Manufacturing of Printed Perovskite PV Modules

Project results and lessons learnt

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Table of Contents

Executive Summary

The project aims to develop high-performance flexible perovskite-based solar cells fabricated by industrial roll-to-roll printing methods. By restricting our deposition techniques to processes commonly used by commercial printers, we are working towards the development of a cost-competitive method that can be rapidly adopted by the Australian manufacturing industry.

Within the overarching objective of the project, the first stage was designed to build a foundation to progress towards the final goal. Therefore, a process for the fabrication of a large-area PV module with an interim target efficiency was developed using commercially available materials. At the same time, new materials were developed to improve performance and durability, and also to replace high-cost components. As durability depends on a device's composition and configuration, durability testing will be continued throughout the project.

The project has been progressing well, as demonstrated by the following highlights:

- a world leading 9% efficiency achieved from a module fabricated by roll-to-roll coating performed in a realistic manufacturing environment.
- 17.8% efficiency from research cells (cell area: 0.16 cm^2) achieved with newly developed materials.
- 8.2% efficiency achieved from fully printed flexible cells with a new conducting paste, which enables low-cost manufacturing by conventional commercial printers.

To achieve the final efficiency goals, the discovery of a deposition process with an improved solar ink will be necessary. One key activity carried out in the first stage of the project was developing a testing method for manufacturing techniques for large-area solar cells. This protocol will be used to find the next generation of deposition processes for large-area modules. The impact of environmental conditions on the new process will also be determined through the testing methods developed in this project. Based on the progress to date, and the expected synergistic effect of the newly developed materials and processes in the pipeline, the project is anticipated to be delivered on time and within the budget.

Project Overview

Project summary

The first stage of the project was designed to build a foundation to progress towards the final goal: achieving a low-cost manufacturing technique for printed perovskite PV. Therefore, the feasibility of applying different deposition techniques to roll-to-roll manufacturing methods was tested to find a process that is suitable for manufacturing high-performance printed perovskite solar cells. New materials were developed to improve performance and durability, and to also reduce the potential manufacturing cost.

Project scope

This project aimed to accelerate the commercialization of flexible perovskite PV (PPV) devices, with a focus on the portable and off-grid PV market. The key problem in the commercialisation of PPV was the absence of a low-cost manufacturing technique that has the potential to achieve the efficiencies already demonstrated by small-scale laboratory-fabricated devices.

The fundamental barrier to solving the problem is the difficulty in fabricating high-quality perovskite thin films on a large scale. While this emerging technology has advanced at an exceptional speed, all of this progress has been made using laboratory techniques that are not scalable or transferable to a manufacturing environment.

Therefore, this project develops materials and deposition techniques that are suitable for the manufacturing of market-competitive solar cells by existing Australian printing industries.

Outcomes

A process for the fabrication of a large-area PV module was developed to be used as a standard method to test the feasibility of new materials in the manufacturing process. New materials have been developed and showed promising preliminary results. A durability testing system was built for the high-throughput testing of devices.

Based on the results to date, the project has been tracking well against the proposed timeline. If the project continues as anticipated, the laboratory technology will be ready to be incorporated into full-size prototypes of portable PV products by the end of the project.

The manufacturing process for the world-first fully roll-to-roll printed perovskite module was recorded for future knowledge sharing. Details of these exciting achievements will be announced through media during the next stage of the project.

Transferability

The competitive advantage of the research team at CSIRO is its extensive knowledge of the manufacturing techniques that it has applied to printed PV over the last ten years. From the earliest stages of this research, the CSIRO team has always been mindful of utilising research methods that can be applied to industry-relevant techniques. Therefore, the technology developed in this project will be transferable to industry more readily than other projects.

In the next stage of the project, a workshop with members of the Australian printing industry will be organised and the knowledge developed in this project would be shared with the potential industry partners. Through this workshop, members of industry may be able to identify how the methods that have been developed in this project can be applied to other areas of their businesses.

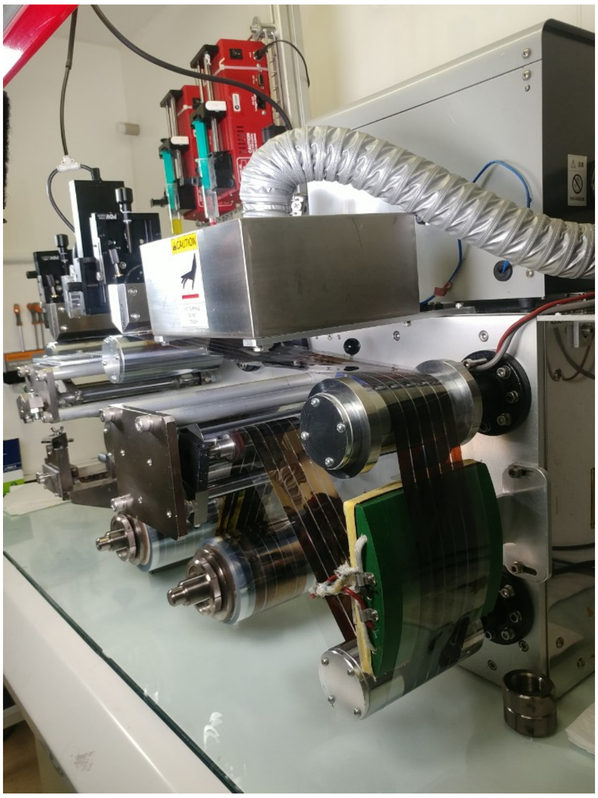

Figure 1. Roll-to-roll fabrication of flexible perovskite PV module

To date, the roll-to-roll fabrication of perovskite PV has been reported by only four research groups, including the research team of this project. The other groups are Solliance, a cross-border Dutch-Flemish-German thin-film photovoltaics research initiative with a large industry network, the National Renewable Energy Laboratory (NREL) in the US, and VTT in Finland.

Conclusion and next steps

The project has been progressing well, with a strong foundation established for future stages. The activities carried out in parallel in the first stage of the project will be combined in the next stage of the project. Combining these developments is anticipated to have a synergistic effect that will increase the rate of progress, and demonstrates a clear pathway to delivering impact on the portable and off-grid PV market. Once a small market is created with flexible PV, industry will be able to develop the technology further to be cheaper and market-competitive for broader application.

Lessons Learnt

Lessons Learnt Report: Manufacturing environment of printed PV

Project Name: *2017/RND012 Manufacturing of Printed Perovskite PV Modules*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	Victoria

Key learning

The project aimed to find a temperature and humidity range suitable for roll-to-roll manufacturing of perovskite PV. Therefore, various deposition techniques were tested under different humidity and temperature conditions. It was found that a suitable range of conditions is composition/process dependant and, moreover, high humidity can also be beneficial for some processes. This knowledge is critical in determining viable locations for potential manufacturing centres.

Implications for future projects

Based on the information collected over the course of this activity, we can now determine which processes and materials can be utilised for the environment conditions present on a given day. This will minimise the occurrence of devices failing due to being fabricated in environments where the relative humidity is either too low or high for a given material composition or device structure.

Knowledge gap

It is generally believed within the research community that low humidity (20–30 % humidity range) or an inert atmosphere is required for the fabrication of perovskite PV. Typically, this has led to dry rooms being used for perovskite research by many leading research groups. This viewpoint has developed through the use of a standard laboratory deposition technique, spin coating, which has completely different solvent drying kinetics from that of industrially relevant manufacturing processes. Based on the results of the project activity in "Identification of suitable temperature and humidity ranges for PPSF fabrication", we can state there is no single optimal set of environmental conditions for all processes and formulations.

Background

Objectives or project requirements

The objective of this component of the project was the "Identification of suitable temperature and humidity ranges for PPSF fabrication". Although the goal was achieved, it was found that one set of conditions was not optimal across all of the materials and device structures employed in this project.

This is a favourable outcome, as the need to control humidity and temperature within a small range at low levels can greatly increase the capital cost of establishing a printing facility.

Process undertaken

A number of device fabrications were performed in a chamber with humidity control, allowing for a direct examination of the effect of humidity on the physical properties of the deposited materials (i.e. film uniformity, crystal size and orientation, etc) and the device performance.

As a result of this process, in addition to experiments performed under artificially controlled humidity, the humidity and temperature of all printing experiments will be recorded and saved in the online database for PV devices. Once enough data are accumulated, the relationship between the performance of the devices and the environmental conditions will be analyzed by big-data analysis techniques and an ideal environment for manufacturing will be verified.