The Australian National University: Perovskite modules that are stable under real-world conditions, 2020/RND008

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Project Details

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Executive Summary

The aim of this project was to develop perovskite solar modules that are stable under partial shading conditions.

Solar cells based on perovskite materials have the potential to further reduce the cost of solar electricity, due to their many attractive properties. They have received intense interest from researchers and manufacturers alike, and several companies are now seeking to commercialise this technology. However, solar cells must be able to operate for at least 25 years while exposed to harsh environmental conditions, and must be demonstrated to be sufficiently stable before they can be deployed. One condition often encountered in practice is that of partial shading, where parts of a solar module – which consists of many individual cells connected together – is partially shaded, as a result of shadows from nearby objects, or leaves or dirt on the module. Partial shading can reduce the electrical current generated in some cells below the level of the current in neighbouring cells to which they are connected. This current mismatch can result in local heating and in the build-up of large voltages, both of which can damage individual cells or the entire module. Perovskite cells appear to be particularly susceptible to this degradation mechanism.

We demonstrated perovskite cells that are able to withstand partial shading for extended periods of time and developed initial guidelines for the design of shading-tolerant cells.

Project Overview

Project summary

We have worked closely with our research partner École Polytechnique Fédérale de Lausanne (EPFL), Switzerland to develop a deeper understanding of the mechanisms responsible for the degradation of perovskite solar cells when exposed to ‘reverse bias’, a condition that occurs when individual cells in a solar modules are partially shaded. Through this improved understanding, we were able to develop reverse-bias tolerant perovskite cells. In addition, we discovered that perovskite cells can display slow or fast ‘recovery’ behaviour, where the power output of the cell is temporarily reduced following reverse bias, even though the cell is not damaged.

Through our investigations, we were able to produce a set of design guidelines for the fabrication of perovskite cells that are not only partial shading tolerant but that also recover quickly following partial shading, to minimise the loss of power generation from the module.

Project scope

Perovskite cells and modules are considered a very promising technology to reduce the cost of solar electricity. However, to move towards commercial viability, it is necessary to demonstrate that these modules are sufficiently stable under the full range of environmental conditions they will be exposed to during operation, including elevated temperatures, large temperature swings, strong illumination, humidity and partial shading. Partial shading can reduce the electrical current generated in some cells below the level of the current in neighbouring cells to which they are connected. This current mismatch can result in local heating and in the build-up of large voltages, both of which can damage individual cells or the entire module. Perovskite cells appear to be particularly susceptible to this degradation mechanism.

At the commencement of this project, partial shading – and the strong ‘reverse bias’ voltages it can lead to in perovskite cells, had received little attention from the research community, despite its ubiquitous nature in the real world. Several research papers had reported some initial results which generally shows that perovskite cells were easily damaged by reverse bias. However, many of the degradation mechanisms were not well understood, and there was no clear pathway to address this problem and design reverse bias-tolerant cells. The goal of this project was to significantly improve our understanding of what happens in a perovskite solar cell under reverse bias, and to use this understanding to design and demonstrate reverse-bias tolerant cells.

Outcomes

This project was led by researchers at the Australian National University (ANU), in collaboration with the École Polytechnique Fédérale de Lausanne (EPFL), Switzerland. The focus and findings of the two groups were highly complementary. At EPFL, the team investigated the factors that contribute to destructive reverse bias behaviour via so-called “hot spots”, which are localized regions where high current appears to flow in the cells, causing these regions to heat up. Analysis of reverse-bias degraded devices showed that contaminants (such as dust particles) were often responsible to the development of hot-spots. This suggests that reverse bias damage is not inevitable, and that good process control to minimise contamination could lead to highly stable perovskite cells in real-world operation.

At ANU, we demonstrated that carefully designed perovskite cells could indeed withstand stressful reverse bias exposure. But our analyses delivered a surprising finding: that perovskite cells, even when they are not damaged by reverse bias exposure, could still take a long time to return to their normal operating characteristics following reverse bias. This means that, following reverse bias, some perovskite cells deliver little output power and also reduce the output power of adjacent cells. Over a period of minutes to hours, the output gradually returns to normal, but in the meantime electrical energy generation is significantly reduced. Event short exposure to non-destructive reverse bias, measuring in minutes, can require periods extending to hours to fully recover. An in-depth theoretical and experimental exploration provided explanations for this slow response, and we identified and demonstrated cell structures which combine both near-instantaneous recovery from reverse bias in addition to reverse bias stability.

This project has thus demonstrated that reverse bias poses twin problems for perovskite solar cells: structural stability needed to ensure long module lifetimes and fast recovery of power output needed to ensure maximal energy yield. It has also proposed, and demonstrated, solutions to these issues. The findings have been disseminated via three journal articles, and three conference presentations. The results have already stimulated interested from industry partners, in Australia and internationally.

Transferability

The technical challenges that the project sought to address are critical to the commercial success of perovskite solar technology and its promise to further reduce the cost of solar-generated electricity. Lower electricity costs can help accelerate the transition to a zero-carbon future and reduce household and business energy bills.

To maximise the impact of the project outcomes, the results are being disseminated as widely as possible through prominent scientific journals and conferences. A final journal paper is currently being prepared, which will provide a comprehensive review of the project findings. We specifically target conferences where there is a large industry presence, to raise awareness of our results with companies involved in the commercial development of perovskite technology.

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

Conclusion and next steps

This project has provided a sound theoretical basis for understanding the behaviour and degradation of perovskite solar cells under reverse bias and led to the creation of a set of design guidelines for the fabrication of reverse bias-tolerant cells. However, further work will be needed to expand on these guidelines and refine the understanding of reverse-bias behaviour.

Ultimately, the benefit of the project will be to facilitate and accelerate the development of commercially produced perovskite solar cells and modules 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 are 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 electricity demand that will arise from both a switch away from coal and gas, and an electrification of the transport system, such a cost reduction will translate to a significant economic benefit.