# Perovskite solar cells

## Future potential design and development of photovoltaics

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## Solar technology research

With help from the AIE Youth Scholarship, I was able to take my studies and curiosity of renewable energy generation and sustainable energy systems to academia in the United States. I was given the opportunity to be involved in research at the Laboratory for Sustainable and Nano-Manufacturing (LSNM) at the University of Wisconsin-Milwaukee (UWM).

One research focus of the LSNM was the investigation and improvement of perovskite solar cell efficiency. Perovskites solar cells have gained considerable attention in recent years due to their rapidly improving cell efficiencies and potential for low-cost manufacturing.

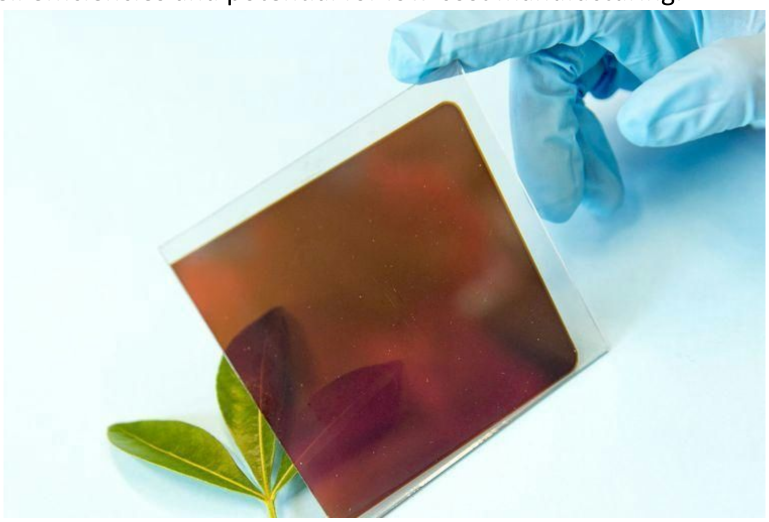

Figure 1: A perovskite solar cell prototype [2]
*Image Credit: Boshu Zhang, Wong Choon Lim Glenn & Mingzhen Liu*

## So what is a perovskite solar cell?

A perovskite is any material with crystal structure identical to calcium titanium oxide ($CaTiO_3$) compound. This specific repetitive order of atoms in a crystal is called the perovskite structure. Any material that has an atomic composition of $ABX_3$ [1] and a perovskite structure is referred to as a perovskite.

In the case of perovskite solar cells, calcium, titanium and oxygen are replaced with other elements and compounds that create a stable material that absorbs an unusually broad range of the solar spectrum. This material is called a perovskite absorber. In creating a perovskite absorber, the A compound is an organic cation, the B compound is a metal, and the X compound is halogen anion or trihalide. One of the most studied perovskite absorbers is methylammonium lead triiodide ($CH_3NH_3PbI_3$), because its combination of materials has been an efficient compound thus far. It is also the material of choice in the research project at UWM.

The picture of a perovskite solar cell is seen in Figure 1. A glass sample is coated with a thin yet dense layer of transparent electrode to prevent an electric charge from being generated by absorbed light leaking out of the cell. Next, a less dense and more porous layer of titanium dioxide ($TiO_2$), an electron transport material or n-Type semiconductor, is evenly laid. A uniform film of the perovskite absorber material is then spread over cell, usually using a spin-coated technique, although other methods like vapour deposition are becoming popular.

The method of deposition is another area of interest within the perovskite solar cell research community due to its ability to affect light absorbability. The hole transport material, or p-Type semiconductor, is then deposited onto the perovskite absorber before adding a metal contact or electrode, usually gold or silver. The result is a lightweight, transparent and flexible solar cell.

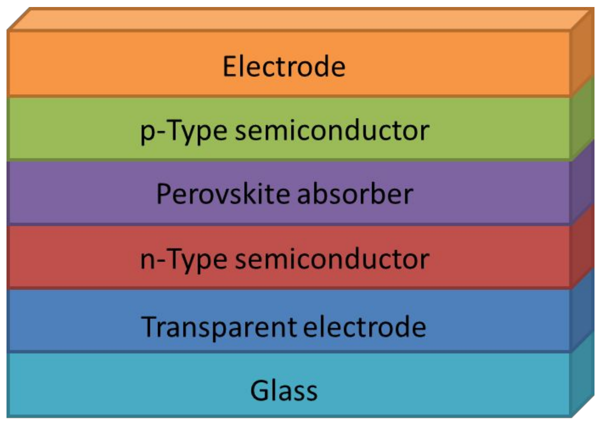


Figure 2: Perovskite solar cell structure

The combination and fabrication of the perovskite cell structure is very important because it has the ability to affect the properties and performance of the finished product. Fabrication and processing are major areas of research within the perovskite solar cell research field.

## Why the hype over perovskite solar cell?

The first published perovskite solar cell efficiency level was documented to be 3.8% in 2009 [3], which nowadays, is considered a low-power conversion efficiency. Yet in 2012, that efficiency jumped to 9.7% [4] by making the perovskite material solid and the cell design simpler with the use of $CH_3NH_3PbI_3$ as the perovskite material. The progress continued and by 2014, the efficiency jumped to 20%[5], enabling perovskites to compete with established technologies. As a result, perovskite solar cells are now a large area of study in the solar industry.

The comparison of perovskite solar cells progress with that of other technologies can be seen in the National Renewable Energy Laboratory's chart below:

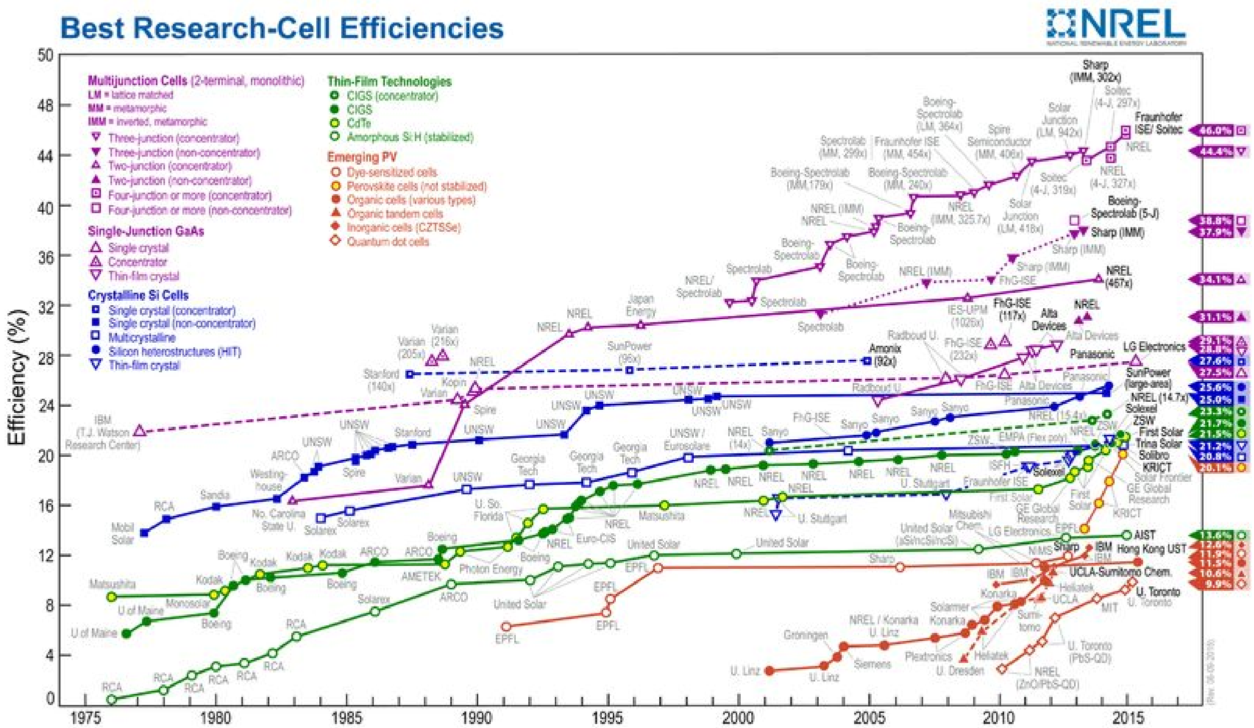


Figure 3: Efficiencies of various cell technologies over years of study and research
*Image Credit: [www.nrel.gov/ncpv](www.nrel.gov/ncpv) [5]*

Perovskite cells are leading in efficiency in the category of emerging PV technologies, and they are now comparable to crystalline silicon cells and thin film. More resources and better equipment for solar cell research have made such strides for the perovskite cells possible. This dramatic increase in efficiency is significant and worth further investigation.

## The advantages of perovskite solar cells

Making a solar cell out of a perovskite absorber has great advantages. Perovskite solar cells have a larger capability to absorb photons than many other materials used to make solar cells. In fact, the perovskite-based absorbers beat the industry-leading material silicon, in that they can absorb a larger spectrum of light. Figure 4 below shows the maximum photon energy utilization per PV technology. Perovskite based cells are among the best in converting light to electricity.

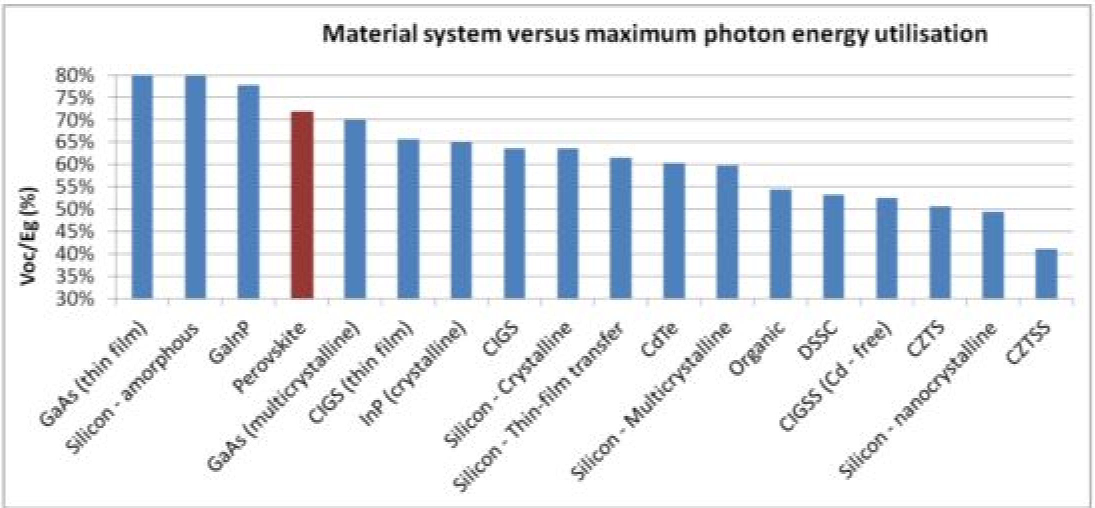


Figure 4: Maximum photon energy utilization for various solar cell technologies [6]
*Image Credit: www.ossilia.com*

Perovskites have the potential to optimize the spectral absorption range. The range of light absorbed by a perovskite material can be adjusted by changing the composition of the material. Adjusting the X compound in the $ABX_3$ perovskite structure, adjusts the band gap in the absorber material. In doing so, different parts of the sun's electromagnetic spectrum become available for absorption. Finding the right combination of compounds in the $ABX_3$ structure has set academia in a race for discovery of the potential to optimize the spectral absorption range.

Another promising area of solar research is the use of perovskite absorbers in multi-junction solar cells. Multi-junction solar cells combine different solar cell technologies. Using two technologies enables absorption of a larger range of the sun's electromagnetic spectrum, which potentially raises conversion efficiency.

Professor Martin Green of the University of New South Wales (UNSW) discusses the potential of combining perovskite and silicon solar cells. Professor Green's estimate of combining a 19.1% efficient perovskite cell with a 25% efficient silicon cell would produce a multi-junction tandem solar cell just below 30% efficiency [7]. This multi-junction solar cell efficiency then increases up to around 40% [7] when multiple perovskite cells are combined with a silicon cell.

Another advantage of the perovskite solar cell is its low cost of fabrication, which ultimately benefits consumers. Two main fabrication methods of perovskite solar cells are liquid-based, spin-coated material and vapour-deposited solid material. These methods rely on common, wet lab equipment, which is why they are cheaper than deposition equipment used in the semiconductor industry.
One of the challenges of current solar technology research is to discover new ways to reduce cost without sacrificing performance and efficiency. Perovskites solar cells have been able to meet these twin goals.
Another advantage the perovskite cell is in its deployability. They can be manufactured to be lightweight, transparent and flexible, increasing their potential range of applicability to areas other

solar cell technologies have not reached. Some complain that current manufactured solar cells are heavy, large, rigid, and can pose as visual eyesore. Perovskite cells, like other thin film solar technologies, have the potential to be manufactured and installed like wallpaper with a role-on process on virtually any surface. The transparent nature of perovskite solar cell technology enables it to be utilized on windows, either as glaze or sandwiched between panes of glass.

### Where do perovskite solar cells need improvement?

Though promising results are generated in labs and produced on the small scale, taking these results and applying them through large manufacturing operations for implementation is a lengthy process. Perovskite cells are still an immature technology in need of much further research and development before they will be market-ready.

One major downside to perovskite cells is their instability. The perovskite absorber material is an organic-inorganic compound, which means it is water-soluble and susceptible to moisture degradation. In fact, after exposure to moisture the perovskite cell deteriorated significantly in just 20 days [8] without any moisture barrier. Also, when the porous layer of the $TiO_2$ is sensitized with the perovskite absorber, UV light induces cell instability. As both moisture and UV radiation are present in real applications, these instabilities must be overcome if perovskite solar cells are to be put into practice.

One possible option to eliminate moisture instability is to encase the perovskite cell. This will require research and development of encapsulation methods that can safely house the solar cells for a reasonable amount of time. A 25-year lifespan warranty is standard for current commercial solar cells. Perovskites solar cells would need to match this lifetime if the industry is to gain from its expected low cost.

Another disadvantage with these cells is the use of lead, a known toxin. Unfortunately the experiments that have produced some of the highest efficiencies have been those that use lead in the perovskite absorber. Some research has used tin in place of lead but, those efforts resulted in reduced efficiency and stability [9].

The efficiency values produced by perovskite solar cells continue to be debated. The accuracy of the recent efficiency gains is considered by some to be unreliable. There is a question of whether the efficiency values have been overestimated due to an observed hysteretic behaviour of IV-curves of the tested perovskite solar cells. A more clearly defined and widely-accepted metric for efficiency of perovskite solar cells needs to be adopted to determine if these cells really are progressing the way we have interpreted.

## Research at LSNM

One of the focuses of nanotechnology research being conducted at the LSNM is the investigation into the various manufacturing process and structures of nanotubes to improve performance of perovskite solar cells. When I joined the LSNM, part of the research being conducted involved the fabrication of $CH_3NH_3PbI_3$ sensitized perovskite solar cells using novel $TiO_2$ nanotube array electrodes. The key results of the experiments were:

- Infiltration of the perovskite material into the TiO2 nanotube array allowed more than 90% of the visible light spectrum to be absorbed.
- The cell showed a significant increase in power conversion efficiency compared to conventional nanoparticle-based solar cells, reaching a conversion efficiency of 6.52%.
- Using an iodide based liquid electrolyte, the device achieved a high photocurrent density of 17.9 $mA^{-cm2}$.

While the efficiency of the cell did not reach record highs, it was indicated that new electrode designs using $TiO_2$ nanotubes could provide the basis for higher-efficiency, solid-state perovskite cells in the future [10].

## The future

The energy industry has entered an exciting period of great change with the maturing and rapid improvement in cost-effectiveness of solar technology. Huge amount of efforts are still being made in research and development of new and innovative solar technologies. High-efficiency, low-cost solar is around the corner. Perovskite solar cells have the potential to become a leading solar contender in the future. It will be exciting to watch the progress of these cells along with other solar technologies and the role they play in devising a more sustainable energy future.

## References


[1] Wenk, Hans-Rudolf; Bulakh, Andrei (2004). *Minerals: Their Constitution and Origin*. New York, NY: Cambridge University Press. ISBN 978-0-521-52958-7.

[2] M. Liu, M. Johnston and H. Snaith, 'Efficient planar heterojunction perovskite solar cells by vapour deposition', *Nature*, vol. 501, no. 7467, pp. 395-398, 2013.

[3] A. Kojima, K. Teshima, Y. Shirai and T. Miyasaka, 'Organometal Halide Perovskites as Visible-Light Sensitizers for Photovoltaic Cells', *J. Am. Chem. Soc.*, vol. 131, no. 17, pp. 6050-6051, 2009.

[4] H. Kim, C. Lee, J. Im, K. Lee, T. Moehl, A. Marchioro, S. Moon, R. Humphry-Baker, J. Yum, J. Moser, M. Grätzel and N. Park, 'Lead Iodide Perovskite Sensitized All-Solid-State Submicron Thin Film Mesoscopic Solar Cell with Efficiency Exceeding 9%', *Scientific Reports*, vol. 2, 2012.

[5] Nrel.gov, 'NREL: National Center for Photovoltaics Home Page', 2015. [Online]. Available: http://www.nrel.gov/ncpv/

[6] Ossila, 'Perovskites and Perovskite Solar Cells: An Introduction', 2015. [Online]. Available: http://www.ossila.com/pages/perovskites-and-perovskite-solar-cells-an-introduction.

[7] M. Green, 'Emergence of Perovskite Solar Cells', University of New South Wales, 2014.

[8] G. Niu, X. Guo and L. Wang, 'Review of recent progress in chemical stability of perovskite solar cells', *J. Mater. Chem. A*, vol. 3, no. 17, pp. 8970-8980, 2015.

[9] N. Noel, S. Stranks, A. Abate, C. Wehrenfennig, S. Guarnera, A. Haghighirad, A. Sadhanala, G. Eperon, S. Pathak, M. Johnston, A. Petrozza, L. Herz and H. Snaith, 'Lead-free organic–inorganic tin halide perovskites for photovoltaic applications', *Energy Environ. Sci.*, vol. 7, no. 9, p. 3061, 2014.

[10] X. Gao, J. Li, J. Baker, Y. Hou, D. Guan, J. Chen and C. Yuan, 'Enhanced photovoltaic performance of perovskite CH3NH3PbI3 solar cells with freestanding TiO2 nanotube array films', *Chem. Commun.*, vol. 50, no. 48, p. 6368, 2014.