

Elimination of LID with innovative new hydrogenation technology facilitates increased PERC cell efficiencies through the use of lower resistivity p-type Cz wafers

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INTRODUCTION

Silicon photovoltaics has always dominated commercial manufacturing, with p-type Cz and multi being the wafers of choice. However the light-induced degradation (LID) due to B-O defects has been a major problem for industrial p-type Cz wafers for decades. This has necessitated the use of more lightly doped wafers than would normally be considered optimal so as to reduce the B concentration and hence the B-O defect formation. This is particularly the case with PERC cells where the lower wafer doping concentration leads to increased lateral resistive losses and higher resistive losses in the vicinity of the rear point contacts. In this work, CEC Energy and UNSW Australia have been working together to exploit the use of atomic hydrogen to passivate defects, particularly B-O defects, within p-type Cz silicon solar cells. Innovative new technology has been developed to control the charge state of interstitial atomic hydrogen atoms within the silicon lattice, which in turn has facilitated improvements in both the diffusivity and reactivity of the hydrogen atoms.

Use of this innovative hydrogenation technology has demonstrated that by controlling the charge-state, hydrogen atoms can be used to passivate B-O defects and other recombination mechanisms within the silicon wafers, transforming the quality and stability of commercial grade p-type Cz silicon wafers, into the equivalent of the very best wafers used by the semiconductor industry that can cost as much as one hundred times more. This potentially enables the use of significantly lower cost wafers in PV manufacturing without performance loss and in fact has simultaneously demonstrated marked improvements in both efficiency and stability.

CEC Energy and UNSW in Australia have developed a prototype production hydrogenation tool that is suitable for demonstrating the hydrogenation technology on large area production solar cells. In particular, this prototype production tool enables the implementation of the hydrogenation technology to solve light-induced degradation in commercial-grade p-type Czochralski (Cz) wafers as well as appearing to also passivate many other forms of recombination potentially due to contamination and crystallographic imperfections.

This new prototype production tool was specifically used to investigate the impact of the innovative hydrogenation technology on the performance and stability of CEC silicon solar cells that are fabricated from low resistivity (0.5 ohm-cm) p-type Cz on normal PERC solar cell production lines. These solar cells after treatment were stable and no longer susceptible to light-induced degradation following the hydrogenation treatment.

In this work, PERC silicon solar cells using industrial grade 0.5 ohm-cm p-type Cz wafers were fabricated on

an existing standard PERC cell production line to the specifications of CEC Energy. These cells are 156-cm x 156-cm screen printed PERC silicon solar cells. Being fabricated from low resistivity commercial-grade p-type Cz silicon wafers, these CEC solar cells are subject to higher than normal levels of light induced degradation, with losses approaching 10% through only 48 hours of light-soaking at 78 mW/cm² and 40degC.

A total of 8 CEC solar cells were divided into two groups of 4 cells each (Group 1 and Group 2). The solar cells from these two groups were put through the following process:

- 1) Obtain PL images and IV characteristics of all the CEC solar cells;
- 2) Solar cells from Group 1 were set aside (no treatment) while the solar cells from Group 2 were treated in the prototype hydrogenation tool using appropriate illumination ramping, peak illumination of 20-suns, peak temperature of 280degC and rapid cooling;
- 3) Obtain PL images and IV characteristics of the Group 2 solar cells after hydrogenation treatment;
- 4) All the cells were subjected to a prolonged light soaking step performed at 40 deg C and 78 mW/cm² under halogen lamp illumination for 48 hours;
- 5) Obtain PL images and IV characteristics of the cells following the prolonged light soaking step.

RESULTS

The PL images and IV characteristics of the Group 1 solar cells show a marked and uniform decrease in performance following the light soaking due to Light Induced Degradation (LID).

Table 1: Summary of the IV data of Group 1 cells showing a marked and uniform decrease in performance following the light soaking due to the apparent formation of B-O defects. Light soaking was at 40 deg C under 78 mW/cm² halogen lamp illumination for 48 hours.

Label		As Received	After Light Soak
SR23	Efficiency (%) :	20.5	19.0
	Voc (mV):	667	641
	Jsc (mA/cm2):	39.3	38.3
	FF (%) :	78.1	77.2
	N:	1.18	1.51
SR33	Efficiency (%) :	20.4	18.87
	Voc (mV):	666	640
	Jsc (mA/cm2):	39.2	38.2
	FF (%) :	77.9	77.2
	N:	1.19	1.54
SR35	Efficiency (%) :	20.4	18.8
	Voc (mV):	666	638
	Jsc (mA/cm2):	39.3	38.1
	FF (%) :	78.1	77.5
	N:	1.20	1.49
SR37	Efficiency (%) :	20.4	18.9
	Voc (mV):	663	636
	Jsc (mA/cm2):	39.2	38.1
	FF (%) :	78.5	78.1
	N:	1.18	1.43

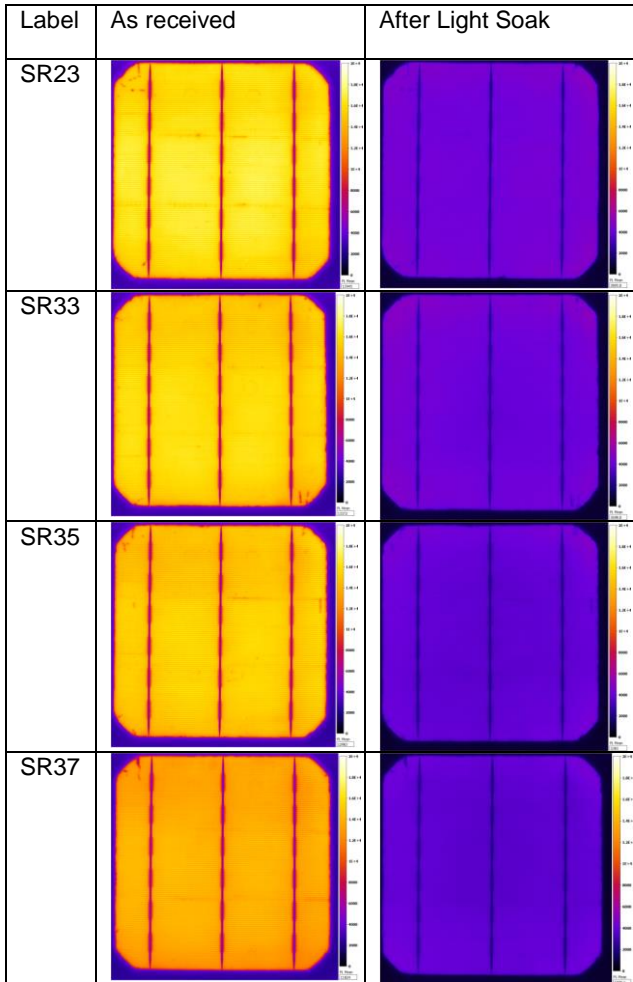


Figure 1: PL images of Group 1 PERC cells as received and following 48 hours of standard light-soaking at 0.78 suns and 40 deg C temperature.

The IV characteristics of the Group 2 solar cells after hydrogenation treatment showed an increase in performance as summarised in Table 2. This suggests

that the hydrogenation treatment using the prototype production tool is doing more than just forming and passivating B-O defects and is likely passivating other forms of recombination in these solar cells possibly due to contamination and crystallographic imperfections.

Table 2: IV data of Group 2 PERC cells showing a significant performance increase following hydrogenation and stable performance following light soaking at 40 deg C under 78 mW/cm2 illumination for 48 hours.

Label		Before H Process	After H Process	After Light Soak
SR24	Efficiency (%) :	20.4	20.8	20.7
	Voc (mV):	666	670	670
	Jsc (mA/cm2):	39.2	39.3	39.2
	FF (%) :	78.3	78.9	78.9
	N:	1.20	1.08	1.07
SR34	Efficiency (%) :	20.5	20.8	20.7
	Voc (mV):	666	670	670
	Jsc (mA/cm2):	39.2	39.3	39.3
	FF (%) :	78.2	78.7	78.5
	N:	1.20	1.07	1.10
SR36	Efficiency (%) :	20.3	20.7	20.6
	Voc (mV):	665	669	668
	Jsc (mA/cm2):	39.2	39.3	39.2
	FF (%) :	78.0	78.6	78.4
	N:	1.20	1.10	1.09
SR38	Efficiency (%) :	20.3	20.8	20.8
	Voc (mV):	665	671	671
	Jsc (mA/cm2):	39.2	39.3	39.3
	FF (%) :	78.0	78.8	78.8
	N:	1.22	1.08	1.08

PL image analysis was conducted on the cells from group 2, before hydrogenation, following hydrogenation and following 48 hours of standard light-soaking. The results of this analysis are shown in Figure 2 and confirm the findings from the IV characteristic in Table 2. The PL images of the Group 2 solar cells showed significant improvement following the hydrogenation treatment, but perhaps more importantly, showed no significant drop in response following the prolonged light-soaking step used to test stability. This indicates that the hydrogenation treatment has likely solved the LID in these CEC solar cells and that they are likely no longer susceptible to LID during operation in the field. However lengthier light-soaking will be performed on these cells for confirmation since the much longer time constants for LID in multi in the order of thousands of hours indicates the need for caution when drawing conclusions.

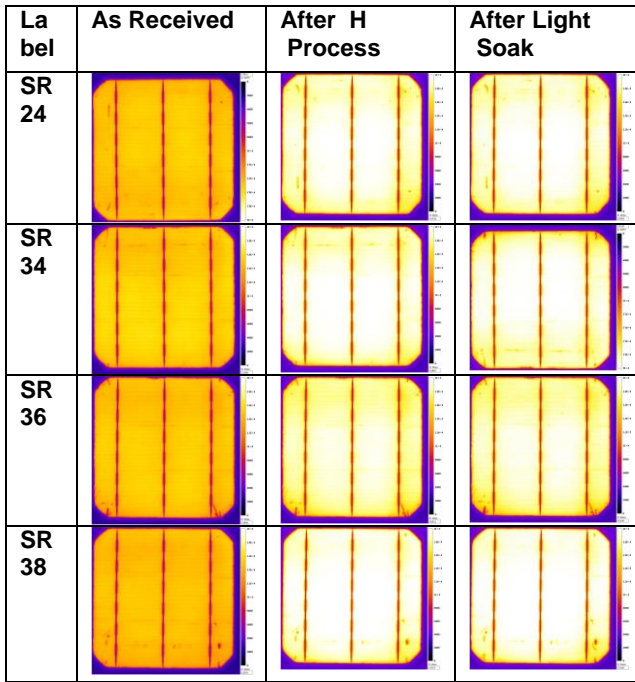


Figure 2: PL images of Group 2 cells before hydrogenation, following hydrogenation in the prototype tool and following 48 hours of standard light-soaking at 0.78 suns and 40 deg C temperature.

ANALYSIS

Figure 3 below depicts in graphical form the stability of the hydrogenated CEC solar cells and their performance advantage relative to non-hydrogenated CEC solar cells after prolonged light soaking. Following the prolonged light soaking step, an average improvement of 1.8% absolute is observed on CEC solar cells that have been treated in the prototype production hydrogenation tool compared to the CEC solar cells that did not receive any hydrogenation treatment. Although it is possible that prolonged light-soaking in the future could see some deterioration in the performance of the hydrogenated CEC Energy cells, the expectation is that further light soaking will in fact lead to a widening in the performance gap between the hydrogenated and non-hydrogenated PERC cells as the latter continue to degrade as B-O defects continue to form.

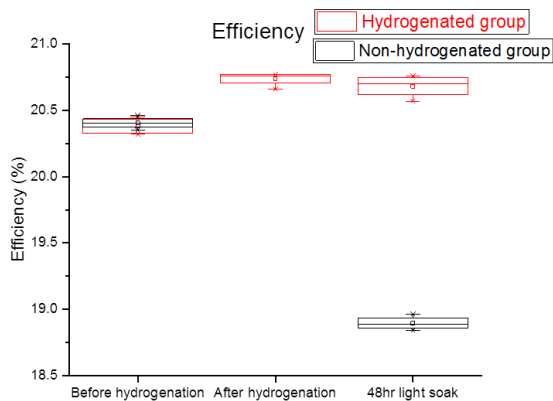


Figure 3: Graphical representation of the illuminated stability of the hydrogenated CEC solar cells and their performance advantage relative to non-hydrogenated CEC solar cells after prolonged light soaking.

Further analysis was also conducted on three of the degraded cells from Group 1 by applying the hydrogenation process to them in the prototype hydrogenation tool. The results are shown in Table 3 and Figure 4. Interestingly, the performance of the cells was not only restored to that matching the devices before degradation, but elevated to levels significantly above their starting values, again suggesting the passivation of other forms of recombination in the devices other than just B-O defects. This also suggests that the damage created by the B-O defects is reversible with the hydrogen able to passivate them and eliminate their damaging impact. Further light-soaking will be conducted to evaluate their stability and later reported.

Table 3: IV data of the Group 1 PERC cells as in Table 1 but also showing a significant performance increase following subsequent hydrogenation.

Label		As received	After Light Soak	H process after LID
SR33	Efficiency	20.4%	18.9%	20.6%
	Voc (mV):	666	640	670
	Jsc (mA/cm2):	39.2	38.2	39.1
	FF (%)	77.9	77.2	78.6
	N:	1.19	1.54	1.07
SR35	Efficiency (%) :	20.41	18.84	20.61
	Voc (mV):	665.70	637.83	669.73
	Jsc (mA/cm2):	39.27	38.12	39.11
	FF (%)	78.09	77.48	78.66
	N:	1.20	1.49	1.09
SR37	Efficiency (%) :	20.39	18.90	20.67
	Voc (mV):	663.26	636.44	667.93
	Jsc (mA/cm2):	39.15	38.05	39.08
	FF (%)	78.54	78.07	79.18
	N:	1.18	1.43	1.08

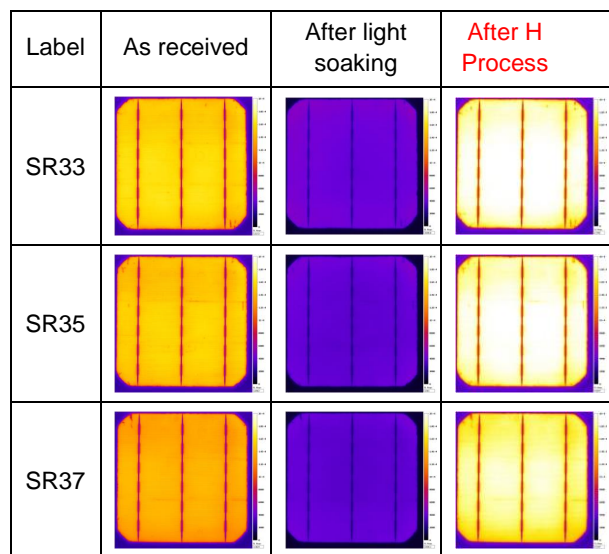


Figure 4: PL images of Group 1 cells as received from the PERC production line, following 48 hours of standard light-soaking at 0.78 suns and temperature of 40 deg C, and following subsequent hydrogenation in the prototype tool to passivate the damage and even enhance the cell performance.

As seen from Table 4, there appears to be the potential to increase PERC cell efficiencies by 0.2-0.3% absolute through the use of lower resistivity wafers. Light-soaking however highlights the severe LID potential of such cells, not only eliminating all the benefits offered by the increased wafer doping, but dragging down the efficiencies to well below those of the normal commercial p-type Cz wafers. This scenario however changes significantly through the implementation of the UNSW advanced hydrogenation via the prototype industrial tool with the elimination of the LID through the passivation of the B-O defects. Not only are the detrimental LID effects of the heavy doping eliminated, but the hydrogenated cells following light-soaking achieve efficiencies 0.3% absolute efficiency above the starting cells and the same performance advantage over PERC cells using the normal 2 ohm-cm p-type Cz wafers that have received the same hydrogenation treatment.

Table 4: IV data of as received PERC cells fabricated using 0.5-1.0ohm.cm wafers in comparison to the normal 1.0-3.0 ohm-cm wafers. Also provided are the efficiencies following light soaking at 40 deg C under 78 mW/cm² illumination for 48 hours for both wafer types, with and without hydrogenation.

Wafer Resistivity ohm-cm	As Received Average Efficiency (%)	After Light Soak WITH NO hydrogenation	After Light Soak WITH hydrogenation
1.0-3.0	20.2%	19.5%	20.4%
0.5-1.0	20.4%	18.9%	20.7%

CONCLUSIONS

Lower resistivity silicon than that used in the 2ohm-cm p-type Cz wafers currently used by the industry appear to offer the potential for increased efficiencies for PERC cells by reducing resistive losses in the wafer and at the rear point contacts. However, corresponding increases in B-O defect formation have prevented such improvements being realized. However innovative new technology has been developed to control the charge state of interstitial atomic hydrogen atoms within the silicon lattice, which in turn has facilitated improvements in both the diffusivity and reactivity of the hydrogen atoms. A new prototype industrial tool for the implementation of this technology has been developed and appears to have solved LID in p-type Cz wafers, now allowing more heavily and optimally doped wafers to be used in PERC cell manufacturing. Following light-soaking, performance increases of almost 10% have been achieved through the use of such hydrogenation technology and with apparent immunity to future LID. Furthermore, already degraded cells have been rejuvenated through the use of such technology, restoring the efficiencies to levels above that originally achieved following device fabrication. The stability of the latter cells is still being tested, but with 48 hours of standard light-soaking appearing to indicate stable operation.

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