LIGHT INDUCED DEGRADATION IN MULTICRYSTALLINE SOLAR GRADE SILICON SOLAR CELLS EVALUATED USING ACCELERATED LID

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ABSTRACT: For solar grade silicon (SoG-Si) from metallurgical process route to be competitive in the future the feedstock must enable the same solar cell efficiency potential as compared to cells from traditional silicon (poly-Si) even after light induced degradation. Therefore the detailed investigation and understanding of the degradation effect will allow for an optimized usage of SoG-Si. The use of the accelerated light induced degradation (ALID) technique enables to assess the effect of degradation and its correlation to the oxygen and dopant concentrations in a more detailed way than in classical LID tests. Especially it enables determination of the distributions of the defects, which gives new insights into the formation and distribution of the defects responsible for LID.

KEYWORDS
solar grade silicon, light induced degradation

1 INTRODUCTION

Crystalline p-type boron doped silicon solar cells generally exhibit a degradation of conversion efficiency during the first hours of exposure to the sun light. This light induced degradation (LID) is associated with the formation of the well known boron oxygen complex which acts as a harmful defect and reduces the minority carrier diffusion length accordingly. LID is therefore related to both, boron and oxygen concentration. For wafers with bulk resistivities in the range of 1-2 Ωcm, LID can reduce the efficiency by up to 5% relative in Cz-Si due to the relatively high oxygen concentration, while LID is typically about 1% in case of multicrystalline Si solar cells. Multicrystalline silicon wafers from SoG-Si feedstock are partly compensated by phosphorous and contain a higher boron concentration as compared to non compensated reference wafers with same resistivity. Recently different research groups reported that phosphorous may somehow prohibit boron oxygen complex formation in boron doped silicon [1,2]. It was assumed, that only the net carrier concentration must be taken into account for minority carrier lifetime reduction due to LID. In this work the method of Accelerated Light Induced Degradation (ALID) by SPV technique and respective diffusion length measurement is used to investigate LID in detail.

2 EXPERIMENTALS

Wafers from different ingot positions were chosen and screen printed solar cells were processed in the ISC Konstanz pilot line leading to efficiencies up to 16,8% before LID. Assuming that LID is most critical for wafers from the bottom part of a multicrystalline ingot, in this work only wafers from the lower part of the bricks were investigated. A selection of cells was exposed to one sun visible light intensity at 25°C for 48 hours. These cells were characterised after LID, regenerated by thermal treatment for 10 min. at 200°C and measured again. Additional analysis was done by ALID using a Semilab PV2000 equipment. Combining illumination and thermal treatment, the ALID process transforms within minutes defects into the distinct states needed to isolate individual contributions from boron oxygen dimers (BO_{2i}) and interstitial iron (Fe_i) using a comparison of surface photovoltage (SPV) diffusion length mapping in different states. The method is described in detail in [3]. The distribution and density of BO_{2i} and Fe_i is determined and compared with the LID determined by cell parameter measurements.

3 RESULTS AND DISCUSSION

In-situ V_{OC} measurements revealed the LID time dependency under one sun illumination and 25°C. The results are shown in Figure 1 for three examples of different defect concentrations.

Laterally resolved diffusion length maps were calculated from SPV measurements on finished solar cells. Figure 2 shows such mappings on a typical cell from the bottom region before and after LID. The calculated BO_{2i} distribution shows, that these defects exist mainly at very local areas.

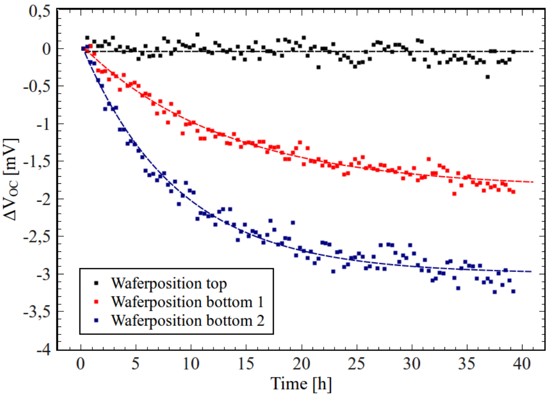
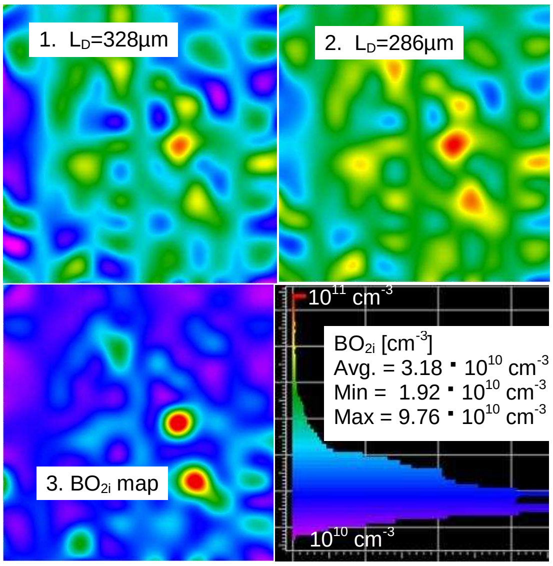


Figure 1:
Time dependent Voc measurement during LID at one sun illumination and room temperature (25°C). Bottom wafers degrade faster and stronger as compared to wafers from the top of the ingot.



1. after 200°C BO_{2i} deactivation anneal
2. after LID
3. calculated BO_{2i} map.

Figure 2:
Typical diffusion length map and calculated BO_{2i} distribution of a bottom wafer measured by ALID technique using the Semilab PV2000 instrument. The unit for BO_{2i} is Fe_i equivalents and does not represent the real boron or oxygen concentration.

Figure 3 shows on four different solar cells the distribution of Fe_i and BO_{2i}. The impact on solar cell parameters is included in each section of the Figure. Comparing the LID measured by IV parameter extraction with the degradation from diffusion length mappings, a clear correlation is observed between the efficiency degradation and the absolute defect concentration in the material (Figure 4).

As a summary, the degradation of solar cells made from Elkem Solar Silicon (ESS) can be limited to values below 1% relative and is therefore almost identical to the degradation of solar cells from poly-Si Feedstock. Only for wafers from the very bottom part of the ingot small deviations are observable by a very detailed investigation and can be explained by the different distribution of dopants for SoG-Si and poly-Si. In Table I average IV parameters are shown from 74 cells of the bottom part of different ingots from both ESS and poly-Si reference material. While the efficiency for ESS cells is slightly higher in the regenerated (annealed) state due to the higher dopant concentration and corresponding higher V_{OC} and FF, the efficiency after LID is the same for both materials.

Table I: Comparison of solar cell parameters in degraded and regenerated state.

averages, 74 cells in total	V_{oc} [mV]	J_{sc} [mA/cm^2]	FF [%]	η [%]
ESS annealed	622.6	33.3	78.9	16.35
Poly annealed	618.5	33.6	78.2	16.24
ESS degraded	619.8	33.1	78.9	16.16
Poly degraded	617.5	33.5	78.2	16.16

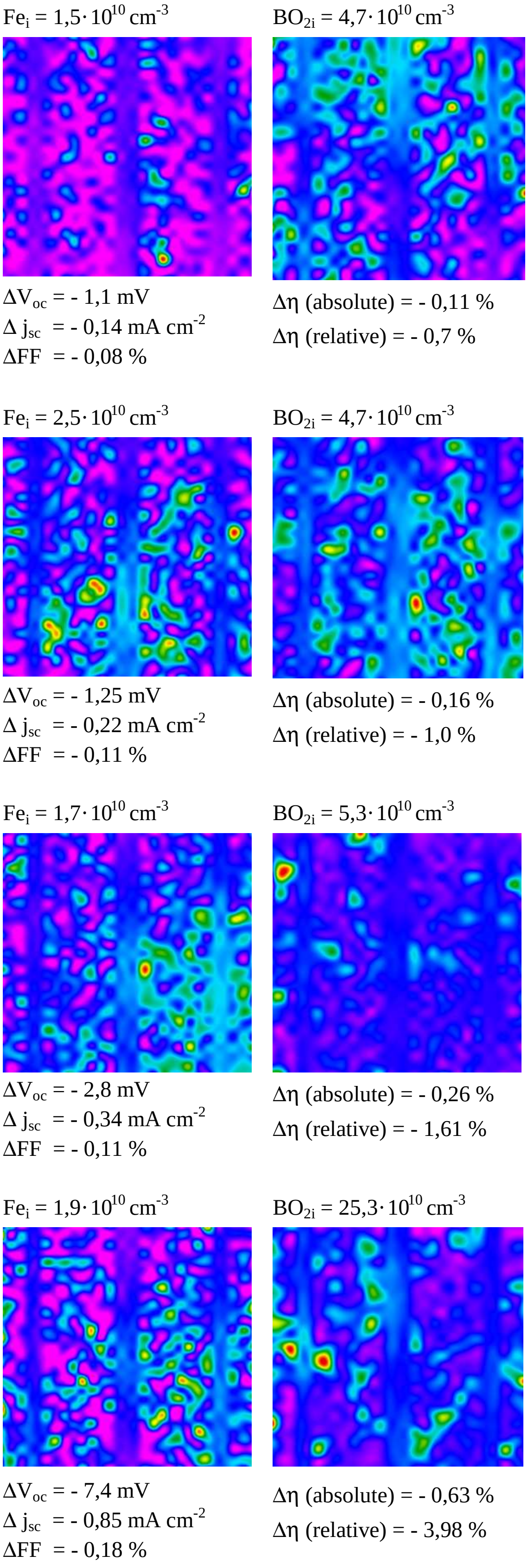


Figure 3: Comparison of change in solar cell parameters and calculated BO_{2i} and Fe distribution from diffusion length mappings by ALID. All efficiencies were in the range η~16%.

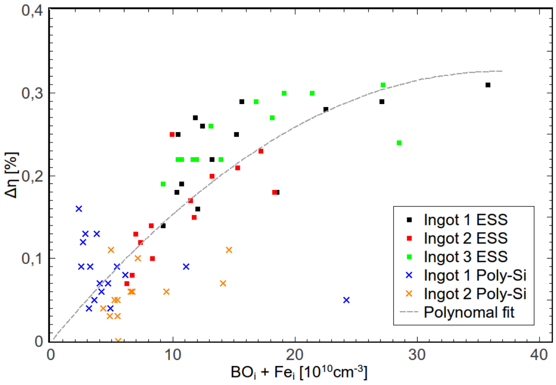


Figure 4: Total BO_{2i}+Fe_i defect concentration vs. LID efficiency loss.

4 CONCLUSIONS

The lateral mapping of the minority carrier diffusion lengths by SPV technique before and after LID, heat treatment and light soaking, enables the localization of B_{O2i} and Fe_i defects in finished solar cells. All cells from this investigation were processed from the lowest 80 wafers of the respective ingots. The comparison of ESS wafers with reference wafers from poly-Si lead to the following conclusions: ESS wafers show slightly higher LID, higher dopand concentration and higher V_{OC} as compared to poly Si. After LID the average efficiency is the same in both cases.

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