Australian National University

# Public Dissemination Report

# Next Generation Industrial Bifacial Silicon Solar Cell (2017/RND015)

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Lead organisation: The Australian National University

Project partners: Wavelabs Solar Metrology Systems GmbH

Project commencement: 5th December 2017

Project completion: 1st September 2021

This project received funding from the Australian Renewable Energy Agency (ARENA) as part of ARENA's Advancing Renewables Program.

# Executive Summary

The bifacial cells are among the fastest growing PV technology due to the potential for high efficiency, lowering the cost of production and the ability to collect sunlight from both surfaces. This technology is specifically beneficial in Australia, where installations with large available land areas, where module installation can be optimised to take advantage of ground reflected light. With continual technological innovation, the technology has the capacity to fill over 70% of the PV market share within the next decade.

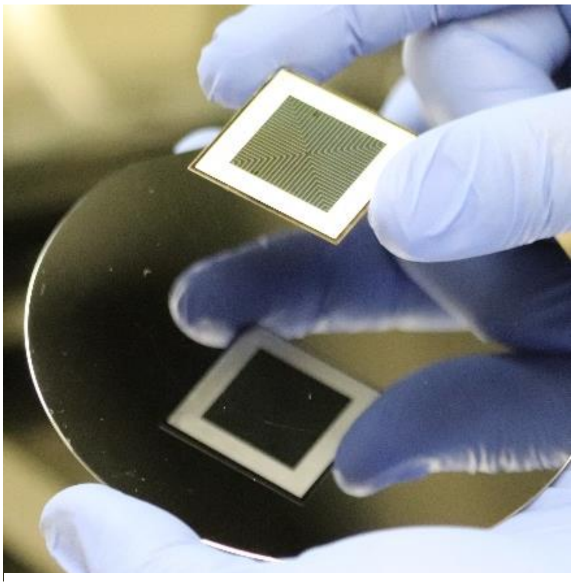

Figure 1: ANU developed 24.3% bifacial device with 96.3% bifaciality

Towards this goal, the ARENA funded 'Next Generation Industrial Bifacial Silicon Solar Cell' was established, led by a world class research team at the Australian National University for the development of advanced fabrication technologies, to deliver excellent research output and simultaneously combining locally developed promising technologies into industry-ready solutions.

The key technological highlight is the development and application of multiple advanced fabrication technologies including laser doping, tunnel-oxide-polysilicon, and Oxide-Nitride-Oxide multi-functional film. Development of these technologies led towards successful demonstrated in a record efficiency achieved using 'laser doping' technology on a 24.3% bifacial device with 96.3% bifacial factor. Furthermore, collaboration with its industry partner led towards development and advancement of polysilicon contact based bifacial solar cells.

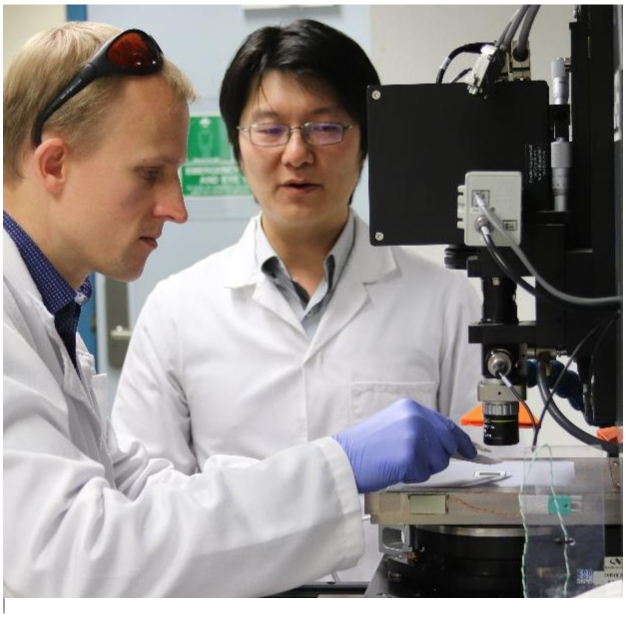

Figure 2: Chief investigators Dr. Fong (right) and Dr. Ernst (left) in action during development of the laser-doped solar cells

The developed enabling technologies from this project remains as valuable building blocks towards other PV technology innovation within Australia. Importantly, the research scientists and their experience from this project will continue to contribute towards future projects and technology innovation in various fields of research in Australia and internationally.

# Project Goals

This project set out to develop enabling advanced fabrication technologies to develop a new generation of bifacial silicon solar cells. This is achieved by identifying combination of promising technologies with synergistic properties into technology-packages which provides cost effective and high-performance devices. Technology development and device demonstration were carried out in collaboration with industry partners to ensure pathway towards industry adoption.

# Outcomes

This project successfully developed and demonstrated multiple bifacial solar cell technology packages. The results are presented in Table 1, with champion devices achieving between 23.2% to 24.3% front surface efficiency with ~95% or greater bifacial factor.

Table 1: Cell efficiency and I-V parameters of champion devices from each technology package

| Batch | Side | Efficiency (%) | $V_{OC}$ (mV) | $J_{SC}$ (mA cm$^{-2}$) | FF | $R_S$ (Ω cm$^2$) | Bifacial Factor |
|---|---|---|---|---|---|---|---|
| **TP1 (n-type cell)** | Front | 23.7 | 701 | 41.1 | 82.3 | 0.33 | 98.7% |
| | Rear | 23.3 | 702 | 40.2 | 82.4 | 0.33 | |
| **TP2 (p-type cell)** | Front | 23.2 | 689 | 41.9 | 80.3 | 0.42 | 94.5% |
| | Rear | 21.9 | 688 | 39.4 | 80.7 | 0.37 | |
| **TP3 (laser doping)** | Front | 24.3 | 702 | 41.6 | 82.8 | 0.35 | 96.3% |
| | Rear | 23.4 | 702 | 40.2 | 82.9 | 0.35 | |

* All measurements are independently measurement at CSIRO Lab, rounded to 1 decimal.

*Technology-package 1 and 2, (n-type and p-type Si cells)* demonstrates the design of bifacial cells incorporating ANU developed Oxide-Nitride-Oxide multi-functional film which acts as an anti-reflective coating while providing excellent surface passivation to both the front and rear textured surfaces. The near-identical fabrication flow for both n-type and p-type provides a comparison between the base wafer performance, demonstrating the impact of higher bulk lifetime in n-type devices to overall performance. The developed technologies form the baseline for further advancement towards incorporation of laser-doping, as is demonstrated in *technology-package 3*.

This project demonstrated the highest efficiency in devices incorporating ANU developed laser technology. The laser process was used for formation of localised selective contacts to reduce the number of high-temperature processing steps while achieving low contact recombination and contact resistivity. The device structure utilising laser-doping at the front contacts is shown in Figure 3. The developed device design utilises phosphosilicate glass as a dopant source, reducing the process steps required to achieve both light and heavy diffusion across the front surface. This technology was the basis of the laboratory bifacial solar cell measuring 24.3% front efficiency, with a bifacial factor of 96.3%. The front efficiency value itself is a record efficiency for devices incorporating laser doping technology.

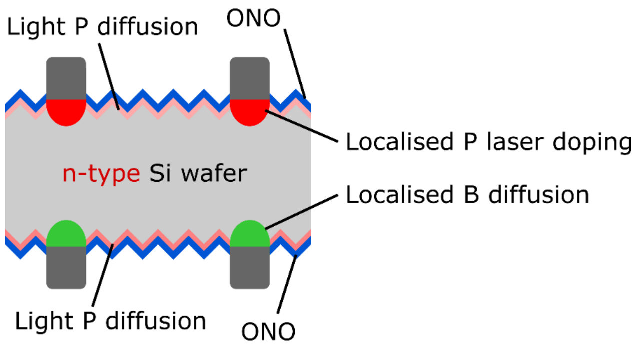

Figure 3: Anatomy of ANU laser doped bifacial cell

3D device simulation of laboratory and industrial bifacial cells were developed as part of the project activity. The 3D mesh of the simulation is illustrated in Figure 4. developed using Quokka3, which is an ANU developed tool incorporating optical and electrical simulation of Si solar cells, inclusive of various features such as shading losses, edge recombination, and conductive contact layers, to achieve a detailed and accurate simulation model of the device. The developed simulation model provides a snapshot of key design deficiencies and identifies areas of improvement for each prototype design. The ability to perform virtual experiments prior to laboratory fabrication of these devices greatly accelerates the rate of technology development.

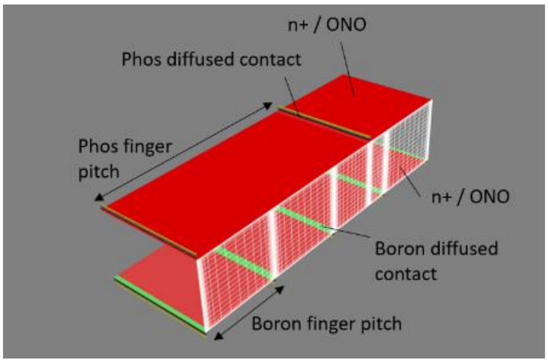

Figure 4: Bifacial solar cell 3D simulation mesh

# Lessons

The key technical lesson learnt is to highlight the importance of long-term research and development strategy adopted by ARENA the funding agencies which has led towards the success of this project. This project benefited from having a baseline of excellent research scientists within a well-established and well-equipped laboratory to handle the demands of the project. The available expertise and equipment additionally bring together home-grown technologies developed within Australia through previous ARENA, ACAP, ARC and other past projects, as building blocks towards new technology designs such as the bifacial cells developed in this project. This highlights the importance of research continuity and home-grown technology development for present and future Australian based R&D projects.

The ANU laboratory had numerous interruptions over the course of this project due to bushfire smoke, hailstorm damage, and multiple COVID-19 related laboratory closures. This project re-routed activities and leveraging against a broad network of collaborators and industry partners to enable continuation of research activities for calibration and fabrication of samples in other laboratories within Australia and internationally. Establishment of an emergency laboratory shut-down plan is essential to soften the impact of major and lengthy laboratory access interruptions.

# Ancillary Benefit

This project employed up to four Research Fellows, and one Research Officer at ANU. Among the research fellows, two went on to receive ACAP funded Research Fellowships to further development of specific technologies developed stemming from discoveries during the course of this project.

The developed polysilicon and laser processes are fully owned by creators in this project, and can therefore be applied as a building block in the development of other promising technologies such as Hybrid IBC solar cells, and Triple-Junction Si-Perovskite Tandem solar cells with a broad network of research and industry collaborators such as University of Melbourne, Jinko Solar, University of Sydney, UNSW, Macquarie University.

# Publications

Activities from this project contributed directly and indirectly to a significant number of journal and conference publication as well as a highly cited media release article.

**Media Release:**

"ANU scientists set new record with bifacial solar cells", https://www.anu.edu.au/news/all-news/anu-scientists-set-new-record-with-bifacial-solar-cells.

**Journal papers:**

- W. Liang, T. Kho, J. Tong, P. Narangari, S. Armand, M. Ernst, D. Walter, S. Surve, M. Stocks, A. Blakers, and K. C. Fong, "Highly reproducible c-Si texturing by metal-free TMAH etchant and monoTEX agent," Solar Energy Materials and Solar Cells 222, 110909 (2021), DOI: https://doi.org/10.1016/j.solmat.2020.110909 .

- L. E. Black*, M. Ernst*, R. Theeuwes, J. Melskens, D. Macdonald, and W.M.M. Kessels, "Self-aligned local contact opening and n+ diffusion by single-step laser doping from POx/Al2O3 passivation stacks," Solar Energy Materials and Solar Cells 217, 110717 (2020), DOI: https://doi.org/10.1016/j.solmat.2020.110717 .

- W. Liang, J. Tong, P. Narangari, S. Armand, T. C. Kho, M. Ernst, D. Walter, S. R. Surve, K. R. McIntosh, M. Stocks, K. J. Weber, A. Blakers, and K. C. Fong, "Impact of Al Doping on Surface Passivation of TiOx on Si," IEEE J. Photovoltaics, 1–5 (2020). https://doi.org/10.1109/JPHOTOV.2020.2982169 .

- M. Ernst, E. Franklin, A. Fell, K. Fong, D. Walter, E.-C. Wang, T. Kho, and A. Blakers, "Fabrication of a 22.8% Efficient Back Contact Solar Cell With Localized Laser-Doping," phys. stat. sol. (a) 31, 1700318, 2017, https://dx.doi.org/10.1002/pssa.201700318 .

- M. Ernst, A. Fell, E. Franklin, and K. Weber, "Characterization of Recombination Properties and Contact Resistivity of Laser-Processed Localized Contacts from Doped Silicon Nanoparticle Ink and Spin-On Dopants," IEEE J. Photovoltaics **7** (2), 471–478, 2017, https://dx.doi.org/10.1109/JPHOTOV.2017.2655028 .

**Conference Presentation and Papers:**

- M. Ernst, Jonas D. Huyeng, K. C. Fong, D. Walter, A. Blakers, "Unravelling the Origins of Contact Recombination for Localized Laser-Doped Contacts," *WCPEC-7*, 2018, http://dx.doi.org/10.1109/PVSC.2018.8547383 .

- K. C. Fong, T. C. Kho, W. Liang, T. K. Chong, M. Ernst, D. Walter, M. Stocks, E. Franklin, K. McIntosh, A. Blakers, "Excellent Phosphorus Doped LPCVD Polysilicon Passivated Contacts via Low Pressure Oxidation," *WCPEC-7*, 2018, http://dx.doi.org/10.1109/PVSC.2018.8547448 . Download presentation.

- Jonas D. Huyeng, M. Ernst, K. C. Fong, D. Walter, A. Blakers, "Implications of Laser-Doping Parameters and Contact Opening Size on Contact Resistivity," *WCPEC-7*, 2018, http://dx.doi.org/10.1109/PVSC.2018.8547209 .

- M. Ernst, E. Franklin, T. K. Chong, K. C. Fong, D. Walter, E.-C. Wang, T. Kho, and A. Blakers, "High Efficiency Locally Laser Doped IBC Solar Cells," in 33rd European Photovoltaic Solar Energy Conference and Exhibition (2017), 2BO.4.5, pp. 358–361, http://dx.doi.org/10.4229/EUPVSEC20172017-2BO.4.5 .

- W.S. Liang, K. Fong, J. Tong, M. Ernst, D. Walter, P. Narangari, S. Armand, S. Surve, T. Kho, K. McIntosh, M. Stocks, K. Weber, A. Blakers, "Fabrication of Bifacial Si Solar Cell with Very High Bifacial

Factor," presented at the 29th International Conference on Photovoltaic Science and Engineering (PVSEC-29), 7WeO1-2.

- K.C. Fong, W.S. Liang, J. Tong, M. Ernst, D. Walter, P. Narangari, S. Surve, T. Kho, K. McIntosh, M. Stocks, K. Weber, A. Blakers, "Fabrication and Comparison of n-type and p-type Bifacial to Mono-facial Si Solar Cells," presented at the 29th International Conference on Photovoltaic Science and Engineering (PVSEC-29), 7WeO1-4.

- J. Tong, K.C. Fong, W.S. Liang, M. Ernst, D. Walter, P. Narangari, S. Armand, S. Surve, T. Kho, K. McIntosh, M. Stocks, A. Blakers, "Investigation of Carrier Selectivity and Thermal Stability of Transition Metal Oxides with Pre-grown Thin SiOx for Si Solar Cells," presented at the 29th International Conference on Photovoltaic Science and Engineering (PVSEC-29), 7MoP.22/1156.

- J. Tong, W. Liang, M. Ernst, D. Walter, M. Stocks, A. Blakers, K. C. Fong, K. McIntosh, "Impact of Interfacial SiOx on Carrier Selectivity and Thermal Stability of Transition Metal Oxides," in 36th European Photovoltaic Solar Energy Conference and Exhibition (2019), 2DV.1.49 (download presentation).

- W.S. Liang, K. C. Fong, J. Tong, P. Narangari, S. Armand, T. Kho, M. Ernst, D. Walter, S. Surve, M. Stocks, K. McIntosh, K. Weber, A. Blakers, "Aluminium Doped TiOx (TiOx:Al): Improving Surface Passivation on Si by Supressing Crystal Phase Formation,"in 36th European Photovoltaic Solar Energy Conference and Exhibition (2019), 2DV.1.17 (download presentation).

- M. Ernst, J. D. Huyeng, D. Walter, K. C. Fong, and A. Blakers, “Implications of Local Contact Size on Contact Resistivity and Recombination,” in Asia Pacific Solar Research Conference 2018 (Sydney, 2018).

- W. Liang, K. C. Fong, P. Narangari, M. Ernst, S. Armand, J. Tong, S. Surve, D. Walter, M. Stocks, K. McIntosh, and A. Blakers, “TMAH etchant and monoTEX agent induced highly reproducible and non-metal contamination c-Si texturing,” in Asia Pacific Solar Research Conference 2018 (Sydney, 2018).

- K. C. Fong, T. C. Kho, W. Liang, M. Ernst, D. Walter, M. Stocks, K. McIntosh, and A. Blakers, “LPCVD doped polysilicon with in-situ thermal oxidation,” in Asia Pacific Solar Research Conference 2018 (Sydney, 2018).

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