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ARENA

Eliminating material quality barriers to low cost, very high efficiency solar cells and modules – RND009.

Project results and lessons learnt

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Executive Summary

This project aimed to develop advanced tools and methods to detect and quantify the root cause of efficiency losses during the production of silicon PV modules. The project targeted loss mechanisms all along the value chain, from the initial silicon ingots, to wafers and cells, and also at the module level. In order to achieve these aims, we brought together a team of complementary experts from leading research institutions (including ANU, UNSW, and Fraunhofer ISE) and industry (such as BT Imaging and Sinton Instruments). This led to the development of powerful new techniques for detecting and studying defects, and for developing effective strategies to eliminate them or reduce their impact. Two of these new techniques, based on luminescence imaging of ingots and modules, are already being commercialised in Australia by project partner BT Imaging. Several others are in earlier stages of commercialisation. As these new methods are adopted in R&D labs in industry and institutes, they will help drive further increases in module efficiency and reliability, resulting in lower costs of solar electricity for end users.

Project Overview

Project summary

This project developed a range of new methods and tools for identifying, quantifying, and eliminating defects in silicon photovoltaics, ranging across the entire value chain, from the silicon ingots, to wafers, cells and modules. The implementation of these new techniques in research laboratories and in factories around the world will help to accelerate the development of silicon PV technology, resulting in increased module efficiency and reliability, and lower costs for consumers.

Project scope

Silicon solar modules are subject to a wide range of power loss mechanisms that in principle can be avoided or reduced. These loss mechanisms range from defects and impurities in the silicon ingots themselves, to imperfect solar cell fabrication processes, to electrical and optical losses during encapsulation in a module. This project aimed to develop advanced characterisation methods and tools to identify these losses, and to quantify their impact. This allows us to focus on the most important loss mechanisms, and through an improved understanding of their properties, to then develop effective strategies and methods to reduce or eliminate them. The project involved a range of industry and institutional partners that brought together world-leading expertise in the development of such advanced characterisation methods and tools, and provided a clear pathway to implementing them in industry.

Outcomes

The project has been very successful in developing advanced methods and tools for analysing loss mechanisms in silicon PV technology. Through collaboration with industry partners BT Imaging and Sinton Instruments, we have developed several new technologies for screening silicon ingots and modules. Two of these have already been commercialised by BT Imaging, based on a novel line-scanning photoluminescence imaging technique developed in this project.

The first of these methods is a new tool for measuring the electronic quality of silicon ingots, and several of these tools are already in industrial R&D laboratories around the world. The second is a novel module screening tool that allows deeper insights into module loss mechanisms than existing methods. This new tool is now being trialled by BT Imaging with their commercial partners, and is likely to be released for sale in early 2019. We have also developed improved photoconductance ingot methods, together with Sinton Instruments, and these are likely to be implemented in future versions of their popular Boule Conductance Tester, which is used in many laboratories around the world.

Further over the horizon, this project has also led to innovative methods for monitoring modules in the field via their infrared emission, using daylight as the source of illumination. These technologies are still at the proof-of-concept stage, but have enormous potential for commercialisation in the ever-growing market for PV system quality control and monitoring.

The project has also led to many advanced methods for measuring and imaging important defects in silicon wafers and solar cells. These outcomes are more fundamental in nature, and have led to over 100 publications in journals and conferences. These new insights and techniques are beginning to be adopted by R&D teams around the world, helping to accelerate the pace of innovation in the field.

Another important, but less tangible, outcome of this project has been its value as a catalyst for driving collaboration between the project partners. A deep and broad partnership has now developed between the ANU and UNSW teams and our other project partners, which will lead to ongoing innovation and success well into the future. This is demonstrated by the annual project workshops where we have had around 30 attendees from ANU and UNSW working together on shared project goals.

Transferability

Many of the metrology techniques developed in this project have potential to be applied to PV technologies other than crystalline silicon, especially thin-film technologies. This includes commercial thin film modules such as CdTe and CIGS, but also emerging PV technologies such as perovskites and silicon tandem devices.

Conclusion and next steps

The project has been very successful in developing new metrology methods for silicon ingots, wafers cells and modules, some of which have already advanced to full commercialisation, and with several others at earlier stages of commercialisation. Building on this success, a follow-on ARENA-funded project commenced in December 2017, which will allow us to further develop some of the most exciting outcomes from this first project, and also to start developing new ideas that at this stage are conceptual only, but with enormous potential. In this new project we have retained several of our previous key partners, but with some new additions, most notably Jinko Solar, currently the world's largest integrated PV manufacturer, who will provide an industrial platform for trialling the most promising ideas from our project teams. We have also brought on board two thin-film module suppliers, MiaSole and Tesla (formerly Solar Century), to allow us to explore the transfer of some of our advanced techniques developed on silicon modules to CdTe and CIGS modules.

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Lessons Learnt

Lessons Learnt Report: Creating a robust project consortium

Project Name: *RND009 Eliminating material quality barriers to low cost, very high efficiency solar cells and modules*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	ACT and NSW

Key learning

This project aimed to develop and demonstrate new solar cell and module metrology technologies. Our aim was to achieve this by forming a consortium of industry partners across the value chain. Our original project consortium included two ingot manufacturers (Apollon Solar and SunEdison), university/institute research teams (ANU, UNSW, Fraunhofer ISE, ISFH Germany, and the University of Warwick), and two industry partners specialising in metrology tools (BT Imaging and Sinton Instruments). Including multiple project partners proved to be beneficial, as it allowed us to bring together a wide range of expertise and interests, and to reduce our reliance on any single partner. The latter point proved important when one of our project partners, SunEdison, went into liquidation. Other project partners were able to fill the gap left by the loss of SunEdison. After the project commenced, we also found it was helpful to include a large integrated ingot, wafer, cell and module manufacturer, in this case Trina Solar, based in China. This additional partner allowed us to conduct large experiments in which a wide range of ingots and wafers were tested at multiple stages as they were processed into large area solar cells. This enabled us to better demonstrate the value of the metrology tools, based on very large sample sets achieved in an industrial setting, which in turn helped to reduce the barrier to implementing these new technologies in industry.

Implications for future projects

Given the clear benefits of involving an integrated PV manufacturer in the project, we would aim to include such a partner from the beginning for future projects. We would also retain multiple partners with complementary expertise to provide a robust consortium that is not too heavily reliant on a single partner.

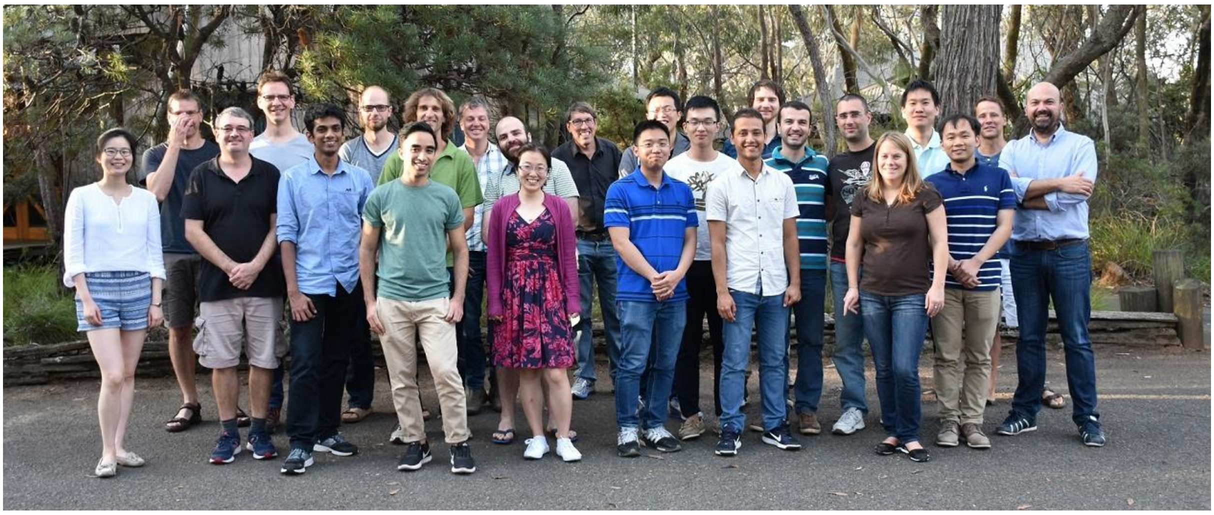
Lessons Learnt Report: Promoting effective collaboration between project partners

Project Name: *RND009 Eliminating material quality barriers to low cost, very high efficiency solar cells and modules*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	ACT and NSW

Key learning

This project brought together multiple partners with complementary expertise. An important aspect of the success of the project was finding ways to promote effective collaboration between the project teams, especially to two main teams at ANU and UNSW. In addition to regular contact between the team leaders and individual group members, this was formally achieved by running 6 monthly project meetings, alternately hosted by ANU and UNSW. Initially, these project meetings were 1 day workshops, but we soon found that this was not sufficient to cover all of the potential topics of collaboration in enough depth. These workshops then evolved into 3 day retreats, hosted away from campus, in order to create a truly collaborative environment with minimal distractions. These workshops have been extremely effective in driving close collaboration and developing trustful relationships between the project teams. They typically included 25-30 participants from ANU, UNSW, and other project partners including BT Imaging and Sinton Instruments. They featured detailed technical presentations from all team members, and open-ended discussion sessions where frank exchanges of ideas and feedback were encouraged. The photograph below shows participants at the project workshop in November 2016 in the Blue Mountains.



Implications for future projects

The workshops developed under this project have become well known and highly valued by the research teams at ANU and UNSW, and they will continue under our new follow-on ARENA project.

We also intend to expand them to include other interested groups from ANU and UNSW in order to drive broader collaboration between our institutes, and we hope that they will become an ongoing event that survives well beyond our current ARENA projects.

The collaboration developed under this project between ANU, UNSW and Fraunhofer ISE has led directly to the establishment of a German government funded Collaborative Cluster for Photovoltaics (CCPV), which funds exchange of research students and staff from Fraunhofer ISE to ANU and UNSW, and runs from 2017-2020. This further demonstrates the ability of projects such as this to seed effective collaborations that persist beyond the end of the initial project.

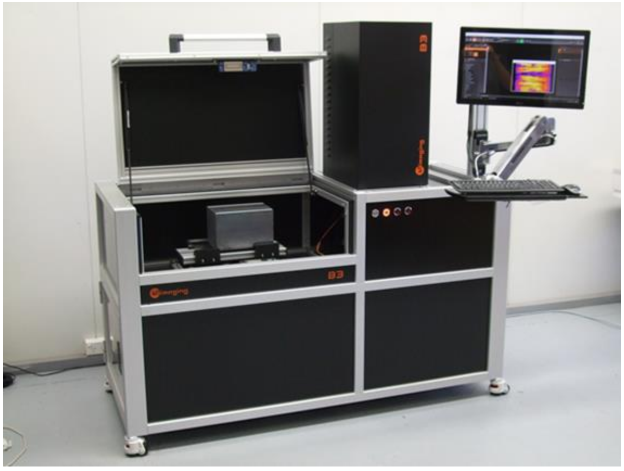
Lessons Learnt Report: Effective methods of commercialising project outcomes

Project Name: *RND009 Eliminating material quality barriers to low cost, very high efficiency solar cells and modules*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	ACT and NSW

Key learning

This project led to the successful commercialisation of two Photoluminescence-based metrology tools, with several more promising techniques that we hope will be commercialised over the next 1-2 years. The key to these positive outcomes was the direct involvement of the commercial partner in the project from the very beginning, and also the involvement of other partners that enabled these tools to be tested in a production environment. The latter was especially important – it provided benefits to the tool developer (BT Imaging), as it allowed their new tools to be demonstrated at scale, and also benefited the integrated manufacturer (Trina Solar), as it gave them an early insight into the benefits of such advanced metrology tools for improving production. The images below show the new photoluminescence-based ingot (LIS-B3 on the left) and module (M1 on the right) testing tools developed through this project in conjunction with BT Imaging.



Implications for future projects

The involvement of a group of complementary project partners that enable the testing and demonstration of project outcomes at scale and in a production environment is extremely helpful in driving the rapid commercialisation of project IP. In future projects we aim to include such complementary project partners, taking care to avoid any potential direct conflicts of commercial interests.

Lessons Learnt Report: Leaving space to explore new developments in R&D projects

Project Name: *RND009 Eliminating material quality barriers to low cost, very high efficiency solar cells and modules*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	ACT and NSW

Key learning

The original Project Plan for this project was very detailed and attempted to foresee our research activities 3 years into the future. In practice, we found that some of the most exciting and potentially valuable ideas (for example the specific methods used for daylight photoluminescence imaging of modules) occurred during the execution of the project, and they could not have reasonably been anticipated beforehand. This is indeed the nature of cutting edge research. Our key learning in this regard is to ensure that a project is scoped with enough flexibility to enable these unexpected opportunities to be fully exploited. This can be done by ensuring that project goals and tasks are not defined too narrowly, so that they can encompass unforeseen opportunities without compromising the achievement of the primary project goals.

Implications for future projects

When scoping a new project, the right balance needs to be struck between setting out a clear and well-defined project agenda, whilst also leaving enough flexibility to enable unforeseen opportunities to be exploited. This is especially the case for cutting edge R&D projects lasting several years, given the rapid pace of PV technology development.