IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 18, Issue 5 Ser. I (Sept. – October. 2023), PP 50-53
www.iosrjournals.org

Towards A Greener Future: Perovskite Solar Cells

José Carlos Arie Saishio Ysunza
Research Scholars Program
Harvard Student Agencies
In Collaboration With Learn With Leaders

Abstract:
Solar panels play a vital role in renewable energy generation, yet their widespread deployment raises concerns regarding environmental safety. This has led to the development and distribution of solar panels across the globe. However, the spread of solar panels presents a major environmental problem given how damaging their production and disposal can be for the environment. This paper presents a discussion on how to environmentally improve the solar industry through the development of an alternative type of solar cell. It presents comparisons between the standard crystalline silicon cells (c-Si cells) and perovskite solar cells (PSCs) in terms of their efficiency potential (EP), the environmental implications of their production and their ease or recyclability. Furthermore, improvements to PSCs are also presented and discussed.

Date of Submission: 06-10-2023 Date of acceptance: 16-10-2023

I. Introduction

This paper mainly focuses on three factors: efficiency potential, implications of the production and ease of recyclability. These are factors that deeply affect the impact that solar panels have on the environment; having a high EP reduces the long-term need for solar cells; the impact of their production determines how damaging it is for humans and nature; ease of recyclability affects how much energy and materials are wasted during this process. Throughout the paper, all of these processes will be broken down and discussed to determine not only why PSCs have a brighter future, but also, improvements for them that will lessen their environmental impact. Ultimately, this paper presents why PSCs should be developed over c-Si cells.

II. Methodology

A secondary hybrid method was used for the purpose of this research. Most of the studies and experiments cited were found in Google Scholar. Exclusion criteria was used to limit the age of the documents; in this case, no studies or articles were used with a publication date prior to 2018. The prompts used involved the following keywords: perovskite solar cell, crystalline silicon solar cell, impact on the environment, efficiency, recycling, production, fabrication, scalability, lead-less, lifespan and enhancement. There were three exceptions: An article from MIT News on PSCs, a website explaining what doping is, and a 2005 article describing the refinement process needed to get high-purity silicon. These exceptions were made to enhance the understanding of the topic.

III. Results

Efficiency potential

Regarding efficiency, two main things were found. The first is that c-Si cells are the most efficient in the market (Li et al., 2018). In fact, they have set "efficiency benchmarks just shy of 27%" (Michel et al., 2022). In contrast, PSCs have shown a power conversion efficiency "up to 25.2%" (Wang et al., 2020). The second aspect was that of the materials the cells can be made out of and how that affects their efficiency potential. As their name suggests, c-Si cells are made out of silicon and the differences between the different cells depend on the way the silicon is treated. Most of the cells in the industry have, as their base, highly doped silicon (Michel et al., 2022). Doping consists of adding impurities to a crystal in order to alter its conductive properties (*Doping: N- and P-semiconductors - Fundamentals - Semiconductor Technology from a to Z - Halbleiter.org*, n.d.) which means that, depending on what you dope silicon with, you will change its efficiency. In the other hand, PSCs can be made from a variety of materials. Perovskites themselves are just crystallized formations of materials that, alone or combined, resemble the structure of calcium titanium oxide (Chandler, 2022). These can be a variety of materials, the most conventional is lead but there have been attempts to make perovskite cells with tin, strontium, germanium and other alkaline metals (Gollino & Pauporté, 2021). Thus, the difference in efficiency comes from the variety of elements that can be used to make PSCs.

It was also found that perovskite cells have already reached the efficiencies of cadmium telluride cells which have been amongst the most efficient for years ((Chandler, 2022), (Li et al., 2018)) despite only being in development since 2009 (Gollino & Pauporté, 2021).

Production

Perovskite cells have a notably low-cost production process when compared to other cells (Liu et al., 2021). A perovskite cell is made out of five or six layers: the metal electrode, a perovskite film, an electron transport layer (ETL), a hole transport layer (HTL), a glass or transparent conductive oxide (TCO) layer and, in some cases, either a mesoporous electron transport layer or a mesoporous hole transport layer (Liu et al., 2021). Now, to make perovskite cells Wang et al. (2020) have published an article that describes the process to make a mini-module perovskite cell for researchers. To make them one has to laser scribble the glass/TCO module, then deposit the perovskite film and the HTL in that order, do another laser scribbling and deposit the metal electrode followed by a final laser scribbling. In this case, perovskite cells are shown to require relatively little amounts of energy to produce.

In the case of Crystalline silicon cells, these require "intensive energy consumption" to make (Xu et al., 2018). To get the silicon required to make the cells, silica has to be extracted and then processed into metallurgical-grade silicon to become high-purity polysilicon which can then be made into cells (Alsema & De Wild, 2005). The purity of the silicon inside solar panels "must have a purity of 99.9999" (Hoseinpur & Safarian, 2021). To achieve this purity, the main element that has to be removed is phosphorus and to do these temperatures of up to 1700 ºC have to be reached (Hoseinpur & Safarian, 2021). Thus, the refining process for silicon is shown to consume great amounts of energy.

Recycling

Let us begin with c-Si cells. As discussed in the previous section, silicon cells consume great amounts of thermal energy for the synthesis of silicon. However, when recycling, only a third of the energy needed to extract usable silicon from the solar cells (Xu et al., 2018). These processes still have some issues, namely, the quality of the silicon extracted. Most methods involve some sort of chemical, thermal, or mechanical method to extract the silicon from the panels (Tembo & Subramanian, 2023). These methods generally result in broken wafers which can only be used as materials for silicon ingots which will need further refinement (X. Xu et al., 2021) and thus, more energy is needed to make them useful in c-Si cells. Locally, X. Xu et al. (2021) have developed a method for extracting intact crystalline silicon wafers from panels, claiming that 86.11% of them come out intact. However, this, like many methods, needs to be rigorously evaluated from a sustainability standpoint" (Tembo & Subramanian, 2023).

Moving on to, perovskite cells, they have a less developed recycling process. Firstly, recycling perovskite implies the recovery of the different valuable and sometimes toxic materials that are contained inside the cells (Liu et al., 2021). Some examples of these materials are the lead contained inside the perovskite layer and the gold or silver in the TCO (Liu et al., 2021). Since we focused on the recovery of the silicon in the last paragraph, let us focus on the recovery of the lead in perovskite cells. Liu et al. (2021) discuss methods in their article "Recycling and recovery of perovskite solar cell" which involves a layer-by-layer decomposition of the perovskite cell to target specific materials. After removing the electrode and the HTL, the perovskite layer would be transformed into methylammonium iodide and lead iodide in water. The methylammonium iodide was then removed with the water leaving lead that could be used in perovskite cells and was only 1.1% less efficient than its original counterparts.

Improvements

Throughout the research, two main factors were identified that are holding PSCs back. The first is their materials, they contain lead which is extremely toxic and environmentally damaging as well as metals like tellurium and lithium which are rare and hard to obtain (Liu et al., 2021). Thus, attempts have been made to make lead-less perovskite cells but their efficiencies are still below those containing lead (Gollino & Pauporté, 2021). The second is their lifespan and scalability. In terms of scalability perovskite cells are presented with a problem, they become less efficient as they cover larger areas (Li et al., 2018). This is true for all solar cells due to uneven coatings of the materials and other difficulties; however, perovskite cells lose more efficiency than other cells when scaled up (Li et al., 2018). Perovskite cells don't have a very long lifespan either, only reporting lifespans of 3,000 hours against the 25 years that are standard in the industry (Q. Wang et al., 2019). However, it is estimated that "once perovskites reach a usable lifetime of at least a decade" they will be commercially viable (Chandler, 2022).

IV. Discussion

Efficiency potential

Initially, it appears that c-Si cells are the best option when it comes to efficiency since they have demonstrated higher efficiency. However, there are two things that should be taken into account. The first is the variety of the materials from which PSCs can be out of. Since they only have to mimic the structure of calcium titanium oxide, perovskites can be made out of several materials, meaning that there is great room for experimentation. In contrast, c-Si cells are limited to the structure of the silicon and the materials that can be used to dope it which presents variety. Of course, variety isn't always good and one could argue that it is irrelevant if the efficiency of c-Si cells is higher than that of PSCs. This is where the second point comes in - the speed of development.

Perovskite solar cells have been in development for a relatively short amount of time (since 2009 as mentioned earlier). In this time, they have not only matched but have surpassed other cells which have been in development for much longer. Even c-Si cells have been in development since the fifties and PSCs are already getting closer to their efficiency levels. This comes to show not only that PSCs have much more variety and potential for innovation, but also that they have had an explosive development which, efficiency-wise, looks very promising.

Production

One of the most important things that we have to look at when comparing two technologies and their environmental impact is their production process. Having a process that uses less materials or requires less energy limits the damage photovoltaics cause to the environment. Additionally, understanding how these technologies are made allows for analysis of their future improvements. Thus, that was the main objective of this part of the research was to understand the environmental impact that these processes have.

When comparing the energy usage of both types of solar cells it quickly becomes apparent that PSCs consume less energy than c-Si cells in their production. While fabricating PSCs relies heavily on the chemical deposition of materials, a process that doesn't require as much energy, the purification process for c-Si cells is very energy-intensive. Even in proposals such as that of Li et al. (2018) for scalable fabrication of PSCs on an industrial level, there is less energy consumption than for the purification of silicon. Additionally, since silicon has to be purified in an extremely hot furnace that means that there are great carbon emissions, leading to a more damaging process for the environment.

Recycling

Perovskite and silicon cells are both extremely good at energy generation and have the potential to change the way the whole world consumes energy. However, the story does not end on the installation. When the cells get damaged, old or lose most of their efficiency they have to be disposed of. This presents a problem because both of them contain heavy metals which "can pollute the environment and pose threats to human health" (Xu et al., 2018). Considering that solar panels, as an industry, are growing incredibly fast (Xu et al., 2018), it becomes imperative to find ways to recycle solar cells.

From the results of the research, it is clear how extracting lead from PSCs takes much less energy than extracting silicon from c-Si cells. However, these methods need "further optimization and investigation" (Liu et al., 2021). Especially considering that, since perovskite cells have not been applied at a large scale, large-scale recycling methods are still under development. So, in this case, it is hard to tell whether perovskite recycling methods will be more effective than those involving silicon. One thing is for sure, perovskite recycling takes less energy than silicon recycling.

Improvements

Having now discussed the advantages of perovskite cells in terms of efficiency and energy consumption, it is also important to discuss the needed improvements for them to succeed in the industry. The materials they are made out of are of great concern since they are rare and toxic. Seeing as alternatives for these materials have shown to be much less efficient it is important to do more experimental research in this field of perovskites to ensure that there is less of an impact on the environment. If that were not to be possible, then having strict recollection policies for solar panels like the ones in Europe would have to be spread and developed to adapt to these new cells.

The second area of improvement is that of scalability and lifespan. As it is clear from the results section, the lifespan of PSCs is still too short to be applicable industry-wide. However, once they are they will present benefits that c-Si cells cannot. PSCs are flexible and lightweight which means that they can be installed on the sides of buildings or on cars without adding extra loads. In general, if this issue can be resolved, PSCs have the potential to revolutionize the market.

V. Conclusion

To conclude, PSCs have shown to be a better environmentally friendly prospect than c-Si cells. From their significant advantage in variety and efficiency potential to their less energetically demanding production and recycling, PSCs have a great prospect to revolutionize photovoltaics if more research and development are put into them. this paper's goal was to give an overall view of why PSCs are more important for the future not only taking into account efficiency but also environmental impact. It is important for us to know how solar cells are managed throughout their life span. As such, it is important to develop better cells, but also, to engineer better production and recycling materials and methods to ensure that solar energy can truly stay green.

Bibliography

[1]. Alsema, E., & De Wild, M. J. (2005). Environmental Impact Of Crystalline Silicon Photovoltaic Module Production. MRS Proceedings, 895. Https://Doi.Org/10.1557/Proc-0895-G03-05

[2]. Chandler, D. L. (2022, July 15). Explained: Why Perovskites Could Take Solar Cells To New Heights. MIT News | Massachusetts Institute Of Technology. Retrieved July 12, 2023, From Https://News.Mit.Edu/2022/Perovskites-Solar-Cells-Explained-0715#:~:Text=The%20term%20perovskite%20refers%20not,A%20whole%20family%20of%20compounds

[3]. Doping: N- And P-Semiconductors - Fundamentals - Semiconductor Technology From A To Z - Halbleiter.Org. (N.D.). Https://Www.Halbleiter.Org/En/Fundamentals/Doping/

[4]. Gollino, L., & Pauporté, T. (2021). Lead-Less Halide Perovskite Solar Cells. Solar RRL, 5(3), 2000616. Https://Doi.Org/10.1002/Solr.202000616

[5]. Hoseinpur, A., & Safarian, J. (2021). Vacuum Refining Of Silicon At Ultra-High Temperatures. Vacuum, 184, 109924. Https://Doi.Org/10.1016/J.Vacuum.2020.109924

[6]. Li, Z., Klein, T. R., Kim, D., Yang, M., Berry, J. A., Van Hest, M. F., & Zhu, K. (2018). Scalable Fabrication Of Perovskite Solar Cells. Nature Reviews Materials, 3(4). Https://Doi.Org/10.1038/Natrevmats.2018.17

[7]. Liu, F., Biesold, G. M., Zhang, R., Lawless, R., Correa-Baena, J., Chueh, Y., & Lin, Z. (2021). Recycling And Recovery Of Perovskite Solar Cells. Materials Today, 43, 185–197. Https://Doi.Org/10.1016/J.Mattod.2020.11.024

[8]. Michel, J. I., Dreon, J., Boccard, M., Bullock, J. S., & Macco, B. (2022). Carrier-Selective Contacts Using Metal Compounds For Crystalline Silicon Solar Cells. Progress In Photovoltaics, 31(4), 380–413. Https://Doi.Org/10.1002/Pip.3552

[9]. Tembo, P. M., & Subramanian, V. (2023). Current Trends In Silicon-Based Photovoltaic Recycling: A Technology, Assessment, And Policy Review. Solar Energy, 259, 137–150. Https://Doi.Org/10.1016/J.Solener.2023.05.009

[10]. Wang, C., Tan, G., Luo, X., Li, J., Gao, X., Mo, Y., Zhang, X., Wang, X., & Huang, F. (2020). How To Fabricate Efficient Perovskite Solar Mini-Modules In Lab. Journal Of Power Sources, 466, 228321. Https://Doi.Org/10.1016/J.Jpowsour.2020.228321

[11]. Wang, Q., Phung, N., Di Girolamo, D., Vivo, P., & Abate, A. (2019). Enhancement In Lifespan Of Halide Perovskite Solar Cells. Energy And Environmental Science, 12(3), 865–886. Https://Doi.Org/10.1039/C8ee02852d

[12]. Xu, X., Lai, D., Wang, G., & Wang, Y. (2021). Nondestructive Silicon Wafer Recovery By A Novel Method Of Solvothermal Swelling Coupled With Thermal Decomposition. Chemical Engineering Journal, 418, 129457. Https://Doi.Org/10.1016/J.Cej.2021.129457

[13]. Xu, Y., Li, J., Tan, Q., Peters, A. L., & Yang, C. (2018). Global Status Of Recycling Waste Solar Panels: A Review. Waste Management, 75, 450–458. Https://Doi.Org/10.1016/J.Wasman.2018.01.036