metal-based hole transport materials can effectively extract holes, have good electrical conductivity, and have the right energy levels. NiOx, CuSCN, CuI, and $CuCrO_2$ are some examples of these materials. One of the main reasons these materials are so widely used is that they are very popular[32]. This is a popular choice because they are both strong and stable in settings that need high performance. As an example, they need to be processed at a very high temperature because they don't dissolve very well. The reasons above are why this is true. With this in mind, it might be hard to make a lot of things at once.

Non-metal-based inorganic HTMs: HTMs are not the same as compounds that are based on metals, like MoOx, WOx, and V_2Ox. It's usually easier to work with these compounds because they don't absorb light as well and they dissolve better. These two things make them simple to use. However, non-metal HTMs may not transport holes as efficiently and possess a greater trap density, potentially diminishing the device's performance[33]. This is the case because the trap density is higher and the hole mobility is lower.

Carbon-based HTMs: Researchers are interested in carbon-based materials as possible HTMs because they have high electrical conductivity, a large surface area, and are compatible with the perovskite layer[34]. People usually use three types of materials: carbon nanotubes (CNTs), graphene, and carbon black.

Carbon black is made up of graphite particles that are only a few nanometres in size. It has a large surface area and doesn't conduct electricity well. Carbon black has a lot of good things about it, but it also has a lot of bad things about it. For example, it doesn't make films very well, and it absorbs light very strongly, which can make it less useful as an HTM[35].

One way to define graphene is thatit is a two-dimensional sheet made up of sp-hybridized carbon atoms arranged in a honeycomb-like lattice. It is in high demand because it is clear, stable, and has excellent hole mobility. Graphene's high sheet resistance and high cost, on the other hand, keep it from being used widely[36].

Carbon nanotubes (CNTs) are cylindrical structures made of graphene. They are different because they are very flexible, see-through, and can carry electricity. Carbon nanotubes (CNTs) are hard to use in commercial-scale solar cells (PSCs) because they are expensive and hard to dissolve. Graphene, on the other hand, is hard to use in PSCs because it is too expensive. Researchers are always looking into these materials to find ways to make them more soluble and resistant to sheets[37]. This is being done by changing the chemical structure of these materials or by adding other chemicals to them.

Working of Perovskite Solar Cells

Light Absorption: When sunlight hits a perovskite solar cell, it goes through the clear conductive oxide layer, which could be ITO or FTO, and then it goes all the way to the perovskite absorber layer (Figure- 4). Perovskite materials have a very high optical absorption coefficient, which means they can absorb most of the visible light even when they are in thin films. The first and most important step in starting the photovoltaic conversion process is the solar cell’s ability to gather light. This directly affects the amount of current the solar cell can produce[38].

Charge Carrier Generation: When photons hit the perovskite layer, they excite electrons from the valence band to the conduction band, which makes electron-hole pairs. Perovskites have a low exciton binding energy, which means that these electron–hole pairs can easily break apart into free charge carriers at room temperature. This is different from many other photovoltaic materials. This efficient way of making charges is a big reason why perovskite solar cells have such a high-power conversion efficiency[39].

Charge Separation: The perovskite absorber and the charge transport layers that are adjacent to it are aligned incorrectly in terms of their energy levels, which allows for effective charge separation to take place after the creation of free charge carriers.

As a result of this alignment, charge separation is achieved effectively. Both electrons and holes move in the direction of the electron transport layer, which is where they are located. Holes migrate toward the hole transport layer. Recombination losses in the perovskite layer and at interfaces are made less severe as a result of the movement of charges in a single direction[40]. As a result, the open-circuit voltage of the solar cell as well as its overall performance are improving.

Charge Transport and Collection: The electron transport layer only lets electrons through to the metal cathode, while the hole transport layer keeps holes from getting through. The hole transport layer, on the other hand, lets holes through but keeps electrons out. This selective transport helps to cut down on energy loss by making sure that charge carriers only flow in one direction. When electrons and holes reach their electrodes, they are collected in a way that creates a potential difference across the device[41]. This is necessary for making electricity.

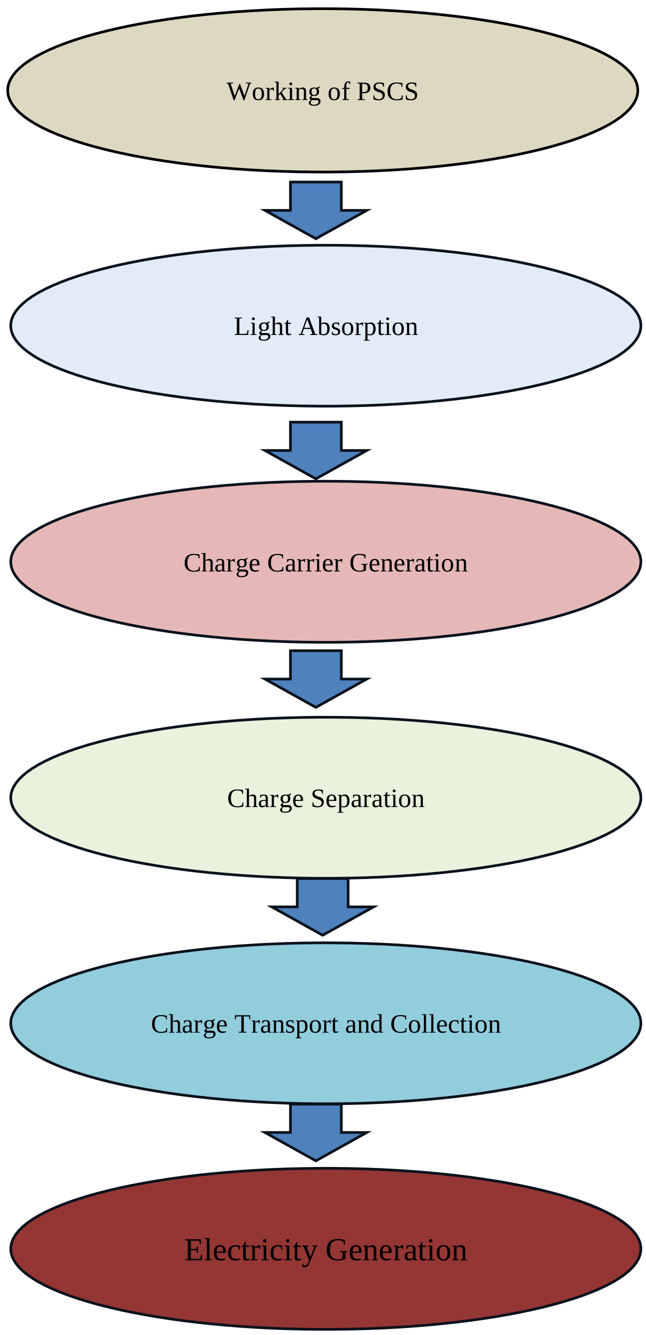

Figure-4: Working of Perovskite Solar Cells.

Electricity Generation: Perovskite solar cells are characterized by the fact that their electrodes are linked to one another by means of an external electrical circuit. During this process, electrons are gathered and then transferred from the cathode to the anode, which ultimately results in the production of an electric current for the device. This process is a consequence of the process described above. For the purpose of energy storage and distribution, this direct current (DC) electrical power can either be used to directly operate electronic devices or it can be incorporated into larger photovoltaic systems. Both of these applications are possible. There are potential applications that could be made use of both of these choices. Both of these options are possible. DC electrical power is produced by the continuous flow of charge that occurs under the illumination of the sun[42].

Applications

Perovskite solar cells are flexible and can be utilized in various ways other than just as solar panels (Figure-5). They can be used in a lot of new ways because they are highly efficient, cheap to make, and have a configurable band gap.

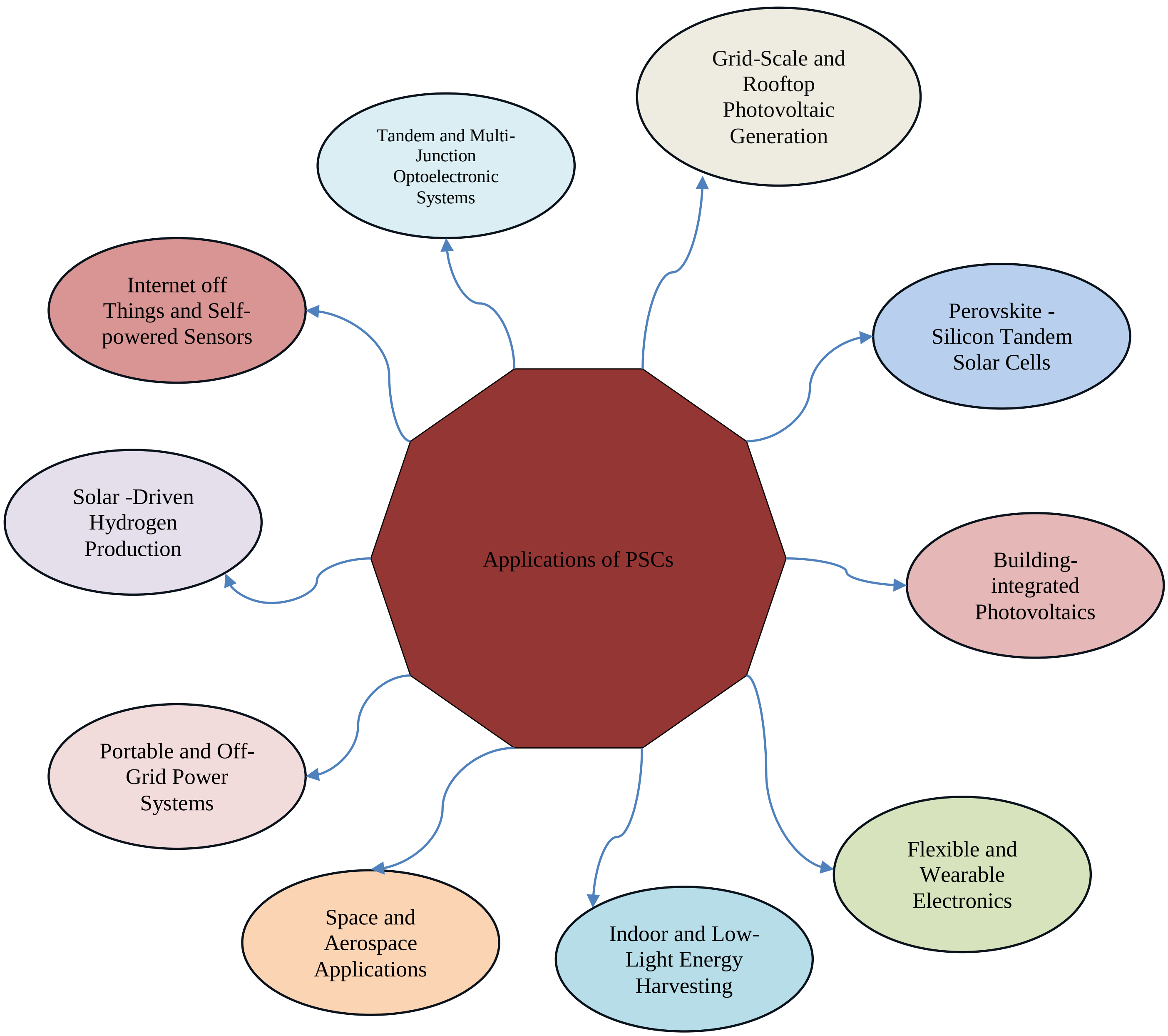

Figure-5: Applications of Perovskite Solar Cells.

Grid-Scale and Rooftop Photovoltaic Generation: Residential and commercial buildings can use PSCs in their rooftop solar panels to make electricity in a way that is good for the environment. PSCs can be used by big solar farms to collect solar energy and send it to the electrical grid. PSCs can be put into the walls, windows, and roofs of buildings, turning them into structures that make energy[43].

Flexible and portable applications: PSCs can be used in wearable devices, on curved surfaces, and in many other types of flexible electronics because they can be placed on flexible surfaces. Lightweight and flexible PSCs are a great way to power portable devices like cell phones, laptops, and sensors. They are also a good choice for people who can't get power from the grid. You can make clothes and shelters that use solar energy by adding PSCs to fabrics. Solar energy has a lot of different uses[44].

Perovskite-Silicon Tandem Solar Cells: Tandem solar cell topologies, especially perovskite-silicon tandems, are one of the most important ways to use photovoltaic cells (PSCs). Tandem devices can go beyond the Shockley–Queisser limit for single-junction photovoltaics. This is done by putting a wide-bandgap perovskite absorber on top of a silicon bottom cell. It has been shown that these tandem systems are more than 33 percent efficient, making them the next generation of solar technologies for use in industry[45].

Building-integrated Photovoltaics: You can change how clear, colourful, and bright PSCs are, which makes them great for building-integrated photovoltaics. You can use asemi-transparent perovskite module in windows, on the outside of buildings, and in skylights. This lets buildings make energy without looking bad. This app helps cities build roads and buildings that last and don't need power[46].

Indoor and Low-Light Energy Harvesting: Perovskite solar cells demonstrate exceptional performance in low-intensity sunlight and indoor lighting due to their high absorption coefficient and minimal recombination losses. As a result, photovoltaic cells (PSCs) are highly effective for powering smart electronics, wireless sensors, and Internet of Things (IoT) devices indoors, where conventional solar cells may not perform optimally[47].

Space and Aerospace Applications: PSCs are good for space and aerospace use because they are light, have a lot of specific power, and can handle radiation. Perovskite solar cells can lower launch costs by a lot while still producing a lot of energy. This makes them good for satellites, high-altitude drones, and space probes[48].

Portable and Off-Grid Power Systems: The lightweight design of PSCs, combined with their straightforward fabrication process, positions them as a highly suitable option for portable and off-grid energy systems. Alongside offering a cost-effective substitute for diesel generators and bulky silicon modules, these systems can be utilized in isolated regions to supply energy for small electronic devices, emergency systems, and rural electrification initiatives[49].

Solar-Driven Hydrogen Production: Perovskite solar cells are being gradually incorporated into photoelectrochemical systems for the purpose of solar-driven water splitting. This is becoming increasingly common. Both the tunable bandgap and the high photovoltage play a significant role in the development of carbon-neutral energy systems and sustainable fuel technologies. This is because they make it possible to effectively integrate with electrolyzers for the production of green hydrogen[50].

Internet off Things and Self-powered Sensors: Power supply controllers are useful for Internet of Things (IoT) devices and automatic sensors when there is not much light. This is because PSCs are good at managing power. These systems also don't need to have their batteries changed often, and they can run for long periods of time without stopping in places like smart homes, smart cities, and industrial monitoring applications. This gives it a big edge over other systems[51].

Tandem and Multi-Junction Optoelectronic Systems: Photonic crystals are used in many high-tech optoelectronic systems, like multi-junction devices that work with different thin-film technologies. Instead, photovoltaics is used most of the time in this case. Their tunable bandgap allows for high-performance energy harvesting and integrated optoelectronic platforms. This lets you change the spectral absorption for each person[51].

Conclusion

This paper discusses perovskite solar cells (PSCs) in general, such as what they are made of, how they work, and what they could be used for. A lot of people are talking about how important these technologies are right now because they are the next generation of solar technologies. First, we need to talk about how the world always needs more energy and how making energy from fossil fuels is bad for the environment and not a long-term solution. As soon as possible, we need to find clean, cheap energy sources. Because they quickly become more efficient and can be made with solution-based technologies that work at low temperatures, photovoltaic cells (or PSCs) are now a very popular choice. There have been a lot of different kinds of PSCs over the years, and it's clear that both how they are made and how they work have improved a lot. Since then, each new version has made it easier, more stable, and more scalable to convert energy. These improvements have been made to the oldest designs, such as mesoscopic and dye-sensitized types, as well as the newest planar and tandem architectures. This means that PSCs are slowly leaving the lab and going to places where they can be used for work. Because they are better at conducting electricity and light, perovskite materials are better than other materials at turning sunlight into energy. This material is great because it has high absorption coefficients, long charge-carrier diffusion lengths, wide band gaps that can be changed, low exciton binding energy, and the ability to deal with defects. Because of changes in the materials' composition and the way the interfaces are built, charges can now move around more easily. This has also cut down on the losses that happen when charges recombine. There are still a lot of problems that need to be fixed before commercialization can happen on a large scale, though. Some of the problems that come up are lead toxicity, ion migration, long-term stability, and being affected by the environment. The environment can also have an effect on them. Photovoltaic cells, or PSCs, need to be able to take in light, quickly generate charge, successfully separate charge, and move charge evenly across carefully built interfaces in order to work properly. Photovoltaic solar cells, or PSCs, can be used in many ways, such as in buildings, to make tandem solar cells, to make flexible electronics, and to collect energy in homes. To fully understand the economic and social benefits of these types of cells, more research is needed in a number of areas.

Acknowledgement

I acknowledge M.J.P.R.U. Bareilly for financial assistance.

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