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An Analysis of Light-Induced Degradation in p-type Silicon Heterojunction Solar Cells

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Introduction

Commercial interest in silicon heterojunction (SHJ) solar cells is rapidly increasing, due to the high efficiencies and relatively simple, low temperature processing sequence offered by this architecture [1]. The high efficiency is achieved by the excellent passivation provided by hydrogenated amorphous silicon (a-Si:H) layers which has led to world-record efficiencies exceeding 26.6% [2]. Industrial SHJ solar cells are fabricated using high lifetime n-type wafers, which are more expensive than industry-standard p-type wafers. Therefore, cost benefits could be obtained by using cheaper wafers in a SHJ cell architecture if comparable efficiencies could be achieved. However, a key challenge associated with the use of p-type silicon is its susceptibility to light-induced degradation (LID) upon illumination [3] caused by boron-oxygen (B-O) defects [4] and light- and elevated temperature-induced degradation (LeTID) [5]. Finding solutions to these problems in high efficiency silicon solar cell architectures like heterojunction solar cells is thus of great importance to the solar industry. In this work, we demonstrate SHJ solar cells fabricated using p-type Cz wafers with stabilised efficiencies of 20.7% with the application of an adapted advanced hydrogenation process (AHP), to improve surface passivation and to address LID. In such cells, the efficiency loss in p-type Cz SHJ solar cells is less than $0.5\%_{rel}$ after LID tests. Additionally, we demonstrate the avoidance of LeTID in p-type multi-crystalline silicon (mc-Si) wafers.

Methodology

Silicon heterojunction solar cells were fabricated using both low cost p-type Cz and mc-Si wafers which underwent defect engineering at UNSW. The deposition of the intrinsic and doped a-Si:H, TCO, and silver metallisation was performed at ASU. Finished cells were then treated using a modified advanced hydrogenation process (AHP) developed by UNSW. A standard 48 hour light soak (LS) was used to assess the influence of LID on cells, both before and after the AHP. Two Cz samples were considered in this study. Sample 1 underwent a 48 hour LS, followed by an AHP treatment and subsequent second 48 hour LS. Sample 2 directly underwent the AHP, followed by a 48 hour LS. *In-situ* monitoring of the pseudo-efficiency and V_{OC} during light soaking was performed using a Suns-V_{OC} stage from Sinton Instruments. Mc-Si solar cells underwent LID testing suitable for LeTID at 75 °C for over 1000 hours with *ex-situ* Suns-V_{OC} measurements.

Results

Table 1 shows the change in photovoltaic characteristics for sample 1 as a result of a series of light soaking tests. After the initial light soaking, the control cell underwent significant degradation, as shown in the in-situ monitoring of pseudo-efficiency in Figure 1 (left). This degradation was due primarily to a reduction in V_{OC} of almost 30 mV. Analysis of injection dependent lifetime spectroscopy curves indicate that this degradation was caused by the formation of B-O defects during the light soaking. After this degradation, sample 1 underwent an AHP. As shown in Table 1, this caused the efficiency to recover to much higher levels than before light soaking. This remarkable result is related to a passivation of V_{OC}, to an impressive value of 708 mV, as well as an improvement in FF of > $3\%_{abs}$. Remarkably, this V_{OC} is higher than that of the world-record 25% PERL cell fabricated using expensive float-zone silicon. After receiving this AHP, sample 1 then underwent the same 48 hour LS. After this second light soak, the efficiency only reduced to 20.6%, a reduction of only $0.1\%_{abs}$. This is also reflected in Figure 1, after the

AHP, the cell shows almost no degradation. Also shown in Figure 1 is the in-situ monitoring of sample 2, which received the AHP directly. This cell is also stable during the LS, indicating the success of the AHP in suppressing LID in p-type SHJ solar cells.

SHJ solar cells were also fabricated on p-type mc-Si wafers, which is an even cheaper wafer source. Figure 1 (right) displays the in-situ monitoring of these solar cells during LeTID test?, which had received a modified AHP treatment. Both the V_{OC} and pseudo-efficiency were stable over the 1000 hour test period. This novel demonstration represents a significant step forward in the development of SHJ solar cells on cheaper silicon substrates.

Table I. Current density - voltage characteristics of a SHJ cell (sample 1) tested for LID

Condition	J_{SC} (mA/cm^2)	V_{OC} (mV)	FF (%)	Efficiency (%)
Initial	39.7	692	70.2	19.3
1st LS	39.2	664	70.6	18.4
LS + AHP	39.6	708	73.5	20.7
1st LS + AHP + 2nd LS	39.5	708	73.4	20.6

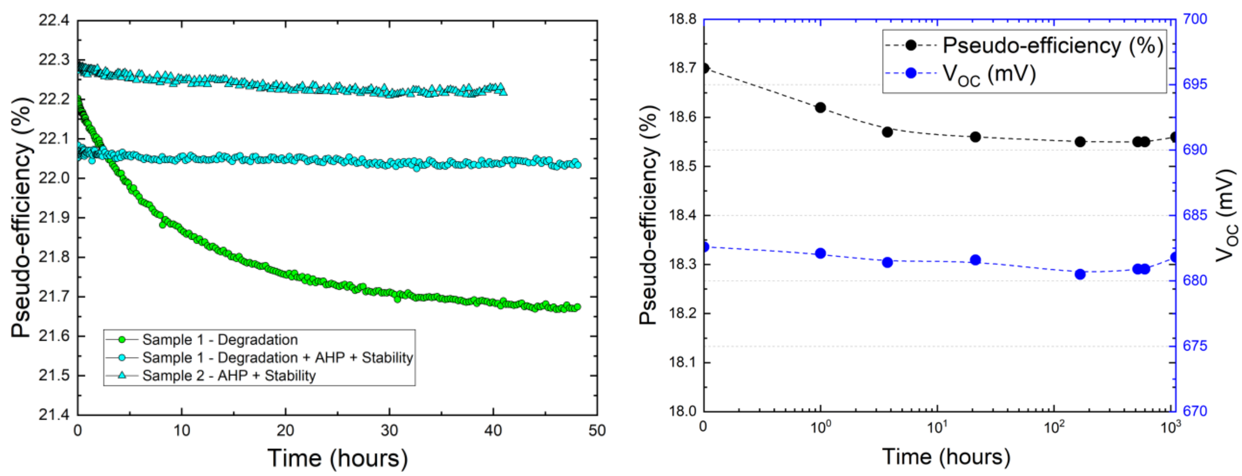

Figure 1. Left: in-situ monitoring of pseudo-efficiency curves for p-type Cz SHJ cells which underwent 48 hour light soaking LID tests, right: in-situ monitoring of pseudo efficiency and V_{OC} of p-type mc-Si which has undergone AHP treatment.

Conclusion and Significance

In this work, we presented a solution for a key issue of susceptibility to light-induced degradation mechanisms for p-type silicon heterojunction solar cells fabricated on either boron-doped Cz or multi-crystalline silicon wafers. We used a multi-stage defect engineering process, incorporating pre-fabrication gettering and hydrogenation, followed by an advanced hydrogenation process on the finished devices. For p-type Cz silicon heterojunction devices, this enabled devices with less than < 0.5%$_{rel}$ efficiency loss due to boron-oxygen related light-induced degradation, resulting in an impressive stabilised V_{OC} of 708 mV and efficiency of 20.6%. For p-type multi-crystalline silicon heterojunction cells, a stabilised V_{OC} > 680 mV was achieved. These results clearly highlight the potential for significant further efficiency enhancements for solar cells fabricated using p-type substrates, and the suitability of such wafers for use with next-generation solar cell technologies featuring passivated contacts and heterojunction structures. As a result, the developments in this work could pave a way for significant cost reductions for high-efficiency solar cells, by avoiding the need to transition to more expensive n-type wafers.

References

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