Australian National University

Monolithic Si/perovskite tandem solar cell: advanced designs towards high-efficiency at low-cost

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Executive Summary

Tandem solar cell design is proven as one of the most promising approaches to further reducing the photovoltaic solar cell cost through improving its efficiency. Perovskite solar cell is an ideal top cell candidate to pair with Si cells for tandems due to their outstanding optoelectronic properties, high efficiency, and low-cost fabrication.

Despite high efficiencies, Si/perovskite tandem architectures remain too complex and contain expensive materials deposited via processes with low material usage, entailing significantly increased manufacturing cost. The ANU team's innovation of interconnect-free Si/perovskite tandems provides an ideal platform to tackle this challenge with a simplified device structure based on commercially relevant Si cells. Building on this innovation, this project is designing and developing more advanced device structures, materials, and processes to achieve high-efficiency, stable and low-cost Si/perovskite tandem technologies.

A range of interfaces, tandem structures, perovskite and contact materials, Si passivating contact processes are being tested and assessed for simplifying tandem structure, lowering the cost and improving the tandem efficiency and stability. This will provide a clear pathway to the commercialisation of Si/perovskite tandems, contributing to an affordable renewable energy future.

Project aim

This project aims to further reduce the tandem cost while achieving high conversion efficiency and excellent stability through substantial improvements to device designs as well as optimising materials and processes, providing a clear pathway to Si/perovskite tandem commercialisation to drive significant cost reductions for PV electricity over the coming years.

The project is developing a set of new technologies (cell architecture, materials and processes) to enable the fabrication of cost-effective, stable, high-efficiency perovskite/Si tandem cells that are industrially feasible. This would lead to a reduction in or removal of barriers to renewable energy uptake through enhancement of PV cost-effectiveness.

This project is conducting cost study for Si/perovskite tandem solar cells and will produce cost analysis reports that benefit the community by providing guidance for research directions towards low-cost processes and materials in parallel with higher efficiency in the Si-tandem area.

This project will deliver increased skills, capacity and knowledge relevant to renewable energy technologies through presenting high-quality research findings to the PV research community, industry and the public.

This project will also increase Australia's research capacity and foster the next generation of Australian PV researchers by providing outstanding training opportunities to early-career Post-doctoral Fellows as well as non-ARENA funded PhD.

Key findings

Two types of Si/perovskite tandem solar cell structures with simplified interconnection design have been developed and tested. The low-resistivity contact behaviour between the emitter on the front side of the Si subcell and the charge transport layer on the rear side of the perovskite subcell, as well as the compatible fabrication process developed for the perovskite cell with the Si bottom cell, are the major enabler for the simplified tandem structure with high efficiency. Tuning of the material

electrical properties, including the doping profile, the energy levels, the defects states, is found to be important to produce contact with outstanding optoelectronic properties, which is delivered by careful material choice, optimising the deposition conditions and post-treatment.

Cost analysis points out that the removal of the interconnect layer increases the cost-effectiveness of the tandem solar cell by reducing the manufacturing cost and meanwhile maintaining high efficiency. Developing indium-free transparent conductive material for the top contact of the tandem solar cell can further reduce the material cost, benefiting the expansion of the PV market. The tandem structures that are being developed are promising to reach a low-cost level to enable them to be cost-advantageous over the conventional Si structure.

The simplified Si/perovskite tandem solar cell shows promising efficiency and stability in preliminary testing. The tandem efficiency reaches ~25% with good stability under various aging conditions (heat, moisture, bias, light).

Lessons learned

High-efficiency performance of tandems relies on the high performance of each subcell, the excellent interface property as well as efficient optical coupling between the subcells, which is a much more complicated system as compared to the single-junction solar cell design. To ensure fast progress, strategies including testing on the interface level before the cell level, conducting simulation and experiment simultaneously, as well as optimising the tandem efficiency in parallel with improving the efficiency for each subcell in parallel will help.

Stability testing of the solar cell under various aging condition is a time-consuming process. To plan the measurement early as well as set up systems for high throughput measurement will be helpful to make fast progress.

Products, patents & publications

This project has produced Si/perovskite tandem devices with simplified structure, high efficiency, and improved stability.

The team is working on publishing the key findings in the world-renowned journals and conferences.

Additional benefits

This project is supporting one PhD student to work on the project, who was awarded Taiwan-ANU PhD scholarship.

The project is supporting 5 early career researchers at the ANU and 1 early career researcher at UoM to work on different aspects of the tandem technology.

Next steps

This project has so far been successful in helping to achieve high efficiency and improved stability with simplified Si/perovskite tandem structures, which is essential for the commercialization of the technology. There are still a number of remaining challenges.

The next stage of the project will focus on further optimising the optical management of the tandem cells as well as refinement and control of each fabrication process for both subcells to push the tandem efficiency higher. The stability testing will be continued, in parallel with modifications to the perovskite and contact materials and structures to improve stability where required. Cost analysis will be continued to understand the effect of the material and process modification on the tandem cost, as well as assessing their cost-effectiveness with comparison to the market-dominating PV technology.

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