Evaluating the Extend of Light-induced Degradation and Regeneration by Electrical Induced Charge Carriers

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Knowledge is key

Outline

- Introduction: Tackling LID
- The degradation-regeneration cycle
- LID Scope for reliable and fast LID testing
  - Working principles
  - Application examples
  - SEMI standard
- Summary

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LID threatens business case

- Efficiency loss caused by LID: 3 - 20 %, relative
- e.g. 200 MW Fab → 6 MW lost (3 %)

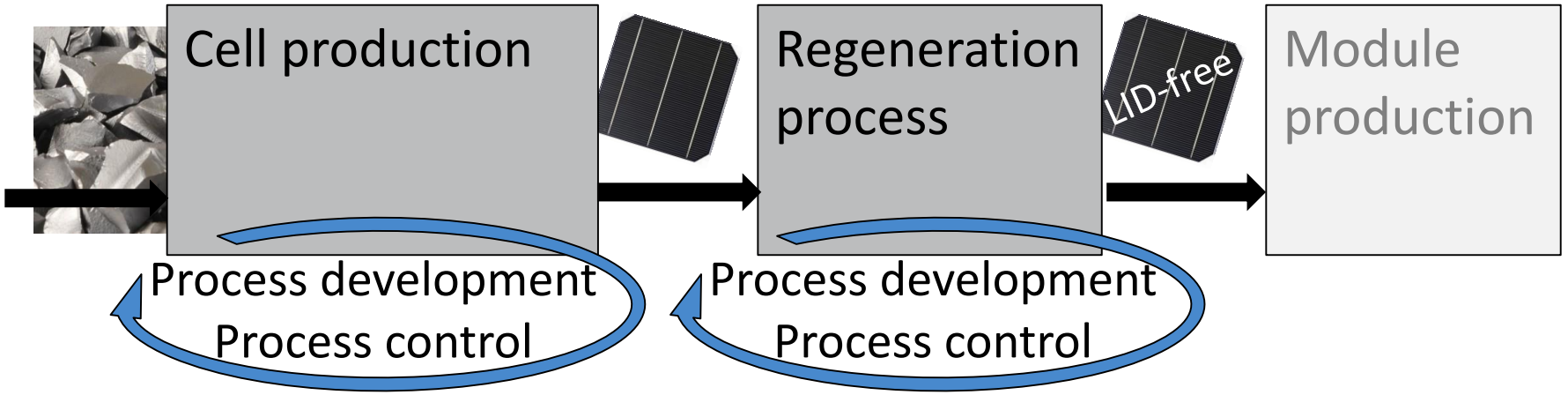
  → $2.3 Mio/a loss of revenue due to LID ($ 0.38/Watt)

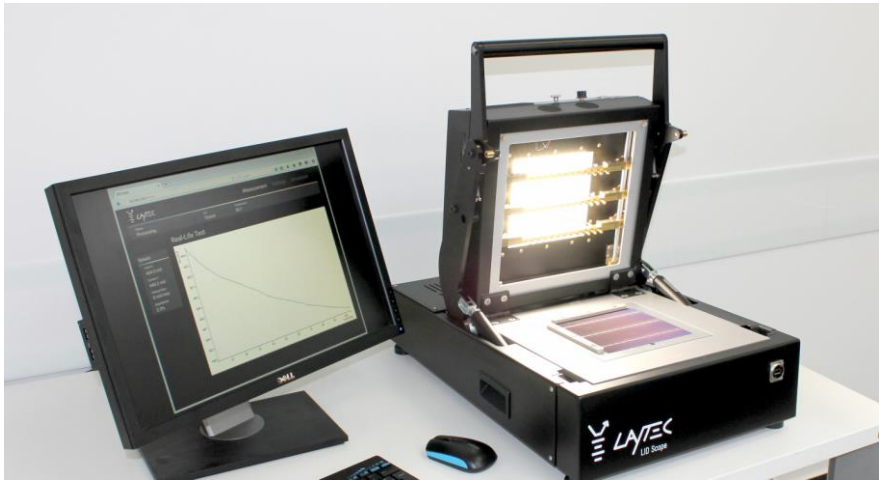
Germany's largest solar park- 166 MW (in Meuro and Schipkau)

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

LID must be tackled.

Production of LID-free solar cells requires LID testing





LID Scope

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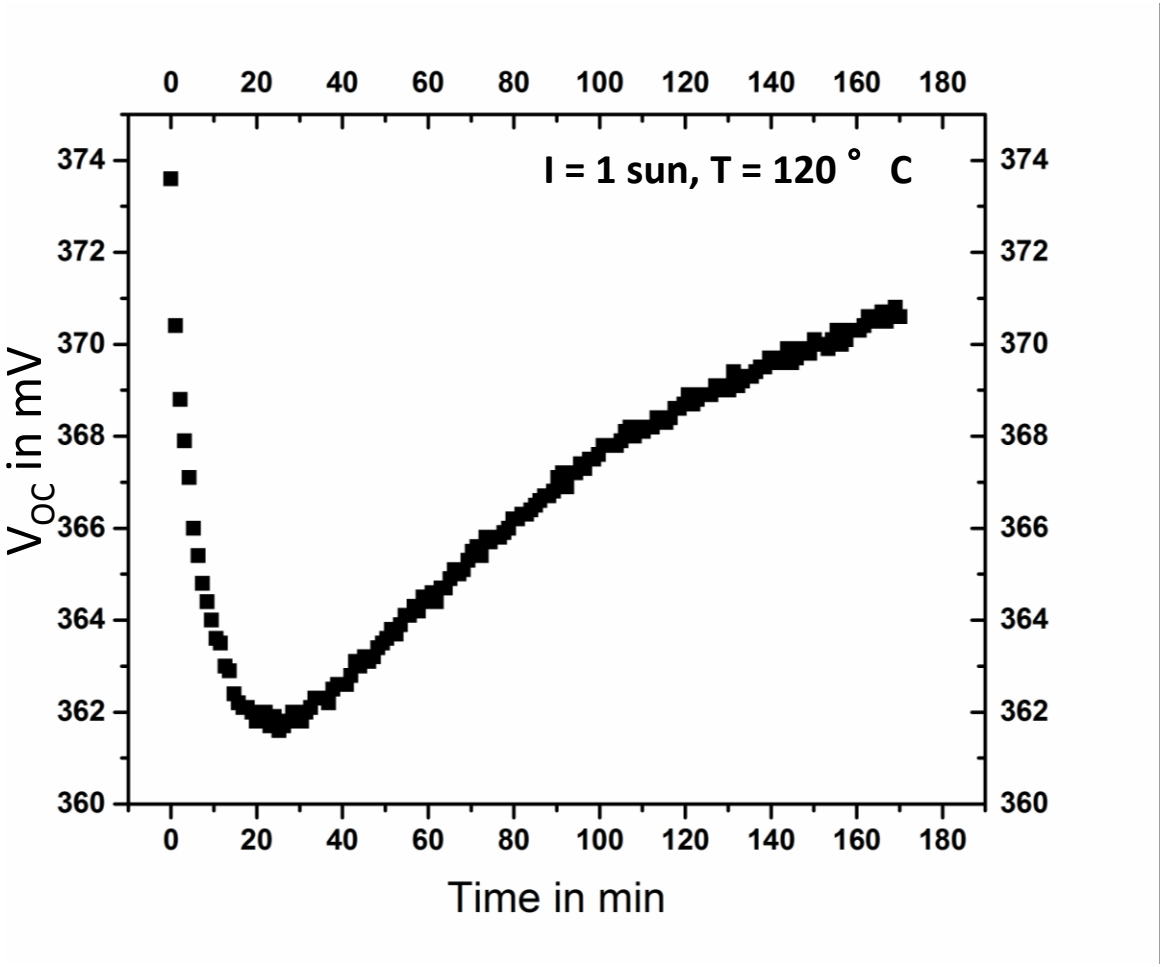
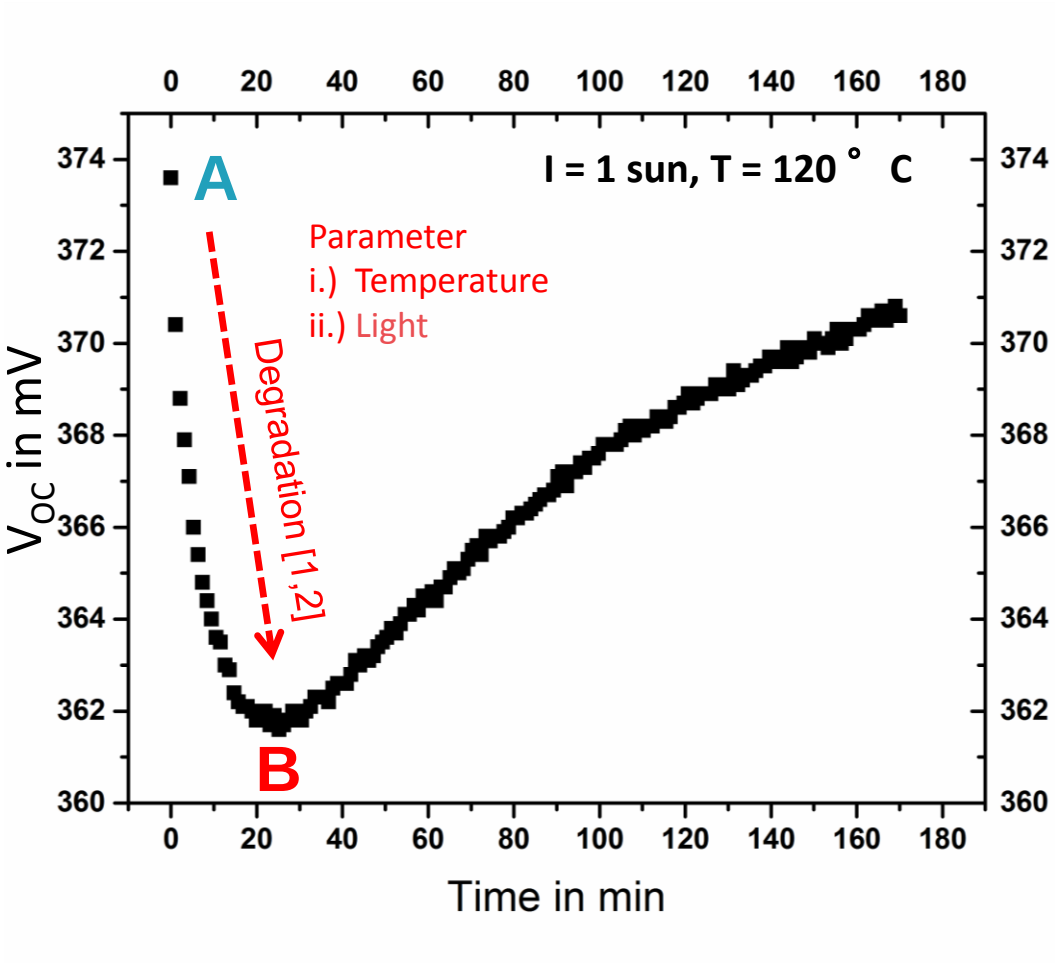
The Degradation-Regeneration Cycle



Degradation

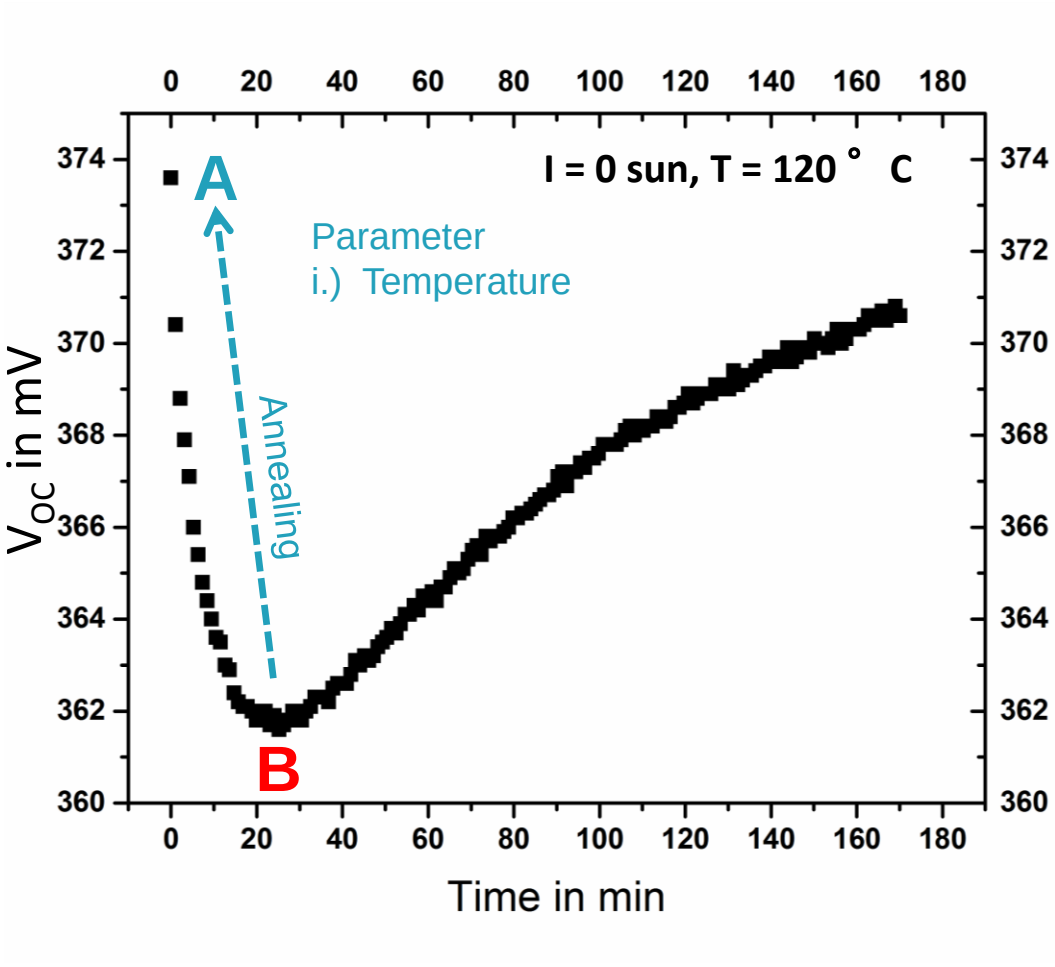


Degradation:
Defect formation
→ τ decreases

$defect_{inactive}$ + free carrier + light → $defect_{active}$

[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)

Annealing



Annealing:
Defect dissociation
→ τ increases

$defect_{inactive}$

↑

$defect_{active}$

Annealed state is unstable
→ will degrade again

[1] Schmidt, J et. al., 3rd World Conference on Photovoltaic Energy Conversion, Osaka, Japan, (2003)
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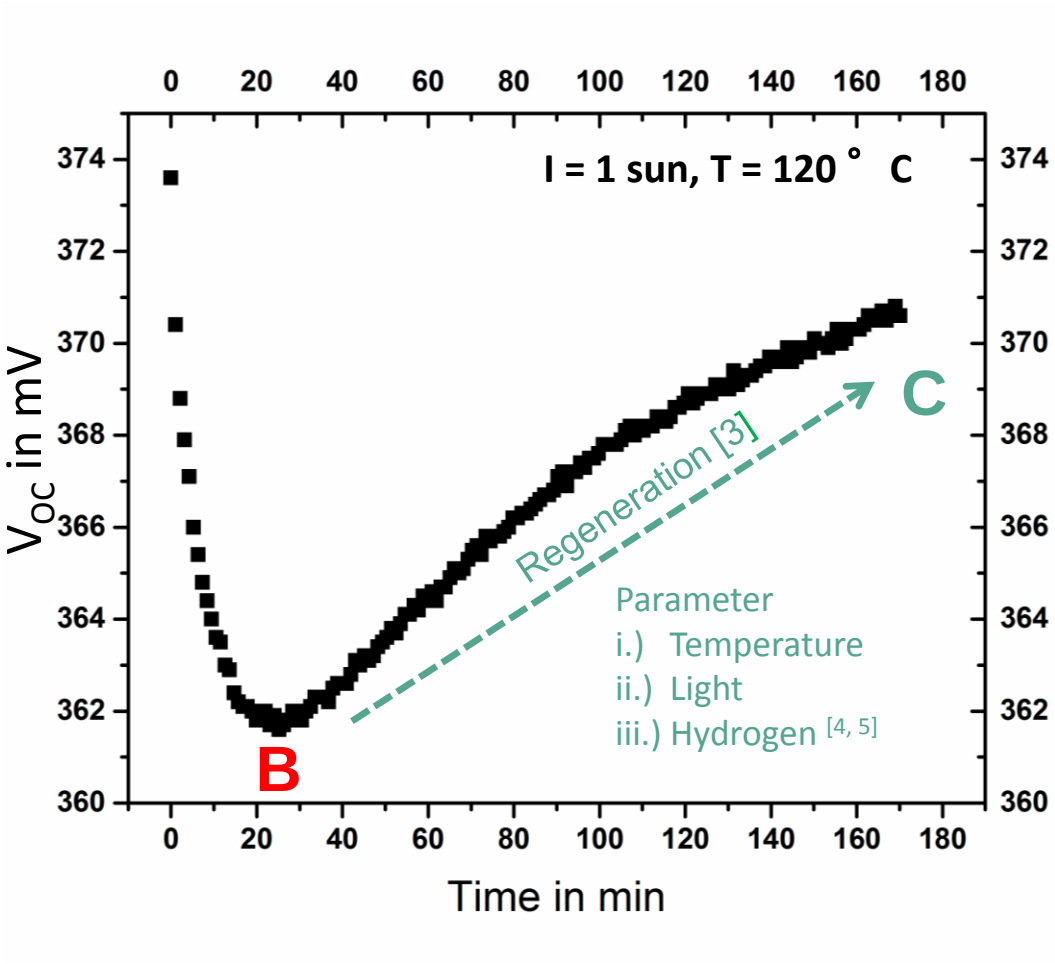
Regeneration Cycle



Regeneration:
Defects become inactive (passivated-likely by H)
→ τ increases

$defect_{active}$ + H + free carriers + light → $defect_{passivated}$

Regeneration → LID-free cells

[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)
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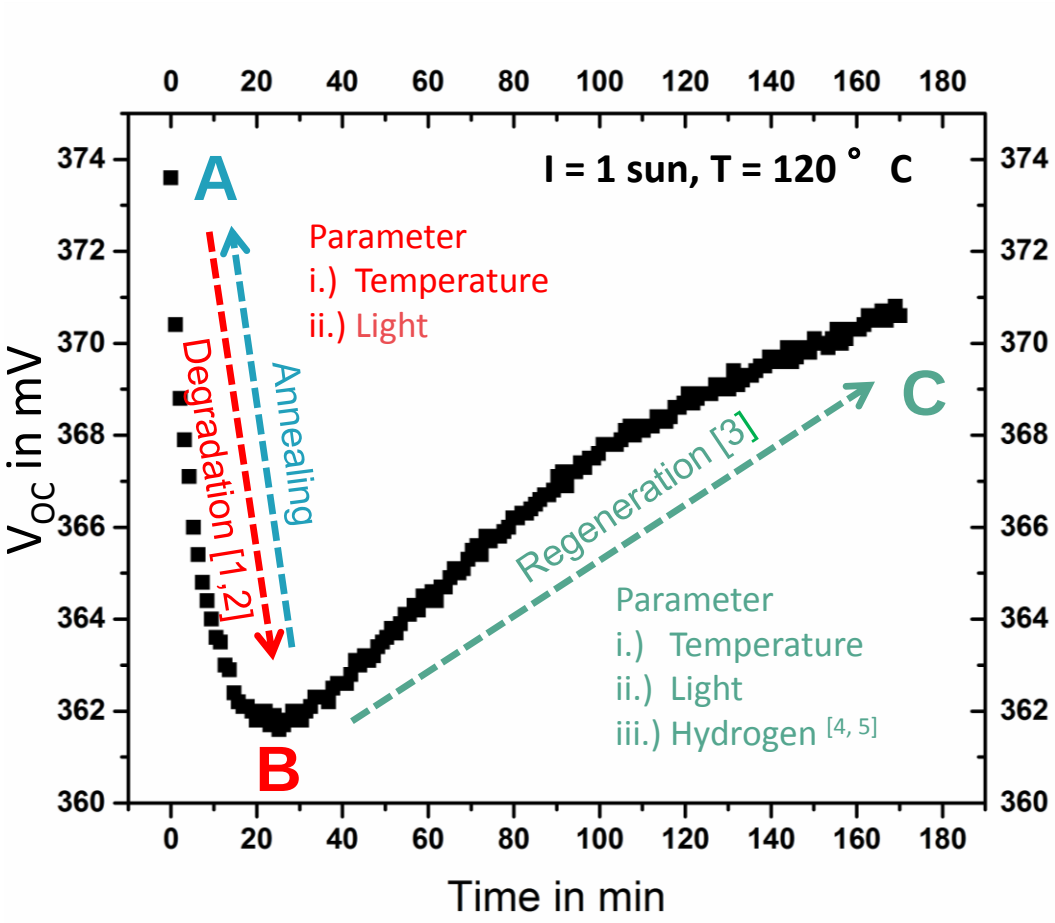
The Degradation-Regeneration Cycle



Degradation:
Defect formation
→ τ decreases

Annealing:
Defect dissociation
→ τ increases

Regeneration:
Defects become inactive (passivated-likely by H)
→ τ increases

Processes take place simultaneously!

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LID Scope

Electrically induced defect formation for best reproducibility

In-situ VOC monitoring for reliable tracking of LID

Low irradiance for maximum sensitivity for LID-susceptibility

High temperature for fast LID-test

LID Scope: reliable, reproducible, fast LID testing

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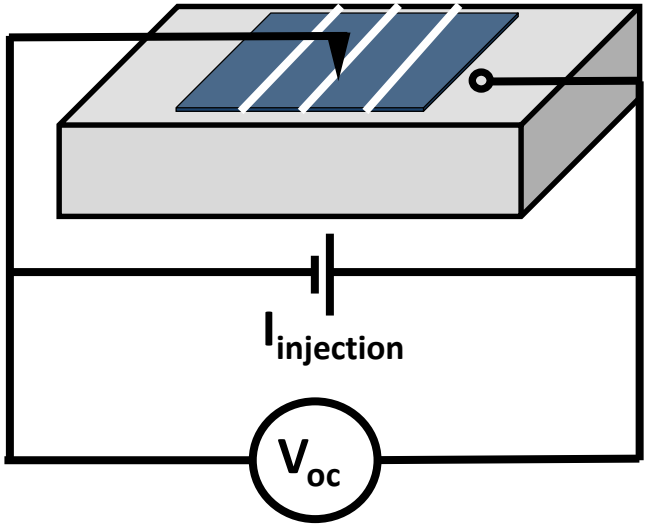
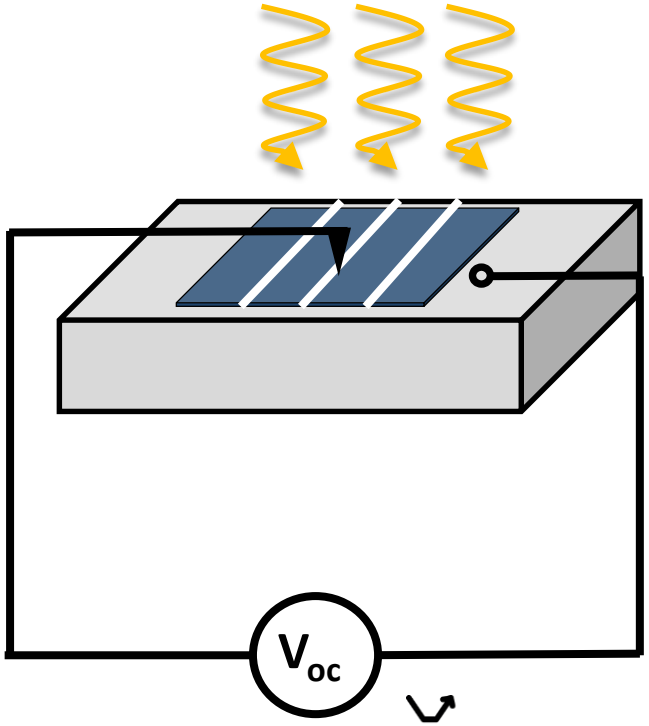
LID Scope: Electrically induced defect formation for best reproducibility

$defect_{inactive}$ + free carrier ⟶ $defect_{active}$

Electrically induced LID



Light induced LID



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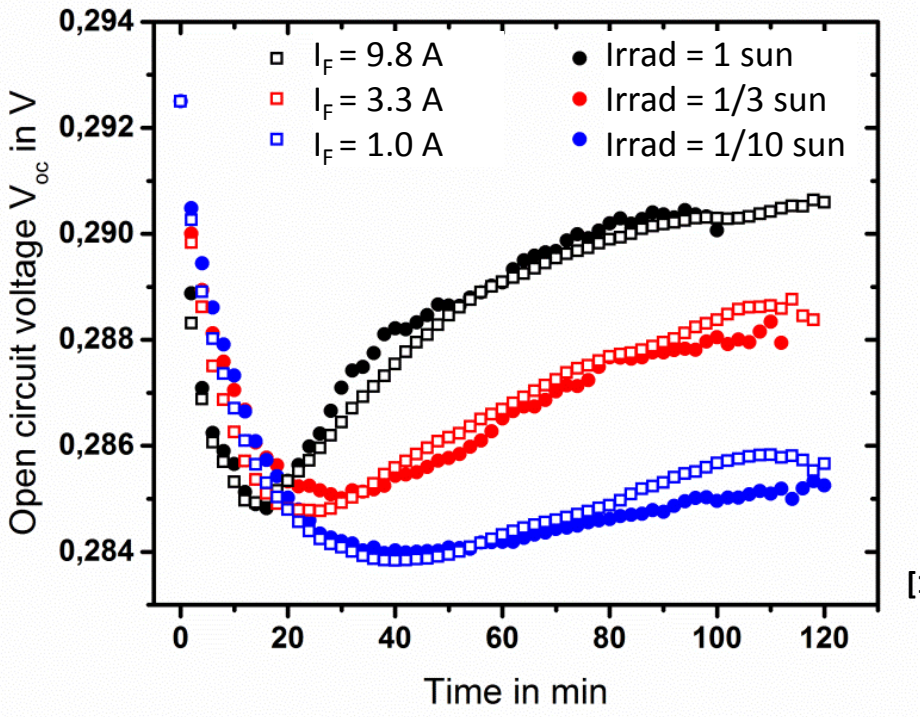
LID Scope: Electrically induced defect formation for best reproducibility



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

- Same injection conditions: $I_{sc} = I_{Forward}$
- Small deviations due to different contents of B, O, H
- Electrical carrier injection is
  - Easier to control
  - More robust
  - Low maintenance

[1]

Light and electrically induced degradation identical.
→ Confirmation: LID is driven by carrier injection.

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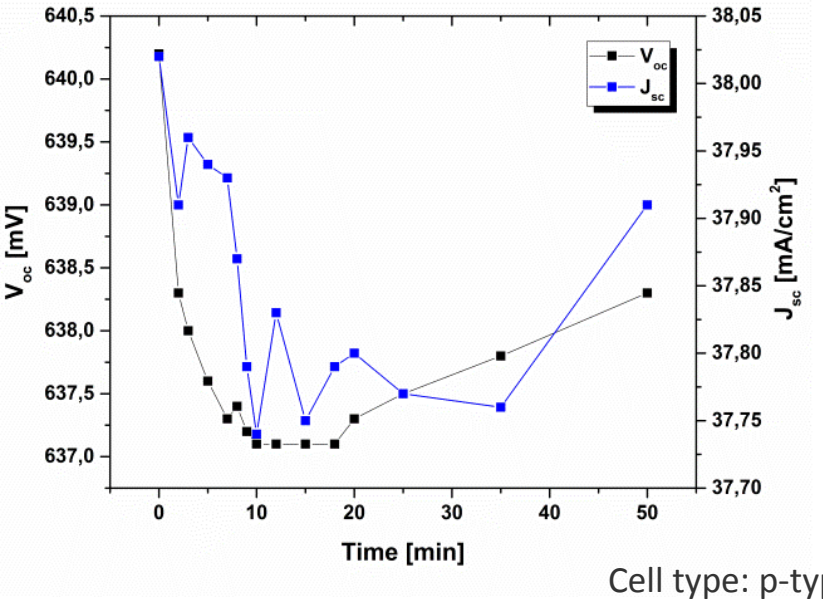
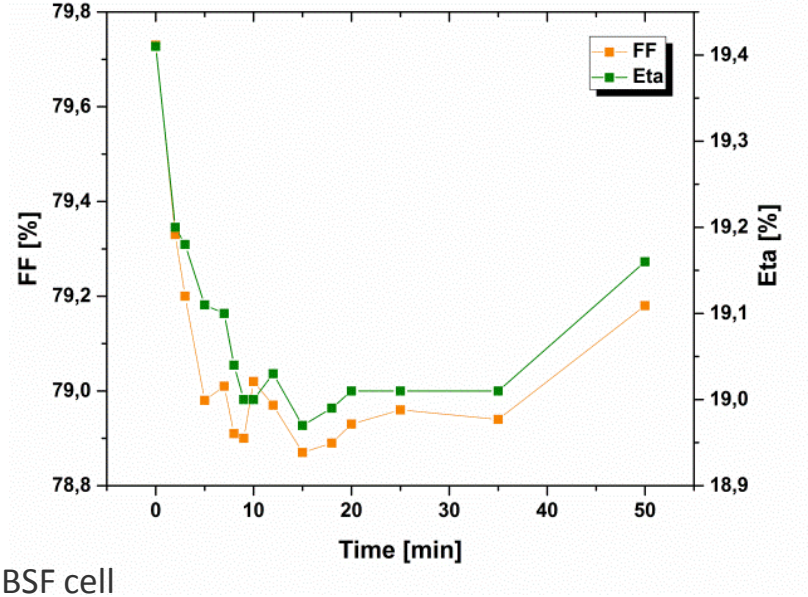
LID Scope: V_{OC} for reliable tracking of LID





Cell type: p-type Cz Al-BSF cell
Degradation condition: 140 °C, 1 sun

All electrical cell parameters suffer from LID.

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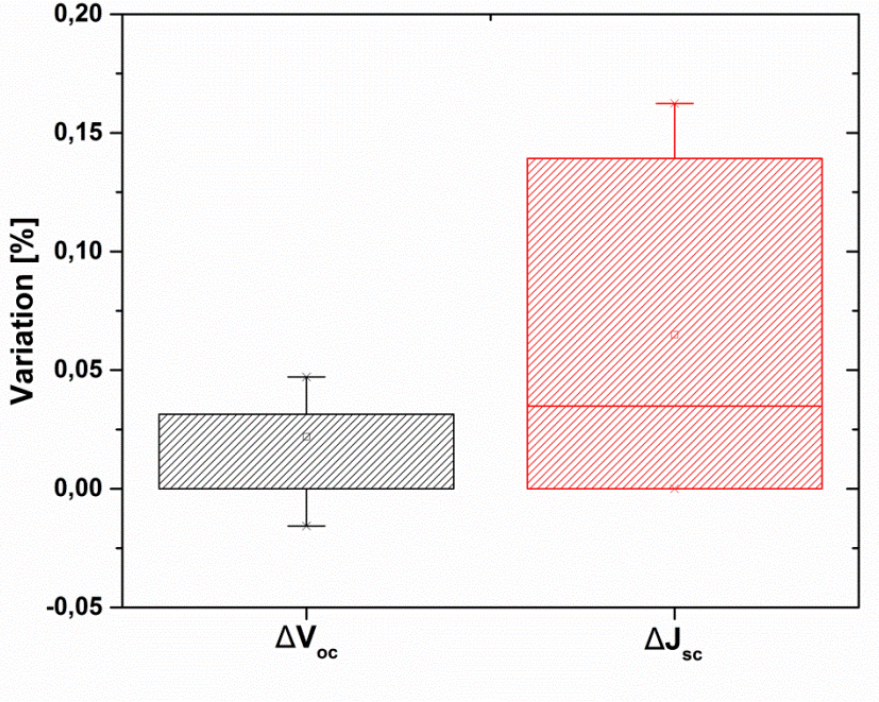
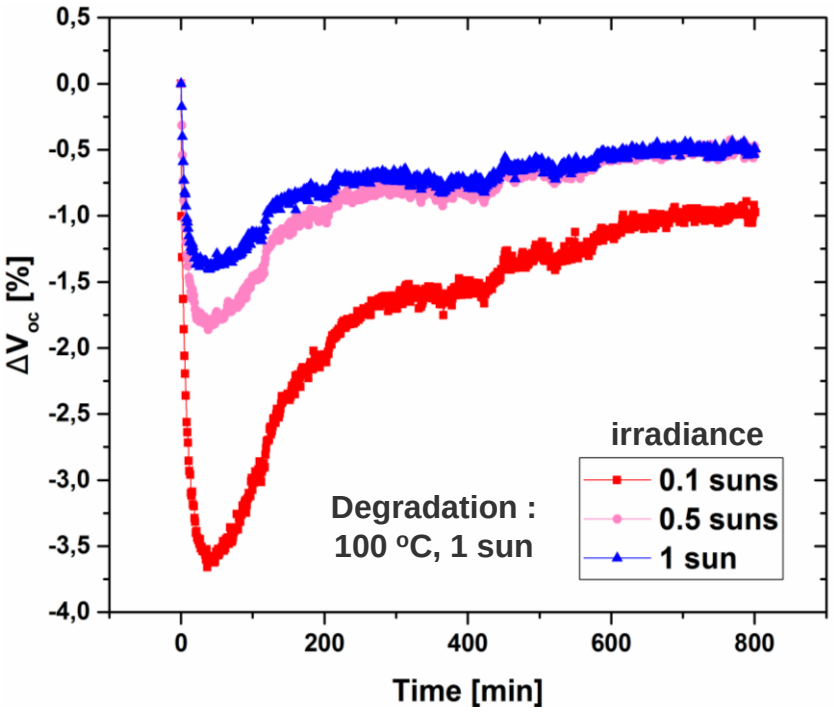
LID Scope: V_{OC} for reliable tracking of LID

- Repeatability test
- Large variation of I_{SC}



V_{oc} measurement is the most reliable for tracking LID.

LID Scope: Low irradiance for maximum sensitivity



- Defects are saturated by high carrier density

Sensitivity for LID-susceptibility is enhanced by lower irradiance.

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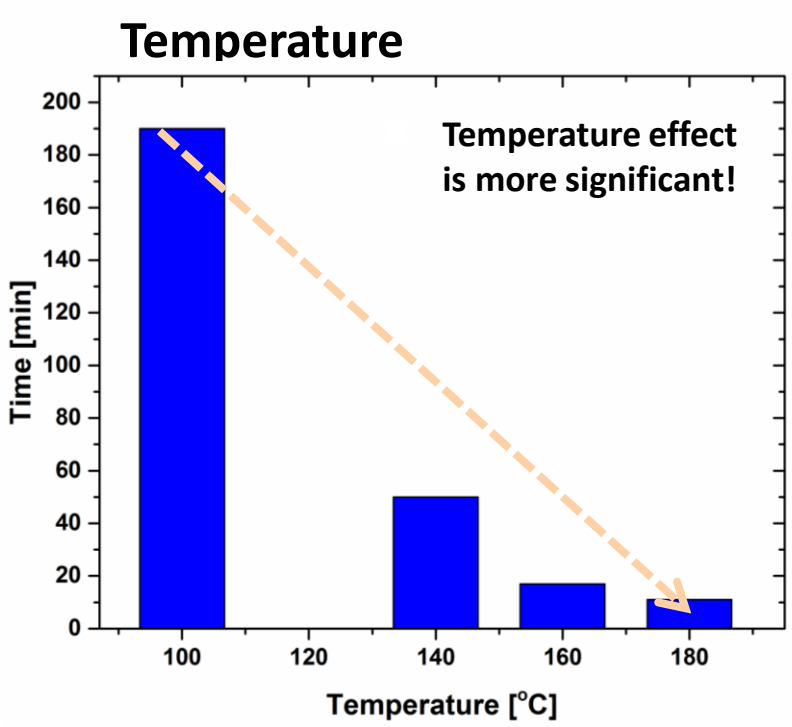
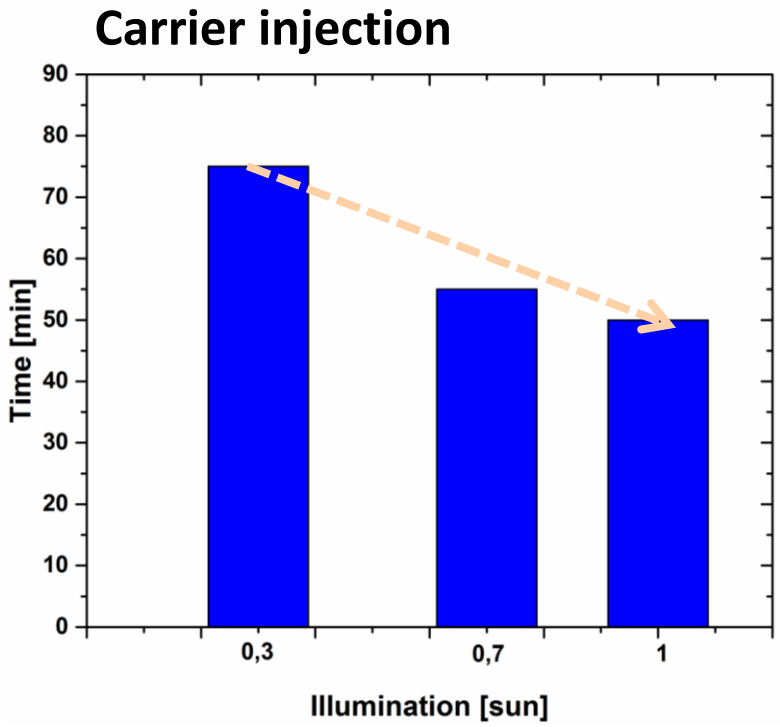
LID Scope: High temperature for fast LID-test





Reduction of test time by 98.5% (80 °C → 160 °C)
High temperature facilitates accelerated test.

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LID Scope: reliable, reproducible, fast LID testing

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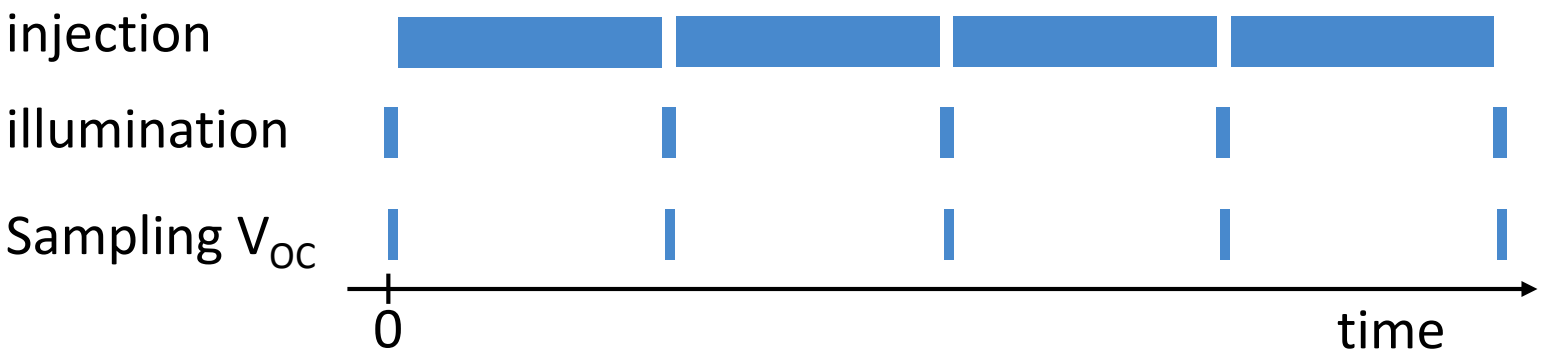
LID Scope: Timing



Features of LID Scope

- Test of solar cells without module construction → fast and cheap
- Free choice of parameters (see data sheet):
  - Temperature
  - Injection
  - Illumination for V_{OC} sampling
  - Timing
  - Termination conditions
- Suitable for process control
  - simplified mode for operators
  - direct results

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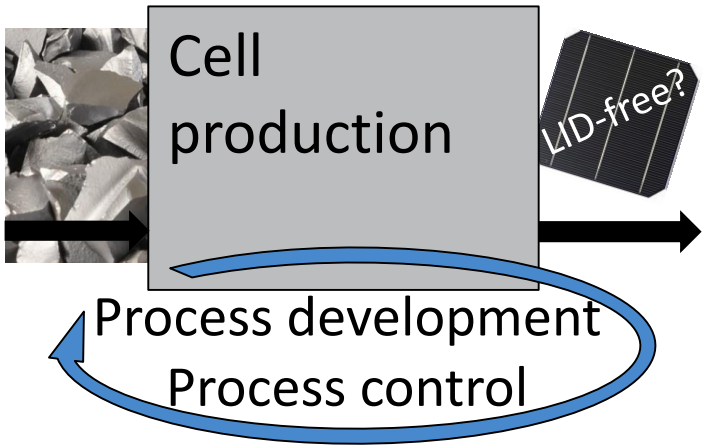
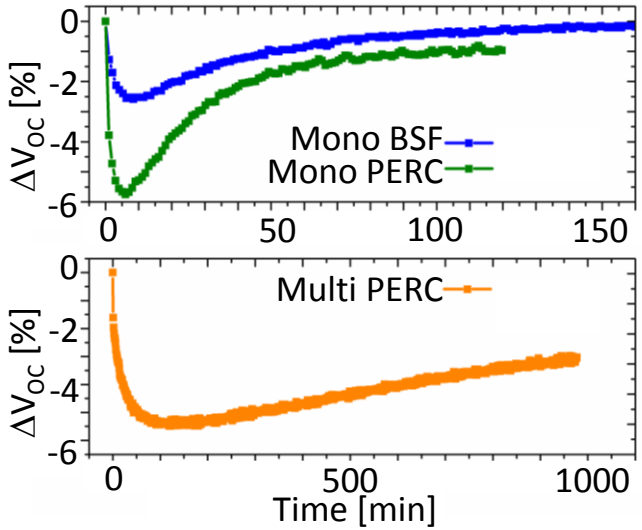
LID Scope: Application examples

- Assessment of regeneration process
- Different cell technologies
- LID test of mini module
- Quick Test vs. Field Conditions

Any more ideas? Try LID Scope at Fraunhofer CSP.





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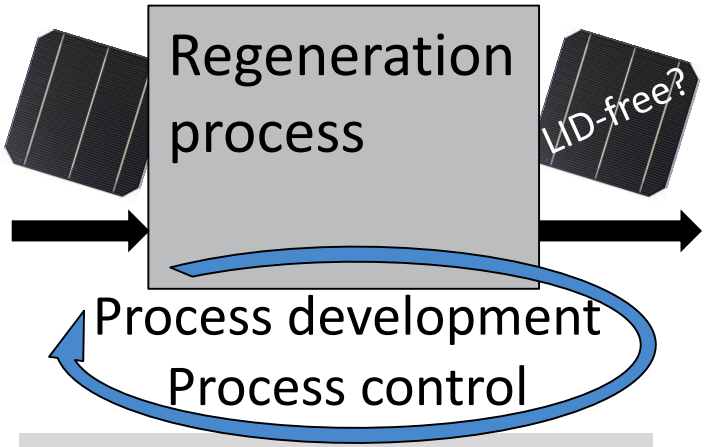
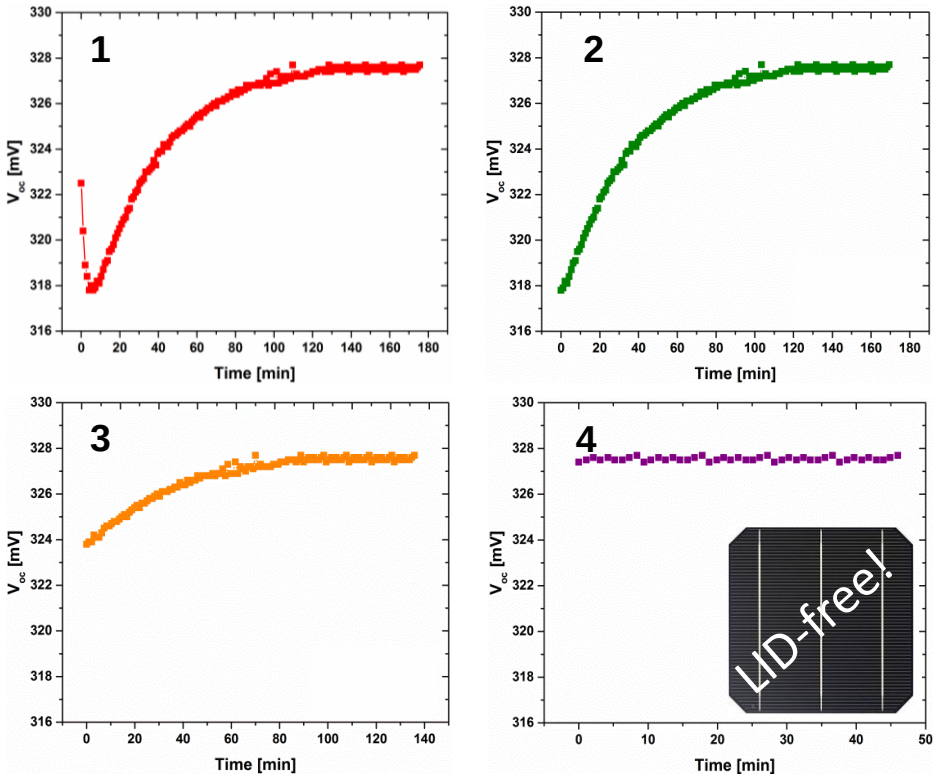
Assessment of regeneration process





LID Scope facilitates development and control of regeneration processes.

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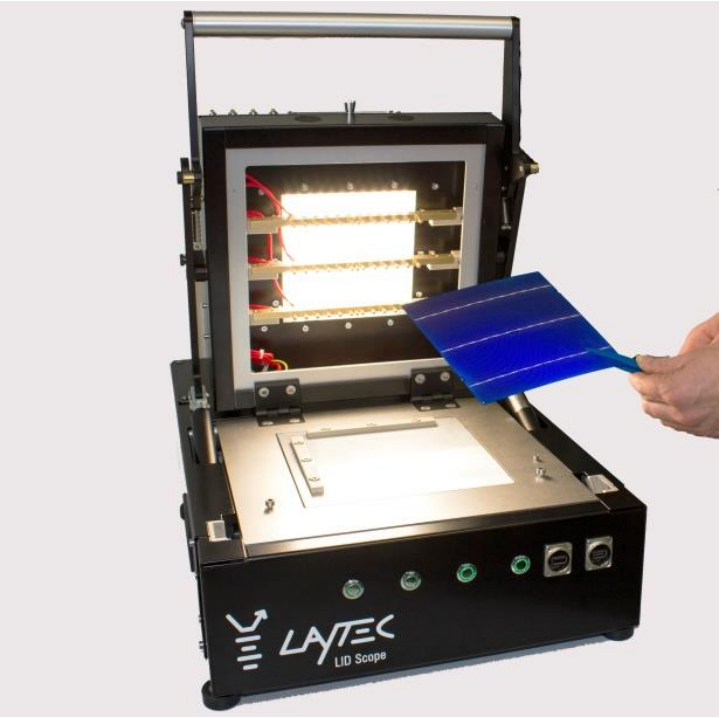
SEMI Standard (draft)

- **Scope:** Test method for LID-susceptibility of solar cells
- Hardware setup ≙ LID Scope



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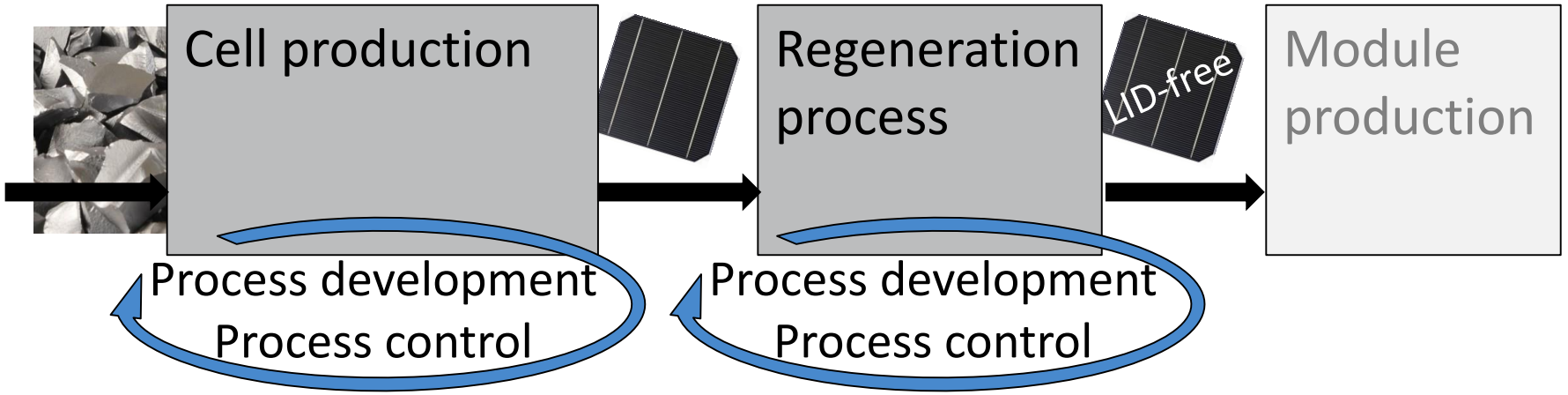
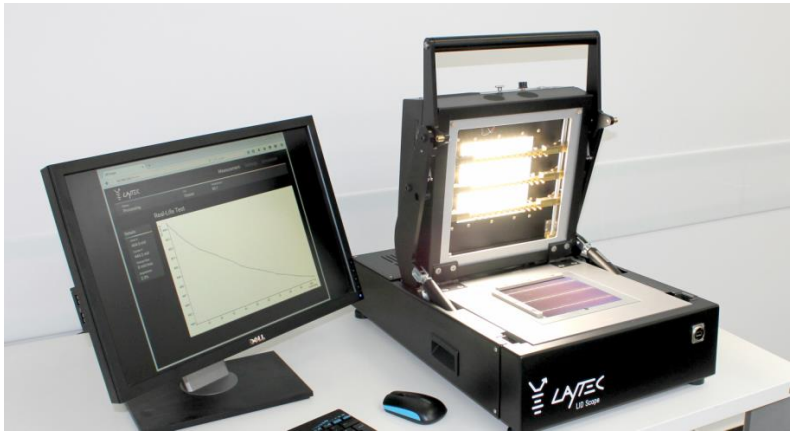
Summary



- **LID Scope: reliable, reproducible, fast LID testing**
- **Essential for producing LID-free cells**
- **SEMI standard under preparation**



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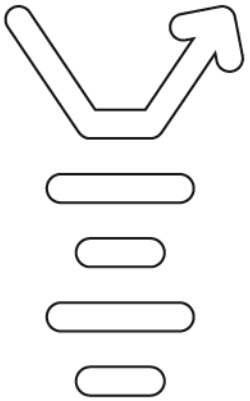

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