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Light-induced degradation of silicon solar cells with aluminium oxide passivated rear side

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Abstract

Light-induced degradation (LID) has been shown to significantly affect the performance of multicrystalline silicon (mc-Si) solar cells with aluminium oxide (AlOx) passivated rear side. Within this work, the impact of LID on the conversion efficiency of different silicon solar cell architectures with and without AlOx passivation is investigated. Under conditions representing realistic module operation, significant light-induced degradation of up to $\Delta\eta$ = -2.9 $\%_{rel}$ in conversion efficiency has been observed for multicrystalline silicon (mc-Si) solar cells with AlOx passivation. This degradation has been found to be higher than the degradation of, both, a mc-Si aluminium back surface field (Al-BSF) solar cell and, remarkably, a Czochralski-grown silicon (Cz-Si) solar cell with AlOx passivation. For a more detailed investigation of the interaction of mc-Si and AlOx passivation during degradation, a photoluminescence-based "effective defect" imaging has been performed on AlOx-passivated mc-Si lifetime samples. The local effective defect lifetime related to recombination due to LID-induced defects is found to vary strongly in the range of $\tau_{eff,defect}$ = 5 to 75 µs and, furthermore, areas with low effective lifetime could be identified as areas with relatively high dislocation density.

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Keywords: Light-induced degradation; multicrystalline silicon; aluminium oxide; passivated emitter and rear cell; solar cells

1. Introduction

In the past, the majority of studies on light-induced degradation (LID) within boron-doped *p*-type silicon have been focused on the formation of a boron-oxygen (BO) complex [1–5] and/or the dissociation of iron-boron (FeB) pairs [6–10]. Czochralski-grown silicon (Cz-Si) has been studied more extensively than multicrystalline silicon (mc-Si) since it generally features relatively high oxygen concentrations in the range of $[O_i] = 5\times10^{17}$ to 10^{18} cm^{-3} leading to significant LID due to BO defect formation [11,12]. The concentration of interstitial iron which is generally higher in mc-Si due to in-diffusion from the crucible and its coating [13,14] can be reduced efficiently by gettering during phosphorus diffusion [15]. Concerning the BO complex, the process of regeneration is well-known [16].

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However, Ramspeck *et al.* have reported LID on cells with a plasma-enhanced chemical vapour deposited (PECVD) aluminium oxide (AlOx) passivated rear side that can neither be explained by BO defect formation nor FeB pair dissociation and can even be higher for mc-Si compared to Cz-Si [17]. Furthermore, the authors have reported LID on mc-Si aluminium back-surface field (Al-BSF) solar cells being significantly higher at elevated temperatures [18], which could also not be solely attributed to BO defect formation and/or FeB pair dissociation. In a recent study investigating Al-BSF cells and cells with PECVD AlOx passivated rear sides, the authors found the defect causing this significantly higher LID is unlikely to be a sole bulk defect and may also be related to changes in the passivation quality of the rear surface [19]. The passivation quality of atomic-layer-deposited (ALD) AlOx [20,21] on *p*-type Si wafers has been reported to improve under light soaking at temperatures $T \leq 50$°C indicating an increase of the fixed-charge density Q_f [22,23]. However, the authors are not aware of light-soaking studies on PECVD AlOx passivation on *p*-type silicon [24], which is applied in Ref. [19] and this work.

This work investigates LID under conditions practically relevant for outdoor module operation. Within this work the key findings reported in Ref. [19], where AlOx passivated mc-Si cells have been shown to be strongly affected under such conditions, are shown and discussed in more detail. Furthermore, the degradation of bulk lifetime in mc-Si wafers and the stability of the rear-side passivation quality are investigated in order to determine the origin of the observed LID effect.

2. LID on cell level

2.1. Experimental Setup

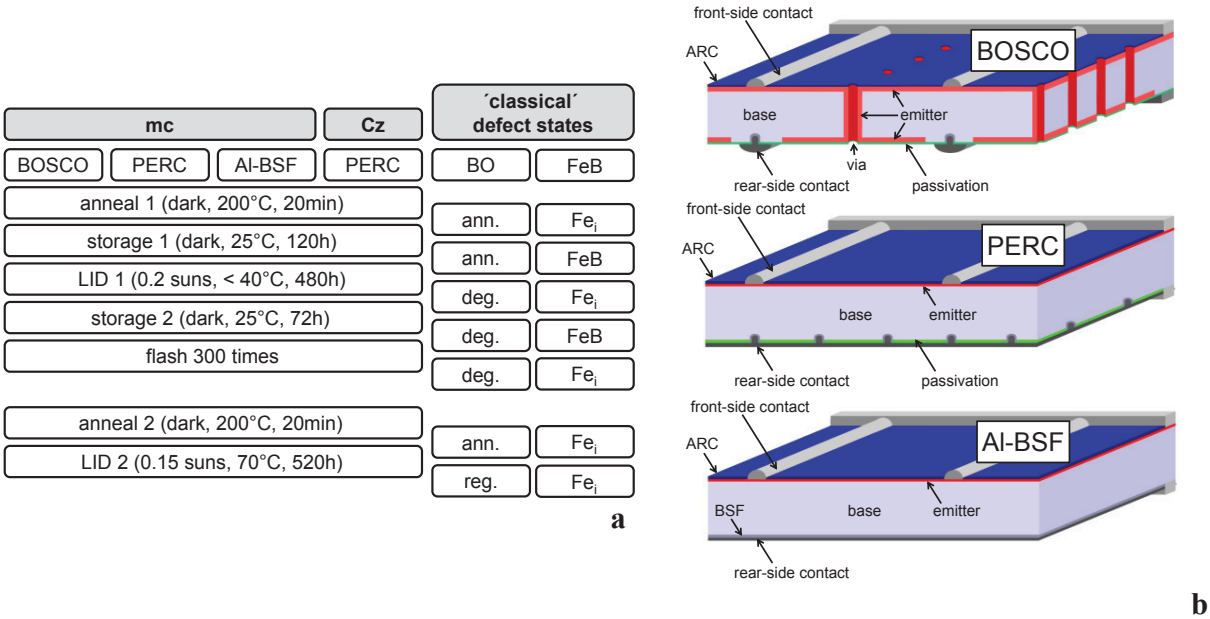

Fig. 1. (a) Experimental setup for systematical exclusion of BO defect formation and FeB pair dissociation and subsequent degradation under conditions emulating critical module operation in the field. (b) Sketch of the three different cell concepts applied for the LID study on cell level. Graphs are taken from Ref. [19].

In order to quantify the impact of the classical BO formation and FeB dissociation, the experimental setup shown in Fig. 1a is applied. For a detailed description of the individual steps up to the second annealing step and their effect on the defect states of BO and FeB, please refer to Ref. [19]. After a second annealing step, the BO complex should be inactive (annealed state) and FeB pairs should be dissociated. The cells are then submitted to a second light soaking step (“LID 2”) at elevated temperatures, the temperature and carrier injection conditions chosen in a way to emulate conditions which are realistical to occur during module operation. The temperature is elevated to