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Project: UPero

Commercial Outlook of Printed Perovskite Solar Cells.

1. Introduction

During the UPero project, the upscaling of all-printed perovskite solar cells were investigated including the manufacturing of mini-modules up to 20 x 25 cm in size.

Depositing the mesoporous metal oxide layers and the carbon top electrode by screen-printing has proven to be reliable and scalable, therefore screen-printing is the baseline process of Solaronix' perovskite solar technology.

The perovskite precursor was early on deposited by a drop casting, and now, thanks to the UPero project, drop-on-demaind inkjet has been successfully developed and scaled-up to the mini-module size (size given by the inkjet equipment at Solaronix).

In the UPero works slot-die coating was investigated on the Empa based coating equipment located at the Coating Competence Center, and slot-die coating allowed the formation of all the layers needed to buld-up the perovskite solar cell using the same equipment. For each layer, only the slot-die coating parameters needed to be adapted to the functional ink characteristics, as the various inks go from very fluid like water to viscous like honey.

When the solar cell active layers are deposited by slot-die coating, the whole substrate area gets covered, additionnal nano-second pulsed laser processes were developed during this project to selectively remove excess material on unwanted area.

The same laser equipment and methods were also employed to scribe the three different separation lines within the active layers, thus allowing the manufacturing of interconnected solar cell modules.

So, the Upero project delivered two production methods:

1. Selective active layer deposition by screen-printing and inkjetting of perovskite precursor ink, allowing for customized sizes and shapes of the solar cells & modules.

2. Slot-die coating of all inks and pastes forming the solar cell active stack, combined with laser patterning, allowing potentially for a very fast and large area manufacturing with industrially proven methods.

2. Market applications

2.1 Building Integrated Photovoltaics

Solar modules with customized sizes have a good potential in building integrated photovoltaics (BIPV), as building skins and facades have mostly intricate shapes and very individual designs, in other words « one size fits all » does definitely not apply to buildings.

Thanks to the printing processes developed during UPero, Solaronix is capable to address such markets requiring highly customized solar products.

During the last year, Solaronix got approached by a German company being, among other, active in pattern-printing façade glass and ceramic surfaces.

Multiple samples and formulated inks have been exchanged over the last months to understand if the processes employed at that company could be capable of printing functional solar cells.

The idea is to leverage their large area printing capacity with the perovskite solar cell processing developed at Solaronix, to build a demonstrator module of about 1 m^2 in size within the next 12 months.

The BIPV market for solar modules covering walls and glass façades is still a small market with ca. 3 B CHF expected volume in 2024, though growing at good 20% per year (Source: iea-pvps.org & Grand View Research).

A other interesting feature of our printed perovskite solar cells are their deep black color, being essential for manufacturing solar panels having a colorful reflection, by taking advantage of spectrally selective coatings, such as the ones developed by the Swiss company SwissInso with their Kromatix® coated glasses.

To have the best effect with such selectively reflecting coatinted glasses, the solar module placed behind must be not only be homogenuous in aspect, but that photovolatic surface needs to be as black as possible.

2.2 Solar Tiles

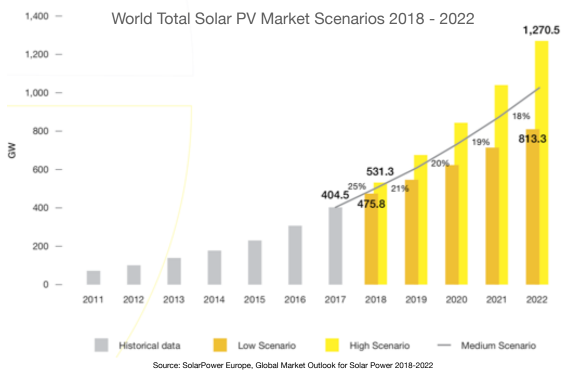
Solar tiles is an emerging market requiring highly specialized solar mini-modules to form pleasant roof coverings resembling traditional tiles or slates.

The prices of such solar tiled roofs are still fairly high ranging from 3’500 to 5’000 CHF per installed kWp according to a recent update found at https://www.theecoexperts.co.uk/solar-panels/roof-tiles. This cost point is more than the double of a conventional solar installation added on a roof.

This market is attractive as the solar modules are of fairly small area, typically ca.30 x 30 cm, and their shape and size are highly customized to fit the specific needs of the customer. Again, these attributes may be well served by printed perovskite technology, such as the one developed within this project. The Swiss company Freesuns even combines solar tiles with color-adapted glasses to form a roof having a historic look, while producing solar power with ca. 100 W per m^2 of roofing.

Obviously for these building related markets, the perovskite photovoltaic technology needs to show a lifetime of over 20 years, moreover shadowing or irregular illumination further demands robustness or means to avoid ‘reverse-bias’ related damages to the solar cell materials.

2.3 Energy Market



Today, photovoltaic (PV) solar modules represent globally a 30 B US$ market, having an expected 20% per year growth in the coming next years.

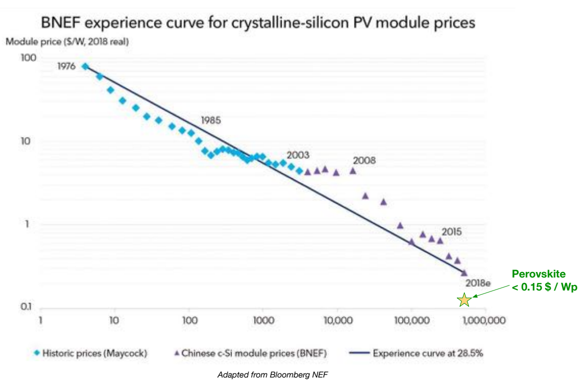
Over the last 12 years, the totally installed PV capacity went from 9.7 GWp in 2007 to 650 GWp in 2019 - a multiple of 67 times.

It is expected that the magic mark of 1’000 GWp (1 tera Watt, TWp) will be reached in the year 2022.

Despite these eloquent figures, photovoltaic solar energy contributes ‘only’ to 2.6% of the totally produced electricity in 2018.

Some countries, like Germany, Greece, and Italy have a fairly large share with up to 7% of their total electricity delivered by the sun, Honduras tops the ranking with 14% of clean PV electricity (http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_T1_35_Snapshot2019-Report.pdf)

Seen from an other perspective, the expansion potential for PV is considerable. In 2017 the World consumed 26’000 TWh of electricity, and it would need 27 TWp of installed PV modules to supply that energy demand - or about 40 times today's market. With the electrification of the society, the PV demand will even more important by 2030 and beyond, when 50% of the primary energy consumed will be in the form of electricity by 2050.

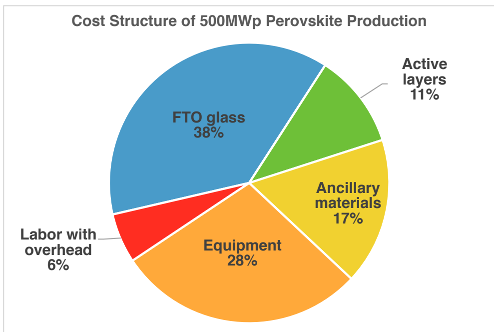


Similarly to the well known Moore’s law ruling the semiconductor industry since over 45 years in terms of cost per transistor, the price trajectory of photovoltaic modules is governed by a learning curve - the Swanson’s Law, first published in Electronics, Volume 38, Number 8, April 19, 1965.

Every time the installed capacity doubles, the cost drops by 28.5%, as obtained from the historical data (G. J. Schaeffer; E. Alsema; A. Seebregts; L. Beurskens; H. de Moor; W. van Sark; M. Durstewitz; M. Perrin; P. Boulanger; H. Laukamp; C. Zuccaro (2004). "Learning from the Sun" Energy Research Centre of the Netherlands).

Currently, crystalline silicon modules cost about 0.23 to 0.4 €/Wp (0.25 to 0.45 $/Wp), depending on module efficiency (typically 17 to 20%) and other manufacturing aspects.

The target with perovskite PV is to go below 0.15 $/Wp, even at a rather small scale of 100 MWp production capacity. This is only possible thanks to an all-printed manufacturing approach, and the use of low cost and abundant materials entering the perovskite solar cell.



For the large scale production of perovskite photovoltaic panels, the costs structure shows that the most expensive part is the fluorine doped tin oxide (FTO) glass with 38% of the total costs share. FTO glass is actually a fairly standard architectural product, employed in so called ‘low-e’ windows in buildings to reduce heat losses, it costs about 6 to 10 US $ per m^2.

The perovskite light converting material itself makes less than 4% of the solar module expenses.

Going for yearly capacities in the GWp range would bring perovskite solar modules down to 0.1 $/Wp, thanks to the economics of scaling that lies still ahead of us.

Additionally, thanks to the all-printed approach employing industrially known equipment, as well as the small amounts of low-cost materials needed, smaller sized factories would become profitable, allowing either for specialty photovoltaic products, or local production sites being closer to the customers.

Solaronix has supplied encapsulated perovskite mini-mode samples to the Italian energy company Edison for their evaluation in terms of performance and durability.

Similarly, Solaronix is involved in a round-robin program happening together with the SUPSI PVLab (Mendrisio) where sealed perovskite mini-modue are exchanged between institutions and tested in various environments.

2.4 Specialty Markets

The perovskite's ability to work efficiently in low light conditions, such as in homes and office rooms, enables the powering of the myriad of electronic goods surrounding us. Effectively, it would be possible to power from the ambient light, for instance, sensors needed to control the heating systems of buildings. Consumer electronics, such as computer keybords, wearable fitness trackers or even certain smartwatches could have their battery life be extended substantially by having a highly sensitive perovskite solar cell attached.

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