POTENTIAL-INDUCED DEGRADATION (PID) AT THE REAR SIDE OF BIFACIAL PERC SOLAR CELLS


Fraunhofer Center for Silicon Photovoltaics CSP, Halle (Saale), Germany

6th bifiPV workshop
Amsterdam
17th September 2019
OUTLINE

- Potential induced degradation (PID) in PV power plants
- PID at the rear side of bifacial passivated emitter and rear cells (PERC)
  - Empirical findings
  - De-polarization PID (PID-p)
  - Corrosive PID (PID-c)
  - Contradictory PID behavior under illumination
- Summary
Conditions for PID in PV power plants
High voltages: the driving force for leakage currents

PID causes severe power losses in PV modules with silicon solar cells
- Addition of serially connected module voltages
- Cause: high voltage between (grounded) module surface and solar cells
- Leakage current $\tilde{J}$ also at the rear side of modules

Series connection of PV modules with a floating potential

PV module under influence of high voltage
Potential induced degradation of bifacial PV modules
An new threat for the rear side

- Rear side power gain achieved by partial metallization at the rear side [1]
- Missing metallization: rear side is no longer shielded against electric fields [2]
- Additional path for leakage currents at the rear side

Rear side PID tests
High voltage stress applied to the rear side only

- Voltage $U = 1$ kV
- High voltage is only applied to the rear side \[1,2,3,4\]

Different test conditions
- Temperature:
  - $40 \, ^\circ\text{C} [1]$, $50 \, ^\circ\text{C} [2]$, $60 \, ^\circ\text{C} / 85 \, ^\circ\text{C} [3,4]$
- Duration: 24 h \[2,3,4\], 40 h \[1\]


Next slides refer to rear side PID tests
Potential induced degradation of bifacial PERC
Laterally homogenous rear side degradation

- Current and voltage loss
- No shunting of p-n junction
- FF is not the dominating loss factor
- Full recovery achieved after illumination (unlike PID of the shunting type, PID-s)

Lateral homogenous degradation, unlike PID-s
Present mechanism: de-polarization PID (PID-p)

Electroluminescence images

Potential induced degradation of bifacial PERC
De-polarization of charges in $\text{AlO}_x$ passivation layer (PID-p)

![Diagram of solar cell structure with front and rear views, showing n-type and p-type regions, AlOx, SiNx layers, and potential differences.]

- De-polarization ~ compensation of field effect passivation \([1,2]\)

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Efficiency losses due to PID at the rear side
Different PID mechanisms at bifacial PERC cells

Rear side PID test at industrial cells [1]
- PID test 60°C, 1000 V, 24 h
- Dark storage: 220 days
- Light soak: 4 h @ 1000 W/m²
- All cells are
  - p-type mono
  - bifacial PERC
  - but from different manufacturers

Power losses (relative to initial state)

<table>
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<tr>
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<th>A</th>
<th>C</th>
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<tbody>
<tr>
<td>PID test</td>
<td>-9.7%</td>
<td>-12.7%</td>
</tr>
<tr>
<td>dark storage</td>
<td>-0.8%</td>
<td>-13.9%</td>
</tr>
<tr>
<td>light soak</td>
<td>-2.1%</td>
<td>-14.7%</td>
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- New PID-type → not PID-p
- Different PID behavior for the same cell type
- Manufacturers need to know the critical process steps

Investigation of the microstructure
Structural defects at the rear surface

Cell type C:

- Lateral inhomogeneous recombination at PID sample after PID test (85°C, 1000 V, 24 h)
- Topography: circle shaped damages of passivation layer → holes → “PID of the corrosion type (PID-c)”
- EBIC reveals independent sub-surface defects → stacking-fault (SF)

Cross section through PID defective area
Hole-like defects due to a corrosive PID type (PID-c)

- Local SiO$_2$ formation at Si / AlO$_x$ interface (30 nm thickness, no native oxide)
- Alkali metal impurities found (Na, K, Ca)

Cross section through PID defective area

In addition: Increased concentration of alkali metals at the Si-interface

- Recombination active stacking fault (lower EBIC signal)
- Alkali metal impurities at Si / AlO$_x$ interface, probably also inside stacking-fault (SF)

PID at the rear side
The role of illumination during the PID test

- W. Luo et al. [1] show that illumination can prevent PID on bifacial p-type PERC cells
- 10 W/m² are sufficient to suppress PID

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PID is relevant under field conditions
- Our experiments [2] show that industrial PERC+ suffer from PID even under illumination

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- Our experiments [2] show that industrial PERC+ suffer from PID even under illumination
- PID cell tester ‘PIDcon’ adopted for bifacial PID testing
- Discrimination between PID-p and PID-c
- Later version with simultaneous illumination

Summary

1) PID-p and PID-c can harm the rear side of bifacial silicon solar cells

2) Susceptibility to PID at the rear side depends on the cell process for the same technology

3) Manufacturers need to know the critical cell process

4) Meaningful rear side PID tests need simultaneous illumination to predict yield losses
Acknowledgements

The authors thank the German Federal Ministry of Education and Research and the German Federal Ministry for Economic Affairs and Energy for financial support of the project “PID-Recovery” (project no. 0324184A) and “FuzzySun” (project no. 03FH024PX5).

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