Australian National University

Monolithic perovskite-silicon tandem cells: towards commercial reality

Public dissemination report

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Executive summary

The aim of this project is to design and demonstrate 'tandem' solar cells using processes and methods that can be easily transferred to manufacturing. In a tandem solar cell, two cells made of different materials are stack on top of each other, so that each cell only absorbs a certain portion of the solar spectrum – the top cell absorbs (and converts to electricity) the 'blue' part of the solar spectrum, while the bottom cell absorbs the red part. In this way, higher conversion efficiency of sunlight to electricity can be achieved than using a single solar cell alone. Solar cells based on perovskite and silicon materials for the top and bottom cell, respectively, are very attractive due to their potentially low cost.

To date, most of the work on such perovskite-silicon tandem solar cells has used special, laboratory-type silicon wafers, rather than the much cheaper, commercial wafers used by solar cell manufacturers. An important step towards commercial application is the design and demonstration of high-efficiency tandem cells that use such commercial wafers. This is what this project set out to do.

Project Overview

Project summary

We have worked closely with our commercial partner Jinko Solar to develop tandem solar cell designs that would allow us to use Jinko's solar cells and fabricate ANU's perovskite solar cells directly on top of them. This required some small modifications to the design of Jinko's cells. Three different cell structures were explored. Silicon cells were fabricated by Jinko and send to ANU, where perovskite cells were fabricated on top of the silicon cells.

The main goal was to demonstrate that high efficiency tandem cells can be fabricated on commercially fabricated silicon cells. A further goal was to fabricate relatively large area ($4cm^2$) tandem cells to demonstrate the scalability of the processes involved. Finally, some preliminary stability testing was carried out.

Project scope

Perovskite-silicon tandem cells technology is considered to be a very promising technology to increase the conversion efficiency of solar cells and modules beyond what can be achieved with standalone silicon modules, which currently dominate the market. Efficiencies exceeding the best efficiency of a silicon cell have already been demonstrated. However, the devices fabricated so far have been relatively small area ($1cm^2$ or smaller) and have generally used specialised silicon wafers and laboratory-type silicon cells. Such cells are extremely expensive and will not be commercially viable. To move towards commercial viability, it is necessary to work with solar cell manufacturers, understand what cell structures can be produced at a reasonable cost, and how they can be integrated into efficient tandem cells. It is also necessary to modify the perovskite fabrication process to exclude materials from the perovskite cell architecture that are expensive or unstable for long term operation. These materials need to be replaced with cheaper and more stable alternatives, and the alternatives must be evaluated and demonstrated in solar cells.

Ultimately, the project goals are to develop and demonstrate new architectures and processes for perovskite-silicon tandem cells that enable both high conversion efficiency and low costs, as required for commercial feasibility, and in the process to develop a deeper understanding of the key technical challenges that need to be resolved. Important to the process is the two-way exchange of information and ideas between the researchers at ANU and Jinko Solar, to ensure all parties can contribute their perspectives and insights.

Outcomes

Following previous results, where a cell efficiency of 21% was demonstrated, we focused on identifying the factors that prevented even higher efficiencies from being achieved, as well as factors that reduced the reliability of the process.

One significant challenge is presented by the rough surface of the silicon cell on which the perovskite cell is deposited. In our previous work, we had developed a process to enable the deposition of continuous perovskite films over large areas. However, even with this technique, the reliability of the cell fabrication processes was still relatively low, with around half of the fabricated cells displaying low efficiencies below 20% due to 'shunt paths' that form as a result of imperfections in the perovskite film and the transport layers that make electrical contact on both sides of the perovskite film. To improve reliability further, we implemented changes to the transport layers. We found that, by implementing inorganic transport layers deposited by appropriate methods, we were able to obtain dense films almost entirely free of local imperfections. The combination of two high quality transport layers and a dense and compact perovskite film enabled a further, significant improvement in the reliability of the cells.

To further improve the efficiency of the cell, we carried out a detailed series of experiments to understand the major source of losses in the perovskite cell, and identified the interface between one of the transport layers (consisting of nickel oxide) and the perovskite film. We then introduced an additional layer at this interface, and investigated a range of polymers for this role. These investigations showed that long-chain organic polymers could provide the greatest performance improvement, which we showed to be due to the influence of the polymer chain length on the thickness of the film. Specifically, a long-chain organic polymer results in a more uniform film thickness that is more effective at reducing energy losses at the perovskite-nickel oxide interface.

We also carried out detailed optical modelling to identify and reduce losses associated with the reflection of light. The enabled us to identify the most suitable material to use for the transparent conducting oxide, which serves the critical function of allowing light to enter the cell while also transporting electrical current to the metal contacts.

As a result of these detailed investigations, we were able to fabricate perovskite-silicon tandem solar cells with a significantly improved performance, with a 4cm^2 cell measured at 24.6% and a 1cm^2 cell measured at 27.6% using our testing facilities at the ANU.

Transferability

The achievements of this project can be applied to other projects that involve perovskite technology. For example, the vacuum-flash technique is a generally applicable and useful method to fabricate high-quality perovskite films. The material configurations can be applied to industrial cell technology, and the insights into the optical properties, and the strategies to reduce interface losses are applicable not only to other perovskite cell architectures, but also could be applied to other perovskite devices such as light emitting diodes and sensors.

We have established a website (perovskitegroup.com.au) which features current projects, latest results, press releases, researchers, opportunities, publications and other information.

All group members regularly attend conferences, visit research institutions and give talks at a variety of fora to both specialist and lay audiences. In addition, significant results also feature in media releases.

Conclusions

This project has helped to bridge the gap between laboratory and commercial processes for tandem solar cell production. Through close collaboration between ANU and Jinko Solar, we were able to develop a silicon solar cell with high efficiency that only requires a few modifications from current, commercially produced cells, and uses only established fabrication processes.

Importantly, we were able to fabricate high efficiency tandem cells without the need for a very smooth surface on which to deposit the perovskite cell. Polishing silicon wafers to produce such a smooth surface is expensive and would result in solar cells that are too costly.

We have been able to demonstrate perovskite-silicon tandem cells with high efficiency, with the best cell achieving a conversion efficiency of 27.6%.

We are currently preparing a manuscript based on our work and results, co-authored by researchers at both ANU and Jinko Solar, for submission to a leading technical journal. In this way, we will share some of the insights and key conclusions we have drawn from our work, and will be able to highlight to the photovoltaics community the potential of perovskite-silicon tandem cell technology based on existing, mass-produced silicon solar cells.

Ultimately, the benefit of the project has been to facilitate and accelerate the development of commercially produced tandem devices on a large scale, which in turn will drive a reduction in the cost of solar electricity. The benefit to the Australian energy system lies in lower cost solar energy generation, which is passed on to domestic and industrial consumers. Given that solar energy is set to dominate electricity production in Australia in the near future (and already dominates new installed electricity capacity), and the massive growth in clean energy demand that will arise from a switch away from coal and gas, as well as the electrification of the transport system, such a cost reduction will result in significant economic benefit.

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