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PEROVSKITE AS AN ENERGY DEMAND FOR TOMORROW

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ABSTRACT

In a carbon-constrained world, solar radiation-based cells are one of the most notable sustainable energy sources that may assist reduce dependency on imported energy while enhancing energy supply security. The methylamine lead halide solar cell is a relatively new addition to solar energy world. The key argument in their favour is that they have the potential to be a more cost-effective and environmentally friendly alternative to traditional silicon-based technologies. This paper evaluates various parameters such as performance, production processes, economic difficulty, current research efforts and technological challenges in future developments. $MAPbX_3$ *PSCs seem to be a more ecologically friendly and sustainable alternative than other PV technologies like silicon based, according to the key results and sensitivity analysis, with the shortest energy payback period. The evaluation and analysis offered here provide useful information and help in identifying future PV design pathways and windows of opportunity. Author has also concluded that in next five demand of solar energy as in the year of 2026-2027 will be 3965.7 MW.*

Keywords: *Solar Cell, Efficiency, Photovoltaic, Perovskite,* $MAPbX_3$.

Introduction

Methylamine Lead Iodide Solar Cell

Perovskite solar cells are low cost and globally feasible sustainable energy device for future opportunity than conventional ones in contexts to the global energy production, security, and green challenges. It has recently appeared as a so-called "third generation solar cell"[1]. In reference to the photovoltaic technology, a systematic research and ecologically wide lifespan supply chain evaluation is done due to the confined environmental assessment of PSCs. This help us to focus on green challenges, environmental safety, and human safety, which are essential for the technology development. [2]

The world's energy usage has been steadily rising. The limited availability of fossil fuels necessitates research into sustainable and renewable energy sources. Figure 1 demonstrated a classification of solar cell.

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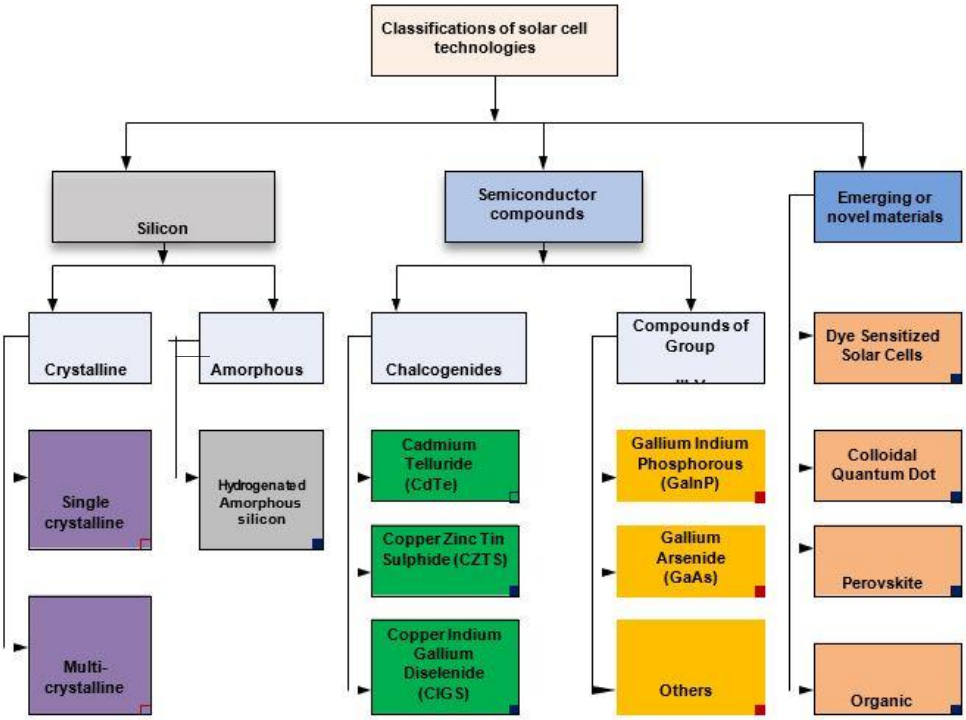


Figure 1: Classification of solar cells [3]

Energy conversion from solar to electricity is truly encouraging research strategies for fulfilling coming generations' increasing energy needs while minimising environmental damage.[4] Solar cell technology converts photon energy directly into electricity in an environmentally sound and renewable manner.

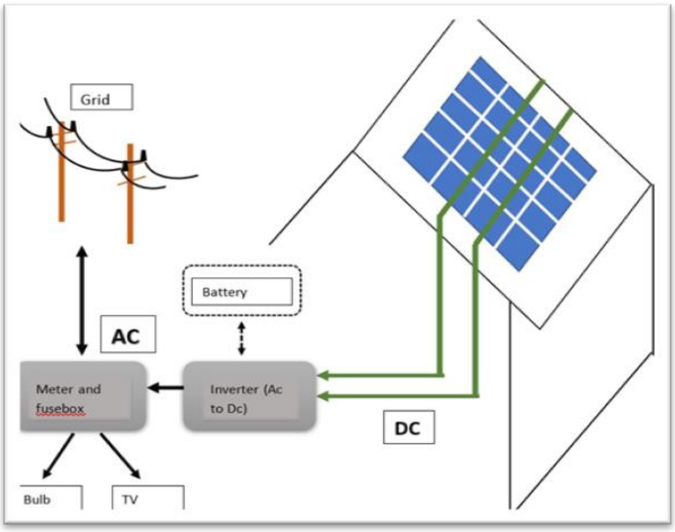


Figure 2: Solar Energy Conversion into Electricity [5]

Perovskite solar cells (PSCs) have lately gained popularity as an expense and ecologically acceptable alternative to conventional solar cell technology for dealing with global energy production and climate change [6]. Figure 2 shows a mechanism related to conversion of solar energy into electricity.

Given PSCs' potential for lower-cost energy generation, a comprehensive environmental profile [7,8] is required, in comparison to other current PV technologies, to validate the claim made by multiple major writers that the benefits of this technology significantly outweigh the effect of dangerous Pb-based hybrid organic/inorganic substances. As a consequence, they examine their environmental profile and possible effect using Life Cycle Assessment (LCA). Traditional PV technologies have had a lot of LCA study done on them, but organic solar cells haven't received nearly as much attention, due to its drawback such efficiency, cost of manufacturing, short life span etc. The most difficult challenge facing Perovskite based solar cells right now is persistent permanency, which necessity be addressed before they can be used in practical applications. Perovskite solar cells' resilience in hostile settings, such as temperature treatment, light irradiation, humidity, and so on, appears to be the barrier impeding their commercialization [8]. To offer an update on the subject, this paper presents an overview of PSCs before concentrating on major breakthroughs in effective perovskite solar cells.

Technology for Converting Solar Energy into Electricity

- **Solar Cells of the 1st Generation**

Crystalline Si wafers were used to make these solar cells. This technology is made from crystalline Si, which is the most expensive method of obtaining pure Silicon crystal. These solar cells are used all over the world and have the highest commercial efficiency. Approximately 80% of the photovoltaic solar market is made up of solar cells with a single crystalline layer. Polycrystalline solar cells with hexagonally structures have a 19.8 percent efficiency, according to Zhao et al (1998). Solar cells made of polycrystalline material are substantially less efficient than those made of crystalline material [9].

  - Solar Cells with a Single Crystalline
  - Solar Cells with Polycrystalline Structure

- **Solar Cells of 2nd Generation**

It uses silicon crystal wafer technology, obtaining pure Silicon is a costlier and time-consuming procedure. However, if thin films of Si (1m) are formed on them, the cost of solar cells may be decreased. When compared to wafer-based technology, thin film technology uses very little silicon. R. Chittick was the first to create amorphous Si deposited thin films [10].

  - Amorphous Silicon
  - Cadmium Telluride

- **Solar Cells of the 3rd Generation**

The third-generation solar cell include Quantum dots-based, inorganic-organic materials, perovskite materials, Dye sensitized solar cell in terms of using thin film. Third generation of solar cells having adjustable band gap as well as ion diffusion length. There are several drawbacks to film base solar cells and Carbon-silicon solar panels in terms of getting better efficiency and establishing themselves as a Photovoltaic technology capable of satisfying all of the requirements outlined in the golden triangle (first generation). In 3rd silicon-based solar cells, the following types of solar cells are employed. To improve solar cell efficiency, all photons in incident sunlight must be absorbed. This cannot be accomplished with a single junction solar cell. As a result, multi-junction solar cells are being considered as a solution to this problem [11]. Figure 3 demonstrated a different generation of PSC.

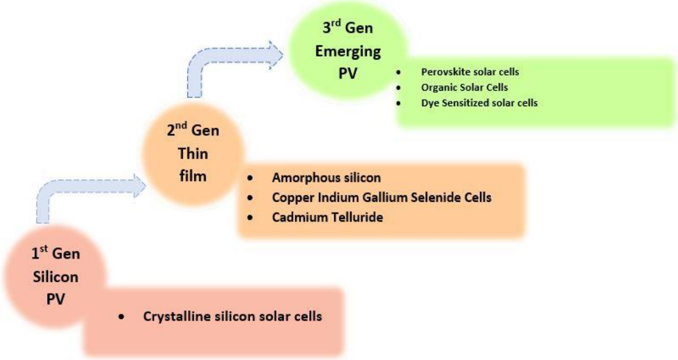


Figure 3: Generations of PSC

The Perovskite Cells

Geologically, perovskite is a sort of mineral. It was named after a Russian nobleman and mineralogist who found it in the Ural Mountains, Lev Perovski (founder of the Russian Geographical Society). Perovskite solar cells are named for its structure, comparable to perovskite crystals. In its solid form, $CaTiO_3$ is a calcium-titanium-oxygen compound. The perovskite mineral's general name is ABX_3, it has a broad variety of physical, optical, and electrical characteristics due to its compositional flexibility. In ultrasound machines, memory chips, and even solar cells have found use of perovskite. When utilised to make solar cells, they have showed promise in terms of excellent performance and low production costs [12].

The conventional perovskite lattice arrangement is depicted, however it can be represented in a multitude of ways, as with many structures in crystallography. A perovskite can be thought of as a big positively charged molecular cation of type 'A' in the centre of a cube. The cube's corners are filled with cations 'B,' and the cube's faces are filled with anions 'X.'

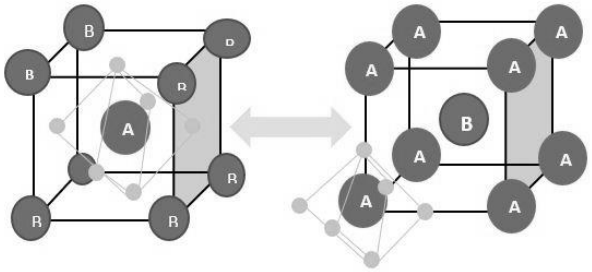


Fig. 4: Equivalent Perovskite Structure [13]

Perovskites can have a variety of interesting properties depending on the atoms/molecules used in their structure, such as superconductivity, spintronics, and catalytic properties. As a response, research teams view perovskites as a potentially interesting frontier for physicists, chemists, and material scientists to explore. The highest efficient perovskites were created with the below different materials in the perovskite form hexagonal lattice (ABX_3). [13]:

A = A large inorganic cation, most commonly lead (II) (Pb2+).

B = Methylammonium (CH3NH3+), an organic cation.

X3= Chloride (Cl-) or iodide (I-) are smaller halogen anion (I-) [12].

All photovoltaic solar cells employ semiconductors to convert light energy into electricity. Semiconductors are materials act as both electrical insulators and metallic conductors. Electrons flow onto semiconductor material electrodes that conduct electricity and generate an electric current because of being exposed to sunlight. Because of its steady features such as optical and electrical, silicon has been regarded as an efficient semiconductor material used in solar cells since the 1950s. Massive silicon crystals, on the other hand, necessitate a costly, consumes a lot of energy due to its multi-step processing, therefore researchers and scientists are looking for a silicon alternative, and therefore, perovskites have been developed to manufacture semiconductors with comparable qualities. Perovskite solar cells may be created with a low cost and minimum energy consumption using simple deposition technologies like coating. Perovskites can also be adjusted to exactly match the sun's spectrum due to their compositional plasticity. [12]

An efficient light photon to electron conversion layer made of lead halide perovskites was developed in 2012 by researchers. Perovskites have improved their efficiency in converting sunlight to energy since then, achieving a new lab record of 25.2 percent in the process. Perovskite solar cells are also being combined with standard silicon solar cells by scientists; the current record efficiency for these "Perovskite on tandem" twin cells is 29.1% and growing swiftly. Perovskite solar cells and perovskite tandem solar cells may soon replace ordinary silicon solar cells as low-cost, high-efficiency alternatives due to considerable improvements in cell efficiency, which has increased from around 3% in 2006 to over 25% now [13]. Perovskite solar cells have come a long way in a short time, but they still have a long way to go before becoming a commercially viable technology. [14]

In recent research on perovskite solar cells, absorber materials based on methylammonium lead halide have prevailed. Even though perovskite materials have been investigated for more than a century, methylammonium lead halides for semiconductor applications have just been explored during the last two decades. Perovskite absorbers were first used in solar cells in 2006, and the results were published in 2009. However, because they relied on a corrosive liquid phase that steadily destroyed other layers inside the device, these cells were inefficient (less than 4% efficiency) and unstable. By 2012, liquid-phase components had been replaced with solid-state connections, resulting in a 10% increase in efficiency. Improvements in performance and stability have emerged because of continuing research into new materials, device topologies, and fabrication processes, resulting in a claimed 20% cell efficiency in 2011 [14]

Construction

The lack of a high-temperature processed mesoporous TiO_2 layer allows for low-temperature manufacturing of PSCs. The two most common perovskite solar cell designs are mesoporous and planar. An ITO or FTO glass-supported conductive transparent oxide is deposited using a thin (mesoporous) layer (10-30nm) of TiO_2. Infiltration of the perovskite solution is carried out and a thick and TiO_2 nanoparticles are placed in a porous layer and sintered. There is absence of mesomorphic layer in planar configurations. HTM is then spin-coated onto the perovskite absorber with a 60-80nm coating of Au as the top contact. In this setup, the HTM and top contact are fully opaque, but the top contact's reflection may aid boost the PCE [15].

After the HTM layer, an n-type semiconductor is placed as an electron selective contact in the p-i-n configuration. Phenyl C61 butyric acid methyl ester is the most often utilised compound (PCMB). Inverted structures are also remarkable because, Except for vacuum dual deposition, which needs costly equipment, they may be used on opaque substrates like metal foils [15]. The mesoporous layer ($MAPbI_3$) is a solution of methylammonium iodide and lead iodide in dimethyl formamide, butyrolactone, and dimethyl sulfoxide deposit by spin coating [16].

As the surplus solvent is released, the adducts create a smooth, homogeneous film of $MAPbI_3$ in dimethyl formamide, which is easier to detect. In DMSO (Dimethyl Sulfoxide), these adducts create a smooth, uniform layer $MAPbI_3$ when PbI_2 is deposited by using spin coating in two steps [17]. A new step includes adding chlorobenzene or toluene to the spinning film [18,19]. However, solvents such as dimethyl formamide, dimethyl Sulfoxide, and butyrolactone do not dissolve the perovskite forces of $MAPbI_3$ nucleation and precipitation resulting in a smoother and more uniform layer. The use of non-stochiometric materials, such as $PbCl_2$ or $Pb\ (CH3COO)_2$, in this situation, extra materials are released from the intermediate phase to create the final perovskite phase, resulting in better surface coverage and grain size, which enhances efficiency. [20,21]

Alternatively, the two-step procedure involves spin coating PbI_2 soaked in DMF or another comparable solvent first, then immersing the film in a MAI isopropanol solution after drying. The films become brown in seconds before being washed with IPA, dried, and annealed. The precise processing settings include immersion times ranging from a few second to several minutes, as well as varying levels of MAI in IPA (Isopropyl alcohol) [21].

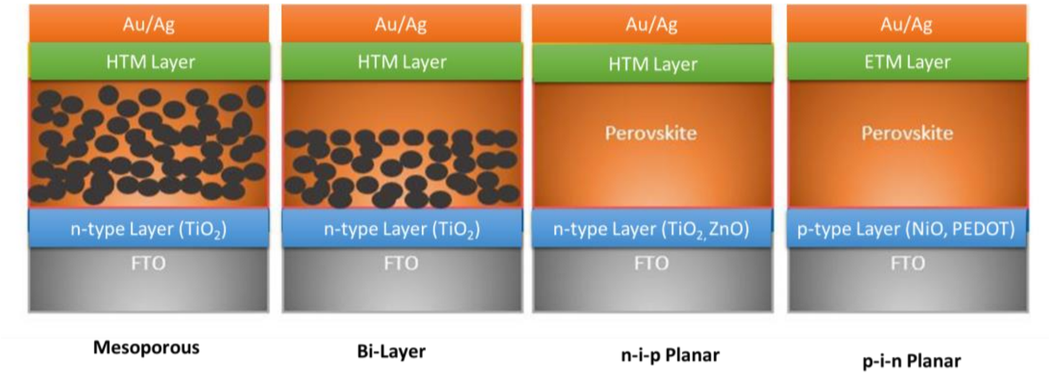


Fig. 5: Mesoporous and Planar structures of Perovskite Solar Cell [22]

Perovskite Solar Cells: How do They Work?

In general, the perovskite layer (i.e., I^-, Cl^-, and Br^-) is made up of organic material such as organic cations (such as methylammonium, ethyl ammonium, and formamidine) and inorganic material such as metal cations (such as Pb^{2+}, Sn^{2+}, and Ge^{2+}) and halide anions. It is worth mentioning that PSCs were originally identified as TiO2 inorganic semiconductor after photon absorption by the sensitizer [23], followed by the extraction of electron to the transparent conductive oxide (TCO). Electrons flow to the platinum (Pt) anode via the external circuit and then into the iodide electrolyte. The dye molecules receive electrons from the electrolyte, which the electrolyte regenerates. As a consequence, dye-sensitized solar cells (DSSCs) have been proposed as a model for describing the operation of PSCs. Because of halide dissolving challenges in a liquid electrolyte, which might affect PSC stability, the liquid electrolyte was replaced with a solid-state hole transportation material (i.e., Spiro-OMeTAD). [24]. In the case of PSCs, the perovskite material is an inherent (neither p-type nor n-type) semiconductor. Due to the low binding energy of perovskite materials (2–55 meV), the free charge carriers (free electrons and free holes) formed inside the perovskite layer can be quickly injected into electron/hole which transports materials with very slow charge carrier recombination, resulting in large diffusion length values. Finally, electrons and holes are removed and delivered to the cathode and anode, respectively. The basic working mechanism of PSCs is presented in Figure 6 [26].

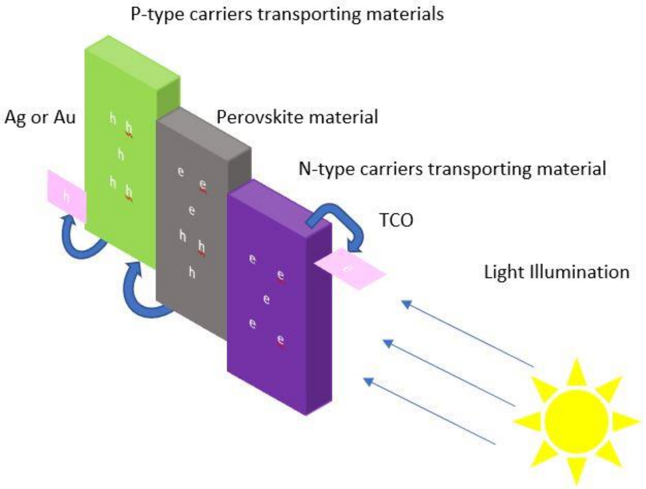


Figure 6: General Working mechanism of PSCs [26]

Perovskite Solar Cell Applications

- **Water Photolysis**

To achieve the thermodynamic requirements, water splitting requires a voltage of at least 1.23V [27]. To attain appropriate reaction rates for practical applications, voltages of 1.8–2.0 V are required [28]. Because the highest output voltage of CH3NH3PbI3 solar cells is roughly 0.9V, water photolysis requires tandem cells. Luo et al. divided water by connecting two $CH_3NH_3PbI_3$ solar cells in series (outside the electrolyser vessel) and achieving a 12.3% sun-to-hydrogen conversion efficiency [28]. A perovskite/$BiVO_4$ water-splitting cell with a $BiVO_4$ photoanode and a single junction $CH_3NH_3PbI_3$ solar cell achieved a solar-to-hydrogen conversion efficiency of 2.5 percent. Combining a $CH_3NH_3PbI_3$ solar cell with a Fe_2O_3 photoanode yielded a 2.4 percent solar energy conversion efficiency, depicted in figure 7 [27].

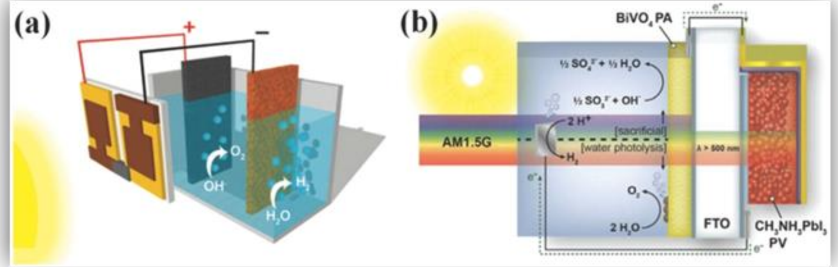


Figure 7: a) A water-splitting device that requires extra electricity; b) With an external power source, a $BiVO_4$/$CH_3NH_3PbI_3$ tandem device is possible [27].

- **The Wearable Power Source**

Because of the popularity of portable devices, the development of portable and wearable power supplies has accelerated. Perovskite solar cells have the potential to be used in wearable power sources because to their high efficiency and adaptability, however safety concerns about Pb toxicity must be addressed. Perovskite solar cells with a bending radius of 1 mm might be worn on a human wrist or even finger. After 1000 bending cycles with a bending radius of roughly 10 mm, the device showed no significant decline in PCE, indicating that it has real-world application potential. Solar cells made of perovskite that appear like fibres were woven into garments as shown in figure 8 [29].

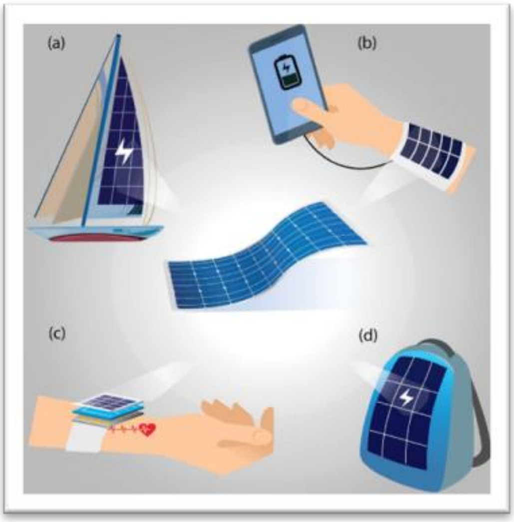


Figure 8: (a) Solar cell made of textile (b) tool for wearable electronics. (c) In-situ health monitoring using self-powered electronics. (d) light in weight wearable power device for solar backpack [30].

- **Photodetector**

Given the amount of research that has gone into PbX_2 -based photodetectors, a move to Pb halide perovskites is a reasonable next step. $CH_3NH_3PbI_3$-based solution-processed photodetectors have a detectivity of 1014 Jones and a rapid photo response, outperforming most organic, quantum dot, and hybrid photodetectors as shown in figure 9. After device noise has been decreased through interface engineering and morphological improvement, visible light intensity of 1 pW cm^{-2} may be observed. Perovskite solar cells have recently been utilised to detect X-rays, demonstrating remarkable sensitivity and responsiveness. These findings suggest that perovskite solar cells have a lot of potential in photodetector applications if stability difficulties can be overcome or avoided [31].

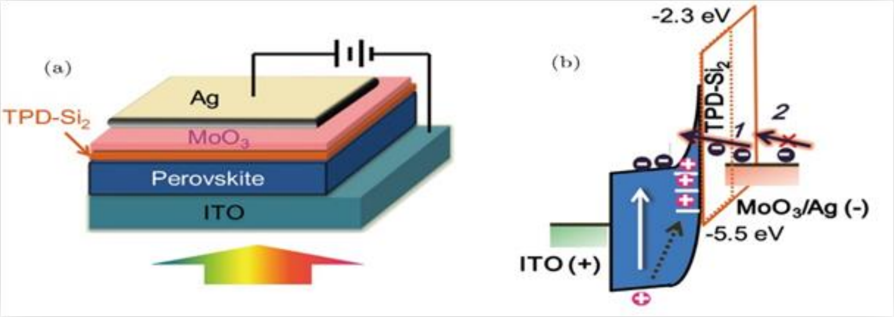


Figure 9: (a)The $CH_3NH_3PbI_3$ photodetector's device construction. (b) Under illumination, the energy curve of the $CH_3NH_3PbI_3$ photodetector under reverse bias is shown [31].

Characterization (I-V Curve)

Two major parameters that govern photovoltaic device performance in every photovoltaic device are open-circuit voltage, a condition when the total current in the external circuit is zero and short circuit current, a current in the external circuit when the applied voltage is zero.

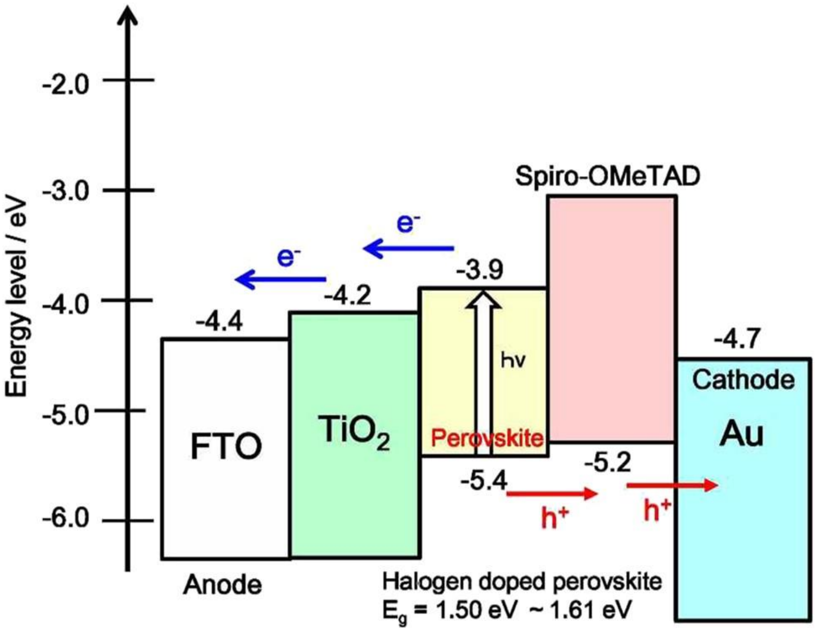


Figure 10; Perovskite Solar Cell Energy Level Diagram [32]

So, Figure 11 shows I-V curve which is obtained in different humidity without degradation.

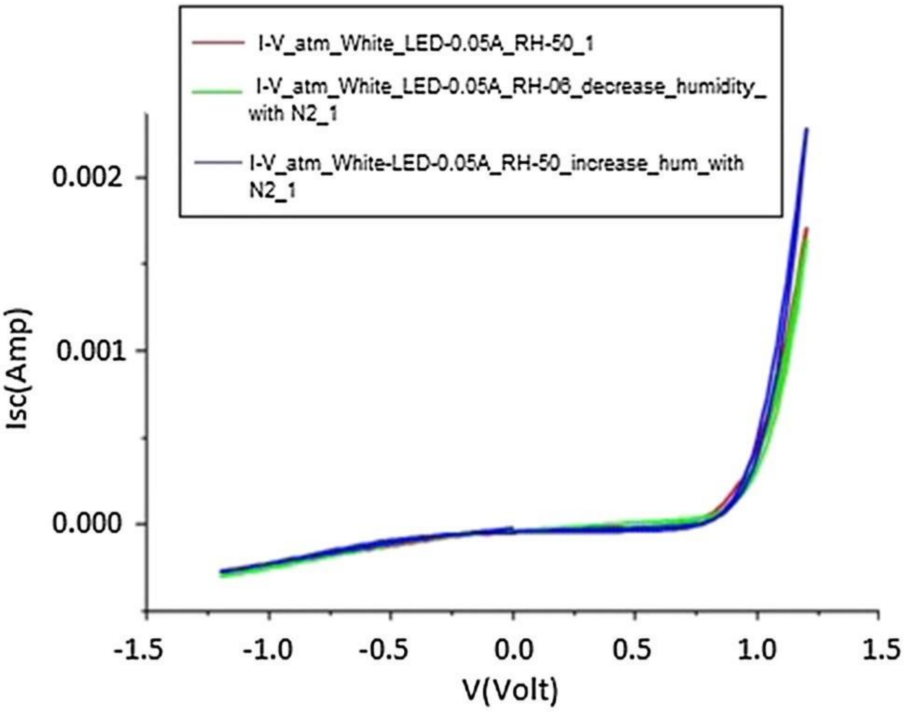
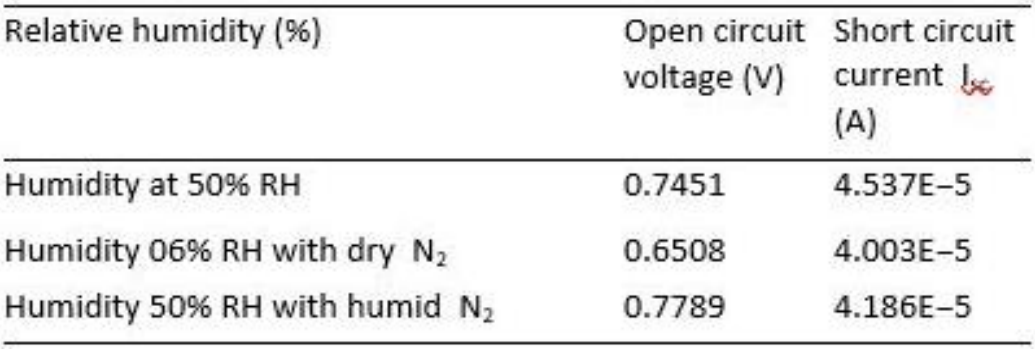


Figure 11: At varying humidity levels, the I–V properties of a perovskite solar cell conditions [32]

- **Perovskite Solar Cell Parameters (without Degradation)**

For measurements, we used a white LED with a very low intensity (around 4–5 mW/cm^2) [32].



Relative humidity (%)	Open circuit voltage (V)	Short circuit current I_{sc} (A)
Humidity at 50% RH	0.7451	4.537E−5
Humidity 06% RH with dry N_2	0.6508	4.003E−5
Humidity 50% RH with humid N_2	0.7789	4.186E−5

- **Measurements of C–f and C–V in Various Humidity Conditions**

To investigate solar cell performance and fault distribution, C–f and C–V data were obtained in a variety of humidity situations. All measurements were obtained in the dark to avoid the impact of photo-generated charge carriers to capacitance.

As seen in Figure 12, capacitance increases as humidity rises. Under both humidity conditions, the value of capacitance at lower and higher frequencies remains constant, according to the C–f data. At medium frequencies, capacitance increases, with the biggest changes occurring around 10–1000 Hz [32].

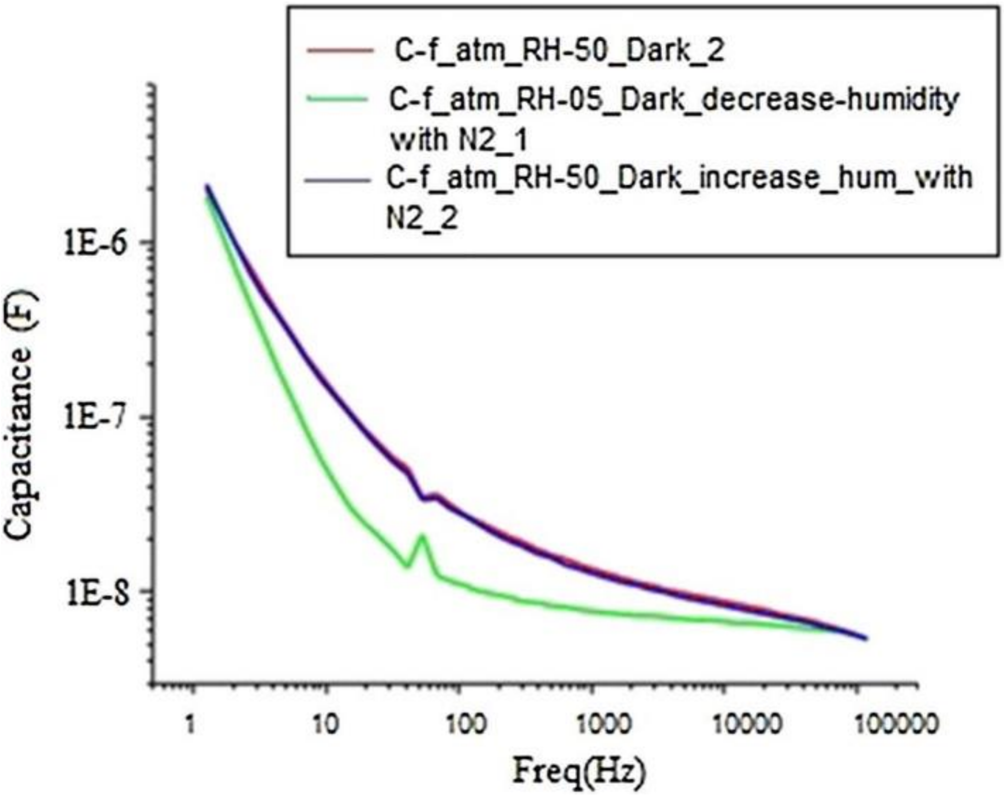


Fig. 12: C–f characteristic with various humidity changing with N_2 flow [32]

Under Fig. 13, the fluctuation of C–V is displayed, with the value measured in dark circumstances and at a frequency of 217 Hz. When humidity rises, capacitance rises as well, but the curve remains intact, and capacitance rises after 0.4 V, which is linked to ion mobility in perovskite solar cells.

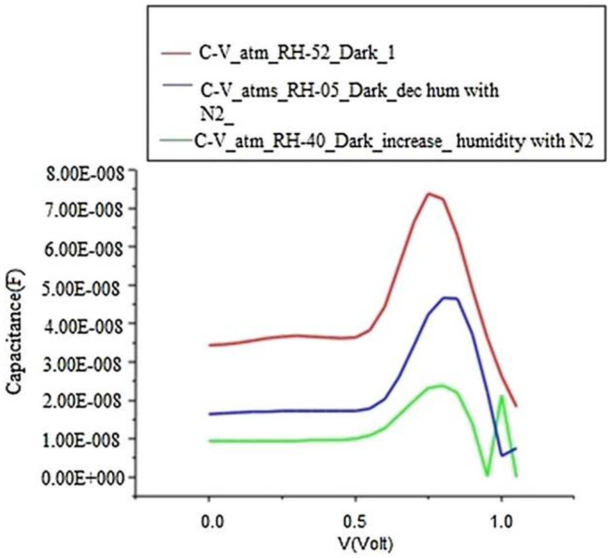


Fig. 13: C–V Characteristics with various humidity changing with N_2 [32]

Profile Industry of Perovskite Solar Cell

Table 1: Annual Solar Power Generation in India as per the Demand

Year	Demand(D) MW
2014-2015	6090
2015-2016	5275
2016-2017	1171
2017-2018	1315
2018-2019	1300
2019-2020	4150
2020-2021	5800
2021-2022	7500

Demand Projection using Simple Exponential Smoothing Method (SEM)

One of the simplest ways to forecast a time series is to use a basic exponential smoothing. The primary premise of this model is that the future will be mostly similar to the (recent) past [33].

a= Actual value
p= predicted value
D (t, a) = Actual demand at time t
D (t+1, a) = Predicted demand at time t+1
α= constant weightage factor (0<α<1)

Table 2: Demand Projection using Simple Exponential Smoothing Method

		D(t+1,p)= αD(t,a)+(1- α)D(t,p)	
Year	**Demand(D) KW**	**α= 0.1 Smp. Exp. smoothing**	**α= 0.8 Smp. Exp. Smoothing**
2014-2015	6090	-	-
2015-2016	5275	6090	6090
2016-2017	1171	6008	5438
2017-2018	1315	4864	1991
2018-2019	1300	1185	1286
2019-2020	4150	1313	1303
2020-2021	5800	1170	3580
2021-2022	7500	4315	5470
2022-2023	-	5970	7160

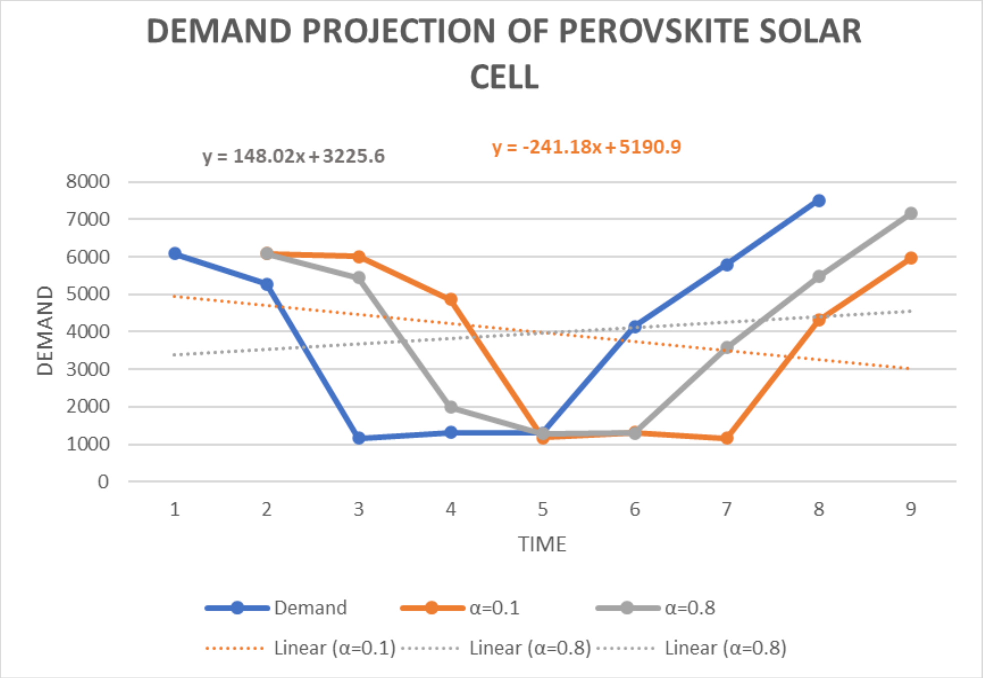


Fig. 14: Demand Projections of Perovskite Solar Cell by using Simple Exponential Smoothing Method (SESM) for α=0.1 and α = 0.8

Table 3: Demand Projection for ά=0.1, y= -241.18*t+ 5190.9 for next 5 year

	BY SESM ά=0.1	**By linear fit on MA data: D = -241.18*t + 5190.9**			
Time (Year)	**2022-2023**	**2023-2024**	**2024-2025**	**2025-2026**	**2026-2027**
Demand (MW)	4949.72	4708.54	4467.36	4226.18	3985

Table 4: Demand projection for ά=0.8, y= 148.02*t+ 3225.6 for next 5 years.

Calculation	**By SESM ά=o.8**	**By linear fit on MA data: D=148.02*t + 3225.6**			
Time (Year)	2022-2023	2023-2024	2024-2025	2025-2026	2026-2027
Demand (MW)	3373.62	3521.64	3669.66	3817.68	3965.7

Here ‘t’ is in number as t=1 for the year 2022-2023, t=2 for the year 2023-2024 and so on.

Advantages of Perovskite Solar Cell

- Material properties that make high-performance devices easier to fabricate are benefits over current photovoltaics. Low processing costs and straightforward establishing attractive products, such as adjustable, transparent, or all-perovskite tandem cell modules, may result from the range of demonstrated technologies. The versatility of perovskite cells may enable them to be directly combine with other cell technologies to produce high-performance twin cells; Si and CIGS units appear to be particularly promising in this regard. [34].
- Perovskites have the advantage of allowing for several commercialization paths along with challenging existing manufacturers, there is also the prospect of partnering with them to produce high-performance twin cell technology that integrates both perovskite and current technologies, perhaps enabling for market release as a new high-quality product. [34].
- It has a high dielectric constant, fast charge separation, large electron – hole transport lengths, as well as a long lifetime for transport dispersing [34].
- Perovskite demands less material to absorb this very same amount of sunlight as silicon. As a result, it prices less than silicon [35].

Disadvantages of Perovskite Solar Cell

- One disadvantage of perovskites is that lead has been found in significant concentrations in all high-performance perovskite cells to date, posing poisoning concerns throughout device production, deployment, and disposal. In addition, when exposed to moisture and UV radiation, they normally degrade (sometimes rather quickly) [35].
- The key concerns is the he film quality and width of perovskites [35].
- Heat, moisture, snow, and other conditions will quickly deteriorate the perovskite substance [35].

Discussion

- The demand for perovskite solar cells reached 7500 MW in the year 2021—the industry is projected to expand in the coming years.
- The demand for PSCs on an involuntary basis continues to grow. Referring to demand data in Table 1, we can infer that the demand mostly kept increasing yearly, but there were several years when there was a downfall in demand.

Conclusion

Photovoltaic technologies are the fastest-growing of all renewable energy technologies now accessible, and they are expected to play a critical part in resolving the world's complex energy issues. PSCs benefit from most criteria, however their high moisture sensitivity, cell stability, and scalability present challenges.

PSC technology has progressed in recent years, giving them a feasible alternative for next-generation solar cells that are low-cost and high-efficiency. PSC have been actively explored in recent years due to the growing demand for cost-effective, high-efficiency solar cells.

We also noticed that various characteristic's such as, solar cell's current-voltage, capacitance–frequency, and capacitance-voltage properties change, and the solar cell's efficiency drops. Researchers will be able to better understand how white light, UV light, and humidity affect the characteristics and stability of perovskite solar cells as a result of our findings.

It is concluded that in next five demand of solar energy will be increases as in the year of 2026-2027, demand will be 3965.7 MW from the Table.4.

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