Current induced regeneration CIR of BO-LID prone silicon solar cells for mass production

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Why is Light-Induced Degradation (LID) important?

Germany´s largest solar park- 166 MW (in Meuro and Schipkau)

Taiwan´s largest solar rooftop power plant (in Tainan)

- Detrimental loss of efficiency (3 - 20 %, relative)
- For 200 MW Fab → ~ 6 MW loss due to LID (3 %) → ~$2.28 Mio per year ($ 0.38/Watt)

  → 0.6 MW loss reduction due to LID control (0.3 %)→ $ 0.23 Mio per year

LID threatens business case of solar parks → Important to prevent or control LID effect!

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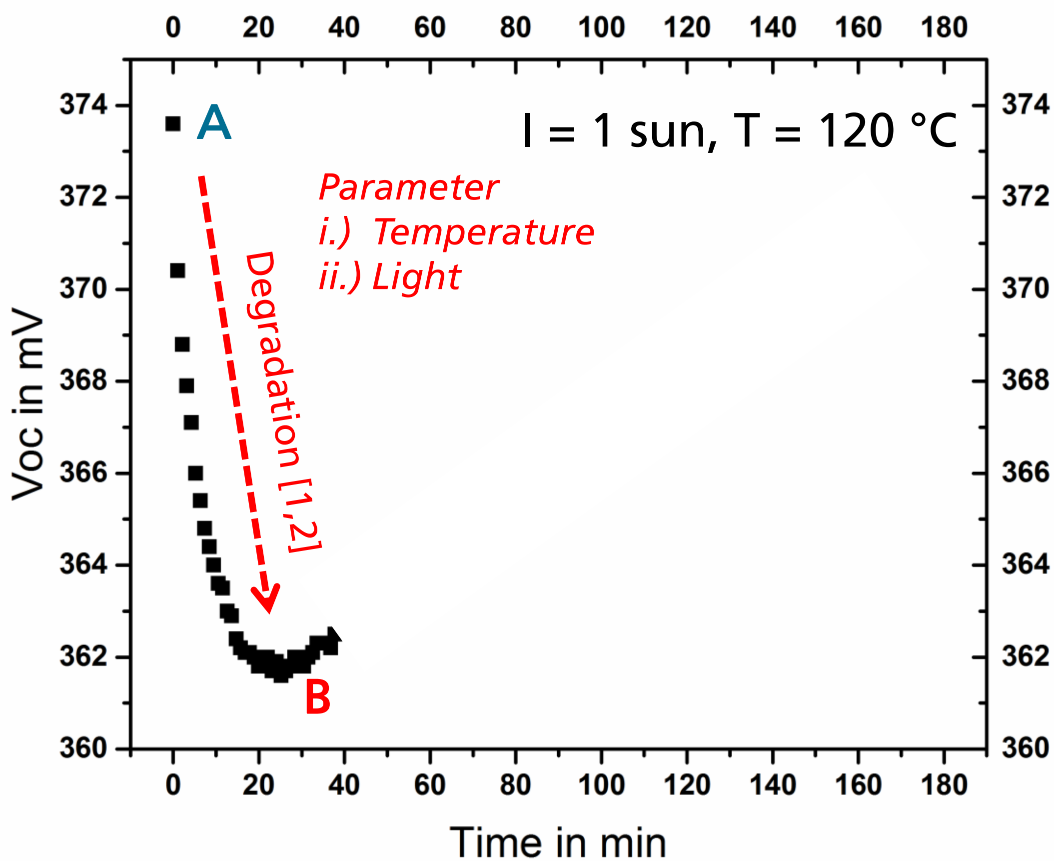
Overcoming LID
Degradation - Regeneration - Cycle



Transient degradation-regeneration cycle of a Cz mono Si cell

- Light induced degradation LID: Reducing τ of Si-bulk during operation

[1] Schmidt, J et. al., 3rd World Conference on Photovoltaic Energy Conversion, Osaka, Japan, (2003)
[2] V. V. Voronkov and R. Falster Journal of Applied Physics 107, 053509 (2010);
[3] Herguth, A et. al. *Prog. Photovolt: Res. Appl.* 16 (2), S. 135–140, (2008)
[4] Münzer, K.A. 24th European PVSEC, Hamburg, Germany, (2009)
[5] Wilking, S. et. al., J. Appl. Phys. 113 (19), S. 194503, (2013)

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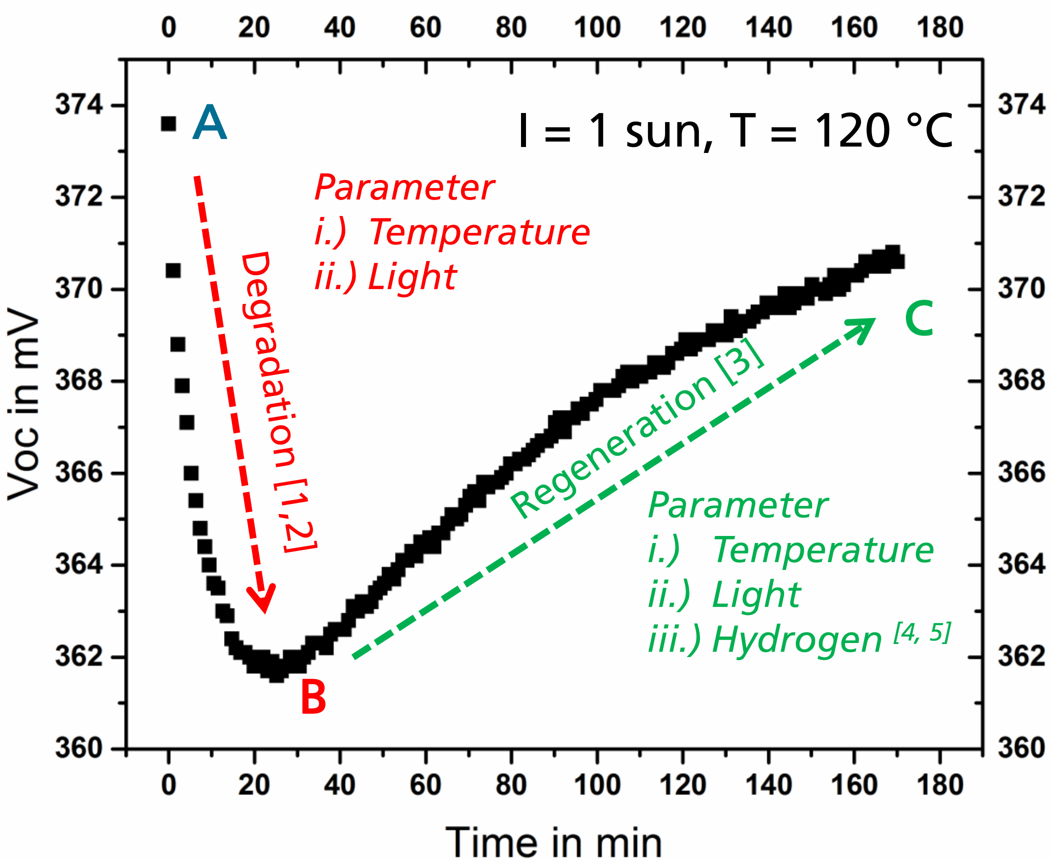

Transcient degradation-regeneration cycle of a Cz mono Si cell

- Light induced degradation LID: Reducing τ of Si-bulk during operation
- Solution: Regeneration process for longterm passivation of defects

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[2] V. V. Voronkov and R. Falster Journal of Applied Physics 107, 053509 (2010);
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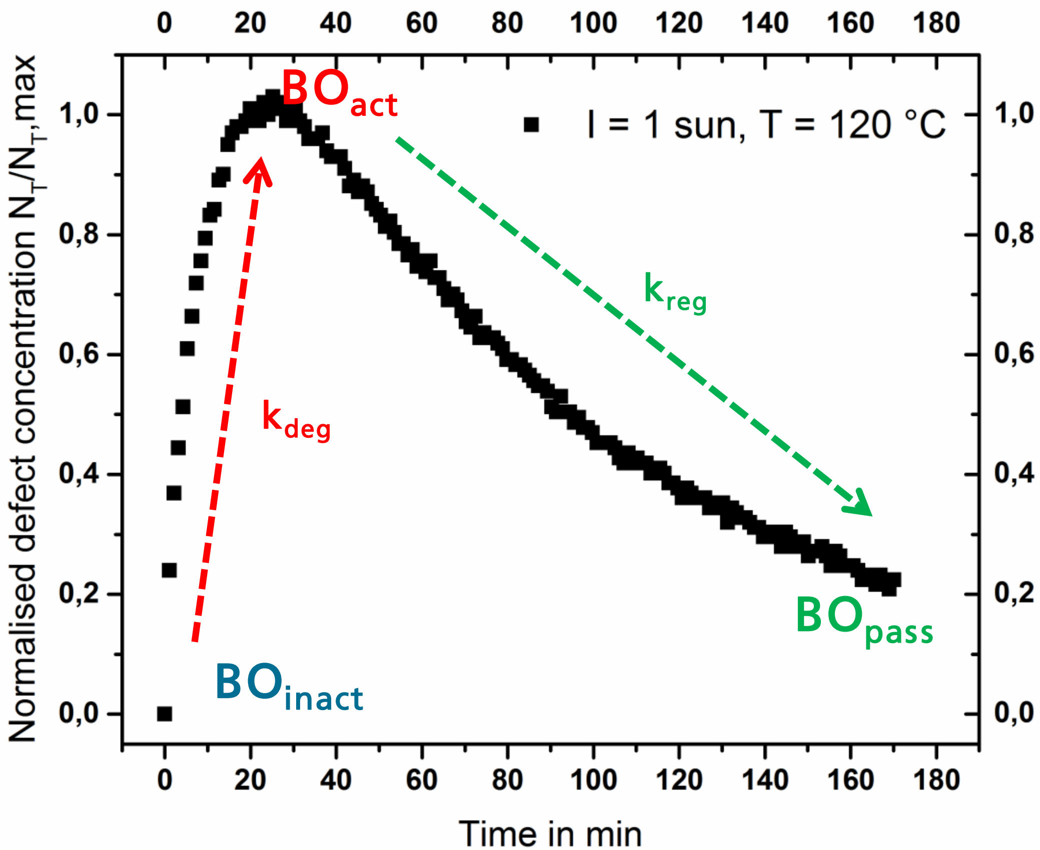

Normalised defect concentration of a transient degradation-regeneration cycle of a Cz mono Si cell

- Consecutive reaction:

i.) Degradation:

$$BO_{inactive} \xrightarrow{k_{deg}} BO_{active}$$

ii.) Regeneration:

$$BO_{active} + H \xrightarrow{k_{reg}} BOH$$

For fast process:

Increase k_{deg} and k_{reg}

Influence of temperature and injection on reaction velocities?

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    - Comparison of LIR and CIR
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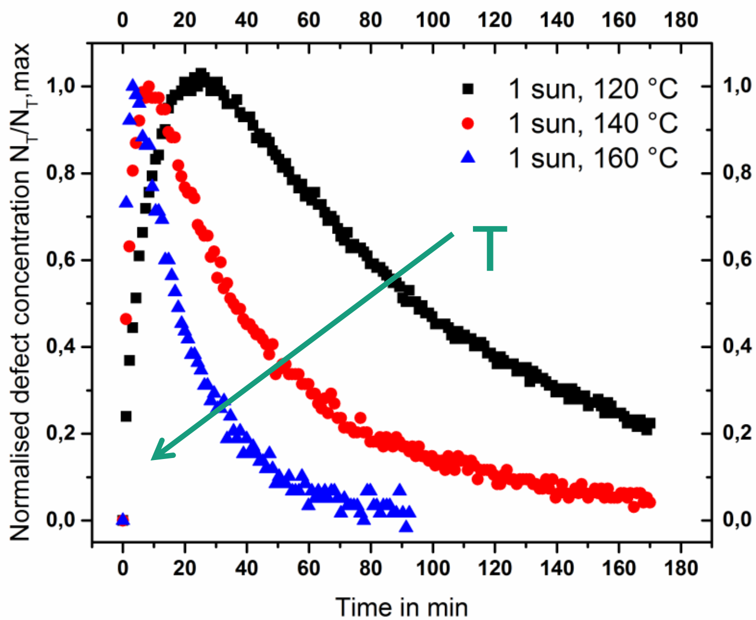
    - Simulations
    - Proof of concept
- Summary

Accelerating the degradation - regeneration - cycle
Influence of temperature and illumination

Temperature



Transient degradation-regeneration cycle of neighboured Cz mono Si cells in dependence on temperature

Exponential increase with T:
$k_i = v_{ch,i} * \exp(-E_{A,i}/kT)$

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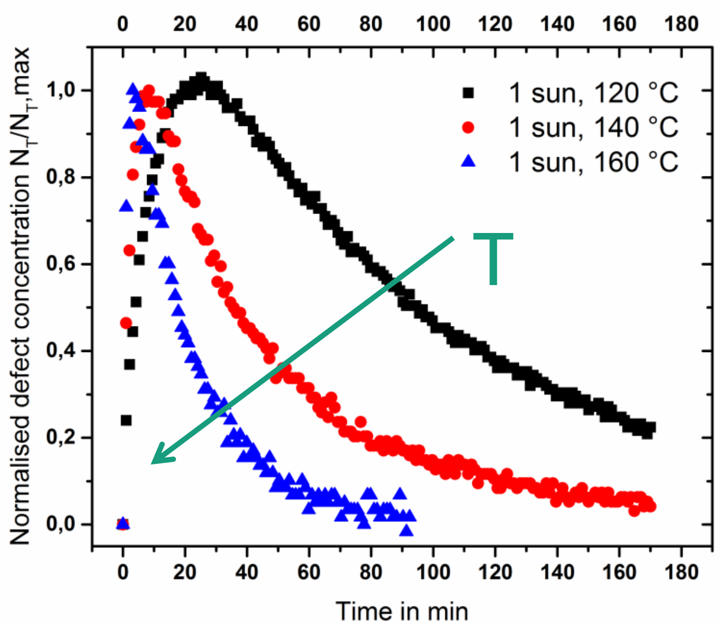
Accelerating the degradation - regeneration - cycle

Influence of temperature and illumination

Temperature



Transient degradation-regeneration cycle of neighboured Cz mono Si cells in dependence on temperature

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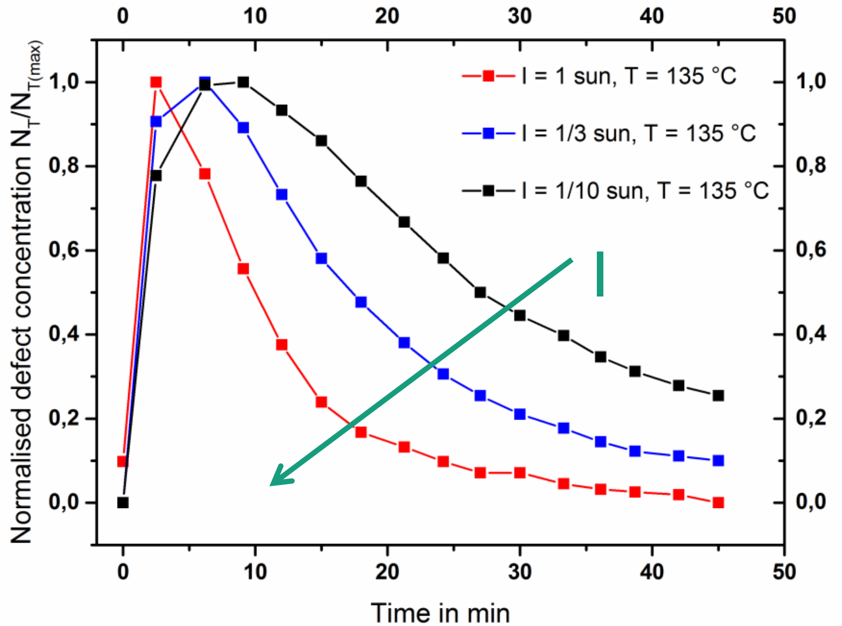
Intensity

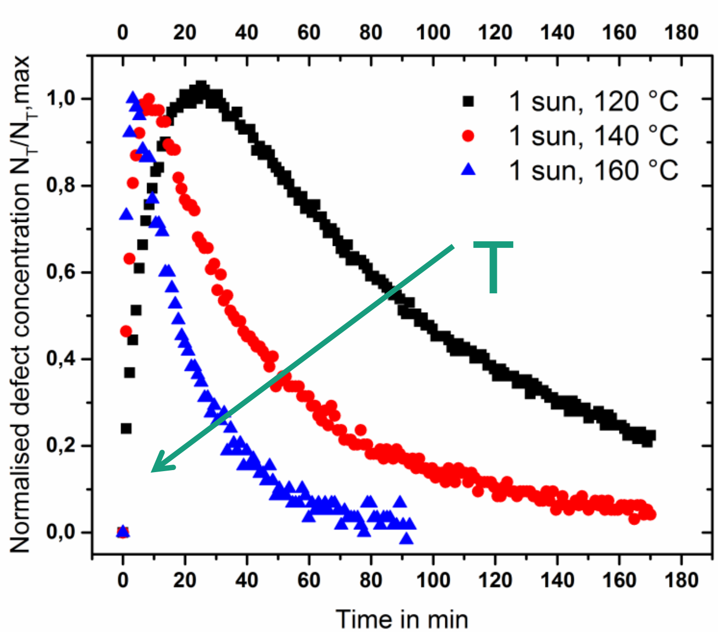


Transient degradation-regeneration cycle of Cz mono Si cell in dependence on light intensity (Data taken from [3])

Linear increase of k_{reg} with I

Accelerating the degradation - regeneration - cycle
Influence of temperature and illumination

Temperature



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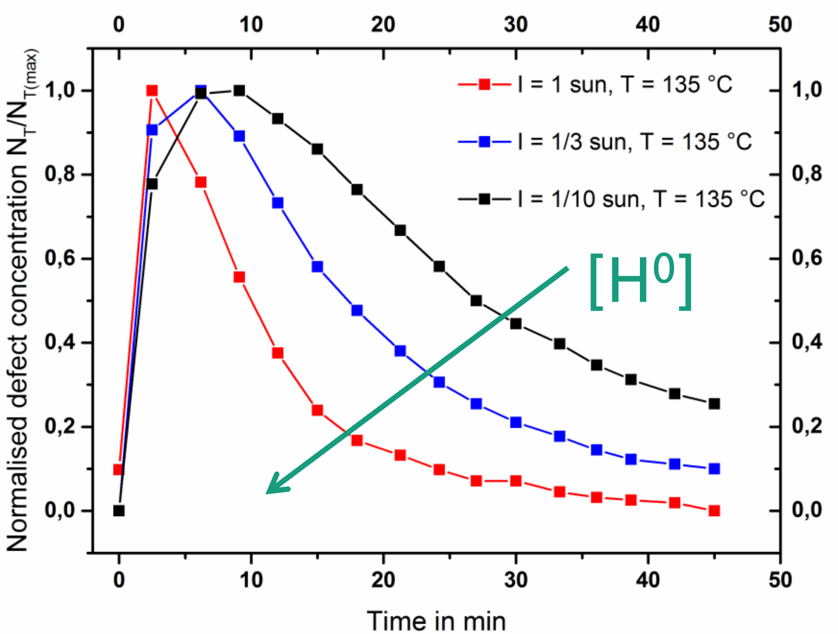

Transient degradation-regeneration cycle of Cz mono Si cell in dependence on light intensity (Data taken from [3])

Exponential increase with T:
$k_i = v_{ch,i} * \exp(-E_{A,i}/kT)$

Linear increase of k_{reg} with $[H^0]$ controlled by **charge carrier density n, p**

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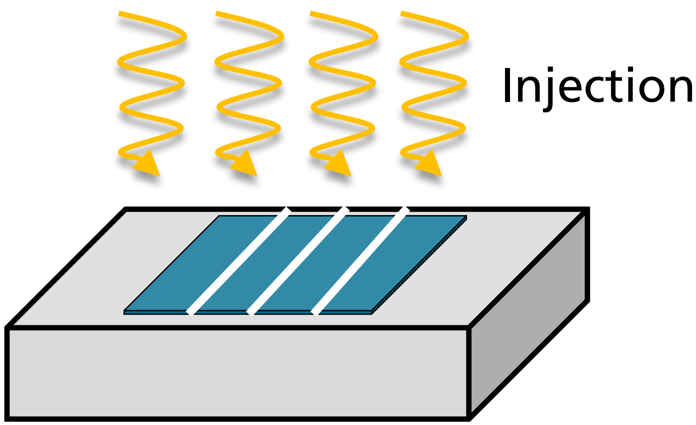
Current induced regeneration CIR

Comparison of LIR and CIR

Light induced regeneration LIR

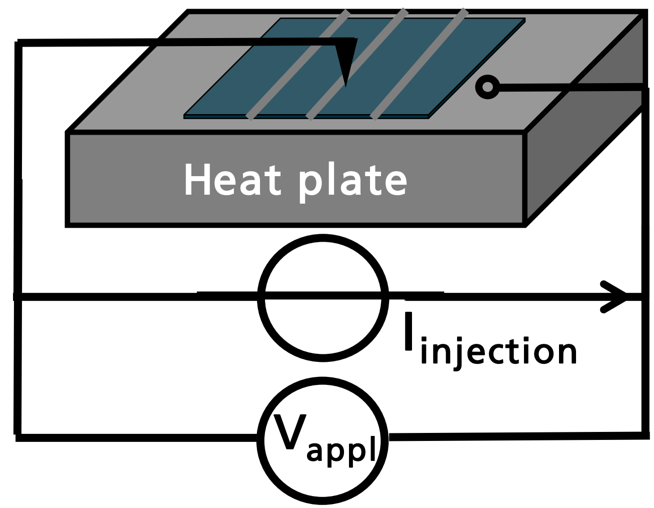
- State of the art for industrial regeneration:



- High illumination (over 100 suns) via laser during or after contact-firing

Current induced regeneration

1. Robust process design
2. No energy transfer losses (η_{Laser} ~30%)
3. In situ process control

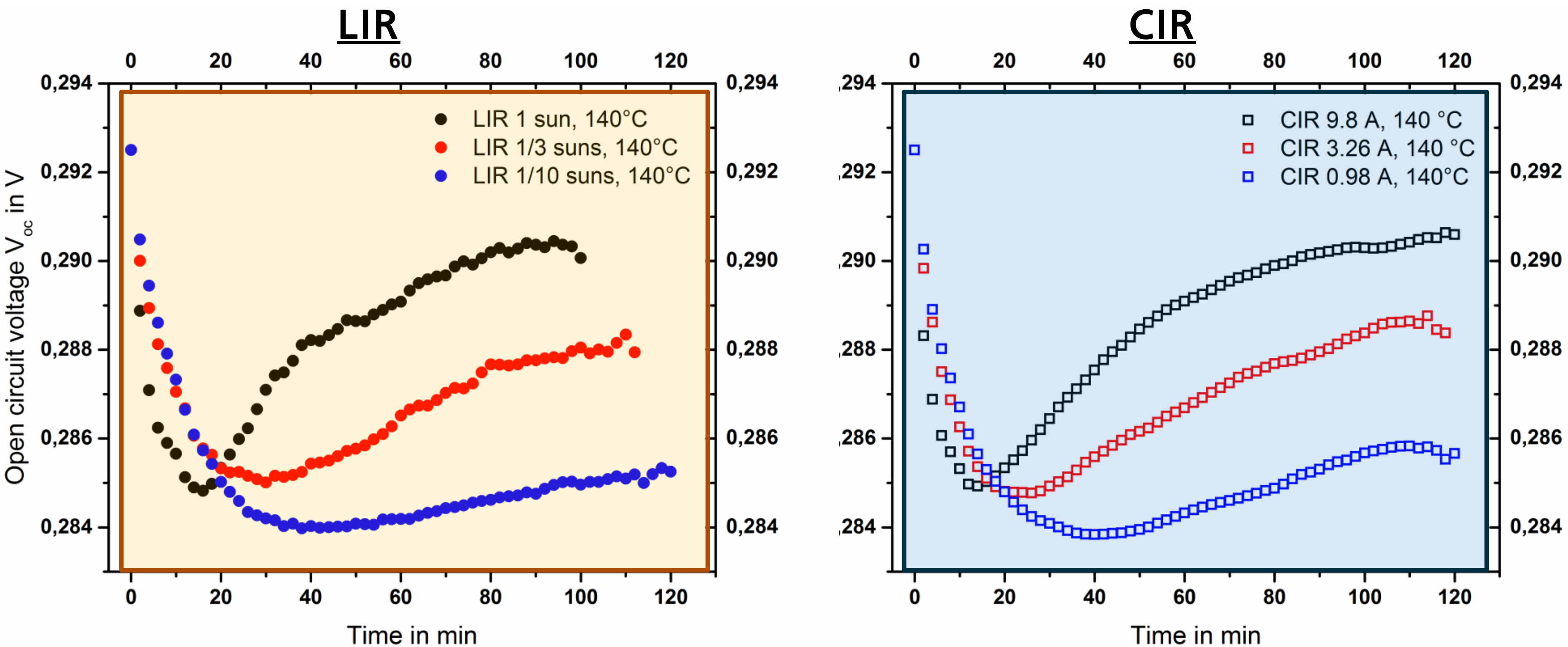


[6] Hallam et al IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 4, NO. 1, JANUARY 2014

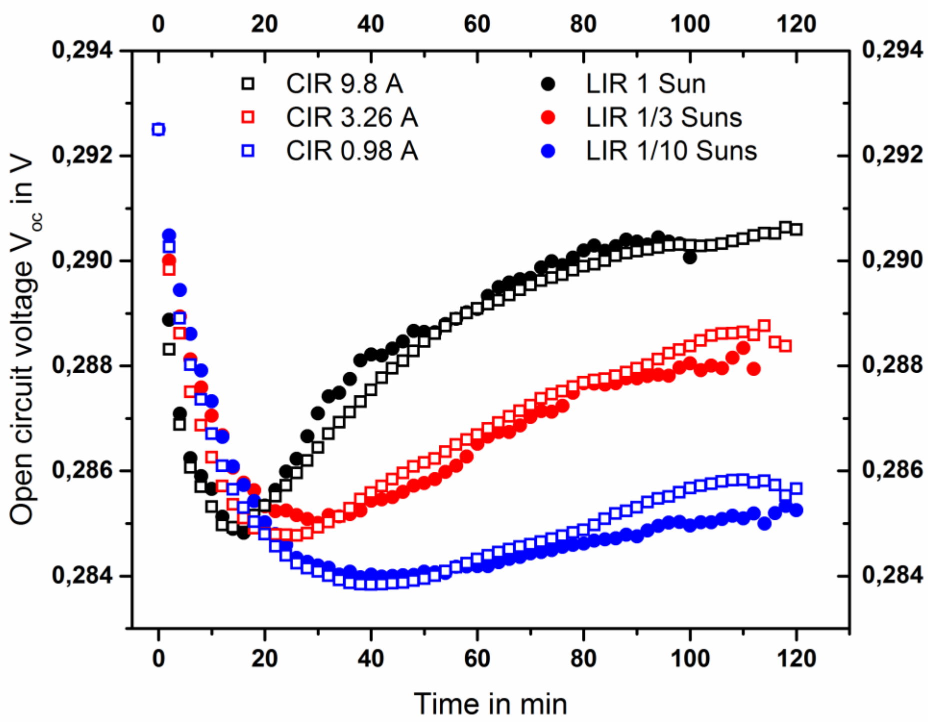
Current induced regeneration CIR

Comparison of LIR and CIR

- light and current induced regeneration using identical solar cells under identical process conditions



Current induced regeneration CIR
Comparison of LIR and CIR



- Using same injection conditions $I_{sc} = I_F$ → same kinetic behaviour
- Proof: Physical mechanism of regeneraiton based on charge carrier injection!

Electrical regeneration as promising alternative for efficiency stabilizaiton!

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Current induced regeneration CIR
Implementing CIR in the value chain

- Forward biasing as an easily convertible approach for charge carrier injection
- Works on series connected cells
- Opens up new process designs and implementation in value chain

CIR on cell level

Advantages:

i.) easy upscaling through cell stacking

ii.) usage of medium process parameters

CIR on module level

„Biased lamination“

i.) usage of lamination process

ii.) no extra heating step necessary

iii.) LID free modules independent of solar cell supplier

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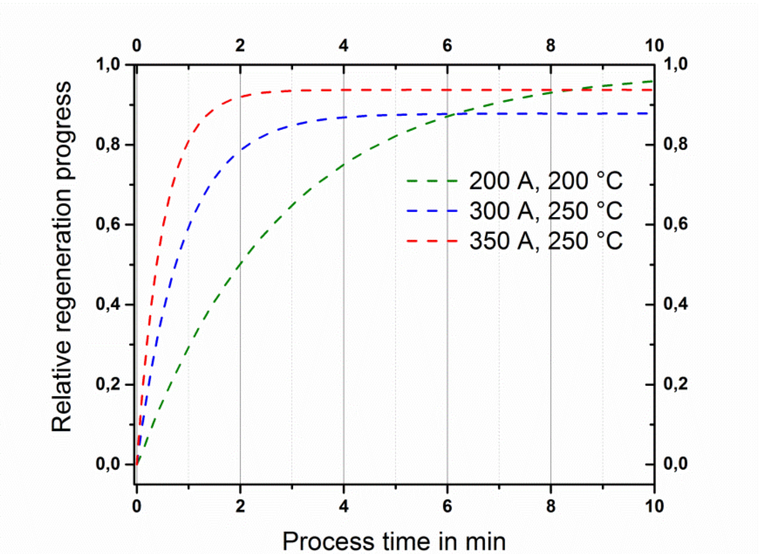
Application on cell and module level

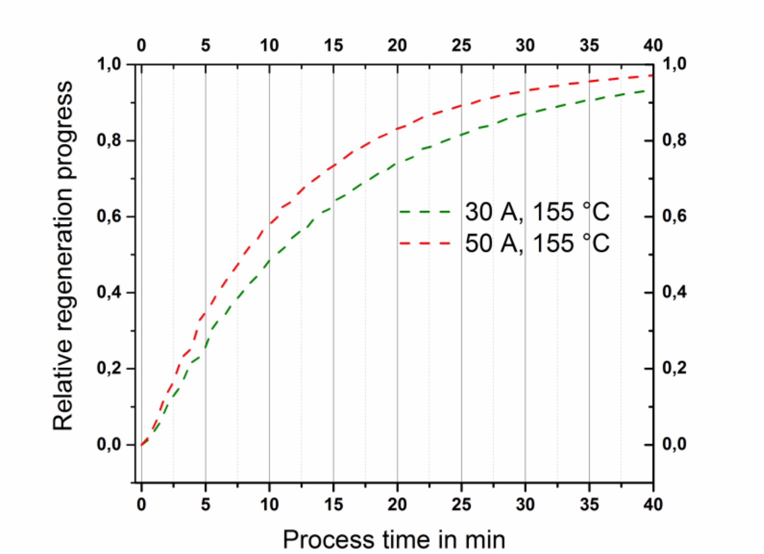
Simulations

- Process parameters for both scenarios differ substantially:
  - Temperature
  - Injection/forward current
  - Time regime
- **Preliminary investigation of regeneration gain and process design by applying kinetical model [1]**

CIR on cell level



CIR on module level



[1] M. Gläser and D. Lausch, *Energy Procedia,* Bd. 77, pp. 592-598, 2015.

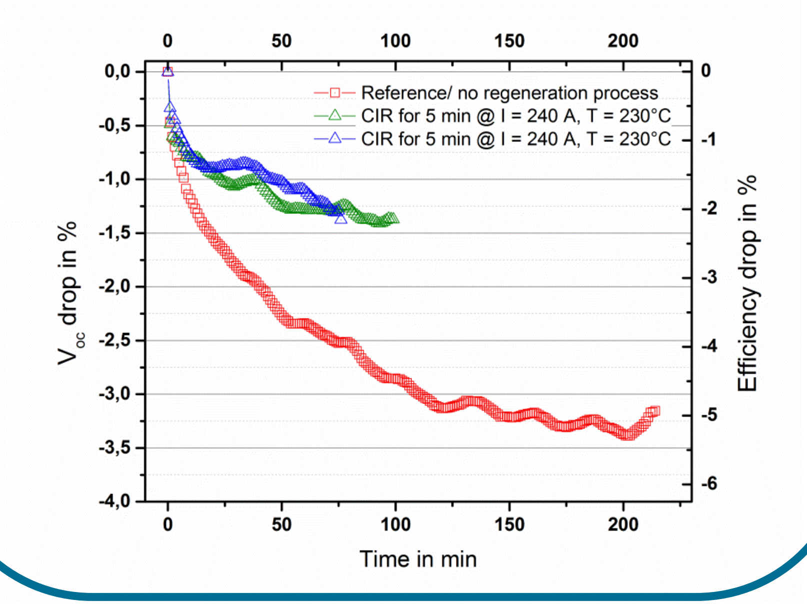
Application of CIR on cell and module level

Proof of concept

- **First experimental investigations by applying CIR processes and subsequent light soaking with 1 sun equivalent at 65 °C**

CIR on cell level

- Development of regeneration tool
  - Up to I = 340 A and T = 300°C
  - In-situ process control via Suns-Voc measurments



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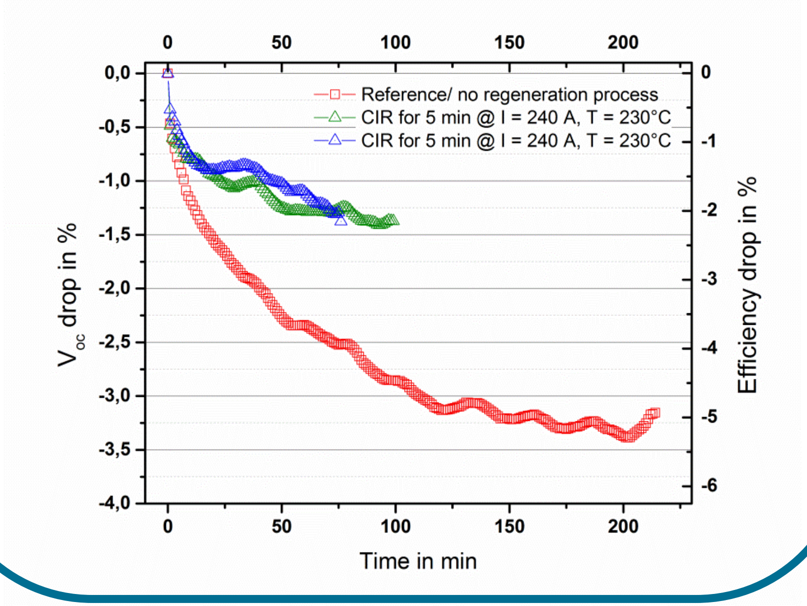
Application on cell and module level

Proof of concept

- **First experimental investigations by applying CIR processes and subsequent light soaking with 1 sun equivalent at 65 °C**

CIR on cell level

50 % less LID!!!



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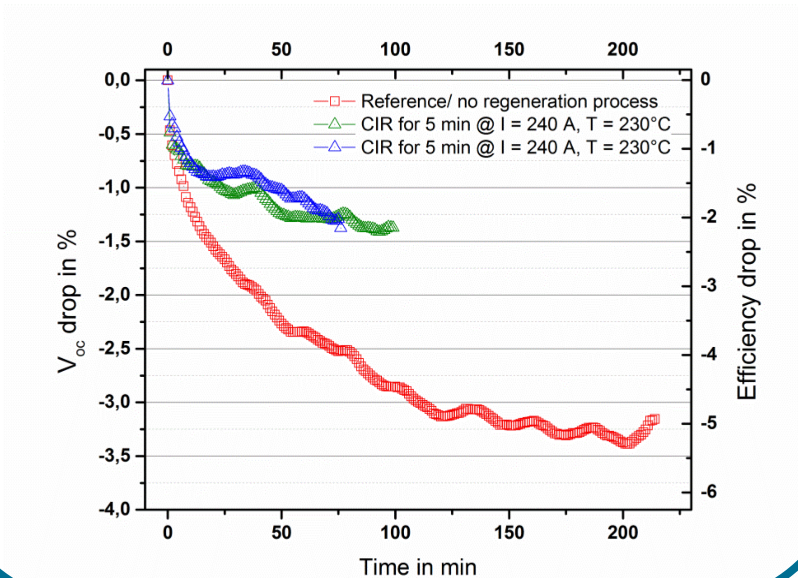
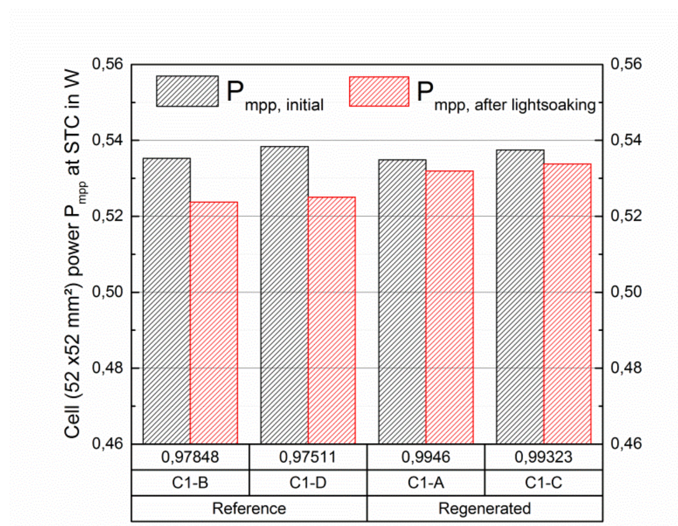


CIR on module level

- Experimental simulation of „biased lamination“ on mini solar cells (52x52 mm²) via LIDScope
- I = 30 A/full cell, T = 155°C, t = 15 min



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Application on cell and module level
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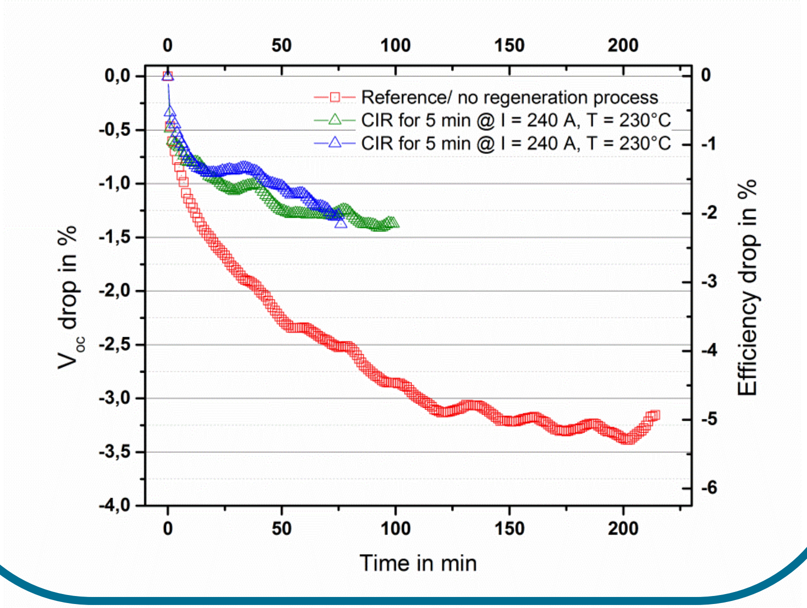
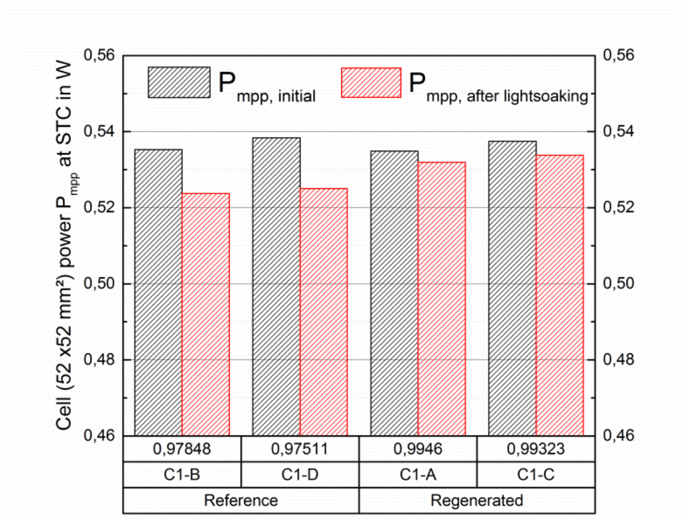


CIR on module level

Efficiency gain of 2 %!!!



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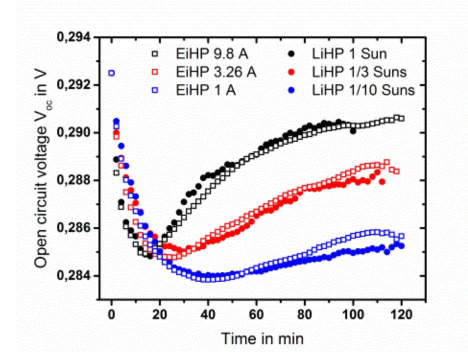
Summary

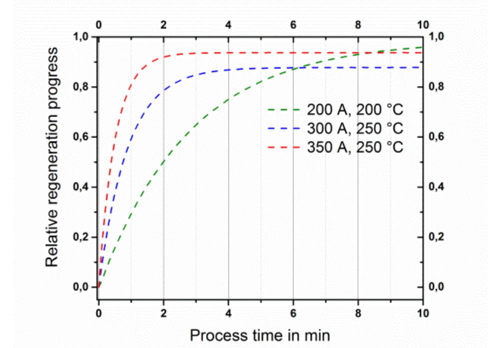
1. Similar kinetic behaviour of LIR and CIR

   → **Current induced regeneration as alternative** for implementation of efficiency stabilization on cell and module level



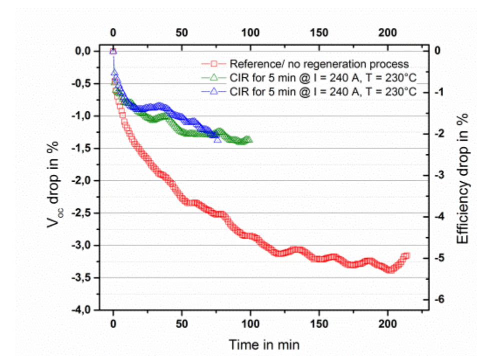
2. **Mathematical description** of transient defect concentration

   →Model for preliminary investigations of process design



3. **Tools for experimental investigations**

   → **Proof of concept** of current induced regeneration **CIR** on **cell and module level**



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