

Perovskite Solar Cells

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ABSTRACT

A solar cell is a device that converts sunlight into electricity. There are different types of solar cells but this is mainly focuses on a type of new generation solar cell that has the name organo-metal halide perovskite, shortly perovskite solar cells. In this respect, the efficiency of power conversion is taken into account to replace the dominancy of traditional and second generation solar cell fields by perovskite solar cells. Perovskite solar cell is a type of solar cell including a perovskite structure, usually a hybrid organic-inorganic lead or tin halide-based material.

Keywords: *Solar Energy, Perovskite solar cell, Photovoltaic cells, Substrate, Electrode.*

I. INTRODUCTION

Solar energy is an alternative source to traditional resources such as coal and fossil fuel for the present growing energy demand. In this perspective, developing solar cells is one of the best approaches to convert solar energy into electrical energy based on the photovoltaic effect. Over the years, silicon-based cells have been used for industrial purposes due to their efficient solar-topower generation (~30%), particularly crystalline silicon. However, the cost of Si-based photovoltaic cells is relatively high and difficult to utilize in large-scale industries. An alternative to silicon solar cells is third generation excitonic photovoltaic devices, which have been developed based on various dye sensitizers, organic and hybrid (organic-inorganic) materials; and these reach a photovoltaic efficiency up to ~15–20%. Among these materials, perovskites (organic-inorganic) have reached top position (~20.1%) within ~5 years, due to substantial improvement of power conversion efficiency and low processing costs. Significant aspects of perovskites are synthetic feasibility, strong optical absorption, charge recombination rate and ease of fabrication. Moreover, hybrid perovskites can be prepared by simple synthetic methods and are easy to capitalize when compared to the existing excitonic photovoltaic technologies such as dye sensitized solar cells (DSSC) and organic solar cells (OSC). Another important aspect is high charge-carrier mobility, which is more useful for developing high-performance solar cell devices. However, toxicity of lead is a major concern which easily degrades on exposure to humidity and ultraviolet (UV) irradiation. Present day research mainly focuses on the commercialization of perovskite solar cells by controlling degradation and toxicity. In this review, we highlight the fundamental aspects of perovskites and recent progress in perovskite-based device fabrication. Still, there exist some issues which need to be resolved in the commercialization of perovskites.

The rapid improvement of perovskite solar cells has made them the rising star of the photovoltaics world and of huge interest to the academic community. Since their operational methods are still relatively new, there is great

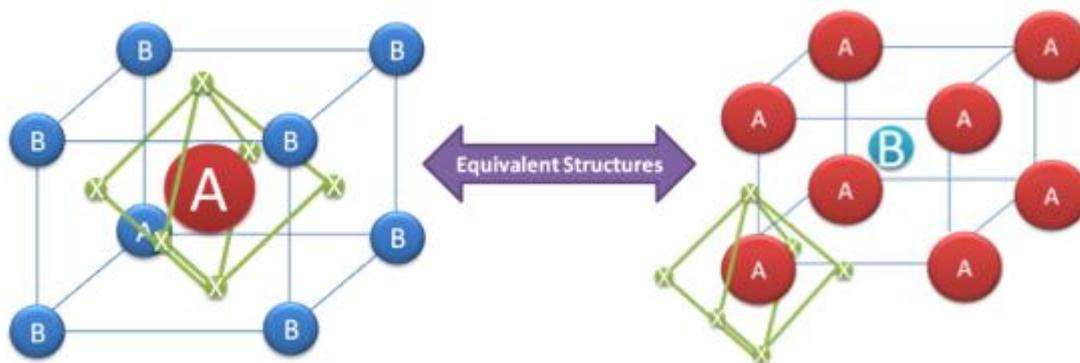
opportunity for further research into the basic physics and chemistry around perovskites. Furthermore, as has been shown over the past two years - the improvement in engineering of perovskite formulations and fabrication routines has led to significant increases in power conversion efficiency (with recent devices reaching over 22%).

II. WHAT ARE PEROVSKITES?

The terms "perovskite" and "perovskite" structure are often used interchangeably. Technically, a perovskite is a type of mineral that was first found in the Ural Mountains and named after Lev Perovski who was the founder of the Russian Geographical Society. A perovskite structure is any compound that has the same structure as the perovskite mineral.

True perovskite (the mineral) is composed of calcium, titanium and oxygen in the form CaTiO_3 . Meanwhile, a perovskite structure is anything that has the generic form ABX_3 and the same crystallographic structure as perovskite (the mineral). However, since most people in the solar cell world aren't involved with minerals and geology, perovskite and perovskite structure are used interchangeably.

The perovskite lattice arrangement is demonstrated below. As with many structures in crystallography, it can be represented in multiple ways. The simplest way to think about a perovskite is as a large atom or molecule (positively-charged) of type A in the centre of a cube. The corners of the cube are occupied by atoms B (also positively-charged cations) and the faces of the cube are occupied by a smaller atom X with negative charge (anion).



A generic perovskite crystal structure of the form ABX_3 . Note however that the two structures are equivalent—the left structure is drawn so that atom B is at the $\langle 0,0,0 \rangle$ position while the right hand structure is drawn so that atom (or molecule) A is at the $\langle 0,0,0 \rangle$ position. Also note that the lines are a guide to represent crystal orientation rather than bonding patterns.

Depending on which atoms/molecules are used in the structure, perovskites can have an impressive array of interesting properties, giant magnetoresistance, spin-dependent transport (spintronics) and catalytic properties. Perovskites therefore present an exciting playground for physicists, chemists and material scientists.

In the case of perovskite solar cells, the most efficient devices so far have been produced with the following combination of materials in the usual perovskite form ABX_3 :

A = An organic cation-methylammonium (CH_3NH_3)⁺

B=A biginorganiccation-usually lead(II)(Pb₂+)

X₃=A slightly smaller halogen anion-usually chloride(Cl⁻) or iodide(I⁻)

Since this is are relatively general structure, the perovskite-based devices can also be given a number of different names, which can either referto a more general class of materials or a specific combination. As an example of this,we've created the below table to high light how many names can be formed fromone basic structure.

A	B	X ₃
Organo	Metal	Trihalide (or trihalide)
Methylammonium	Lead	Iodide (or triiodide)
	Plumbate	Chloride (or trichloride)

The perovskite name picking table: pick any one item from columns A,BorX₃ to come up with a valid name. Examples include:Organo-lead-chlorides, Methyl ammonium-metal-tri halides,organo-plumbate-iodides etc



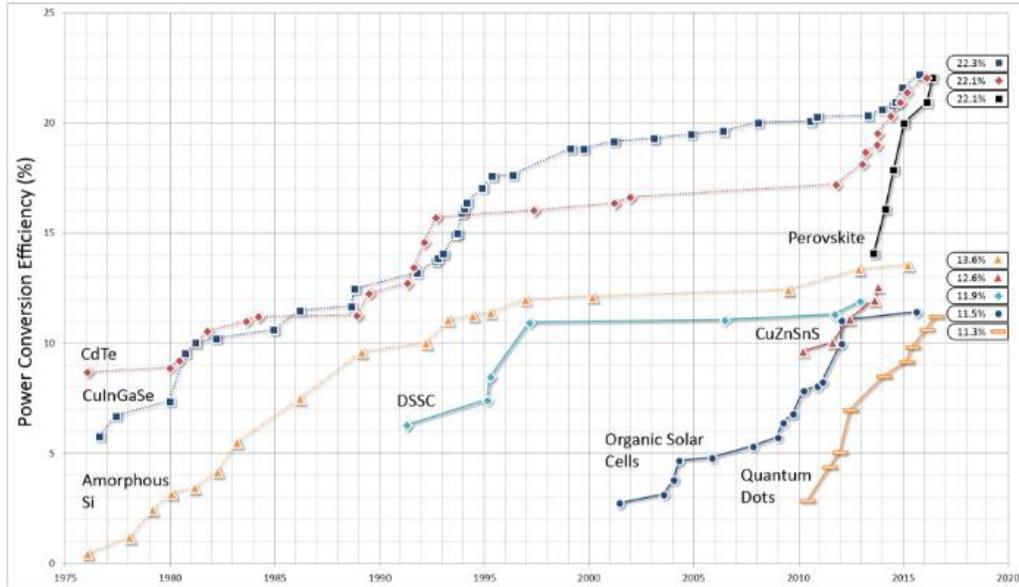
2.1 Why are perovskite solar cells so significant?

There are two key graphs which demonstrate why perovskite solar cells have attracted such prominent attention in the short time since their breakthrough paper of 2012.

The first of these graphs (which uses data taken from NREL solar cell efficiency tables) demonstrates the power conversion efficiencies of the perovskite-based devices over recent years in comparison to emergent photovoltaic research technology and also traditional thin-film photovoltaics.

The graph shows a meteoric rise compared to most other technologies over a relatively short period of time. In the space of three years, perovskite solar cells have managed to achieve power conversion efficiencies comparable to Cadmium Telluride, which has been around for nearly 40 years. Although it could be argued that

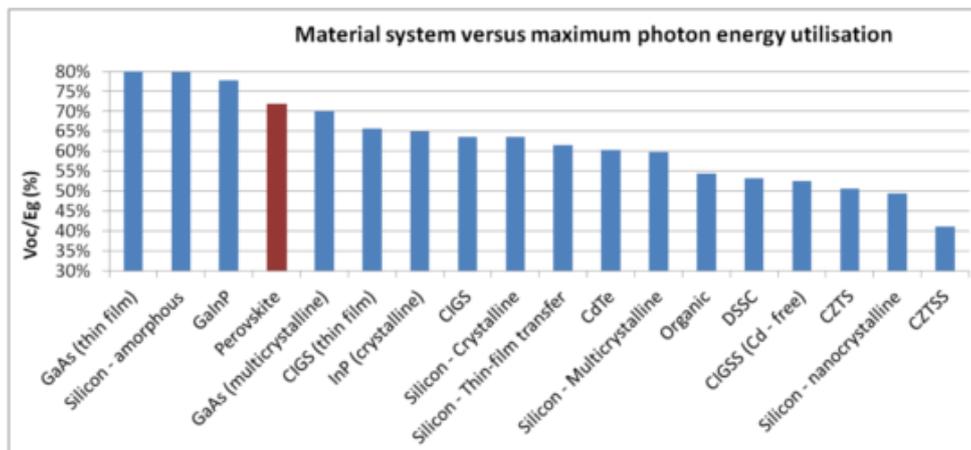
more resources and better infrastructure for solar cell research have been available in the last few years, the dramatic rise in perovskite solar cell efficiency is still incredibly significant and impressive.



Perovskite solar cells have increased in power conversion efficiency at a phenomenal rate compared to other types of photovoltaics. Although this figure only represents lab based "hero cells", it heralds great promise.

The second key graph below is the open-circuit voltage compared to the band gap for a range of technologies that the perovskites compete with.

This graph demonstrates how much of a photon's energy is lost in the conversion process from light to electricity. For standard excitonic-based, organic-based solar cells, this loss can be as high as 50% of the absorbed energy. However, for perovskite-based solar cells, the loss is far less. Perovskite-based solar cells are fast approaching the same level of photon energy utilisation as the current leading monolithic crystalline technologies, such as silicon and GaAs. Furthermore, they also have the potential for much lower processing costs.



The maximum photon energy utilisation (defined as the open circuit voltage V_{oc} divided by the optical bandgap E_g) for common single junction solar cells material systems.

Currently, the only major unknown in the field of perovskite research is the stability of devices over their operational lifetime. Although lifetime studies of actual devices are limited, research into the stability of these films has shown that there are several reaction pathways leading to degradation that involve water, oxygen, and even the diffusion of electrode materials. Current leading research is focused upon reproducing the high power conversion efficiencies, but with the addition of stabilising agents such as Caesium and Rubidium.

Another issue yet to be fully addressed is the use of lead in perovskite compounds. Though it is used in much smaller quantities than that which is currently present in either lead- or cadmium-based batteries, the presence of lead in products for commercial use is problematic. There is potential for a lead alternative to be used in perovskite solar cells (such as tin-based perovskites), but the power conversion efficiency of such devices is still significantly behind lead-based devices. Finally, there has also been little discussion of the optical density of these materials - which although is higher than silicon, is still lower than other active materials. As a result, the perovskite devices require thicker light-harvesting layers which may cause some fabrication limitations. These limitations apply particularly to solution processed devices where creating such thick layers with high uniformity can be difficult.

Over the past two years, the improvements in precursor material blends for the fabrication of perovskite solar cells have led to a significant increase in power conversion efficiency. A key development has been the improvement in processing techniques used. Previously, vacuum-based techniques offered the highest efficiency devices but lately, improvements in solution-based deposition through the use of solvent quenching techniques has shifted the record-breaking devices to solution-based processing.

To enable a truly low cost-per-watt will require perovskite solar cells to have the much heralded trio of high efficiency, long lifetimes, and low manufacturing costs. This has not yet been achieved for other thin-film technologies but perovskite-based devices so far demonstrate enormous potential for achieving this.

III. FABRICATION AND MEASUREMENT OF PEROVSKITE SOLAR CELLS

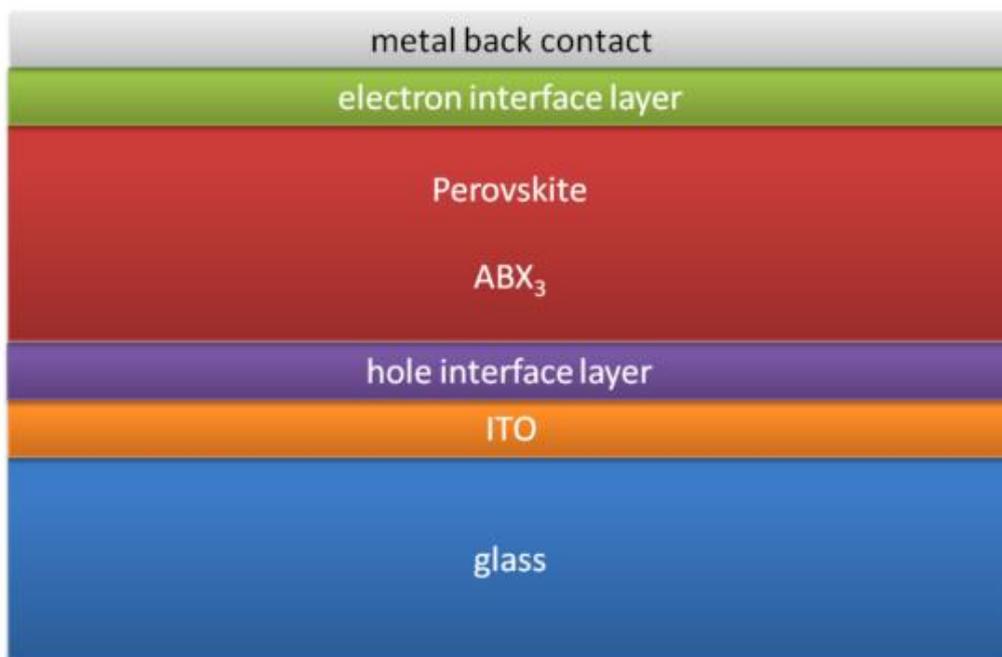
Although perovskites come from a seemingly different world of crystallography, they can be incorporated very easily into a standard OPV (or other thin film) architecture. While the best perovskite structures have been vacuum deposited to give better, more uniform film qualities, this process requires the co-evaporation of the organic (methylammonium) component at the same time as the inorganic (lead halide) components. The accurate co-evaporation of these materials to form the perovskite therefore requires specialist evaporation chambers that are not available to many researchers. This may also cause the practical issues of calibration and cross-contamination between organic and non-organic sources which would be difficult to clean.

However, the development of low temperature solution deposition routes offer a much simpler method to incorporate perovskites and can even be used with existing materials sets. Although the perovskite solar cells originally came out of DSSC research, the fact that they no longer require an oxide scaffold means the field is branching out, and that many device architectures now look very similar to thin-film photovoltaics except with the active layers substituted with the perovskite. The key to enabling this is that the perovskite precursor

materials use relatively polar solvents for deposition. Therefore, orthogonal solvent systems for the different layers can be fairly easily developed.

The structure below represents a standard (non-inverted) perovskite solar cell based upon a standard glass/ITO substrates with metal back contact. All that is required to form a working device from the perovskite are two charge-selective interface layers (for the electrons and holes respectively).

Many of the standard interface layers from the world of organic photovoltaics work relatively well. For example, PEDOT:PSS and the PTAA-class of polymers work well as hole interface layers, while PCBM, C₆₀, ZnO and TiO₂ makes effective electron interfaces. However, the field is so new that there is a vast archive of possible interface materials to be explored. Understanding and optimising the energy levels and interactions of different materials at these interfaces offers a very exciting area of research.



Generic structure of a standard (non-inverted) perovskite solar cell.

The main issues for practical device fabrication of perovskite solar cells are film quality and thickness. The light-harvesting (active) perovskite layer needs to be several hundred nanometres thick – several times more than for standard organic photovoltaics. Unless the deposition conditions and annealing temperature are optimised, rough surfaces with incomplete coverage will form. Even with good optimisation, there will still be a significant surface roughness remaining. Therefore, thicker interface layers than might normally be used are also required. However, the fact that efficiencies of over 11% have already been achieved for spin coated devices is highly encouraging.

It is for this reason that we look forward to watching the progress of solution-processed perovskite solar cells, and to developing the techniques and devices to help researchers at the cutting-edge.

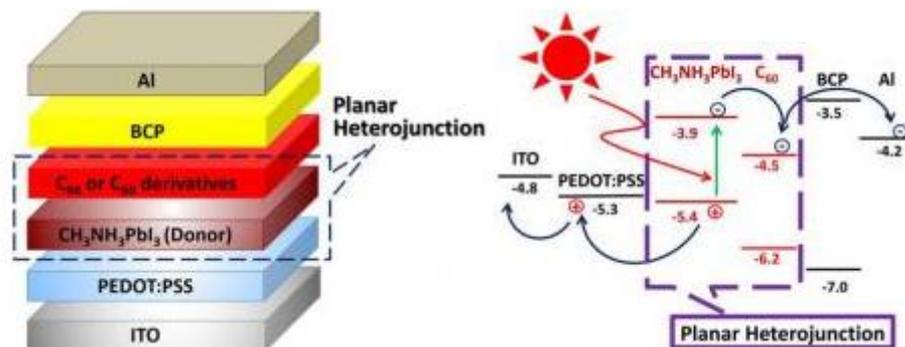
IV. HOW DOES THE PV MARKET LOOK TODAY?

In general, Photovoltaic (PV) technologies can be viewed as divided into two main categories: wafer-based PV (also called 1st generation PVs) and thin-film cell PVs. Traditional crystalline silicon (c-Si) cells (both single crystalline silicon and multi-crystalline silicon) and gallium arsenide (GaAs) cells belong to the wafer-based PVs, with c-Si cells dominating the current PV market (about 90% market share) and GaAs exhibiting the highest efficiency.

Thin-film cells normally absorb light more efficiently than silicon, allowing the use of extremely thin films. Cadmium telluride (CdTe) technology has been successfully commercialized, with more than 20% cell efficiency and 17.5% module efficiency record and such cells currently hold about 5% of the total market. Other commercial thin-film technologies include hydrogenated amorphous silicon (a-Si:H) and copper indium gallium (di)selenide (CIGS) cells, taking approximately 2% market share each today. Copper zinc tin sulphide technology has been under R&D for years and will probably require some time until actual commercialization.

V. WHAT IS A PEROVSKITE SOLAR CELL?

An emerging thin-film PV class is being formed, also called 3rd generation PVs, which refers to PVs using technologies that have the potential to overcome current efficiency and performance limits or are based on novel materials. This 3rd generation of PVs includes DSSC, organic photovoltaic (OPV), quantum dot (QD) PV and perovskite PV.



Perovskite solar cells are, without a doubt, the rising star in the field of photovoltaics. They are causing excitement within the solar power industry with their ability to absorb light across almost all visible wavelengths, exceptional power conversion efficiencies already exceeding 20% in the lab, and relative ease of fabrication. Perovskite solar cells still face several challenges, but much work is put into facing them and some companies, are already talking about commercializing them in the near future.

VI. WHAT ARE THE ADVANTAGES OF PEROVSKITE SOLAR CELLS?

Put simply, perovskite solar cells aim to increase the efficiency and lower the cost of solar energy. Perovskite PVs indeed hold promise for high efficiencies, as well as low potential material & reduced processing costs. A

big advantage perovskite PVs have over conventional solar technology is that they can react to various different wavelengths of light, which lets them convert more of the sunlight that reaches them into electricity.

Moreover, they offer flexibility, semi-transparency, tailored form factors, light-weight and more. Naturally, electronics designers and researchers are certain that such characteristics will open up many more applications for solar cells.

VII. REASON FOR HOLDING PEROVSKITE PVS BACK?

Despite its great potential, perovskite solar cell technology is still in the early stages of commercialization compared with other mature solar technologies as there are a number of concerns remaining.

One problem is their overall cost (for several reasons, mainly since currently the most common electrode material in perovskite solar cells is gold), and another is that cheaper perovskite solar cells have a short lifespan. Perovskite PVs also deteriorate rapidly in the presence of moisture and the decay products attack metal electrodes. Heavy encapsulation to protect perovskite can add to the cell cost and weight. Scaling up is another issue - reported high efficiency ratings have been achieved using small cells, which is great for lab testing, but too small to be used in an actual solar panel.

A major issue is toxicity - a substance called PbI is one of the breakdown products of perovskite. This is known to be toxic and there are concerns that it may be carcinogenic (although this is still an unproven point). Also, many perovskite cells use lead, a massive pollutant. Researchers are constantly seeking substitutions, and have already made working cells using tin instead. (with efficiency at only 6%, but improvements will surely follow).

VIII. WHAT'S NEXT?

While major challenges indeed exist, perovskite solar cells are still touted as the PV technology of the future, and much development work and research are put into making this a reality. Scientists and companies are working towards increasing efficiency and stability, prolonging lifetime and replacing toxic materials with safer ones. Researchers are also looking at the benefits of combining perovskites with other technologies, like silicon for example, to create what is referred to as "tandem cells".

IX. CONCLUSION AND FUTURE CHALLENGES

Organic-inorganic halide perovskites are significant for research and commercialization of solar cells in the next few years due to high efficiency and durability. Advantages of PSC include low processing cost and simple execution of desirable products such as flexible, transparent or all-perovskite tandem cell modules than existing photovoltaics. PSC can show better performance if integrated with other cell technologies. However, few problems need to be resolved with respect to commercialization: (1) toxicity of Pb atoms, (2) long-term durability and (3) cost-effectiveness. Until now, the highest efficiency has been obtained only from lead-based perovskites. However, utilization of Pb-based materials in solar cells is restricted due to their toxicity. In order

to overcome this issue, majority of research is on lead-free-based materials together with commercialization. Fortunately, Sn-based materials have been developed and reached efficiency of approximately ~7% .

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