2017/RND017 – Driving increased efficiency and reliability in silicon photovoltaics – from ingots to modules

Final Public Dissemination Report

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Executive Summary

This project has developed new techniques and tools to identify the most important loss and degradation mechanisms in industrial silicon photovoltaic technology, extending along the value chain from silicon ingots, wafers, cells and through to the final modules. A focus of the project has been the development of rapid and accurate inspection tools based on luminescence, in conjunction with BT Imaging, an Australian metrology company that services the global PV industry. A key outcome here has been the development of innovative new methods for rapid module inspection and fault detection in-the-field, without the need for electrical isolation. We have also worked closely with Jinko Solar, one of the largest manufacturers of PV modules worldwide, to develop and apply new methods for improving their ingots, wafers and cells, and to demonstrate high efficiency solar cells on these materials with industrially-compatible processing. The project also supported collaboration with Fraunhofer ISE in Germany and the National Renewable Energy Laboratory in the USA, to explore new possibilities for improved characterisation of silicon materials and solar cells. The project has resulted in several exciting new methods for wafer, cell and module inspection, the most promising of which will continue to be progressed towards full commercialisation after completion of the project.

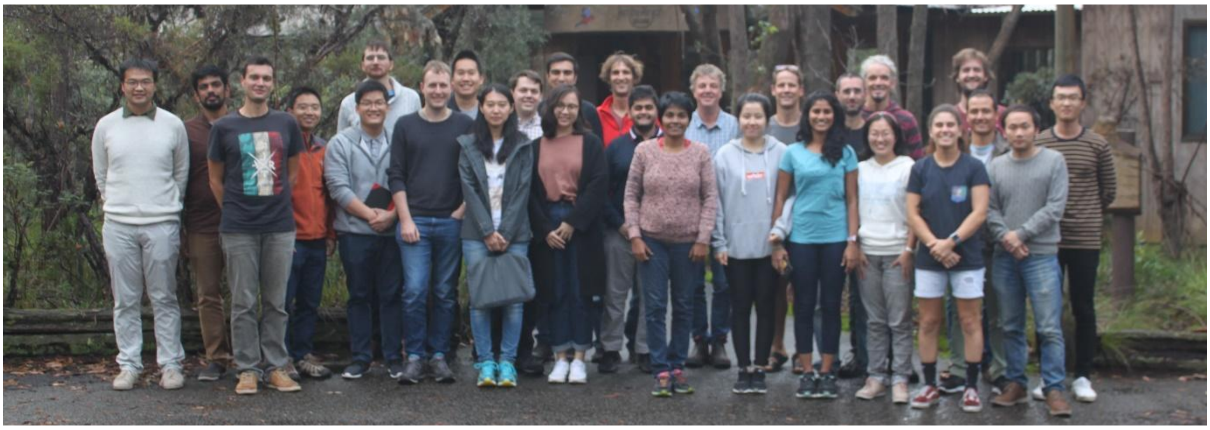
Project Overview

Project scope

This project has delivered a range of new technologies and techniques focussed on silicon ingots, wafers, cells and modules. These new tools will help to find practical solutions to these loss mechanisms, leading to higher efficiency solar cells and modules in mass production, and therefore lower costs for solar electricity for consumers. The project is founded on a long-standing and very productive collaboration between the silicon characterisation groups at ANU and UNSW, who together have world-leading expertise in the development of such methods. This project has provided a platform for them to further extend their collaboration to include other world-leading institutional partners such as Fh-ISE and NREL, and industry partners including Jinko Solar, BT Imaging and Sinton Instruments. These partnerships provide a clear pathway for demonstrating promising technologies at scale in industrial settings, accelerating their commercialisation.

Outcomes

The project has been very successful in promoting collaboration between the project teams and partners. For example, the ANU and UNSW teams held annual project workshops in which we presented and shared our ideas and results, as shown in the image below, taken from our workshop in the Blue Mountains in 2019. This collaboration resulted in many joint publications between the project partners. Overall, the project supported over 80 journal and 70 conference publications. These partnerships will continue well beyond the end of this project, and will seed new ideas for future projects.



As a result of these strong partnerships, the project has delivered many successful outcomes in terms of technology development. The most significant of these are described below in terms of the four project Work-Packages.

Work-Package 1 – Silicon ingots

New ingot metrology methods based on photoconductance and photoluminescence measurements have been developed and trialled with industry partners. Meaningful correlations have been identified between ingot data and the final cell performance for large batches of industrial high efficiency cells fabricated in a pilot line at Jinko Solar. These correlations are proving to be useful in optimising both ingot growth and cell fabrication processes.

Work-Package 2 – Silicon wafers

Performance limiting defects in silicon wafers were identified using a suite of advanced opto-electrical characterisation techniques. Novel micro-PL approaches were developed and applied to study bulk wafer degradation mechanisms under very high injection levels, and to understand the properties of recombination-active oxygen-related defects in silicon wafers. Advanced wafer diagnostics based on PL imaging with spatially non-uniform illumination were also developed and demonstrated. New insights and methods for passivating defects using hydrogen and fluorine were also developed in this project.

Work-Package 3 - Solar cells

New methods for removing unwanted metallic impurities from silicon wafers based on doped poly-silicon films were discovered and explained. The use of non-contact PL data as a faster alternative to inline IV data was evaluated in a high-throughput industrial settings. A range of powerful new methods for analysing diffused regions, bulk defects and deposited layers in silicon solar cells were also developed. Key approaches include high spatial resolution spectrally-resolved micro-PL mapping for dopant and dislocation mapping in cells and pre-cursors, the use of time-modulated multi-wavelength excitation to allow rapid contactless quantum efficiency measurements, the development of non-linear 2-photon absorption processes to allow depth-resolved PL analysis of devices, and the application of spatially non-uniform illumination with PL imaging to study emitter and series resistance losses.

Work-Package 4 – Modules

Methods for assessing light- and temperature-induced degradation in silicon modules using high intensity local illumination and PL imaging were developed, enabling fast and accurate determination of a module's current degradation state, and to predict further degradation. PL methods for in-field outdoor testing of modules without the requirement for electrical isolation were also developed, based on time-modulated partial illumination of modules and high resolution filters. The application of machine learning to identify defects types and failure modes was also explored, and PL-based module inspection techniques developed for crystalline silicon modules were extended to CIGS and CdTe thin-film modules.

Several of the techniques developed in this project have the potential for a very large impact in industry, such as contactless daylight PL testing of modules, and contactless PL testing of cells in production to replace the traditional IV test. We have a clear pathway to commercialising these technologies through project partner BT Imaging. Other more complex and specialised characterisation techniques, such as spectrally-resolved PL methods, may not be suitable for use in commercial tools. Nevertheless, publishing such methods in the scientific literature ensures that other R&D groups can apply them for the further development of PV technologies.

Conclusions and next steps

This project has led to the development of many new methods for loss and fault detection in silicon solar cells and modules. The most promising of these new methods will be further developed towards commercialisation after the project has finished. The project has demonstrated the value of strong collaborations between research groups in universities and industry, providing a clear pathway for the trialling of promising methods in industrial settings at scale.