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Public Dissemination Report

Project title: 2017/RND013 Developing a New Type of High Efficiency Building Integrated PV Cell
Lead organisation: Monash University
Project partners: CSIRO, Viridian Glass
Project commencement and completion date: 11 December 2017 – 30 October 2021

This Project received funding from ARENA as part of ARENAs Advancing Renewables Program.

Executive Summary

Building integrated photovoltaics (BIPV) can take the form of semi-transparent solar cells integrated into a framing system – essentially a tinted window that can generate electricity with the light that it absorbs. To date, there has not been a solar cell technology that combines suitable levels of efficiency and light transmission at an adequate price point to allow for broad adoption. The objective of this project was to demonstrate that perovskites, a rapidly emerging class of photoabsorber material, can be incorporated into semi-transparent solar cells at a scale, efficiency and lifetime that make them suitable for building integrated applications.

This project demonstrated on a laboratory scale that a perovskite-based solar cell could meet the electricity generating and aesthetic (namely average visible transmittance (AVT) and colour) requirements for such a product. This project achieved world-record efficiencies across a range of AVTs, and considerably improved upon the lifetime of comparable devices made to date.

The project also used desktop modelling to better understand the potential of this technology across a number of human-inhabited environments. The study showed that the wide deployment of conventional rooftop solar coupled with building integrated (i.e. wall and window mounted) PV can produce the majority of electricity produced by a city. For example, the city of Melbourne could have 77% of its electricity needs met through solar cells deployed in the immediate area.

Future work in this field will focus on scaling-up device fabrication to window sizes common in industry. This will necessitate translating production methods to laboratory-based techniques to scalable production methods, such as slot-die coating. Device lifetimes will also need to be improved greatly to meet the onerous requirements of building-integrated applications. It is anticipated this will be achieved through further optimisation of the device components and through improved encapsulation using industry-standard products, such as integrated glass unit (IGU) double glazed windows.

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Outline aim of the project

The ultimate objective of this project was to create a semi-transparent perovskite solar cell that has an efficiency and transparency that was suitable for a building integrated application. Optimisation of this solar cell necessitates an in depth investigation into each layer of the device, with a view to creating a stable solar cell that can be fabricated commercially.

This project aimed to incorporate this semi-transparent solar cell into the design of an integrated glass unit (IGU), an industry-standard design for windows, thereby creating a product that could be easily implemented in building design, while adding critical functionality through electricity generation.

Furthermore, this project aimed to demonstrate the utility of BIPV through a desktop study, which calculated the broad deployment of this technology in a city could generate an appreciable portion of the electricity used by the area's inhabitants.

Outline key findings

- Building integrated PV applications require operational lifetimes that extend beyond those of even conventional silicon solar cells. This creates challenges when using a material such as a lead-halide perovskite, which is yet to demonstrate comparable efficiencies. However, this project demonstrated that eliminating organic components from the perovskite layer to make an all-inorganic analogue significantly improved the stability of the device. It is anticipated that a similar perovskite formulation will ultimately be used commercially.
- Further improvements in device lifetime can also be achieved through changing other components of the device. One widely used conventional charge transport layer (Spiro-OMeTAD) was replaced with an alternative (VNPB) that more effectively limited water vapour transmission. This limited the perovskite-layer degradation, thereby greatly enhancing the stability of the device.
- Careful optimisation of the solar cell through perovskite band gap tuning (or changing the absorption profile of the material), allows for careful control of both the appearance and efficiency of the device. Over the course of this project, efficiencies spanning from 4.2% and 15.4% over an average visible transmittance (AVT) range 52.4–20.8% were achieved. Tuning the band gap not only affected the AVT of the device but also affected the perceived colour, with higher AVT devices appearing more yellow, while lower AVT devices trended towards dark brown in colour.
- The wide deployment of BIPV in a city environment could generate a significant portion of the energy used within the area. Modelling of the city of Melbourne showed that up to 74% of the electricity consumption could be covered by a combination of conventional roof top solar (88% of electricity generated) and vertical BIPV and ST-PV windows (8 and 4% electricity generated, respectively).

- In the neighbourhood environment, the portion of electricity generated by ST-PV windows will increase to 18%, with fully glazed skyscrapers capable of using 100% of their surface area for ST-PV windows. This presents a massive market opportunity for the technology.

Describe learning of benefit to others in the sector

- Designing novel BIPV devices presents a broader range of challenges than conventional solar cell development. In addition to optimising efficiency and lifetime, careful consideration needs to be directed towards device aesthetics and also making products that can be integrated into products that are already familiar to installers (e.g. the IGU used by glaziers in residential and commercial environments.) To ensure the requirements of the manufacturers, integrators and end-users are adequately considered, it is important to engage widely with all stakeholders during the early stages of the project.
- Scale-up of fabrication remains a challenge for perovskite solar cells. Spin coating remains an excellent method for prototyping devices on a lab-scale to understand the relationship between efficiency, average visible transmittance, colour appearance and stability, but it will never be suitable for at-scale production. When designing precursor solutions for perovskite deposition, it is important not only to consider how the solution is used for spin coating, but also how it translates for use with scalable deposition methods, e.g. slot-die coating and reverse gravure.
- Replicating IGU construction on a laboratory scale is difficult. The industrial equipment used by commercial partners offers superior performance. However, this equipment cannot be readily used on a smaller scale devices, necessitating the use of alternate methods to create proof-of-concept prototypes. Finding an approach that readily allows for small scale prototyping, while offering the encapsulation properties of commercially-available IGUs will accelerate the development of the technology.
- Solution precursor aging presents the potential to affect device performance. It is highly preferable to synthesise perovskite precursor solutions as close to the point of deposition as possible. While this is easy to achieve on a laboratory scale, this may have ramifications for commercial preparation. It is anticipated that onsite precursor solution preparation will be preferred over synthesis by a third party to ensure consistency in the precursor solution.
- To the best of our knowledge, no industry-wide standard exists for how to design and integrate a BIPV window into the electrical system of an existing building or a new construction. The establishment of such a standard will be essential before the technology can be widely deployed, and will greatly assist installers onsite.

List any products, patents applied/granted and or publications produced as part of this project and how they can be accessed.

Publications

1 ‘Prospects of photovoltaic rooftops, walls and windows at a city to building scale’, Jasieniak et al., Solar Energy 230 675–687 (2021): https://www.sciencedirect.com/science/article/pii/S0038092X21009130. 2. Semi-transparent perovskite solar cells with cross-linked hole transport layer’, Yu et al., Nano Energy, 71 104635 (2020): https://doi.org/10.1016/j.nanoen.2020.104635. Submitted for publication 1 ‘High-performance and stable semi-transparent perovskite solar cells through composition engineering’, Yu et al., submitted for review.
State any ancillary benefits (eg. PhDs awarded, jobs created, follow-on funding secured, etc.) This project has supported the training of a postdoctoral fellow and of 5 Final Year and Master’s Engineering Students at Monash University.
Outline next steps in the area of research, development or deployment toward the ultimate goal, which is to make the technology more commercially and economically viable Building integrated applications place the most stringent requirements on PV technologies, particularly in terms of operational lifetime and aesthetic appeal. While this project used organic-cation-free perovskite formulations to fabricate ST-PeSCs with greatly improved lifetimes, further efforts are required to extend lifetimes to the 30-40 year timeframes required for these applications. While this is anticipated to come from changes to device composition and fabrication methods, integration into IGUs using industry compatible methods are anticipated to significantly progress the technology in this regard. BIPV are highly visible, necessitating designs that seamlessly integrate into the aesthetics of their environment. While the target AVT values were achieved over the course of this project, the brown tinge to the cells, which is a function of the perovskite’s absorption spectrum, may not be suitable in all spaces. To expand the potential deployment of the technology, other layers in the device should be engineered to give a more neutral (gray-scale) appearance. Finally, scale-up of fabrication remains a primary concern for all perovskite-based PV technologies. While the various approaches to fabrication present various benefits and disadvantages, roll-to-roll solution processing offers the greatest potential for cost production. Therefore, it is anticipated that the cheapest product will be made if this process can be used in the production of integrated glass units containing perovskite solar cells, potentially through the manufacture of a perovskite solar cell laminate that could be applied to glass surface prior to window construction.

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