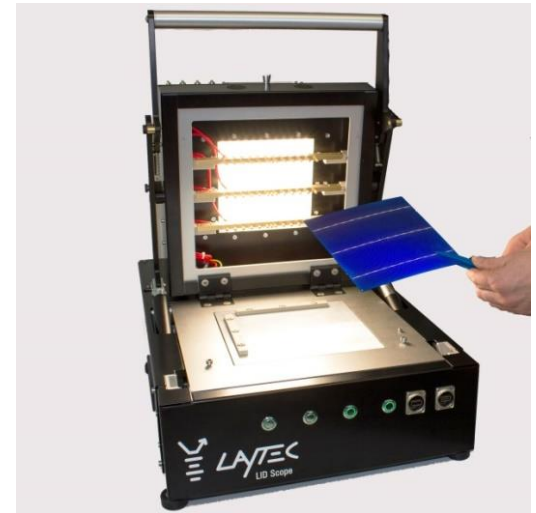


# An Accelerated Quality Control for Light-Induced Degradation (LID) on solar cell level

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Dominik Lausch

## Aim:

Introduction of an accelerated, reliable LID test based on experimental and modelling results.



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# Content

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- Important fundamentals
- Comparison of electrical and light induced degradation
- Introduction of an accelerated LID Test
  - LID Scope
  - Reproducibility and reliability
  - Accelerated LID Test and Measurement examples
- Conclusion

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# Content

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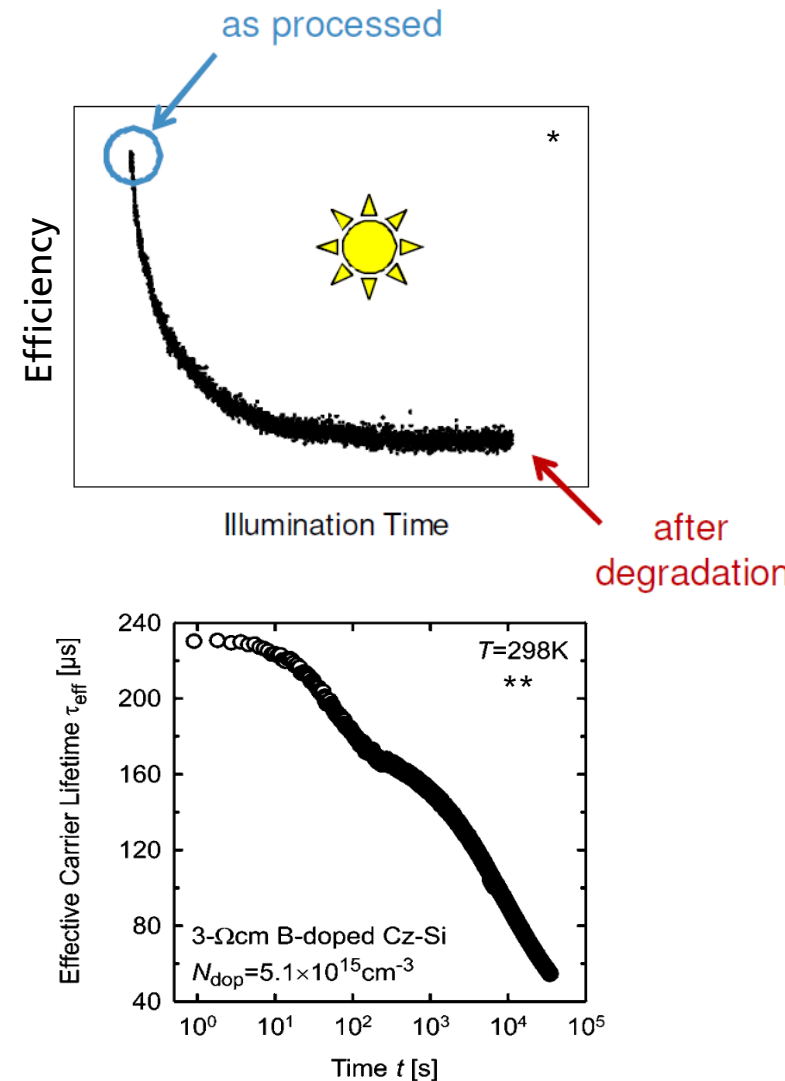
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# What is Light-Induced Degradation (LID)?

## How is LID characterized:

- LID = Loss of module power output under illumination
- Various types of LID in
  - Thin Film Technology
  - Silicon Solar Cells
  - Module Components
- Most common LID in silicon solar cells
  - decrease of lifetime by formation of recombination active defects

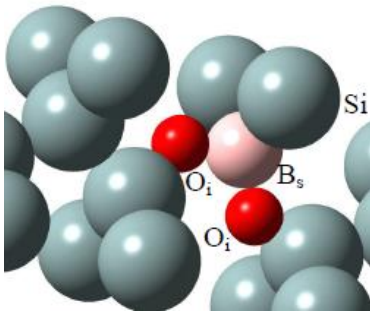
**LID threatens business case of solar parks → Important to prevent or control LID effect!**



# Different Types of LID on Silicon Solar Cell Level

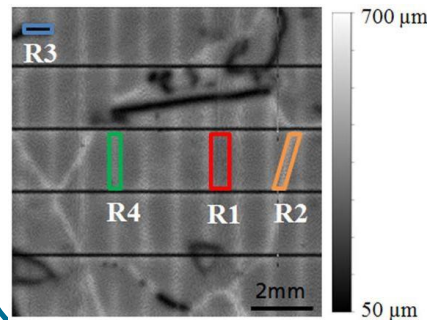
## B-O LID<sup>1</sup>

- B-doped CZ mono-Si
- complexes:  $B_5O_{2i}$ , ...
- ~ 5–10 % rel.



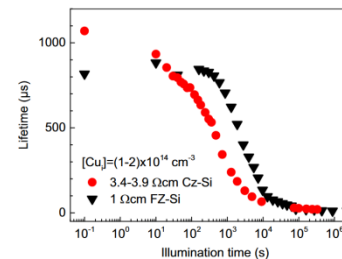
## LeTID<sup>2</sup>

- PERC techn. on mc-Si
- complexes: unknown
- ~ 5-20 % rel.



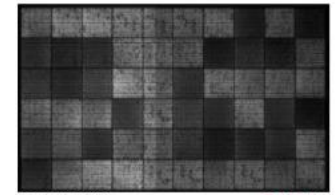
## Contam. of mc-Si<sup>4</sup>

- mc-Si
- complexes: metals, unknown



## Further

- all solar cell concepts
- complexes: unknown

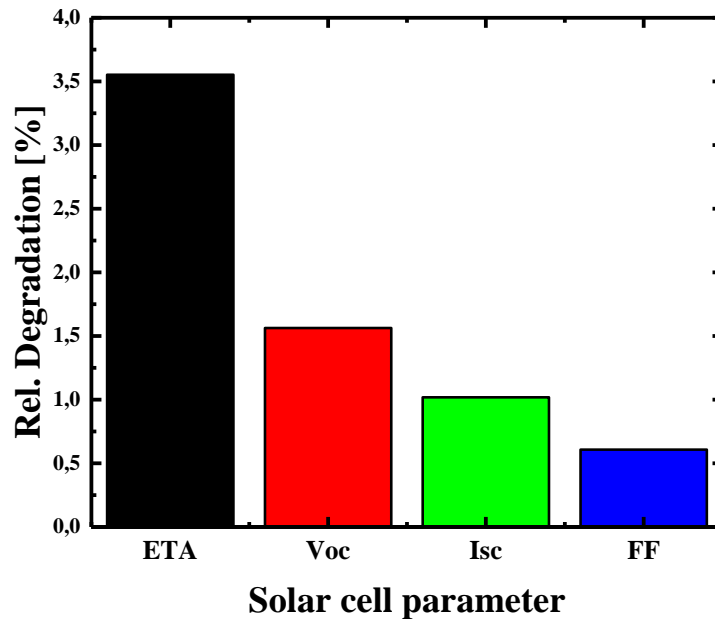


LID effects traced back on solar cell level → Test of Solar Cells!

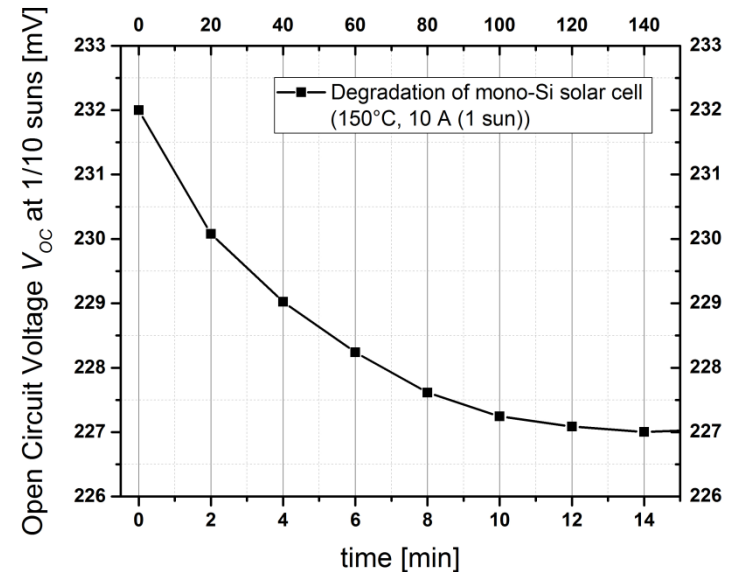
5 [1] K. Bothe and J. Schmidt, J. Appl. Phys. 99, 013701 (2006)  
[2] T. Luka et al., to be published in Solar Energy Materials and Solar Cells  
[3] Lindroos, J. et al., Solar Energy Materials and Solar Cells, V. 147, pp. 115–126.

# How to measure/quantify LID

## ■ All Parameters decrease\*

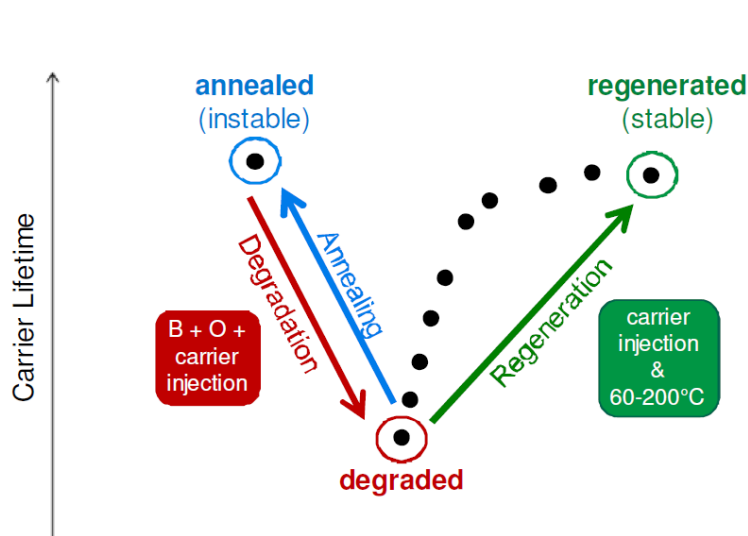


## ■ Voc used to quantify LID

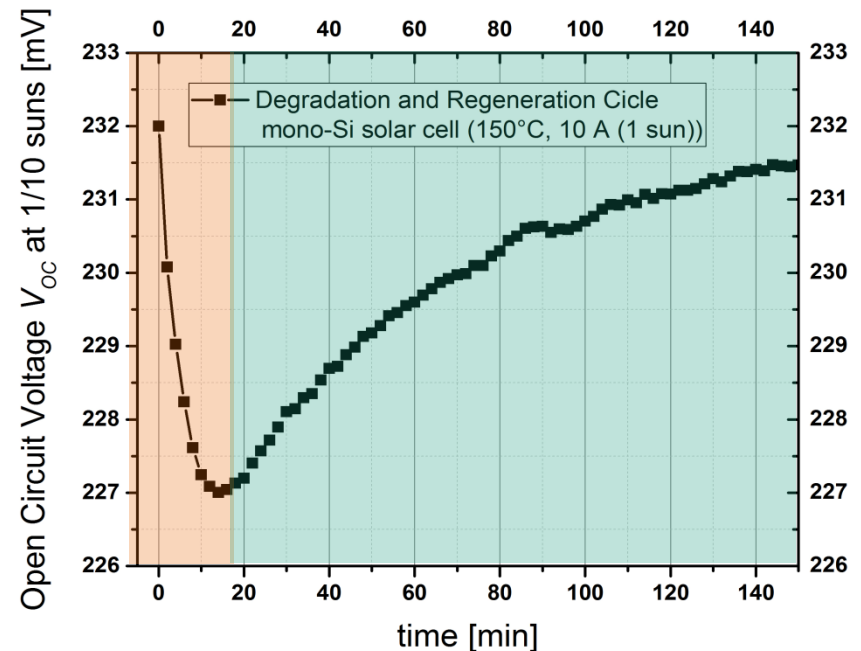


$V_{oc}$  used to quantify degradation → Decreased  $V_{oc}$  indicates LID!

# The Degradation- and Regeneration Cycle

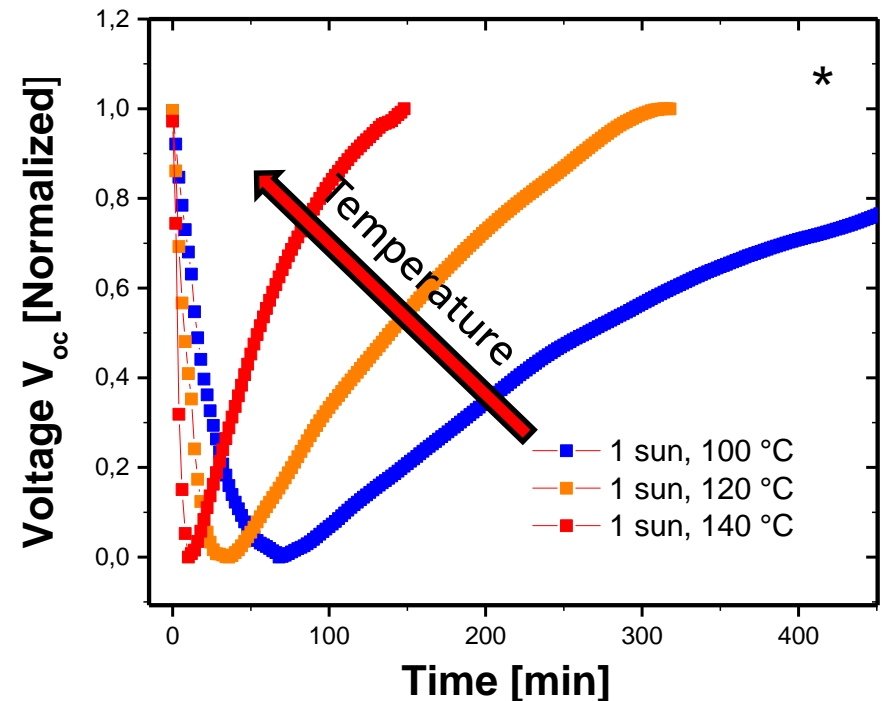
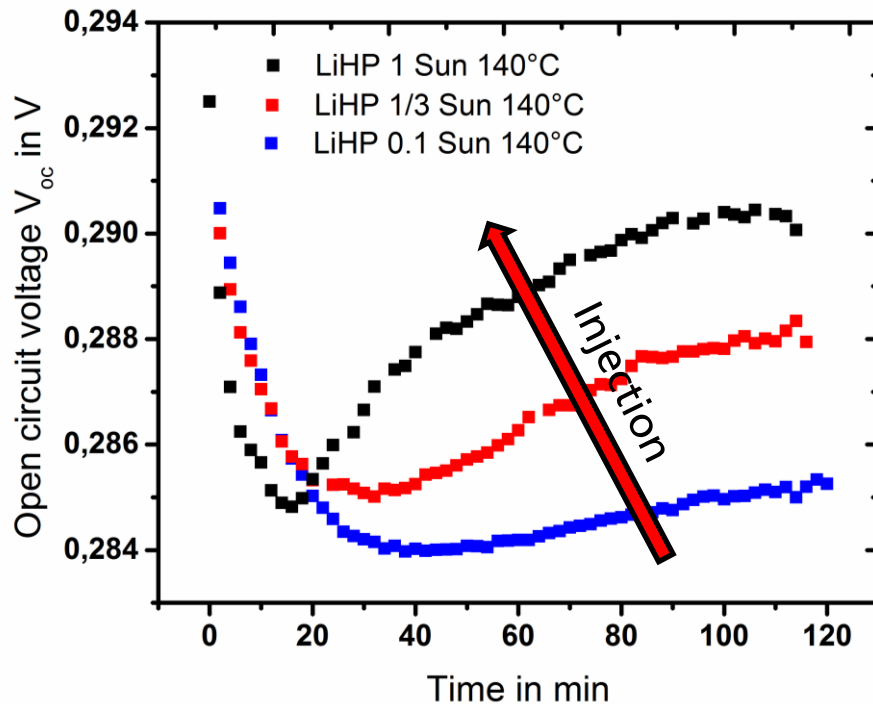


Graph after: Herguth et al., Proc. 32nd IEEE PVSC (2006) 940.



- **Degradation:** Formation of recombination active defects due to light  
→ decrease of carrier lifetime → decrease of  $V_{oc}$
- **Regeneration:** Formation of inactive (passivated – likely by H) defects of formed complexes
- Process takes place simultaneously

# Influence of Temp. and Injection on the Degradation



Degradation and Regeneration influenced by:

- Injection: higher  $\rightarrow$  shorter cycle time
- Temperature: higher  $\rightarrow$  significant shorter cycle time



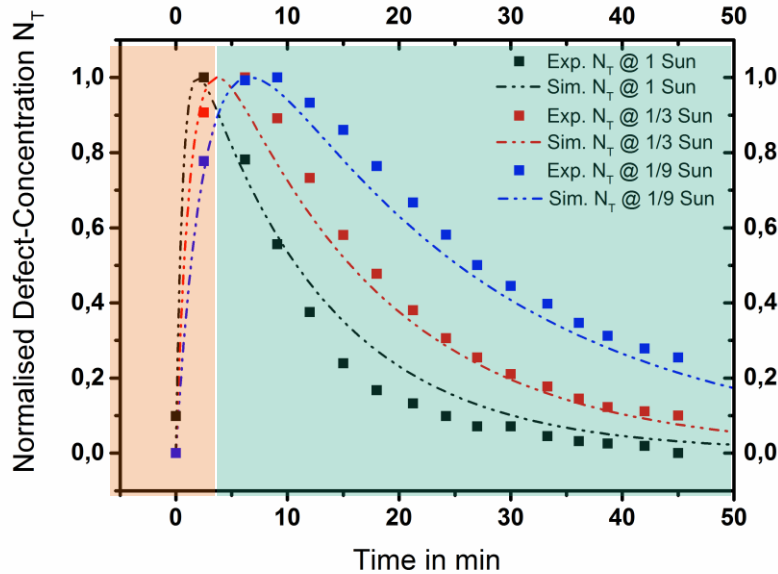
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# Modeling of the degradation and regeneration cycle



Injection of electron and holes by forward bias?

■ Model based on:

■ Chemical reactions:



■ Semiconductor physics

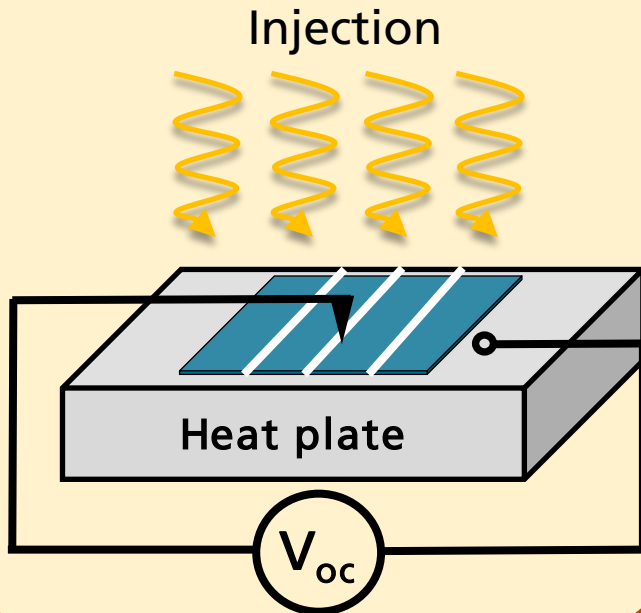
■ Influence of light: Occupancy ratio  $\alpha$  for determining amount of  $H^0$

$$\alpha = \frac{K * n_1 + p}{K * n + p_1}$$

■ Electrons and holes only parameters influenced by light (based on model)

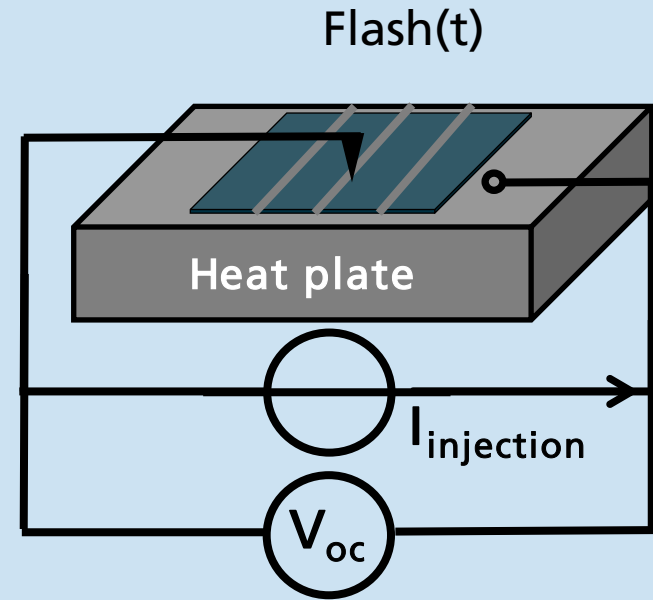
# Experimental setup

## ■ Light induced LID



VS

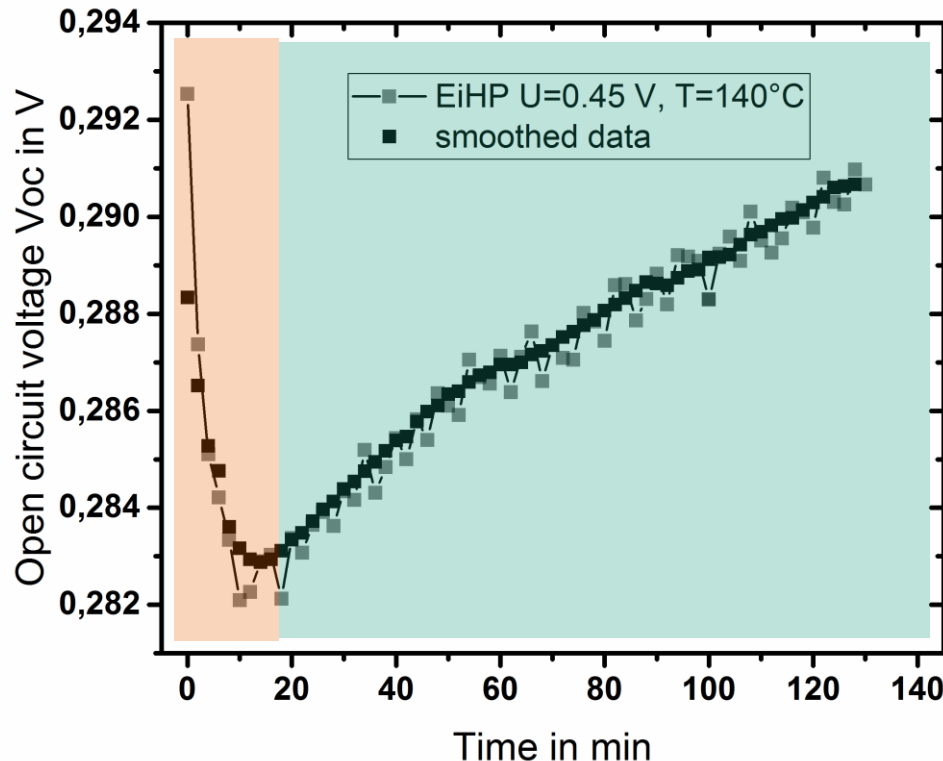
## ■ Electrically induced LID



**Comparison of light and electrical induced degradation!**

# Electrically induced Degradation and Regeneration

- Forward biased standard cz-p-type solar cell without illumination



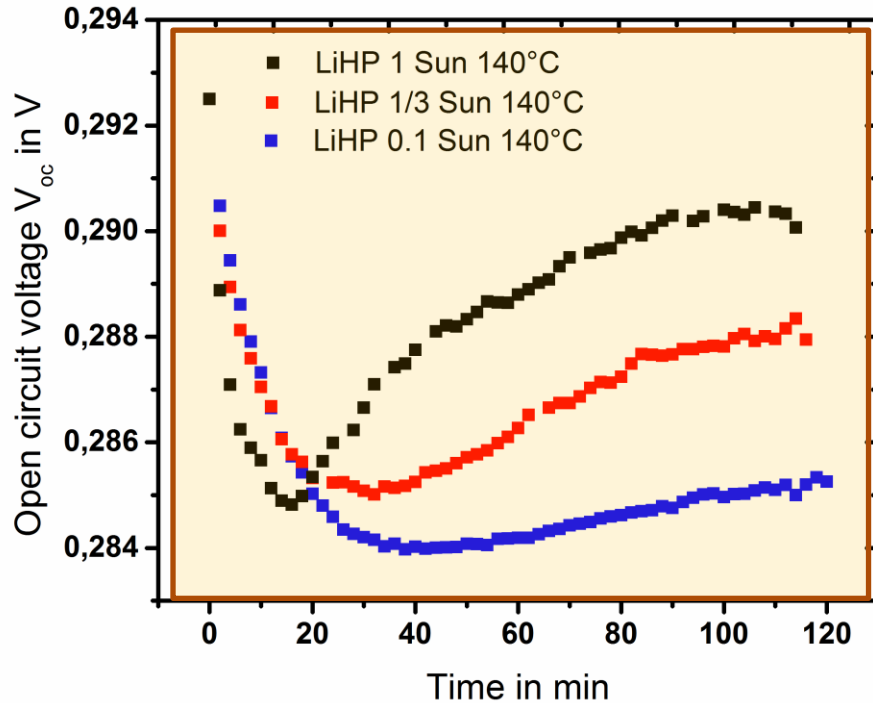
- In situ measurement of  $V_{oc}$ 
  - Low  $V_{oc}$  because of high temperature
  - Oscillating  $V_{oc}$  caused by T-oscillation can be neglected

**Electrically induced degradation is possible!**

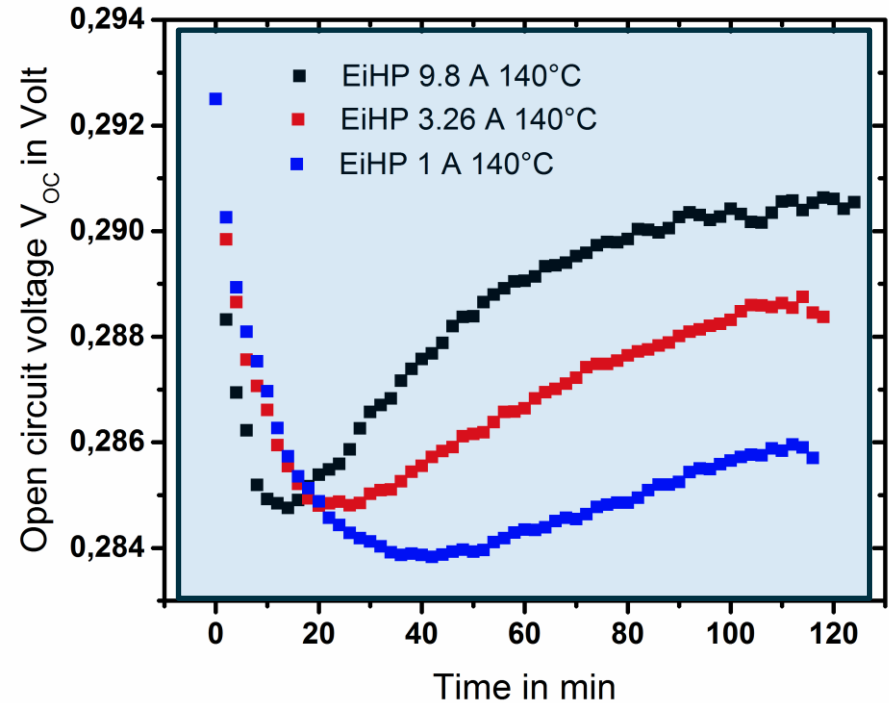
<sup>12</sup> [\*] also shown by diverse authors i.e. Münzer et al.

# Correlation of light vs. electrical induced degradation

## Light induced



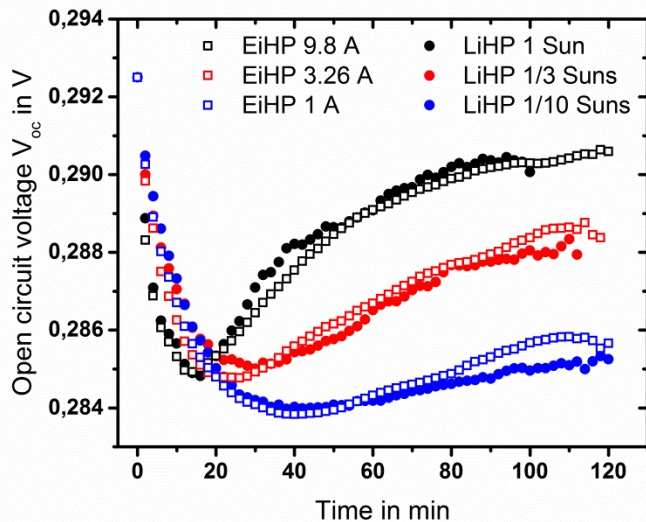
## Electrical induced



**Light and electrical induced degradation identical!**

**→ Physical mechanism based on carrier injection!**

# Correlation of light vs. electrically induced degradation



- Using same injection conditions  $I_{sc} = I_F$   
→ same kinetic behaviour
- Small deviations due to different samples (variation of B, O, H in bulk)

Electrical injection = Sun

## Development of measurement procedure based on electrical injection:

1. Easy and flexible control of „illumination“
2. Flexible and independent choice of temperature and injection
3. Compact design possible and easy to control
4. Accurate and correct injection control

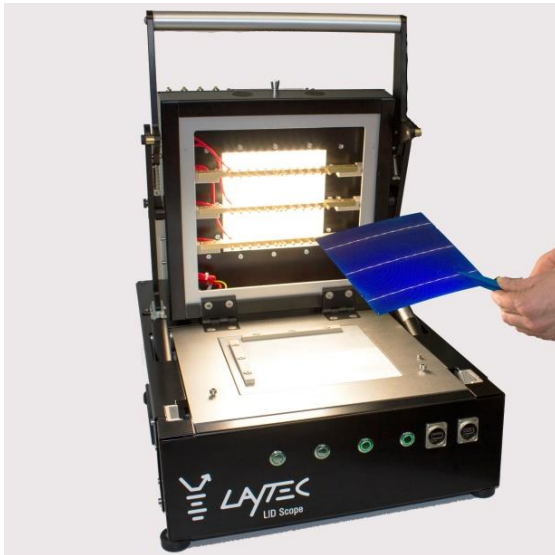
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-

# The LID Scope



## LID Scope test\*:

- Test of solar cells without module construction
  - Suitable for process control (simplified for operators, direct result)
  - Reliable and reproducible
- *cost effective and quick LID testing*



## Results:

- Benchmark for LID susceptibility
- In-situ recording of  $U_{oc}$
- Free choice of parameters (temperature and injection)



# LID Scope commercial available



## LID Scope

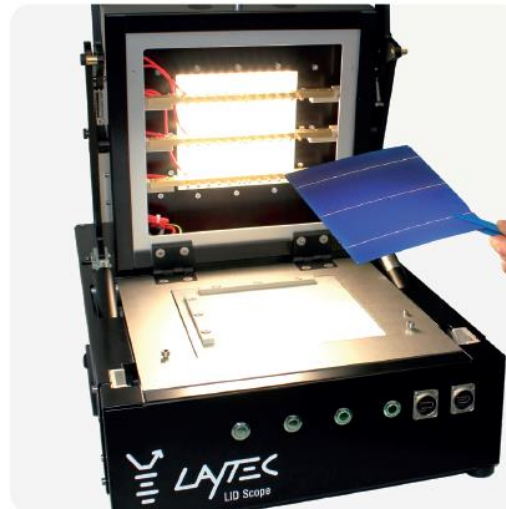
Monitoring of Light Induced Degradation (LID) effect in solar cells with ease!

LayTec offers the first easy-to-use, automated system that tests the LID effect for:

- quality control already on solar cell level
- production optimization
- tracking of material and process variations
- scientific investigation
- communication between companies

LID has a huge impact on cell efficiency and is the dominating cell defect in current cell technologies with direct impact on €/W.

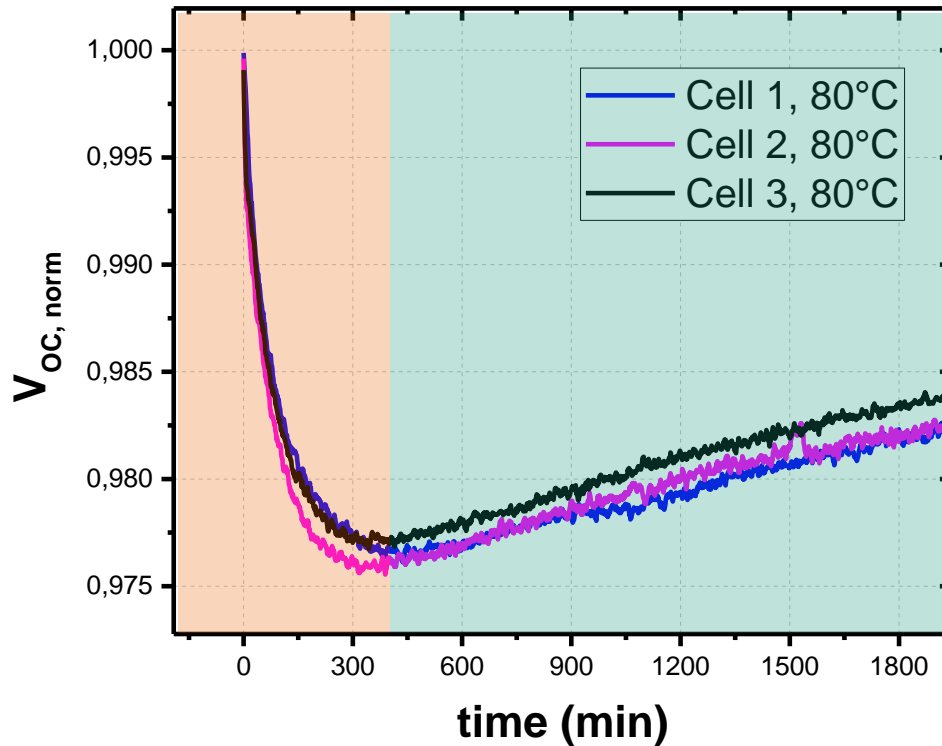
LID Scope quantifies the efficiency loss of any solar cell within minutes! The tool performs accelerated or real-life degradation tests fully automatically. It delivers highly reproducible results and a permanent monitoring of  $V_{oc}$  changes by integrated metrology. These features make the tool an inevitable part of quality control and production optimization in PV industry.



LID Scope table-top system

- LID Scope commercial available by LayTec Inline GmbH
- For more information see Both E3-550

# Reproducibility and Reliability

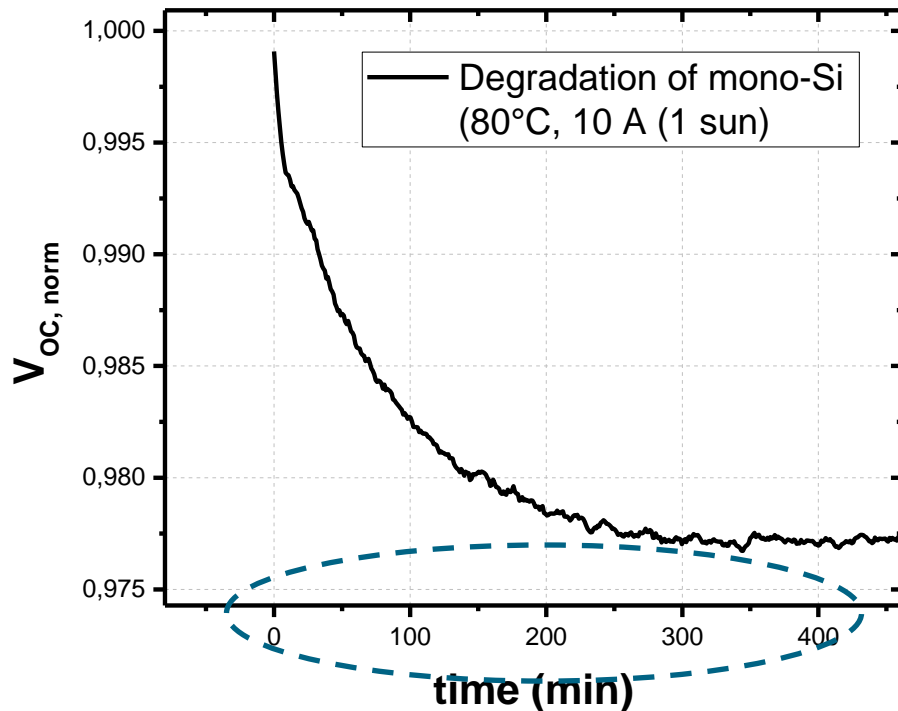


- Reproducibility test with 3 solar cells from one manufacturer
- Deviations caused by different solar cell characteristics i.e. O, B content, SiN layer, ...

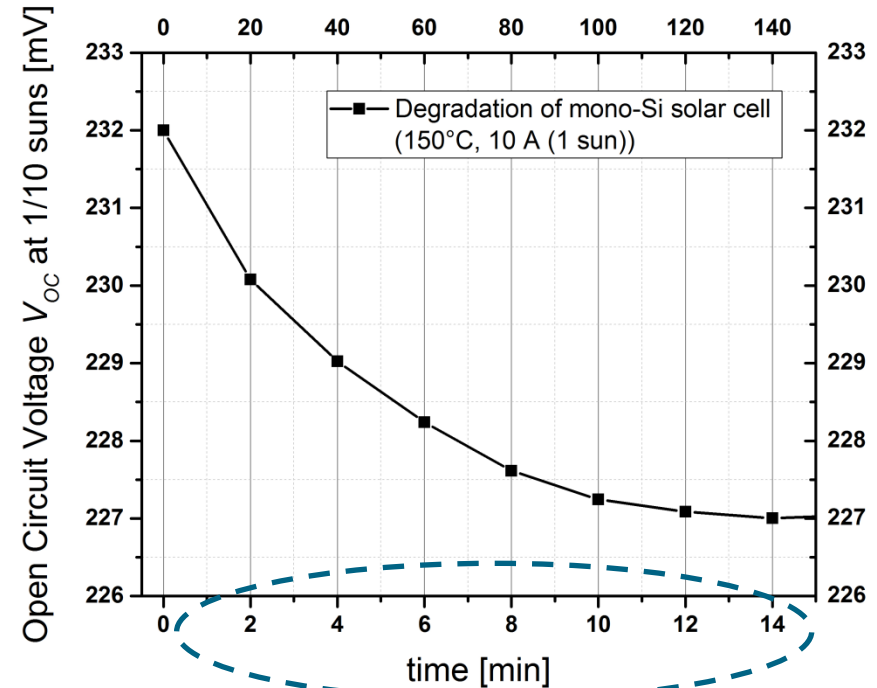
➔ Solar cell tests using LID Scope reproducible and reliable!

# Accelerated LID Test

## Test at 80 °C



## Test at 150 °C

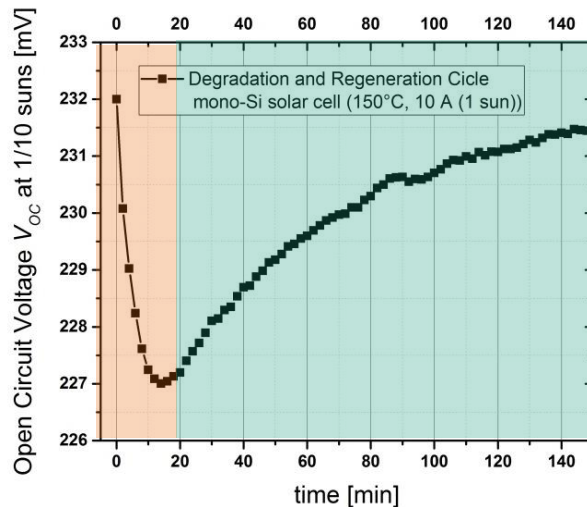


→ Quick Test: Test duration can be significant reduced by increased temperature!

# Measurement Examples

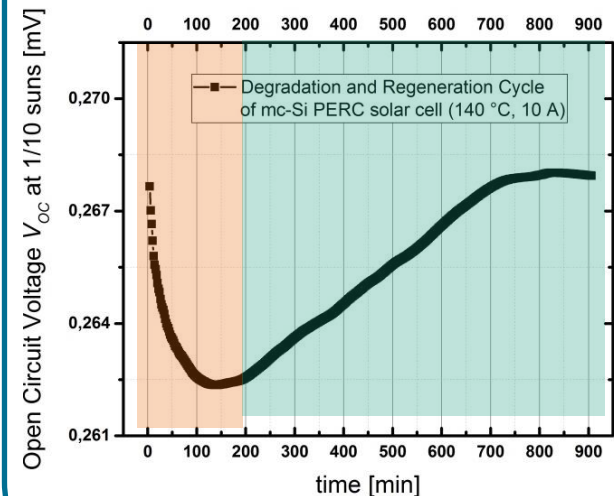
## B-O LID<sup>1</sup>

➤ mono-Si



## LeTID<sup>2</sup>

➤ PERC techn. on mc-Si



➔ LID test can be applied independent on the degradation mechanism!

# Conclusion/Summary

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## Summary:

1. Light and electrically induced Degradation identical!
2. Accelerated test (LID Scope) is a reliable and reproducible for testing solar cells LID characteristic!
3. Accelerated test (LID Scope) can be applied to all types of LID and solar cell concepts

## Outlook

1. Procedure to predict efficiency loss
2. Quantitative comparison with module tests