International Journal of Computer Information Systems and Industrial Management Applications
ISSN 2150-7988 Volume 18(15s) 2026 pp. 692-712
https://doi.org/10.70917/ijcisim-2026-4465
Article

Comparative Study of Perovskite PV Cells with other PV Cells and Analysis of Experimental Perovskite solar cells with Simulation Results and their Efficiency Analysis

Daphny Shallet M[1], Jackuline Moni D[2], H.Victor Du. John[3], Prince Allen Jebakumar J[4], D. Gracia[5]

[1]Department of Electronics and Communication Engineering, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu & Assistant Professor, Department of Electrical & Electronics Engineering, Dr.T. Thimmaiah Institute of Technology, KGF
[2]Department of Electronics and Communication Engineering, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu
[3]Department of Electronics and Communication Engineering, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu
[4]Department of Electronics and Communication Engineering, Karunya Institute of Technology and Sciences, Coimbatore, Tamil Nadu
[5]Kumarguru college of Technology, Coimbatore, Tamil Nadu
***Corresponding Author: Prof. Daphny Shallet M**

Abstract: In recent years Photovoltaic technology has achieved tremendous growth as a sustainable source of energy. Silicon cells are more effective in turning sunlight into energy, but they have higher production costs. Off late specialized category of solar cells like Perovskite solar cells (PSC) emerged which can be used in satellites and the military application, which is the very low weight with high efficiencies and comparatively lower in cost. This paper gives an intensive assessment on the near investigation of PSC with other PV cells and its proficiency examination. Between every one of the three ages of photovoltaic cells and boundaries like Short Circuit Current Density (Jsc), Open Circuit Voltage (Voc), Fill Factor (FF) and Power Conversion Efficiency (PCE) is studied. Many factors, such as the composition of the material, the methods used during manufacture, and the surrounding environment, might affect the performance of perovskite solar cells. In order to forecast and comprehend how these photovoltaic cells operate in various settings, simulation tools serve as a useful and cost-effective platform. Perovskite PV cell simulation using Silvaco Atlas software and SCAPS 1D were studied for the analysis. A detailed survey and comparative study are done and its durability, reliability, efficiency, stability and price variations are presented in this paper, which would be helpful to pursue research on perovskite solar cells in the future.
Keywords: - PSC, PCE, Photovoltaic, Silvaco Atlas, SCAPS 1D

1. INTRODUCTION

Due to the increasing Fossil-fuel consumption like Coal, gasoline, and shale gas, non-renewable resources of energy cause a worldwide problem. Solar, wind, biomass, hydro, and geothermal energy are some of the renewable energy sources studied by researchers. Photovoltaic (PV) solar technology is one of the most efficient renewable power sources on the planet, has witnessed rapid growth over the last several years. It justifies the world's developing interest in energy since it is quite possibly the main challenge that our general public is confronting. The PV cell is made of silicon-based Photovoltaic cells and has a PCE of 4.5 percent. was invented in Bell lab, USA, in 1953, marking the beginning of Photovoltaics [1]. Photovoltaic cells made of GaAs, CdTe, InP, and CIGs were made for sunlight-based photovoltaics and they were for the most part dependent on III-V gadget structure.

The 3rd generation Dye-sensitized Solar cells (DSSC) and Quantum Dot solar cells(QDSC) were introduced in the early 1990s. Organic Photovoltaic (OPV) cells were first introduced in the 2000s. With the increased interest in nanomaterials, researchers are focusing on developing advanced materials for photovoltaic devices that are cheaper. Perovskite solar cells were invented in the year 2009[2]. Amongst various types of solar cells, Perovskite solar cells exhibited phenomenal progress in the latest years of the remarkable increase in Performance of conversions, from estimates of about 3% in 2006 to over 25% in 2020, within a very short period making it more reliable and important among all the photovoltaic cells thus creating huge interest to researchers as there is a great opportunity for further research [3]. National Renewable Energy Laboratory (NREL) showed that PCE of about 92 percent of solar panels manufactured in the lab is made of Si, subsequently 5% CdTe, 2% CIGS and less than 1% Amorphous Silicon Hydrogen. [4].

Perovskite solar cells had similar cell efficiencies within 4 years of their breakthrough, which has been around for over 40 years. Yingzhuang Ma stated that flexibility and tunable transparency is another advantage over conventional solar cells [5].

A perovskite structure is made up of a Calcium titanate (CaTiO3) compound. It has an ABX3 molecular shape, where A denotes methylammonium (CH3NH3+) or formamidinium (NH2CHNH2+), B for inorganic cation (typically Pb2+ or Sn2+), and C for halogen anion commonly chloride (Cl-) or iodide (I-). The materials with such properties acquire admirable photoelectric characteristics inferior exciton-binding energy and high coefficients of optical captivation (up to 104 cm-1). Perovskites have the potential to successfully collect photovoltaic energy since it has a light-assimilating covering [6].

Perovskite PV cells have advanced rapidly, in any case, a few pivotal factors might restrict their progression. Environmental factors consume a noteworthy consequence on the constancy of organic lead halide perovskite material leading to declining instability. As a result, cultivating a high-reliability device formulation, which includes the light-assimilating layer, electron/hole transport layer, electrode materials, and a practicable and elegant device-packaging strategy, will be crucial in furthering the practicality of these types of gadgets. Since this lead element used in perovskite solar cells is extremely hazardous, it can be difficult to promote and build perovskite solar cells in the manufacturing industries. As a result, finding a low- or non-toxic component to substitute Pb will be important [7].

2. Evolution of Solar Cells

2.1 Silicon Solar Cells

The first-ever crystalline silicon solar cell was manufactured at Bell Telephone Laboratories in the year 1953 that had an efficiency of 4.5% [1]. It was found out that light with a wavelength lower than 1.2 microns can produce electron-hole pairs, the efficiency of energy conversion diminishes for short wavelengths [8]. Vanguard I IGY Satellite (1958 Beta) was the world's first solar-powered satellite. The structure of the solar cell was Grid-contact B diffused created by Hoffman Electronics, thus this cell uses grid contact to reduce the resistance of the cells [9]. A commercially available Phosphorous-Diffused Silicon Solar Cells with 14.5% ground-based cell efficiency was fabricated in 1962, this cell exhibited high radiation resistance, for high-resistivity base cells a very high long-wavelength collection efficiency is achieved and high short-wavelength collection is also attained [10].In a PESC cell wherein the utilization of a slender, emitter diffusion, a narrow passivating oxide layer with much higher sheet resistivity and a methodology that all of these factors work together to prevent emitter recombination by limiting the interfacial area in between the upper metal substrate and the silicon to low values. Parameters obtained by the PESC cell included proficiency of 19.8% with F.F of 81.9% [11]. Later the same year the structure was modified by using micro-grooved surfaces, the majority of the silicon cell surface is covered in 5μm deep slats with a 10μm pitch. Thus increasing the efficiency of the cell to 20.9% [12].

The surface of the material could be successfully shaped using a suitable selective etching process, resulting in a reduction in overall optical reflection. The advent of relatively inexpensive silicon in square-shaped slices of virtually arbitrary dimensions opens the door to automated solar cell manufacturing systems, resulting in significant cost savings. The cell exhibited 12.5% AMO efficiency and AM1 value 14% [13]. PERL cell was fabricated in the Photovoltaics Research Centre in the UNSW. Conservation of the majority of the cell surface areas with elevated TCA (trichloroethane) produced SiO2 which is a massive benefit of the PERL cells. Protection is provided by highly phosphorous and boron diffused zones on both the front and back metal contact surfaces hence contact resistance is improved by inhibiting contact recombination. The light-trapping technique created by the inverted pyramid in both the front and rear surfaces of the mirror is remarkable. The PERL cell with FZ substrate and 1ohm-cm resistivity exhibited efficiency with a range of 24-25% [14]. Devised inverted-pyramid photonic crystal IBC solar cell that employs an innovative method for producing thin, flexible 15 μm-thick c–Si sheets with a square-lattice pattern. They employed a photonic crystal with a matrix of interlocked back connections called a micro-pyramid. This cell recorded an efficiency of 30-31% with Jsc and Voc of 44.39mA/cm2 and 0.7908V respectively with a fill factor of 87.67%. To ensure enhanced light-trapping ability of the c–Si photovoltaic cell by simulating Maxwell's equations, a reliable FDTD approach is utilized, which is done by using the software program Electromagnetic Template Library (EMTL) [15].

2.2 Second Generation Solar cells

Using a p-Cu2-xTe/n-CdTe structure, Cusano developed the first effective polycrystalline thin-film PV cell with a PCE of 6% have been achieved [16]. PV cells were made by reactively depositing thin films of n-n-In2O3 upon single-crystal p-CdTe. The cell functioned as a buried homojunction that recorded efficacy of 13.4% with a F.F of 74.5% [17]. By fabricating CdTe/CdS thin-film heterojunction PV cell, chemical bath deposition was utilized to create CdS films, while close-spaced sublimation was used to manufacture p-CdTe films and used glass/SnO2/CdS/CdTe structure. The decreased sensitivity at lower wavelength implies that there is a predominant loss in the window layer absorption that showed an efficiency of ɳ=15.8% [18]. The construction of the ZnO/CdS/CdTe/ZnTe cell model was mimicked utilizing the ADEPT 1D reenactment instrument. A slender CdTe absorber layer and a ZnTe back surface field (BSF) were used to replicate the device, resulting in a reasonable energy conversion efficiency of 24.66% [19]. According to reports, the CdTe technique is around 30% relatively lower in cost than the CIGS technique and 40% affordable compared to a-Si technology [20]. The Solar Cell Capacitance Simulator-1D (SCAPS-1D) was utilized to recreate cadmium sulfide (CdS) and cadmium telluride (CdTe) based photovoltaic cell (ZnO/CdS/CdTe/NiO/Au). The PV cell with the best performance exhibited a phenomenal PCE of 28.04% with a Fill Factor of 87.84%. The greatest power conversion efficiency was achieved with a carrier density of 1017 cm3 and a width of 1000 nm, correspondingly [21]. Cu (In, Ga)Se2 is utilized in a slender film (CIGS) based sun powered cell, wherein, substrate glass with an area of 1 cm2, layers from base to top are Molybdenum back contact, the p-doped Cu(In(1-x), Gax)Se2 as safeguard layer, the n-doped ZnO layer as window layer or transparent conducting oxide (TCO). The performance of the cell improves as the temperature drops. The conversion efficiency achieves a peak of 32.45% at 240 degrees Celsius, which is 9.53% higher than the previous record [22]. By strengthening and retrofitting the cell buffer layer and introducing an electron reflector layer, a model with a 28.3 percent efficiency was developed. It was inferred that, choosing better appropriate materials, like transparent conducting oxide (in this case, ZnO: Al), a window layer, and a buffer layer with a bigger bandgap, because less light absorption in these layers boosts efficiency [23]. CIGS with a novel device architecture p-Si/p-CIGS/In2S3/ZnO/Al-ZnO was developed which obtained efficiency approximately equal to 26%. A system with a Cd-free buffer layer with an economical CIGS-based extremely thin photovoltaic cell was designed using a 1 D SCAPS simulator. The main drawback of this model is the efficiency of 26% increases with an enhancement in the absorber material's size [24]. By simulating a highly-efficient n-CdS/p-CIGS/p+-CGS dual heterojunction solar cell 47% efficiency was achieved [25].

Table 1. Comparison of CdTe/CIGS/GaAs Solar cells

Reference	**Layer Topology**	**Description**	**Jsc (mA/cm^2)**	**VOC (V)**	**F.F %**	**ɳ (%)**	**Advantages**	**Disadvantages**
D. A. Cusan'o, 1963	CdTe/CdS	Heterojunction	12	0.75	0.7	6	First efficient polycrystalline thin-film solar cell using p-Cu2-	Instabilities associated with Cu_2-xTe

							xTe/n-CdTe	
Nakazawa, 1987	n-In_2O_3/CdTe	Buried Homojunction	20.1	0.892	74.5	13.4	High open-circuit voltage	The substrate surface has to be carefully treated.
J Britta and C Ferekides, 1993	CdTe/CdS	Heterojunction	25.09	0.8429	74.48	15.8	-	Combination of CdTe/CdS
Sultana et al., 2017	CdTe/CdS	Heterojunction	34.4	0.946	75.78	24.66	High efficiency	Combination of CdTe/CdS
Ahmed et al., 2020	CdTe/CdS	Heterojunction	29.09	1.09	87.84	28.04	Good Efficiency	Combination of CdTe/CdS
Repins et al.,2008	ZnO/CdS/CIGS/Mo	Heterojunction	35.5	0.69	81.2	19.9	High Fill Factor	Use of Zn and Cd
Kamada et al., 2016	Al/ MgF_2/ ZnO:B/ i-ZnO/ (Zn(O,S,OH)) / (CIGSSe)/ $(Mo(S,Se)_2)$ / (Mo) / $(SiO)_2$ /glass substrate	Buffer layer (Zn,Mg)O/Zn (O,S,OH)	41.4	0.71	77.5	22.8	CdS free	KT-PDT is still under investigation
Fatemi Shariat Panahi et al., 2020	ZnO:Al/ Zn0.83Mg0.17O/ CdS/ CIGS/ CIS/ GaAs/MO	Heterojunction	54.7	0.84	83.9	27.9	CdS free	Use of Zn and Cd
(Bouabdelli et. Al, 2020	Glass/Mo/p CIGS/n CdS/I ZnO/n ZnO/Ni-Al Contact	Heterojunction	40.3	0.95	86.68	32.45	Good efficiency	CdS buffer

Mostaque, S.K et al., 2021	n-CdS/p-CIGS/p+-CGS	dual heterojunction solar cell	59.94	0.98	80.07	47	High efficiency	CdS
King et al.,2002	GaInP/GaInAs/Ge	3 junction solar cell	17.4	2.716	86.3	30.1	Good efficiency	Increase in cost
Patel et al.,2012	InGaAs/GaAs/InGaP	IMM4J	46.84	3.236	85	34.5	Good efficiency	Complex
Pham DP et al.,2021	AZO/ZnO/P-type GaAs/GaInP BSF/p^+-GaAs contact/Glass/n^+-a-Si/a-Si/c-Si bottom cell/a-Si/p^+-a-Si	4 terminal GaAs/c-Si tandem PV cell	30.48	1.11	88.60	35.16	Low cost	-

CIGS cell in which KF was vaporized on the absorber surface using molecular beam epitaxy after the absorber was formed and PDT was used to anneal the absorber. To increase the VOC, the degree of KF deposition was studied and obtained 22.8% efficiency. KF-PDT is impactful on sulfur-containing absorbers manufactured using a two-step process, which would be a viable mass-production procedure that can be used for 1 GW manufacturing [26].The electron reflector layer should be made of a suitable material while the cell's absorber layer should be made of a different material to boost efficiency up to 27.9% [27].

Lower bandgap middle cells such as GaInAs middle cells, and greater bandgap top cell materials can both boost efficiency. In freeloading consuming layers like tunnel junctions, the use of broad bandgap and indirect-gap materials enhances light transmission to the functional layers of cells beneath [28]. With IMM4J AM0 conversion efficiency has improved. Another trial best AM0 competence of 34.2 percent was achieved due to recent material and fabrication process advances [29]. A 6J inverted metamorphic concentrator solar cell which with reasonably elevated quality junction materials can approach 50% efficiency, it had the architecture Front metal contact/Ga4In6As/InSbxP1-xCGB/GaxIn1-xP CGB/Ga7In3As/AlGaIn/As CGB/GaAs/Al2Ga3As/Al2Ga3In5P/Front metal grid with VOC= 5.15V, JSC =5.6 mA/cm2 and F. F= 0.86% [30]. A 4 terminal GaAs/c-Si tandem PV cell with architecture AZO/ZnO/P-type GaAs/GaInP BSF/p+-GaAs contact/Glass/n+-a-Si/a-Si/c-Si bottom cell/a-Si/p+-a-Si, obtained the efficacy of 35.61% with Voc, Jsc and F.F of 1.1V, 30.48 mA/cm2 & 88.60% respectively. These findings point to a huge future potential for high-efficiency and minimal cost multi-junction PV cell manufacturing [31]. Second-generation solar cells and their performance can be seen in Table 1.

2.3 Third Generation Solar Cell

A DSSC is a moderately reasonable PV cell. This cell, otherwise called the Gratzel cell, was concocted by Michael Gratzel and Brian O'Regan. It depends on a photoelectrochemical framework in which a semiconductor is made between a photosynthesized anode and an electrolyte. It is a kind of thin-film PV cell [32]. A sensitizer is fixed to the exterior of a broadband semiconducting material, and it captivates light. Charge separation occurs at the contact because of dye-induced electron injection into the solid's conduction band. Carriers crossing the semiconductor's conduction band are collected by the charge collector. The combination of broad-band sensitizers and nanocrystalline-morphology oxide sheets allows a significant amount of sunlight to be gathered. The conversion of input photons into electric current is virtually quantitative over a wide spectral range, from ultraviolet to near-infrared. To control the self-assembly of the N3 dye at the TiO2 interface, Guanidinium thiocyanate was added to the electrolyte. At the contact with the N3 anions, the guanidinium cations are adsorbed, preventing the sensitizer's lateral coulombic repulsion and permitting the self-assembly of a compact dye monolayer. As a result of the reduction in dark current, the cell voltage increased significantly to about 10.6% with F.F 0.748% [33]. DSSCs are intriguing because, in comparison to the two preceding kinds of photovoltaic cells, they are less expensive, simpler to construct on big panels, lighter and more flexible, and provide transparency [34]. Because of their remarkable light-harvesting capabilities beneath prevailing light conditions, DSSCs have a lot of potential for light energy recycling in indoor solar applications. The high power-conversion efficiency (PCE) of over 30% under indoor lighting circumstances, as well as their colourful aesthetics, cost-effectiveness, consistent device functioning, and PCE retention of up to 99 percent, demonstrate DSPVs' utility for ambient energy collection [35]. The major challenge in DSSC design is the use of a liquid electrolyte, which is not very stable at different temperatures. At a relatively low temperature, the electrolyte can freeze, resulting in a loss of power and physical harm. When the liquid expands at higher temperatures, it becomes more challenging to encapsulate the surfaces. [36] To address this issue, solid-state DSSCs using glass coated with FTO and conducting glass as the substrate was created. The initial layer was a thin compact layer of TiO2, followed by a mesoporous layer of TiO2 or spiro-OMeTAD as HTM. The HTM, combined with a thin HTM overstanding layer, is then infiltrated into the porous structure. Finally, over the HTM a metal contact is vaporized. Direct metal-to-TiO2 contact could also produce shunting. The latest copper complex-based HTM devices have surpassed the performance of spiro-OMeTAD as HTM. In the solid phase, Cu phenanthroline complexes were used as a molecular hole-carrying material for solid-state DSSC. When it comes to electron transfer, it has a high self-exchange rate and requires little driving force to regenerate dye. With Cu(tmbpy)2 as HTM using Y123 Dye, PCE= 11.3%, VOC= 1.08 V, JSC =13.87(mA/cm) and F.F= 0.75 [37] Due to increased charge recombination from titanium dioxide to HTMs, low intrinsic conductivities of HTMs, poor electrical contact between HTMs, dye molecules due to insufficient penetration of solid HTMs into the TiO2 matrix, the PCE of most solid-state DSSCs which is derived from organic HTMs is reduced [38]. One of the greatest challenges with the DSSC integration is counter electrode deterioration. Because of its great electrocatalytic effectiveness and high electrical conductivity for the I/I3 redox process, platinum is frequently chosen as the catalyst material for electrode coating. On the other hand, Pt coatings are unsuitable for commercialization because they are chemically unstable in iodide or triiodide-based electrolytes and are too expensive [39]. The use of nanoporous films in dye-derived wideband semiconductor research culminated in a key breakthrough in dye-sensitized solar cells (DSCs) in photoelectric energy conversion. In simulated photovoltaic light, the basic incident photon to contemporary conversion effectivity (IPCE) yield was once 7.1–7.9%, whilst in diffuse daylight it used to be 12%. Since then, DSCs have gotten a lot of attention from academics and businesses because of their great efficiency, prospective low price, and manufacturability [40]. Researchers exhibited cell proficiency of 8.2 percent utilizing a novel solvent-free liquid redox electrolyte comprised of three salts as an option in contrast to utilizing natural solvents as an electrolyte arrangement [41].Mesoscopic solar cells with a redox-based electrolyte and a custom-manufactured zinc porphyrin dye as a sensitizer (named YD2-o-C8) slow interfacial back electron transport from the nanocrystal film's conduction band to the oxidized cobalt mediator, allowing for photovoltages approaching 1 volt. The device's performance is further improved by co-sensitizing the dye with another organic dye, which results in a measured PCE of 12.3 percent over simulated air mass 1.5 [42].

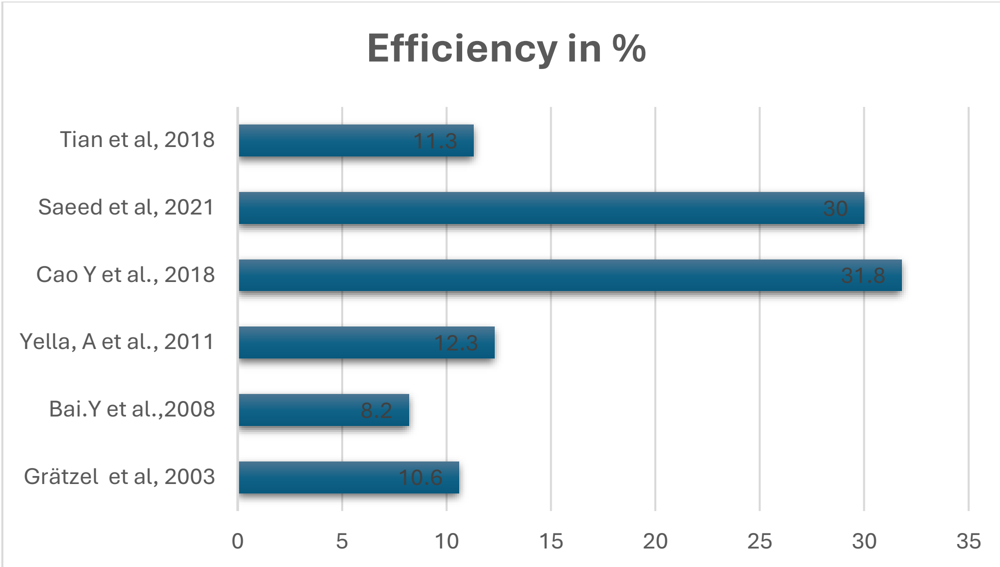


Fig.1. Comparison of proficiency of Dye Synthesized Solar Cell

Table 2. Comparison between DSSC/QDSC/OSC

Reference	Cell	Description	Jsc (mA/cm^2)	VOC (V)	F.F %	η (%)	Inferences
Bai.Y et al.,2008	DSSC	DMII/EMII/EMITCB/I_2 /NBB/GNCS (12:12:16:1.67:3.33:0.67)	14.26	0.741	77.4	8.2	Solvent-free electrolyte. But not applicable for large scale door production
Yella, A et al., 2011	DSSC	Co(II/III)tris(bipyridyl)–based redox electrolyte with YD2-o-C8 as the synthesizer.	17.66	0.935	74	12.3	High photovoltage but has losses due to volatile acetonitrile solvent.
Cao Y et al., 2018	DSSC	TiO_2/FTO/ Meso-TiO_2/Dye/ Electrolyte/ Sealant/ Insulating porous spacer/ Counter electrode	0.138	0.878	77.3	31.8	Higher Efficiency
Gao, J et al., 2011	QDSC	ITO/ZnO/PbS QD/metal	18.145	0.524	46.2	4.04	Poisonous lead is used
Pan Z et al., 2014	QDSC	CIS/ZnS core/shell QDs	19.73	0.58	58	6.66	Cd & Pb free with less performance

Jiao S et al., 2017	QDSC	N-MC/Ti CE	25.53	0.785	63.2	12.23	Improved efficiency with Poor stability
Zhang. L et al., 2021	QDSC	FTO/c-TiO_2/$CsPbI_3$ QDs/Spiro-OMeTAD/MoOx/Ag	17.58	1.23	74.3	16.07	Good efficiency but causes lead poisoning
Lungenschmied et al., 2007	Organic	Al/P3HT: PCBM/PEDOT: PSS/ITO/Substrate	13.9	1.38	29	0.5	Stable and Low efficiency
Kang, M.G et al., 2010	OSC	Al/LiF/ P3HT: PCBM/ PEDOT: PSS/ITO/Substrate	8.75	0.59	69	3.5	Scalable and Low efficiency
Farooq. W et al., 2020	OSC	ITO/PEDOT: PSS/P3HT: PCBM/TiO_2/PEDOT: PSS/PTB7: PCBM/TiO_2/Al	22.6	0.85	68.21	13.5	High-Temperature stability with moderate performance
Jin K, 2021	OSC	ITO/PEDOT: PSS/D18-Cl: N3: PC61BM (D: A1:A2)/PDIN/Ag	28.22	0.85	78	18.69	Higher efficiency
Fu, Jiehao, et al.,2023	OSC	PM6:BTP-eC9 organic solar cell	27.88	0.861	80.39	19.31	High efficiency
Chen, Chen, et al..2024	OSC	D18:L8-ThCl/L8-BO:L8-ThCl Ternary p-BHJ	27.5	0.91	80.3	20.1	Increased efficiency

A DSC architecture achieves 13.1% efficiency under air mass 1.5 global, 100 mW cm2 solar radiation, and 32% PCE under a standard Osram 930 Warm White fluorescent tube light at 1,000 lux intensity. Direct contact of the dye-impregnated TiO2 layer with the hole-collecting poly(3,4-ethylenedioxythiophene) (PEDOT) reference electrode considerably improves the cell [43]. CIS-Z QD sensitizer was used to build high-efficiency "green" Quantum Dot Solar Cells. These solar cells have a verified efficiency of 6.66%, which is a new high for Cd- and Pb-free QD solar cells and the maximum for QDSCs [44]. In QD-SSCs, a single layer of nanoparticles is chemically assimilated on an electron acceptor such as TiO2 or ZnO. The electrons are injected into the nanoporous electron acceptor and the holes are retrieved by a liquid electrolyte when photogenerated excitons (pairs of electron holes) are formed from a QD monolayer. As a result, the QDs in the QD-SSCs can only serve a single function as a layer of absorption with a recorded efficiency of 12.2%. Furthermore, the single-layer thickness of QDs restricts their application [45]. By including ZnI2 as the dopant in the synthesis process, an anion/cation synergy technique was exhibited to increase the stability and photoelectric characteristics of CsPbI3 QDs. The photovoltaic performance of PV cells made of Zn: CsPbI3 QDs is superior as well as stable with an efficiency of 16.7% [46]. For more than 1000 hours in the air, the device has remained incredibly stable. As a result, the focus of this research is on air-fabricated devices having an ITO/ZnO/PbS QD/metal configuration. The photovoltaic cell efficacy can be increased to over 4% by tempering PbS QD film at low temperatures up to 140 degrees Celsius [47]. On both glass substrates and flexible ultra-high barrier foils, interlinked massive organic solar cells were developed. Flexible solar cell modules with a 0.5 percent efficiency, made up of three series-connected components was realized with Jsc, Voc and Fill factor of 13.9 mA/cm2, 1.38V, 29% respectively. In the case of the P3HT: PCBM-based cells, the ultra-high barrier material can last up to 6000 hours on the shelf, or more than 8 months [48]. An essential approach is used to produce exceptional BHJ morphology in a short amount of time, paving the door for scalable high-efficiency polymer solar cell manufacturing with 3.5% efficiency [49]. Integrated P3HT: PCBM and PTB7: PCBM results in a hybrid tandem structure. The proposed architecture is more efficient (13.5%) and more stable at high temperatures, indicating that it is better suited for actual applications [50]. Cell architecture of ITO/PEDOT: PSS/D18-Cl: N3:PC61BM (D: A1:A2)/PDIN/Ag with high PCE of 18.69%, JSC of 28.22 mA/cm2, OC Voltage of 0.85V and F.F of 78% is obtained [51].Using a self-assembled molecule of 2-(9H-carbazol-9-yl) (2PACz), the self-assembled interlayer (SAI) technique is created, which uses a thin layer of 2–6 nm to form a full coverage on the substrate via both covalent and van der Waals connections. In addition to optimizing the electrical and optical properties of OPVs, allowing for a world-record efficiency of 20.17% (19.79% certified), the simple spin coating eliminates the need for additional rinsing and annealing steps and streamlines the laborious production process. A record light usage efficiency of 5.34% is made possible by the SAI method, which is particularly helpful in enhancing the absorption selectivity for semi-transparent OPVs [52].Using 1,3,5-trichlorobenzene as a crystallization regulator, a nonmonotonic intermediate state manipulation strategy for cutting-edge organic solar cells optimizes the film crystallization process and controls the bulk-heterojunction's self-organization in a non-monotonic way, i.e., by first promoting and then relaxing molecular aggregation. As a result, we have produced effective organic solar cells with lower non-radiative recombination loss and prevented the excessive aggregation of non-fullerene acceptors. Our approach effectively provides a record binary organic solar cell efficiency of 19.31% (18.93% certified) in PM6:BTP-eC9 organic solar cells with a very low non-radiative recombination loss of 0.190 eV. Additionally, the PM1:BTP-eC9 organic solar cell has a lower non-radiative recombination loss of 0.168 eV (19.10% efficiency) [53]. Creating L8-ThCl, a thiophene-ended non-fullerene acceptor, which induces the fibrillation of both the host acceptor and the polymer donor, surpassing the 20% efficiency milestone of organic solar cells. In addition to the host acceptor L8-BO assembling into nanofibrils with improved structural order, the initial weak and less continuous nanofibrils of polymer donors, such as PM6 or D18, are well expanded and refined after the addition of L8-ThCl. With specific values of 19.4% and 20.1% for the PM6:L8-ThCl/L8-BO:L8-ThCl and D18:L8-ThCl/L8-BO:L8-ThCl devices, respectively, the improved structural order can be maintained by modifying the layer-by-layer deposition method. The latter is certified at 20.0%, the highest certified efficiency noted thus far for single-junction organic solar cells [54].

Table 2 shows the simulation parameters such as PCE, FF, Voc, Jsc and the features of the third-generation solar cells.

3.Progression of PSC Device Architecture

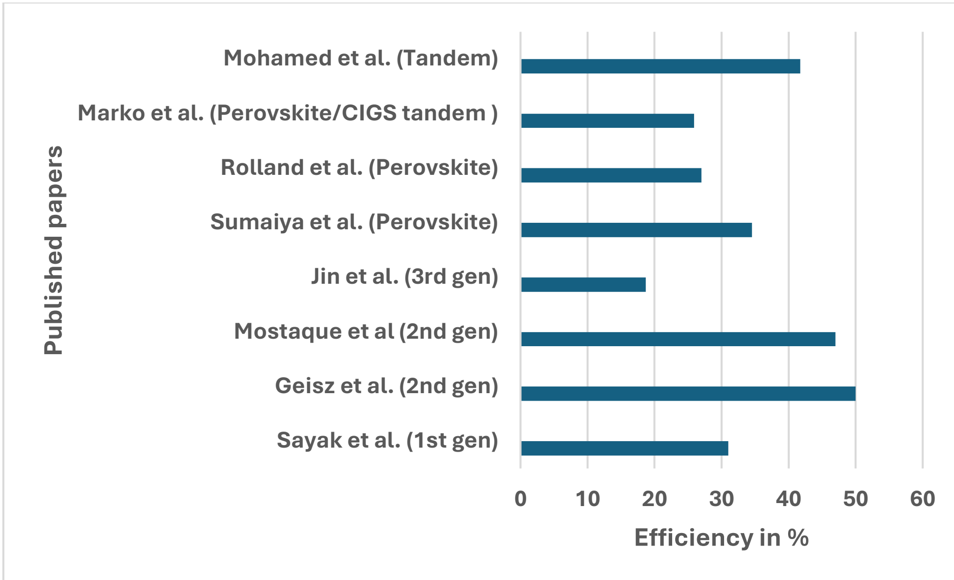
Over the last years, a new group of perovskites attracted considerable interest in science, emerged into existence called Hybrid Organic-Inorganic Perovskites, consisting of CH3NH3+, an ammonium cation; and Sn2+, Pb2+, etc which is a divalent metal cation and Cl-, Br- and I-, which are halide ions. Kojima was the first person who publishes a report on the photovoltaic solar cell, he fabricated dye synthesized solar cells with liquid electrolytes. It used CH3NH3PbI3 (MAPbI3) and CH3NH3PbBr3 (MAPbBr3) as sensitizers that achieved 3.81% efficiency. No consideration was given to this device due to its reduced stability and efficiency [55]. There came up groundbreaking results when Solid State hole transport material was incorporated instead of liquid electrolyte, as the efficiency strikingly enhanced up to 9% [56]. When Al2O3 based PSC with mixed halide (CH3NH3PbI2Cl) is used as buffer layer the PV cell exhibited a maximum efficacy of 10.9% [57]. Li doped film-based podium with CH3NH3PbI3 as absorber material exhibited an enhanced short circuit current with a remarkable 19.3 percent efficiency [58]. Perovskite solar cell with 20.7% power conversion efficiency and the device was stable for over 90 days maintaining the efficiency 20% [59]. PSCs with methylammonium format (MAF) could remain stable for a longer duration compared to PSCs without MAF and recorded proficiency of 19.5% with F.F of 0.71 [60]. Bai in 2016 synthesized crosslinked C60-Sam layer on MAPbI2 to PbI3 layer and inferred that crosslinked C60-Sam layer improved the water stability of the cell [61].

4. Review on PSCs

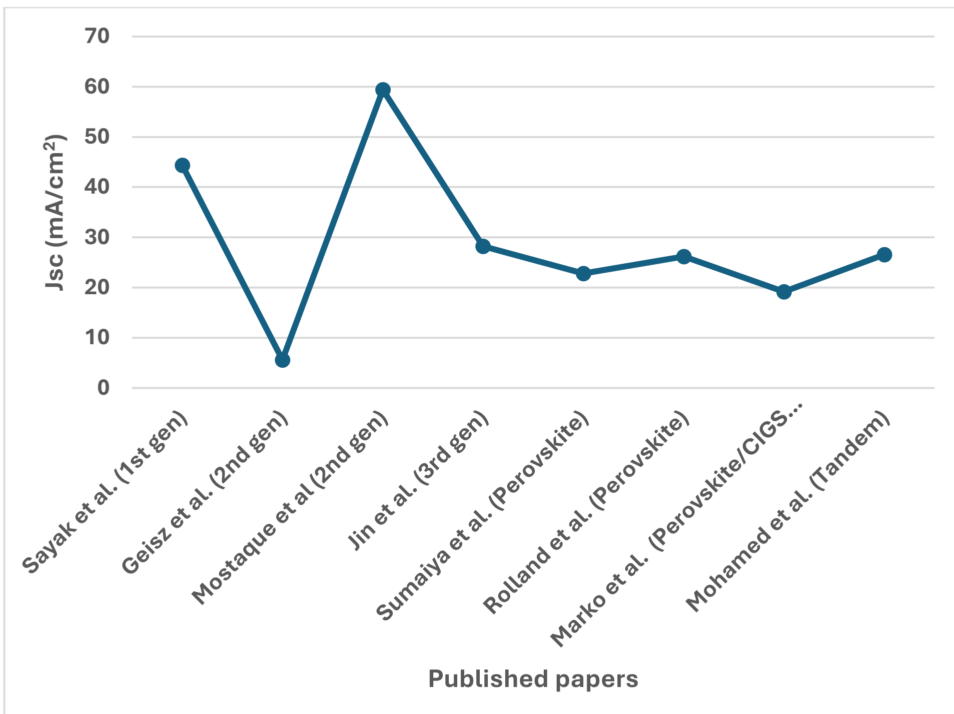
Low-cost materials with simple manufacturing processes can be used to manufacture PSCs. But its main challenge is to maintain the stability of the module level and durability concerning outdoor applications as loss in efficiency is observed as the area of PSC increases [62]. PCS lasts only for 6 months whereas silicon solar panels work up to 25 years [63]. Using first-principle measurements and thermodynamic modeling and found that the limit of absolute maximum efficiency was in the range of 25-27 % concerning the band-gaps of the metal halide perovskites [64]. Beneath real-world weather patterns, simulated functional Perovskite/Si tandem solar cells and showed that Si will increase the efficiency gain of tandem cells up to 12.9% by enhancing parasitic cell resistance, non-radioactive recombination, and optical loss. A greater efficiency gain can be obtained by optimizing the Perovskite cell by minimizing non-radioactive recombination and optimizing electrical and optical losses [65]. A small "loss-in-potential" value results in Perovskite cells' VOC greater than 1.1 V. Making it a potential competitor for solar cells with crystal silicon (1.1 eV) [66]. Studies showed that solar cell-oriented perovskite (CH3NH3PbI3) considering the structure of n-i-p. Stated that, an integrated structure with zinc oxide as ETM and nickel (II) oxide as HTM, using a hybrid optical and electrical approach with SCAPS -1D software, outscores the performance of the traditional photovoltaic cell. The PCE recorded was 24.94% for the conforming Voc and JSC obtained were 1.3V and 23.58mA/cm2 respectively and fill factor was 0.83 [67]. Lead-free ecofriendly cell with antimony based (MA_3Sb_2I) Active layer and tungsten disulfide (WS_2) interlayer to form a p-i-n heterojunction solar cell that achieved an efficiency of 20.36%. However, the bandgap of Antimony (Sb) is always higher than the optimal value which makes it difficult to achieve maximum PCE due to less recombination [68]. For enhanced performance, laser-scribing methods are employed to shape the module segment, eliminate dead space, and optimize aperture area efficiency. The module's dead area is less than 16 percent, demonstrating the benefits of laser scribing technology. This laser scribing has reduced the PCE by 2.6% and also has lesser values of Voc, Jsc concerning reference cell because of photocurrent loss [69]. With changed ZnO-nanorod interfacial construction with further developed security. With the device layers: FTO/ZnO-nanorods/PCBM/$CH_3NH_3PbI_3$/Spiro- OMeTAD/Au. The use of ZnO nanorods has increased the Jsc and Voc by 18.6% and 18.5% respectively. These ZnO-based nanorods are not user-friendly for fabrication because of their higher cost [7071]. Lead-free perovskite sun-based cell by utilizing tin and the imperfections in buffer layer are displayed by utilizing exponentially decaying band tails for shallow-level deformities and Gaussian dispersion for the profound level deformities. The layer topology is ITO/Glass/PEDOT: PSS/$MAGeI_3$/PCBM/Au. The PCE obtained is not economical whereas if we replace $MAGeI_3$with $MAPbI_3$the PCE is around 4% higher. This design is used for synthesizing lead-free eco-friendly perovskite solar cells [72]. The deposition of SALD (Spatial atomic layer deposition)) TiO_2 films on the fluorine-doped tin oxide substrate work on the fog at mid-long frequencies, repaying the optical misfortune brought about by the retention of the TiO_2 layer in short-frequencies. The layer topology is Au/spiro-OMeTAD /perovskite/SnO_2/TiO_2(sol-gel SiO_2/SALD SiO_2)/FTO. The use of SALD has led to an increase of Voc by 4.6% and Jsc by 2%. Increasing the TiO_2 thickness up to 10nm reduces the Jsc by 75%. It can be used for producing solar cells with a low hysteresis index [73].When compared to an encapsulation approach using a glass cover with ultraviolet-cured resin at the module edges, the epoxy resin-based encapsulation method reduces the lead leakage rate by a factor of 375. Its enhanced mechanical strength and ideal self-healing properties under operational conditions are linked to the epoxy resin encapsulation's higher Pb leakage reduction. Based on suitable encapsulation, these results clearly imply that Pb leakage from perovskite solar products can be minimized during deployment [74].

5. Review on Device Modeling and Simulation

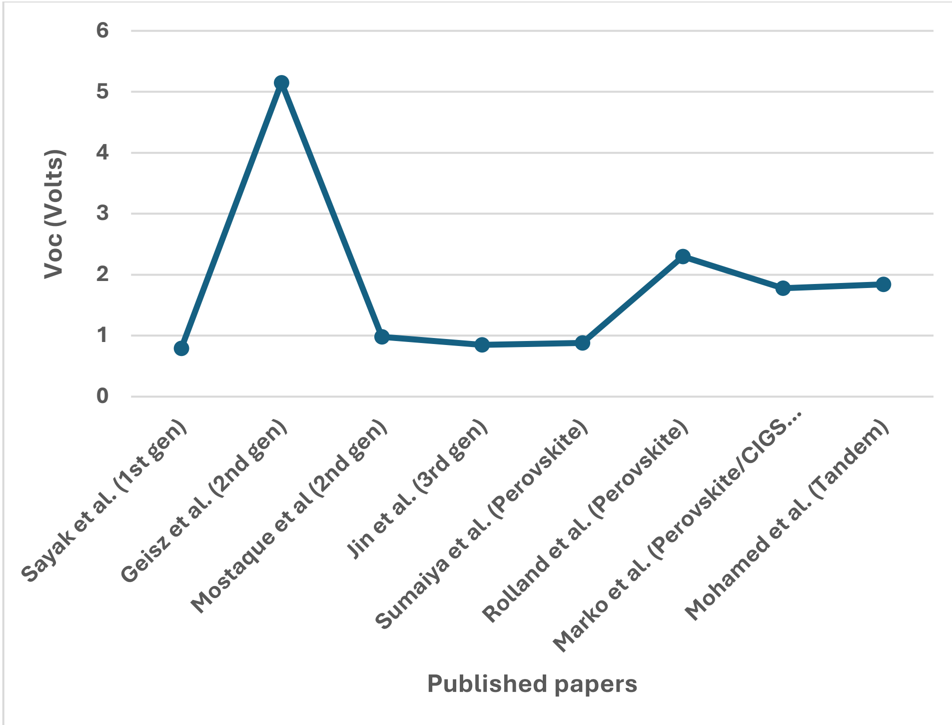
Methodology Numerically modeled PSC in Relying upon this Poisson and continuity, a drift-diffusion approximation has been developed. with planar p-i-n structure and showed that Perovskite absorber thickness and its consistency affect the efficiency, i.e., the preferred thickness of 500-600 nm with a broader range of Diffusion of 1-1.5 μm leads to 25-27% efficiency [75]. In addition to assessing the efficiency of metal electrode work in the fabrication of PV cells, work was carried on perovskite/p-Si heterojunction perovskite planar solar cell with Silvaco Atlas Software and concluded that VOC, JSC, and FF can be influenced by adjusting the working feature that fits the front and back electrodes [76]. By modeling monolithically integrated series-connected tandem solar cells i.e., hybrid perovskite on silicon tandem solar cells with Silvaco software. This research provides strong evidence that the $CH_3NH_3PbI_{3(1-x)}Br_{3x}$ alloy of perovskite methylammonium lead iodide-bromide is a highly promising absorbing material for escalated performance and low-cost tandem photovoltaic cells based on silicon, as it gives maximum efficiency of about 27% [77]. By incorporating a PSC on Si-based Tandem solar cell with Silvaco, wherein PSC acts as top cell since it is low in cost and has high absorption and yields transmittance >50% in a near-infrared spectral region. The whole module is encapsulated by a double-layer antireflection coating consisting of Al_2O_3 with SiO_2, LiF and MgF_2 were satisfactory, since the optimized Power conversion efficiency was found to be 26.75% [78]. An equivalent circuit for four miscellaneous forms of PSCs related to physics-based analytical models (n-i-p/n-p-p and p-i-n/p-p-n and) was therefore developed using MATLAB since analytical modeling has the potential to forecast the supreme output of the panel of individual PSCs and it can map efficiency of the and module's gap to the statistical distribution of one or more cell parameters and suggest enhancement prospects [79]. A convenient and cost-effective way of producing high-performance solar cells is recommended that could extend the spectral response range to form a 4-terminal perovskite/Si tandem architecture a Si bottom cell layered beneath a PSC top, increasing the efficacy of the tandem cell by about 20% compared to the Si solar cells reference [80].


Mohamed et al. (Tandem)
Marko et al. (Perovskite/CIGS tandem)
Rolland et al. (Perovskite)
Sumaiya et al. (Perovskite)
Jin et al. (3rd gen)
Mostaque et al (2nd gen)
Geisz et al. (2nd gen)
Sayak et al. (1st gen)
Published papers
0
10
20
30
40
50
60
Efficiency in %

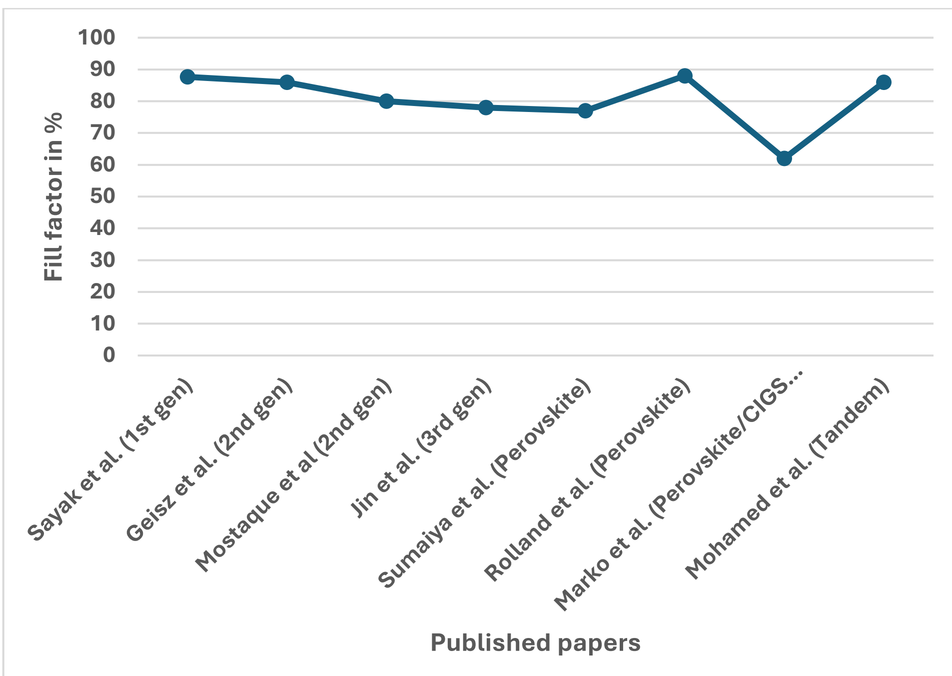
(a)


70
60
50
40
30
20
10
0
Jsc (mA/cm²)
Sayak et al. (1st gen)
Geisz et al. (2nd gen)
Mostaque et al (2nd gen)
Jin et al. (3rd gen)
Sumaiya et al. (Perovskite)
Rolland et al. (Perovskite)
Marko et al. (Perovskite/CIGS...
Mohamed et al. (Tandem)
Published papers

(b)



(c)



(d)

Fig. 2. a) Comparison of proficiency of diverse kinds of PV cells. b) Comparison of Jsc of various PV cells. c) Comparison of Voc of different types of solar cells. d) Comparison of Fill factor of different kinds of PV cells.

Considering Fig.2. a), b) and c), we can conclude that the second generation (2nd gen) solar cells have the maximum recorded efficiency, Jsc and OC Voltage values of 50%, 59.4 mA/cm2 and 5.15 V respectively. This is because of the use of indirect bandgap materials like GaAs, CdTe, etc. which have low hysteresis loss and higher stability. Also the Fig. 2. d) shows that Perovskite has the highest Fill factor of 88% which is almost the same as the Si-based solar cells.

6. Analysis of Experimental and Simulated Results

In a mesoporous perovskite photovoltaic cell when a limited quantity of n-butyl amine (BTA) is added into PbI2 to obtain optimal quality, seamless Perovskite films with huge kernels of crystal, and elevated crystal quality thus the rate of crystallization in PbI2 due to moisture can be hindered. Without BTA PCE was 11.38%, but PSC demonstrated with BTA constituent showed improved efficiency of 16%, there is an improvement in all the parameters of the PSC [81]. P-i-n-type solar cells with γ-CsPbI3 phase obtained by co-evaporation method recorded PCE of 12.5% with improved stability of 50days [82]. Perovskite/CIGS tandem PV cells likewise have extraordinary potential that had accomplished a proficiency of 25.9%. Coordinated with radiation hardness and flexibility, there is a wide scope of utilizations, where Perovskite/CIGS tandem cells could be beneficial over other perovskite pair sun-oriented cells [83]. The morphology of BHJ for exceedingly effective p-i-n-type ISCs that integrate a Perovskite with MAPbI3 and organic BHJ absorbing NIR showed that highly efficient PSCs with photogenic absorption are feasible as a modern Photo - voltaic architectural design and the important rules for PSC optimization and obtained 0.77 Fill Factor with PCE 16.36% [84]. Later with the utilization of P3HT as an HTM layer in PSC with no dopants was recorded a PCE of 22.7 percent with a hysteresis of ±0.51 percent; Without encapsulation, it demonstrates incredible adequacy at 85 percent relative to clamminess and when a thin layer of wide-bandgap halide perovskite is molded on top of the restricted bandgap light-fascinating layer by an in situ reaction of n-hexyl trimethyl ammonium bromide on the perovskite surface, it shows long-stretch practical strength for 1,370 hours under 1-Sun lighting at room temperature, keeping 95 percent of the fundamental capability, and an FF of 0.79 is obtained [85]. By Simulating perovskite/silicon tandem solar cells in a new three-terminal design, with one terminal in front and two in the back, in which the top and bottom cells are either inverted or have the same polarity. Layer topology is MgF2/ITO/HTM/ETM/n-type Si/ITO/Ag. It employs an additional layer over ITO called MgF2 that increases the efficiency up to 32%. The PCE increases by 4% as the thickness of the perovskite layer grows by 50nm, but this can be exploited to generate higher PCE for solar cells with thicker perovskite layers [86]

Table 3. Comparison of experimental and simulated Results

Reference	Technique	VOC in Volts	J_{sc} in mA/cm^2	F.F	PCE in %	Type
Jian Wu et al., 2018	Experimental	1.10	22.29	0.65	16	Mesoporous Perovskite Solar Cell
Becker et al 2018	Experimental	0.96	17.8	0.73	12.5	P-i-n-type Solar Cells
Junghwan Kim et al., 2016	Experimental	1.06	20.04	0.77	16.36	P-I-N type ISCs
Marko Jošt et al.,2020	Experimental	1.78	19.2	0.62	25.9	Perovskite/CIGS Tandem Solar Cells
Abdelkader Himaa, et al., 2018	SILVACO ATLAS software	1.1	21.1	0.88	18.16	Perovskite-based n-i-p Planar Heterojunction
Rolland et al	SILVACO ATLAS software	2.3	26.2	0.88	27	Hybrid Perovskite on Silicon Tandem Solar Cell

Masood Mehrabian &SinaDalir ,2017	SILVACO ATLAS software	1.02	15.92	0.70	11.3	Perovskite Heterojunction Solar Cell
Eui Hyuk Jung et al.,2019	Experimental	1.152	24.88	0.81	23.3	DHA based PSC incorporating P_3HT
Mohamed Mousa et. Al, 2021	SCAPS Software	1.84	26.54	0.86	41.73	Two-terminal double junction tandem cells
Alsalme et.Al,2023	SCAPS Software	1.77	14.51	84.05	21.62	$MAGeI_3$-based lead free PSC
Alanazi,Terek, 2023	SCAPS Software	1.33	17.44	62.59	14.62	$Cs_2AgBiBr_6$-based lead free PSC
BHATTARAI et al, 2022	SCAPS Software	0.876	33.19	76.19	22.16	Lead-free $MASnI_3$-based PSC
Sabbah, Hussein, et al.,2023	SCAPS Software	1.278	23.30	88.21	26.34	Hydrogenated lead-free Cs2AgBiBr6 double PSC with inverted p-i-n structure
Bhattarai, Sagar, et al.,2023	SCAPS Software	1.108	31.89	85.01	30.10	Lead free Cs_2BiAgI_6/CIGS based PSC
Wahid M.F, et al.,2024	SCAPS Software	1.053	33.92	88.57	31.63	Lead free FTO/WS_2/$CsSnI_3$/P3HT/Au

Over 41% efficiency was reached by simulating high-current tandem PV cells with balanced currents, where the layering topology of the proposed cell is Glass/TCO/ZnOS/IDL1/ MAPbI32/CuO/ZnO/CdS/GeTe. Temperature causes efficiency, OC Voltage and F.F to drop. Using the incident spectrum AM 1.5, in recent years, two-junction tandem cells have achieved some of the maximum PCE. This cell is favorable since it has only two connections, which reduces the complexity and expense of solar cells significantly [87]. MAGeI3-based PSCs were studied with SCAPS-1D software. After being numerically modelled, PSCs with the device architecture FTO/ZnOS/MAGeI3/spiro-OMeTAD/Au showed increased performance at 300K f 21.62%[88].FTO/SnO2/Cs2AgBiBr6/Spiro-OMeTAD/Au has been used as the cell layout. By adding a ZnO0.4S0.6/Cs2AgBiBr6 DETL system, a double ETL structure was found to solve the absorber/ETL problem, boosting efficiency from 10.35% to 14.23% for an absorber with a thickness of 140 nm and 400 nm for the single and double ETL structures, respectively [89]. PSC with architecture ZnO/MASnI3/CuSbS2 is simulated CuSbS2 as HTM and ZnO as ETM can be utilized as an exceptional candidate to supplement the expensive Spiro-OMeTAD and ZnO as ETM for better band alignment and higher mobility factors , which notably enhances the efficiency of up to 22.16% and becomes useful in further optimizing the lead-free Sn-based PSC device making it cost effective[90].Hydrogenated lead-free Cs2AgBiBr6 double perovskite solar cells with an inverted p-i-n structure have their structural characteristics adjusted. The absorber and hole transport layer thicknesses and doping concentrations, as well as the effects of band alignment and ETL doping on performance, are carefully adjusted in this study using numerical modeling using SCAPS-1D. According to the study, the use of ZnO as an electron transport layer material results in an impressive power conversion efficiency of around 26.34%, showing the possibility of creating stable, extremely efficient, and reasonably priced Cs2AgBiBr6-based perovskite solar cells for use in future commercial applications [91]. ITO/ZnO/Cs2BiAgI6/Spiro-OMeTAD/Au, ITO/ZnO/CIGS/Spiro-OMeTAD/Au, and ITO/ZnO/Cs2BiAgI6/CIGS/Spiro-OMeTAD/Au are the three configurations whose performances will be compared. The use of materials like Cs2BiAgI6 and CIGS as light absorbers in solar devices is restricted due to their limited absorption of light. However, by adding a second light active layer made up of the graded active layer of both Cs2BiAgI6/CIGS, the device's ability to absorb light can be improved, hence increasing the configuration's efficiency. The suggested solar cell models in this study were analyzed using the SCAPS-1D program. The optimum output parameters that were attained are as follows: FF of 85.01%, PCE of 30.10%, VOC of 1.108 V, and JSC of 31.89

mA/cm2 [92]. Due to their potential as a perovskite absorber layer in the device architecture, lead-free double perovskite solar cells (DPSCs) have attracted a lot of research interest recently. They are also reasonably priced, exhibit exceptional stability, and have great performance. Commercialization of perovskite solar cells (PSCs) still faces challenges due to their lead and non-biodegradable material basis. Using SCAPS-1D software, an inorganic, non-toxic substance, Cs2AgInBr6, is studied. The simulation result indicates that the Cs2AgInBr6-based DPSC has reached a maximum efficiency of 26.9% at an absorber layer thickness of 600 nm [93]. SCAPS-1D software was used to determine the structure FTO/WS2/CsSnI3/P3HT/Au's properties, which include an open-circuit voltage of 1.053V, an efficiency of 31.63%, a short-circuit current density of 33.92 mA/cm2, and an FF of 88.57%. With its exceptional quantum efficiency in the visible and near-infrared spectrums, this structure will contribute to the development of more stable lead-free solar cells that could serve as the foundation for flexible technology [94].

$MAPbI_3$ layers with excess PbI_2 experimental data were used in this study to investigate a primary n-i-p planar structure (ITO/SnO_2/$MAPbI_3$/spiro-OMeTAD/Au) using drift-diffusion SCAPS-1D simulations. According to the calculations, the power conversion efficiency (PCE) was high, at about 24 percent. In order to enhance device efficiency, a number of parameters affecting photovoltaic performance were investigated, including $MAPbI_3$ thickness, series resistance, shunt resistance, defect density, and recombination methods (radiative and Auger). Adding ohmic contacts (IZO at the back and Azol at the front) to an optimized structure (AZO/SnO_2/$MAPbI_3$/spiro-OMeTAD/IZO) also increased the PCE to 26.03%. For the development of high-efficiency bifacial $MAPbI_3$ perovskite solar cells, these findings provide insightful information. Furthermore, the optimization of these parameters could lead to even higher efficiencies in future designs, as researchers continue to explore novel materials and architectures. Continued advancements in fabrication techniques and scalability will be crucial for the commercialization of these high-performance solar cells [96].

Table 3 provides a detailed comparison between the simulated and experimented solar cells based on their specifications.

7. Efficiency Comparison between Silicon PV cells, 2nd Generation Solar Cells, 3rd Generation Photovoltaic Cells and Perovskite Photovoltaic Cells.

7.1 Efficiency Comparison of Silicon Photovoltaic cell and Perovskite Solar cell.

The first Silicon Solar Cell, invented in 1953, could only achieve a 31 percent efficiency over 70 years, whereas PSCs could achieve high efficacy in just ten years which can be witnessed in Fig. 3.

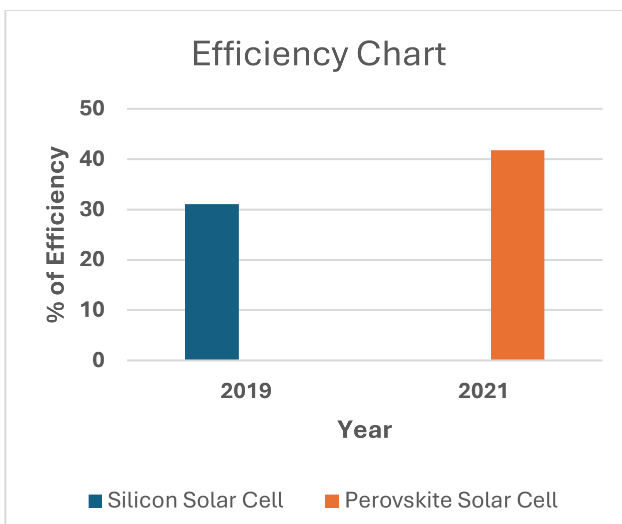


Fig.3 Efficiency comparison between Silicon and Perovskite solar cells.

7.2 Efficiency Comparison of CdTe/CIGS/GaAs and Perovskite Solar cell

The graph in Figure 4 depicts the year-by-year incremental efficiency of CdTe/CIGS/GaAs and Perovskite Solar cell. When comparing various solar cells, it is discovered that gallium arsenide is the best material for solar cell architecture since it has excellent light reception. GaAs concentrator Photo Voltaic cells have better efficiency than the other second-generation solar cells. PSCs could reach a phenomenal efficacy of 41.73% within a 14-year span, which can be termed as a great achievement, whereas GaAs solar cells could reach 50% in 60 years.

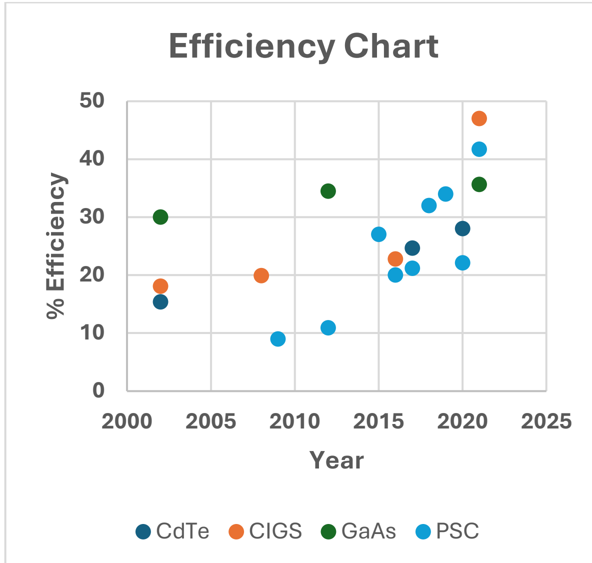


Fig.4 Efficiency comparison between second generation (2nd gen) and Perovskite solar cell.

7.3 Efficiency Comparison of DSSC/QDSC/OSC and Perovskite Solar cell

The graph in Fig.5 shows an efficiency comparison between Dye Synthesized PV cell, QD PV cell, Organic PV cell and PSC. It can be deduced that, even though PSCs were developed considerably later than other emerging cells, their performance is far exceptional. Fig.5 shows an Efficiency comparison between DSSC, QDSC and PSC.

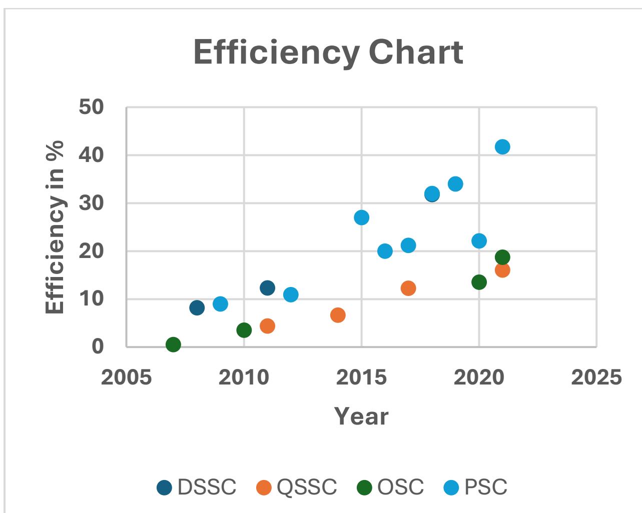


Fig.5 Efficiency comparison between Dye-sensitized, Quantum dots and Perovskite solar cells.

8. Conclusion and Future Work

According to the report, solar cells are simulated and manufactured using a variety of ways, each of which will produce a variable performance depending on the materials and technology employed. Solar cells encounter various challenges like high production cost, insufficient output, bulkiness, complexity, stability and design parameters. The efficiency of DSSCs and PSCs, which are among the future third-generation solar cells, is astounding. However, PSC outperformed DSSC in terms of performance. Important aspects that could influence PSC includes design parameters, stability and production cost. As an outcome of the literature review, it can be concluded that a tandem Perovskite/GaAs and Perovskite/CIGS solar cell will improve overall cell efficiency. The integration of an established manufacturing method that uses Perovskite Solar cells would be promising for the future photovoltaic market [97]. By fabricating high-efficiency modules with high precision in PSCs can be attained to design a cost-effective module making it more curious to explore. Device stability is also another important aspect to be considered while modeling since the stability of PSC is still not satisfactory. Either lead or tin is the prime constituent of Perovskite Cell, both lead and tin cause pollution, so a suitable substitute for Pb and Sn has to be spotted which can maintain or even improve PCE. It can also be seen that tandem perovskite photovoltaic cells are much highly reliable than Traditional perovskite photovoltaic cells [98]. It can be concluded that device modeling and simulation are very important tools that have a great impact on electronic technologies [99] and can state that simulation done by SILVACO ATLAS software can reach a closer simulated model to the experimental one [100]. It can be determined that among SCAPS-1D and other simulation software, SCAPS does have huge benefits like that of the capacity to interpret heterojunction and multi-junction photovoltaic devices, the ability to reproduce up to seven unique layers with non-routine estimations (C-V, C-f), tandem cells, and is not difficult to learn and exact to control [101]. Furthermore, the simulation result is consistent with past experiment protocols. We could analyze that the PSC parameters found experimentally are nearly equal to the parameters obtained by Simulation. Perovskite solar cells can be simulated using various software like Silvaco Atlas, SCAPS 1D, wxamps, Amps, Sentaurus TCAD, etc. Silvaco software offers 1D, 2D, 3D simulations. Modeling with the help of SCAPS 1D, Silvaco and Sentaurus Tcad software offers better accuracy. From the statistics, it can be shown that both the simulated and actual results agree well.

Statements & Declarations

Acknowledgement

We appreciate all the support and guidance provided by the administration and higher authorities of Karunya Institute of Technology and Sciences.

Author Contributions

The comparative analysis of perovskite solar cells and other PV cell types was a collaborative effort by all the authors. The manuscript's first draught was authored by Daphny Shallet. M. The final manuscript was approved by all the authors, who also contributed.

References

1. Pearson GL. PV founders award luncheon. Conference Record, 18th IEEE Photovoltaic Specialists Conference, Las Vegas, IEEE, New York, (1985).
2. Green, Martin, Ewan Dunlop, Jochen Hohl-Ebinger, Masahiro Yoshita, Nikos Kopidakis, and Xiaojing Hao. "Solar cell efficiency tables (version 57)." Progress in photovoltaics: research and applications 29, no. 1 (2021): 3-15.
3. National Renewable Energy Laboratory, Best research-cell efficiencies chart (2020); www.nrel.gov/pv/assets/pdfs/bestresearch-cell-efficiencies.20200218.pdf.
4. Ramanujam, Jeyakumar, and Udai P. Singh. "Copper indium gallium selenide based solar cells–a review." Energy & Environmental Science 10, no. 6 (2017): 1306-1319.
5. Ma, Yingzhuang, Shufeng Wang, Lingling Zheng, Zelin Lu, Danfei Zhang, Zuqiang Bian, Chunhui Huang, and Lixin Xiao. "Recent research developments of perovskite solar cells." Chinese Journal of Chemistry 32, no. 10 (2014): 957-963.
6. Zhou, D., Zhou, T., Tian, Y., Zhu, X. and Tu, Y., 2018. Perovskite-based solar cells: materials, methods, and future perspectives. Journal of Nanomaterials, (2018)
7. Peng, Guiming, Xueqing Xu, and Gang Xu. "Hybrid organic-inorganic perovskites open a new era for low-cost, high efficiency solar cells." Journal of Nanomaterials 2015 (2015).
8. Chapin, Daryl M., Calvin S. Fuller, and Gerald L. Pearson. "A new silicon p-n junction photocell for converting solar radiation into electrical power." Journal of Applied Physics 25, no. 5 (1954): 676-677.
9. Green, Martin A. "The path to 25% silicon solar cell efficiency: History of silicon cell evolution." Progress in Photovoltaics: Research and Applications 17, no. 3 (2009): 183-189.
10. Mandelkorn, J., C. McAfee, J. Kesperis, L. Schwartz, and W. Pharo. "Fabrication and Characteristics of Phosphorous-Diffused Silicon Solar Cells." Journal of the Electrochemical Society 109, no. 4 (1962): 313.
11. Green, M. A., A. W. Blakers, S. Narayanan, and M. Taouk. "Improvements in silicon solar cell efficiency." Solar cells 17, no. 1 (1986): 75-83.
12. Blakers, A. W., and M. A. Green. "20% efficiency silicon solar cells." Applied physics letters 48, no. 3 (1986): 215-217.
13. Fischer, H., and W. Pschunder. "Low-cost solar cells based on large-area unconventional silicon." IEEE Transactions on Electron Devices 24, no. 4 (1977): 438-442.
14. Zhao, Jianhua, Aihua Wang, and Martin A. Green. "24· 5% Efficiency silicon PERT cells on MCZ substrates and 24· 7% efficiency PERL cells on FZ substrates." Progress in photovoltaics: research and applications 7, no. 6 (1999): 471-474.

15. Bhattacharya, Sayak, and Sajeev John. "Beyond 30% conversion efficiency in silicon solar cells: a numerical demonstration." Scientific reports 9, no. 1 (2019): 1-15.
16. Cusano, D. A. "CdTe solar cells and photovoltaic heterojunctions in II–VI compounds." Solid-State Electronics 6, no. 3 (1963): 217-232.
17. Nakazawa, T., K. Takamizawa, and K. Ito. "High efficiency indium oxide/cadmium telluride solar cells." Applied physics letters 50, no. 5 (1987): 279-280.
18. Britt, J., and C. Ferekides. "Thin-film CdS/CdTe solar cell with 15.8% efficiency." Applied physics letters 62, no. 22 (1993): 2851-2852.
19. Safa Sultana, Rucksana, Ali Newaz Bahar, Md Asaduzzaman, and Kawsar Ahmed. "Numerical modeling of a CdS/CdTe photovoltaic cell based on ZnTe BSF layer with optimum thickness of absorber layer." Cogent Engineering 4, no. 1 (2017).
20. Zapukhlyak, Z. R., L. I. Nykyruy, G. Wisz, V. M. Rubish, V. V. Prokopiv, M. O. Halushchak, I. M. Lishchynskyy, L. O. Katanova, and R. S. Yavorskyi. "SCAPS modelling of ZnO/CdS/CdTe/CuO photovoltaic heterosystem." Physics and Chemistry of Solid State 21, no. 4 (2020): 660-668.
21. Ahmmed, S., Aktar, A., Rahman, F., Hossain, J., & Ismail, A. B. M. A numerical simulation of high efficiency CdS/CdTe based solar cell using NiO HTL and ZnO TCO. Optik, 165625. (2020).
22. Mohamed Wahid Bouabdelli, Fatiha Rogti, Mostefa Maache, Abdelaziz Rabehi, Performance enhancement of CIGS thin-film solar cell, Optik, Volume 216, (2020), 164948, ISSN 0030-4026
23. Panahi, Seyed Reza Fatemi Shariat, Abdollah Abbasi, Vahid Ghods, and Meysam Amirahmadi. "Improvement of CIGS solar cell efficiency with graded bandgap absorber layer." Journal of Materials Science: Materials in Electronics 32, no. 2 (2021): 2041-2050.
24. Mohottige, Rasika N., and Sandanuwan P. Kalawila Vithanage. "Numerical simulation of a new device architecture for CIGS-based thin-film solar cells using 1D-SCAPS simulator." Journal of Photochemistry and Photobiology A: Chemistry 407 (2021): 113079.
25. Mostaque, Shaikh Khaled, Bipanko Kumar Mondal, and Jaker Hossain. "Simulation approach to reach the SQ limit in CIGS-based dual-heterojunction solar cell." arXiv preprint arXiv:2103.08841 (2021).
26. Kamada, Rui, Takeshi Yagioka, Shunsuke Adachi, Atsushi Handa, Kong Fai Tai, Takuya Kato, and Hiroki Sugimoto. "New world record Cu (In, Ga)(Se, S) 2 thin film solar cell efficiency beyond 22%." In 2016 IEEE 43rd Photovoltaic Specialists Conference (PVSC), pp. 1287-1291. IEEE, (2016).
27. Fatemi Shariat Panahi, S., Abbasi, A., Ghods, V. et al. Analysis and improvement of CIGS solar cell efficiency using multiple absorber substances simultaneously. J Mater Sci: Mater Electron 31, 11527–11537 (2020)
28. King, R.R., Fetzer, C.M., Colter, P.C., Edmondson, K.M., Ermer, J.H., Cotal, H.L., Yoon, H., Stavrides, A.P., Kinsey, G., Krut, D.D. and Karam, N.H., 2002, May. High-efficiency space and terrestrial multijunction solar cells through bandgap control in cell structures. In Conference Record of the Twenty-Ninth IEEE Photovoltaic Specialists Conference, (2002). (pp. 776-781). IEEE.
29. Patel, P., Aiken, D., Boca, A., Cho, B., Chumney, D., Clevenger, M.B., Cornfeld, A., Fatemi, N., Lin, Y., Mccarty, J. and Newman, F. Experimental results from performance improvement and radiation hardening of inverted metamorphic multijunction solar cells. IEEE Journal of Photovoltaics, 2(3),(2012) pp.377-381.
30. Geisz, John F., Myles A. Steiner, Nikhil Jain, Kevin L. Schulte, Ryan M. France, William E. McMahon, Emmett E. Perl, and Daniel J. Friedman. "Building a six-junction inverted metamorphic concentrator solar cell." IEEE Journal of Photovoltaics 8, no. 2 (2017): 626-632.
31. Pham DP, Lee S, Yi J. Potential high efficiency of GaAs solar cell with heterojunction carrier selective contact layers. Physica B: Condensed Matter. 2021 Jun 15;611:412856.
32. Grätzel, Michael. "Dye-sensitized solar cells." Journal of photochemistry and photobiology C: Photochemistry Reviews 4, no. 2 (2003): 145-153.
33. Fakharuddin, Azhar, Rajan Jose, Thomas M. Brown, Francisco Fabregat-Santiago, and Juan Bisquert. "A perspective on the production of dye-sensitized solar modules." Energy & Environmental Science 7, no. 12 (2014): 3952-3981
34. Saeed, Muhammad Ahsan, Kicheon Yoo, Hyeong Cheol Kang, Jae Won Shim, and Jae-Joon Lee. "Recent developments in dye-sensitized photovoltaic cells under ambient illumination." Dyes and Pigments (2021): 109626
35. Yeoh, Mian-En, and Kah-Yoong Chan. "A review on semitransparent solar cells for real-life applications based on dye-sensitized technology." IEEE Journal of Photovoltaics 11, no. 2 (2021): 354-361
36. Tian, Haining, Gerrit Boschloo, and Anders Hagfeldt, eds. Molecular devices for solar energy conversion and storage. Singapore: Springer, 2018
37. B. Li, L.Wang, B. Kang, P.Wang, and Y. Qiu, “Review of recent progress in solid-state dye-sensitized solar cells,” Sol. Energy Mater. Sol. Cells, vol. 90, no. 5, pp. 549–573, Mar. 2006
38. Song, Min Young, Kiran N. Chaudhari, Jinsol Park, Dae-Soo Yang, Jung Ho Kim, Min-Sik Kim, Kimin Lim, Jeajung Ko, and Jong-Sung Yu. "High efficient Pt counter electrode prepared by homogeneous deposition method for dye-sensitized solar cell." Applied energy 100 (2012): 132-137.
39. Lee, Byunghong, Jiaqing He, Robert PH Chang, and Mercouri G. Kanatzidis. "All-solid-state dye-sensitized solar cells with high efficiency." Nature 485, no. 7399 (2012): 486-489
40. O'Regan, B., Grätzel, M. A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO_2 films. Nature 353, 737–740 (1991) .

41. Bai, Yu, Yiming Cao, Jing Zhang, Mingkui Wang, Renzhi Li, Peng Wang, Shaik M. Zakeeruddin, and Michael Grätzel. "High-performance dye-sensitized solar cells based on solvent-free electrolytes produced from eutectic melts." Nature materials 7, no. 8 (2008): 626-630.
42. Yella, Aswani, Hsuan-Wei Lee, Hoi Nok Tsao, Chenyi Yi, Aravind Kumar Chandiran, Md Khaja Nazeeruddin, Eric Wei-Guang Diau, Chen-Yu Yeh, Shaik M. Zakeeruddin, and Michael Grätzel. "Porphyrin-sensitized solar cells with cobalt (II/III)–based redox electrolyte exceed 12 percent efficiency." science 334, no. 6056 (2011): 629-634.
43. Cao, Yiming, Yuhang Liu, Shaik Mohammed Zakeeruddin, Anders Hagfeldt, and Michael Grätzel. "Direct contact of selective charge extraction layers enables high-efficiency molecular photovoltaics." Joule 2, no. 6 (2018): 1108-1117.
44. Pan, Zhenxiao, Iván Mora-Seró, Qing Shen, Hua Zhang, Yan Li, Ke Zhao, Jin Wang, Xinhua Zhong, and Juan Bisquert. "High-efficiency “green” quantum dot solar cells." Journal of the American Chemical Society 136, no. 25 (2014): 9203-9210.
45. Jiao, Shuang, Jun Du, Zhonglin Du, Donghui Long, Wuyou Jiang, Zhenxiao Pan, Yan Li, and Xinhua Zhong. "Nitrogen-doped mesoporous carbons as counter electrodes in quantum dot sensitized solar cells with a conversion efficiency exceeding 12%." The journal of physical chemistry letters 8, no. 3 (2017): 559-564.
46. Zhang, Linlin, Cuiting Kang, Guizhi Zhang, Zhenxiao Pan, Zhaoshuai Huang, Shuaihang Xu, Huashang Rao et al. "All-Inorganic CsPbI3 Quantum Dot Solar Cells with Efficiency over 16% by Defect Control." Advanced Functional Materials 31, no. 4 (2021): 2005930.
47. Gao, Jianbo, Sohee Jeong, Octavi E. Semonin, Randy J. Ellingson, Arthur J. Nozik, and Matthew C. Beard. "Annealing effect Of PBS quantum dot solar cells." In 2011 37th IEEE Photovoltaic Specialists Conference, pp. 002619-002621. IEEE, (2011).
48. Lungenschmied, Christoph, Gilles Dennler, Helmut Neugebauer, Serdar N. Sariciftci, Markus Glatthaar, Toby Meyer, and Andreas Meyer. "Flexible, long-lived, large-area, organic solar cells." Solar Energy Materials and Solar Cells 91, no. 5 (2007): 379-384.
49. Kang, Myung-Gyu, Hui Joon Park, Se Hyun Ahn, Ting Xu, and L. Jay Guo. "Toward low-cost, high-efficiency, and scalable organic solar cells with transparent metal electrode and improved domain morphology." IEEE Journal of Selected Topics in Quantum Electronics 16, no. 6 (2010): 1807-1820.
50. Farooq, Waqas, Aimal Daud Khan, Adnan Daud Khan, Abdul Rauf, Sultan Daud Khan, Haider Ali, Javed Iqbal, Rehan Ullah Khan, and Muhammad Noman. "Thin-film tandem organic solar cells with improved efficiency." IEEE Access 8 (2020): 74093-74100.
51. Jin, Ke, Zuo Xiao, and Liming Ding. "18.69% PCE from organic solar cells." Journal of Semiconductors 42, no. 6 (2021): 060502-060502.
52. Guan, Shitao, Yaokai Li, Chang Xu, Ni Yin, Chenran Xu, Congxu Wang, Mengting Wang et al. "Self-assembled interlayer enables high-performance organic photovoltaics with power conversion efficiency exceeding 20%." Advanced Materials 36, no. 25 (2024): 2400342.
53. Fu, Jiehao, Patrick WK Fong, Heng Liu, Chieh-Szu Huang, Xinhui Lu, Shirong Lu, Maged Abdelsamie et al. "19.31% binary organic solar cell and low non-radiative recombination enabled by non-monotonic intermediate state transition." Nature communications 14, no. 1 (2023): 1760.
54. Chen, Chen, Liang Wang, Weiyi Xia, Ke Qiu, Chuanhang Guo, Zirui Gan, Jing Zhou et al. "Molecular interaction induced dual fibrils towards organic solar cells with certified efficiency over 20%." Nature Communications 15, no. 1 (2024): 6865.
55. Kojima, Akihiro, Kenjiro Teshima, Yasuo Shirai, and Tsutomu Miyasaka. "Organometal halide perovskites as visible-light sensitizers for photovoltaic cells." Journal of the American Chemical Society 131, no. 17 (2009): 6050-6051.
56. Kim, Hui-Seon, Chang-Ryul Lee, Jeong-Hyeok Im, Ki-Beom Lee, Thomas Moehl, Arianna Marchioro, Soo-Jin Moon et al. "Lead iodide perovskite sensitized all-solid-state submicron thin film mesoscopic solar cell with efficiency exceeding 9%." Scientific reports 2, no. 1 (2012): 1-7.
57. Lee, Michael & Teuscher, Joël & Miyasaka, Tsutomu & Murakami, Takurou & Im, Jeong-Hyeok. (2012). Efficient Hybrid Solar Cells Based on Meso-Superstructured Organometal Halide Perovskites. Science (New York, N.Y.). 338. 10.1126/science.1228604.
58. Giordano, Fabrizio, Antonio Abate, Juan Pablo Correa Baena, Michael Saliba, Taisuke Matsui, Sang Hyuk Im, Shaik M. Zakeeruddin, Mohammad Khaja Nazeeruddin, Anders Hagfeldt, and Michael Graetzel. "Enhanced electronic properties in mesoporous TiO 2 via lithium doping for high-efficiency perovskite solar cells." Nature communications 7, no. 1 (2016): 1-6.
59. Anaraki, Elham Halvani, Ahmad Kermanpur, Ludmilla Steier, Konrad Domanski, Taisuke Matsui, Wolfgang Tress, Michael Saliba et al. "Highly efficient and stable planar perovskite solar cells by solution-processed tin oxide." Energy & Environmental Science 9, no. 10 (2016): 3128-3134.
60. Seo, Ji-Youn, Taisuke Matsui, Jingshan Luo, Juan-Pablo Correa-Baena, Fabrizio Giordano, Michael Saliba, Kurt Schenk et al. "Ionic liquid control crystal growth to enhance planar perovskite solar cells efficiency." Advanced Energy Materials 6, no. 20 (2016): 1600767.
61. Bai, Yang, Qingfeng Dong, Yuchuan Shao, Yehao Deng, Qi Wang, Liang Shen, Dong Wang, Wei Wei, and Jinsong Huang. "Enhancing stability and efficiency of perovskite solar cells with crosslinkable silane-functionalized and doped fullerene." Nature communications 7, no. 1 (2016): 1-9.

62. Rong Y, Hu Y, Mei A, Tan H, Saidaminov MI, Seok SI, McGehee MD, Sargent EH, Han H. Challenges for commercializing perovskite solar cells. Science. 2018 Sep 21;361(6408):eaat8235.PMID: 30237326.
63. Kaur, Kamalpreet. "Perovskite solar cells-A futuristic approach." In 2019 IEEE 2nd International Conference on Renewable Energy and Power Engineering (REPE), pp. 187-190. IEEE, 2019.
64. Grånäs, Oscar, Dmitry Vinichenko, and Efthimios Kaxiras. "Establishing the limits of efficiency of perovskite solar cells from first principles modeling." Scientific reports 6, no. 1 (2016): 1-6.
65. Moritz H. Futscher& Bruno Ehrler,etal,"Modeling the Performance Limitations and Prospects of Perovskite/Si Tandem Solar Cells under Realistic Operating Conditions". ACS Energy Lett. (2017), 2, 2089−2095.
66. Assadi, M. Khalaji, S. Bakhoda, R. Saidur, and H. Hanaei. "Recent progress in perovskite solar cells." Renewable and Sustainable Energy Reviews 81 (2018): 2812-2822.
67. Bendib, T., H. Bencherif, M. A. Abdi, F. Meddour, L. Dehimi, and M. Chahdi. "Combined optical-electrical modeling of perovskite solar cell with an optimized design." Optical Materials 109 (2020): 110259.
68. Pandey, Saurabh Kumar, and Srest Somay. "Device Engineering Approach Toward Stable, Efficient, and Eco-Friendly Perovskite Solar Cell." IEEE Transactions on Electron Devices 68, no. 3 (2021): 1142-1148.
69. Moon, Soo-Jin, Jun-Ho Yum, Linus Löfgren, Arnaud Walter, Laurent Sansonnens, Mustapha Benkhaira, Sylvain Nicolay, Julien Bailat, and Christophe Ballif. "Laser-scribing patterning for the production of organometallic halide perovskite solar modules." IEEE Journal of Photovoltaics 5, no. 4 (2015): 1087-1092.
70. Xu, Yang, Yi Wang, Jichao Yu, Bingjie Feng, Hai Zhou, Jun Zhang, Jinxia Duan et al. "Performance improvement of perovskite solar cells based on pcbm-modified ZnO-nanorod arrays." IEEE Journal of Photovoltaics 6, no. 6 (2016): 1530-1536.
71. Wahid, Sumaiya, and Md Kawsar Alam. "Efficiency Enhancement of Perovskite Solar Cells Using Heterojunction Bipolar Transistor Configuration." IEEE Transactions on Electron Devices 67, no. 2 (2020): 552-557.
72. Pathak, Chetan, and Saurabh Kumar Pandey. "Design, performance, and defect density analysis of efficient eco-friendly perovskite solar cell." IEEE Transactions on Electron Devices 67, no. 7 (2020): 2837-2843.
73. Hsu, Chia-Hsun, Ka-Te Chen, Lu-Sheng Liang, Peng Gao, Sin-Liang Ou, Wan-Yu Wu, Pao-Hsun Huang, and Shui-Yang Lien. "Improved Perovskite Solar Cell Performance by High Growth Rate Spatial Atomic Layer Deposited Titanium Oxide Compact Layer." IEEE Journal of the Electron Devices Society 9 (2020): 49-56.
74. Jiang, Yan, Longbin Qiu, Emilio J. Juarez-Perez, Luis K. Ono, Zhanhao Hu, Zonghao Liu, Zhifang Wu, Lingqiang Meng, Qijing Wang, and Yabing Qi. "Reduction of lead leakage from damaged lead halide perovskite solar modules using self-healing polymer-based encapsulation." Nature Energy 4, no. 7 (2019): 585-593.
75. Malyukov, S. P., A. V. Sayenko, and A. V. Ivanova. "Numerical modeling of perovskite solar cells with a planar structure." In IOP Conference Series: Materials Science and Engineering, vol. 151, no. 1, p. 012033. IOP Publishing, 2016.
76. Zheng, Xiaopeng, Abdullah Y. Alsalloum, Yi Hou, Edward H. Sargent, and Osman M. Bakr. "All-Perovskite Tandem Solar Cells: A Roadmap to Uniting High Efficiency with High Stability." Accounts of Materials Research 1, no. 1 (2020): 63-76.
77. Rolland, Alain, L. Pedesseau, Alexandre Beck, Mikael Kepenekian, Claudine Katan, Yong Huang, Shijian Wang, C. Cornet, Olivier Durand, and J. Even. "Computational design of high performance hybrid perovskite on silicon tandem solar cells." arXiv preprint arXiv:1509.01612 (2015).
78. Zhao, Peng, Man Yue, Chen Lei, Zhenhua Lin, Jie Su, Dazheng Chen, Chunfu Zhang, Jincheng Zhang, Jingjing Chang, and Yue Hao. "Device simulation of organic–inorganic halide perovskite/crystalline silicon four-terminal tandem solar cell with various anti reflection materials." IEEE Journal of Photovoltaics 8, no. 6 (2018): 1685-1691.
79. Sun, Xingshu, Reza Asadpour, Wanyi Nie, Aditya D. Mohite, and Muhammad Ashraful Alam. "A physics-based analytical model for perovskite solar cells." IEEE Journal of Photovoltaics 5, no. 5 (2015): 1389-1394.
80. Chen, Dazheng, Shangzheng Pang, Weidong Zhu, Hongxiao Zhang, Long Zhou, Fengqin He, Jingjing Chang et al. "Efficient semitransparent perovskite solar cells using a transparent silver electrode and four-terminal perovskite/silicon tandem device exploration." Journal of Nanomaterials 2018 (2018).Volume 2018, Article ID 4012850, 8 pages.
81. Wu, Jian, Jing-Jing Dong, Si-Xuan Chen, Hui-Ying Hao, Jie Xing, and Hao Liu. "Fabrication of efficient organic-inorganic perovskite solar cells in ambient air." Nanoscale research letters 13, no. 1 (2018): 1-7.
82. Becker, Pascal, José A. Márquez, Justus Just, Amran Al-Ashouri, Charles Hages, Hannes Hempel, Marko Jošt, Steve Albrecht, Ronald Frahm, and Thomas Unold. "Low temperature co-evaporation of hollow γ-$CsPbI_3$ perovskite layers for solar cells."
83. Jošt, Marko, Lukas Kegelmann, Lars Korte, and Steve Albrecht. "Monolithic perovskite tandem solar cells: A review of the present status and advanced characterization methods toward 30% efficiency." Advanced Energy Materials 10, no. 26 (2020): 1904102.
84. Kim, Junghwan, Geunjin Kim, Hyungcheol Back, Jaemin Kong, In-Wook Hwang, Tae Kyun Kim, Sooncheol Kwon et al. "High-Performance Integrated Perovskite and Organic Solar Cells with Enhanced Fill Factors and Near-Infrared Harvesting." Advanced Materials 28, no. 16 (2016): 3159-3165.
85. Jung, Eui Hyuk, Nam Joong Jeon, Eun Young Park, Chan Su Moon, Tae Joo Shin, Tae-Youl Yang, Jun Hong Noh, and Jangwon Seo. "Efficient, stable and scalable perovskite solar cells using poly (3-hexylthiophene)." Nature 567, no. 7749 (2019): 511-515.
86. Santbergen, R., Uzu, H., Yamamoto, K. and Zeman, M., 2019. Optimization of three-terminal perovskite/silicon tandem solar cells. Ieee Journal of Photovoltaics, 9(2), pp.446-451.

87. Mousa, Mohamed, Fathy Z. Amer, Roaa I. Mubarak, and Ahmed Saeed. "Simulation of Optimized High-Current Tandem Solar-Cells With Efficiency Beyond 41%." IEEE Access 9 (2021): 49724-49737.
88. Alsalme, Ali & Altowairqi, Malak & Alhamed, Afnan & Khan, Rais Ahmad. (2022). Optimization of Photovoltaic Performance of Pb-Free Perovskite Solar Cells via Numerical Simulation. Molecules. 28. 224. 10.3390/ molecules28010224.
89. Alanazi, Tarek(2023) Design and Device Numerical Analysis of Lead-Free Cs2AgBiBr6 Double Perovskite Solar Cell. Crystals. 13. 267. 10.3390/cryst13020267.
90. Bhattarai, Sagar, Rahul Pandey, Jaya Madan, Asya Mhamdi, Abdelaziz Bouazizi, Deboraj Muchahary, Dipankar Gogoi, Arvind Sharma, and T. D. Das. "Investigation of carrier transport materials for performance assessment of lead-free perovskite solar cells." IEEE Transactions on Electron Devices 69, no. 6 (2022): 3217-3224.
91. Sabbah, H., Abdel Baki, Z., Mezher, R. and Arayro, J., 2023. SCAPS-1D Modeling of Hydrogenated Lead-Free Cs2AgBiBr6 Double Perovskite Solar Cells with a Remarkable Efficiency of 26.3%. Nanomaterials, 14(1), p.48.
92. Bhattarai, Sagar, M. Khalid Hossain, Rahul Pandey, Jaya Madan, D. P. Samajdar, Md Ferdous Rahman, Mohd Zahid Ansari, and Mongi Amami. "Perovskite solar cells with dual light absorber layers for performance efficiency exceeding 30%." Energy & Fuels 37, no. 14 (2023): 10631-10641
93. Deswal, Vishal, Shubhda Kaushik, Rahul Kundara, and Sarita Baghel. "Numerical simulation of highly efficient Cs2AgInBr6-based double perovskite solar cell using SCAPS 1-D." Materials Science and Engineering: B 299 (2024): 117041.
94. Wahid, Md Ferdous, Md Shahriar Rahman, Nowshad Ahmed, Abdullah Al Mamun, Md Nuralam Howlader, Tarpan Paul, Md Motiur Rahman Tareq, Md Sazedur Rahman, and Md Mizanur Rahman. "Performance enhancement of lead-Free CsSnI 3 perovskite solar cell: design and simulation with different electron transport layers." IEEE Access 12 (2024): 8296-8312.
95. Rabhi, Selma, Karthick Sekar, Karol Kalna, Yacoub Ibrahim Bouderbala, Nabil Bouri, Nouredine Oueldna, Nasreddine Belbachir, Karima Dadda, Mohammed Saleh Aida, and Nadir Attaf. "Experimental findings and SCAPS-1D simulations for high-efficiency MAPbI3 perovskite solar cells beyond 31%." Optical and Quantum Electronics 56, no. 8 (2024): 1372
96. Rabhi, Selma, Karthick Sekar, Karol Kalna, Tarak Hidouri, Dip Prakash Samajdar, Babban Kumar Ravidas, Hichem Bencherif, Roberto Fornari, Kouloud Albaidani, and M. Khalid Hossain. "Enhancing perovskite solar cell performance through PbI 2 in situ passivation using a one-step process: experimental insights and simulations." RSC advances 14, no. 46 (2024): 34051-34065.
97. Song, Tze-Bin, Qi Chen, Huanping Zhou, Chengyang Jiang, Hsin-Hua Wang, Yang Michael Yang, Yongsheng Liu, Jingbi You, and Yang Yang. "Perovskite solar cells: film formation and properties." Journal of Materials Chemistry A 3, no. 17 (2015): 9032-9050.
98. Cai, Molang, Yongzhen Wu, Han Chen, Xudong Yang, Yinghuai Qiang, and Liyuan Han. "Cost-performance analysis of perovskite solar modules." Advanced Science 4, no. 1 (2017): 1600269.
99. Tessler, Nir, and Yana Vaynzof. "Insights from device modeling of perovskite solar cells." ACS Energy Letters 5, no. 4 (2020): 1260-1270.
100. Hima, Abdelkader, Nacereddine Lakhdar, Boubaker Benhaoua, Achour Saadoune, Imad Kemerchou, and Fatiha Rogti. "An optimized perovskite solar cell designs for high conversion efficiency." Superlattices and Microstructures 129 (2019): 240-246.
101. Burgelman, Marc, Johan Verschraegen, Stefaan Degrave, and Peter Nollet. "Modeling thin-film PV devices." Progress in Photovoltaics: Research and Applications 12, no. 2-3 (2004): 143-153.