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ICP Institute of Computational Physics

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Complementary techniques to investigate degradation mechanisms in solar cells

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SWISS PHOTONICS 10.09.2015

Who we are

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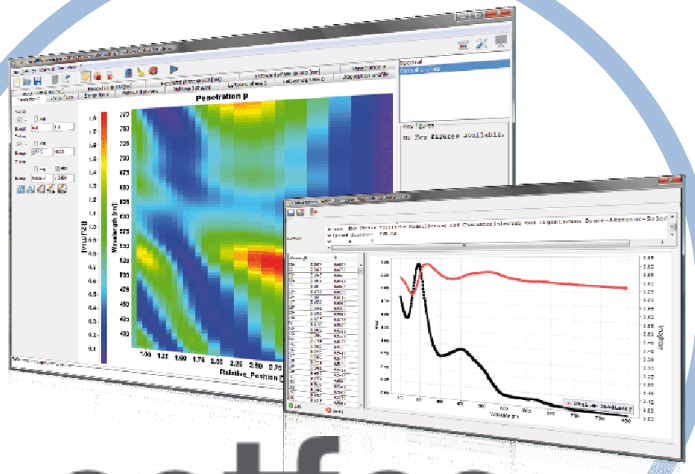
Simulation Software



setfos

paios

Measurement Hardware

Research on
OLED and OPV

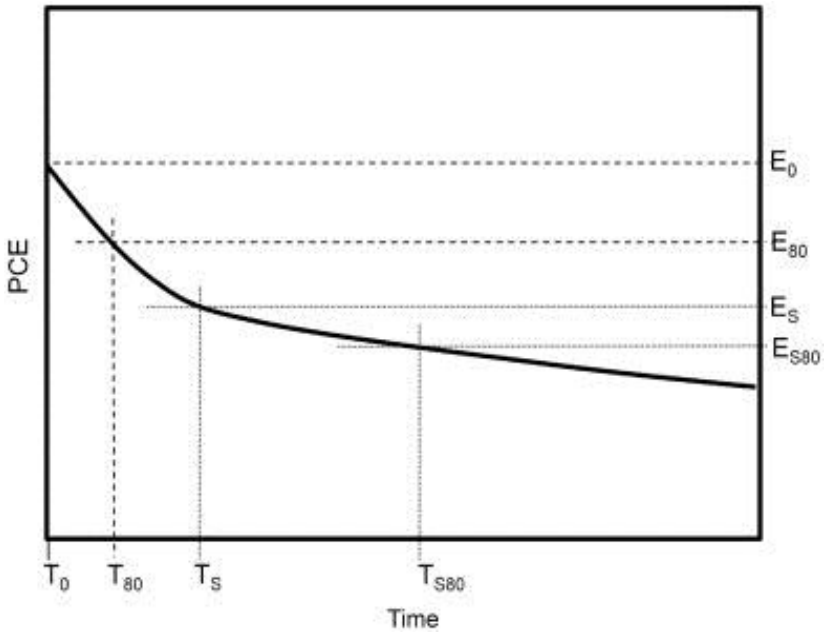
AEVIOM

IM³OLED
RESEARCH FOR SUSTAINABLE LIGHTING

Sunflower

swiss made
software

Stability of Solar Cells



How to characterize and compare stability?

→ Standardization!

- IEC 61215 for c-Si
- IEC 61646 for thin-film
- ISOS Protocols for OPV

Reese et al., Solar Energy Materials and Solar Cells, (2011), 95, 1253

But: focussed on steady-state, where valuable information on degradation is concealed.

Techniques we propose:

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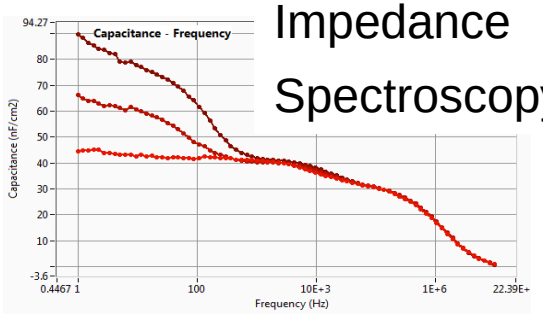
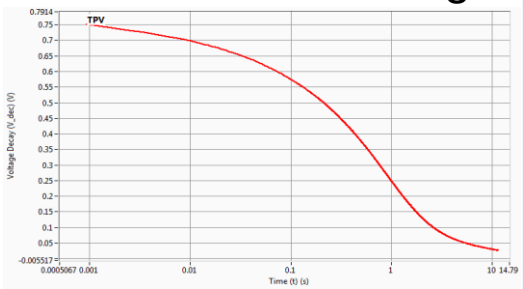
Impedance Spectroscopy



Transient Photovoltage



paios

The revolutionary platform for all-in-one characterization of solar cells

Capacitance-Voltage

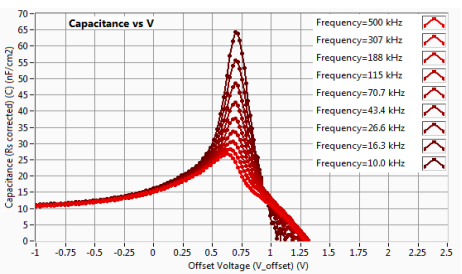
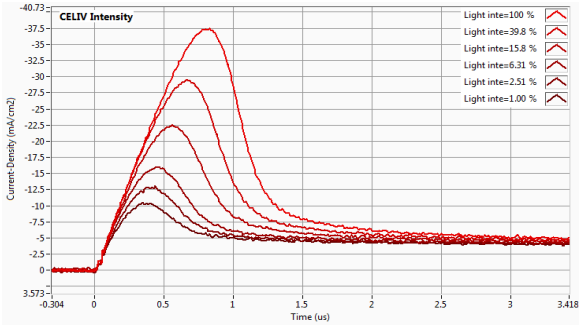
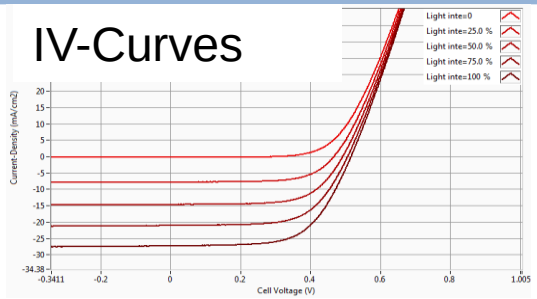


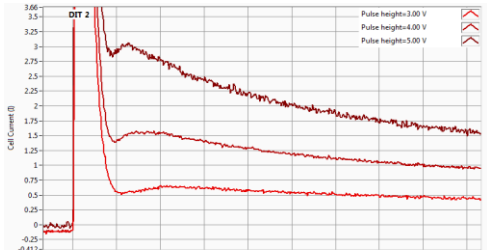
Photo-CELIV



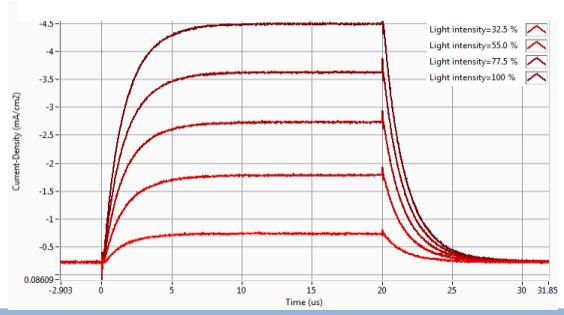
IV-Curves



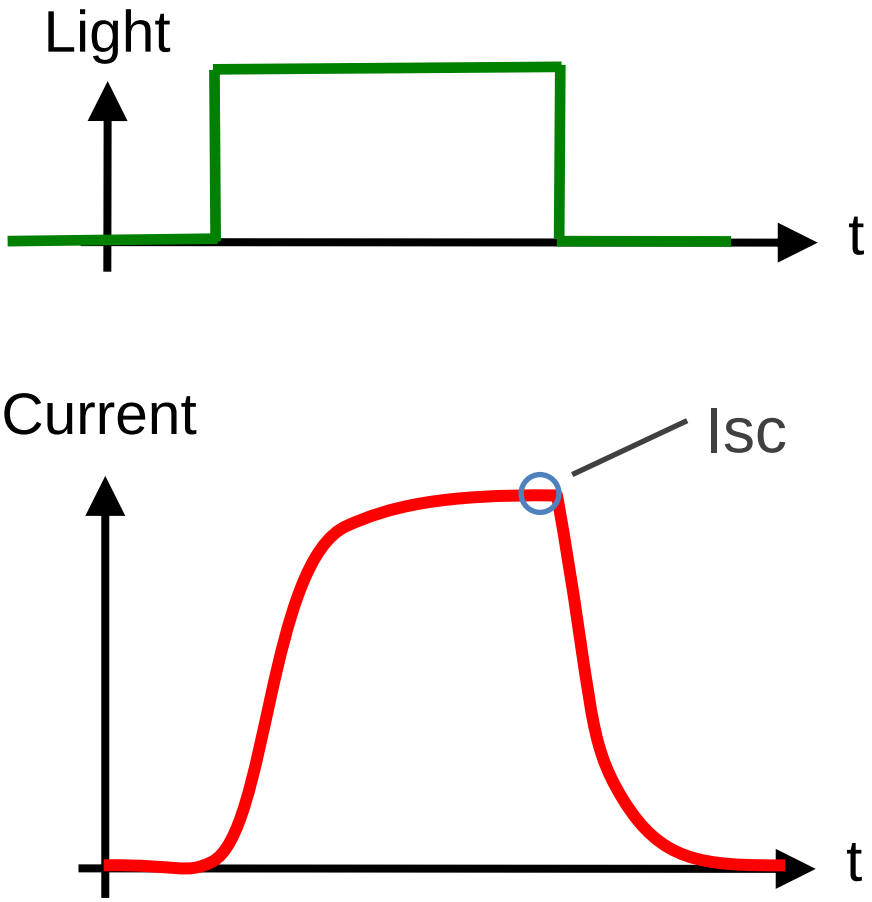
Dark Injection Transients



Transient Photocurrent



Transient Photocurrent TPC



- Cell is flashed at constant voltage
- Qualitative investigation of charge **carrier mobility**
- Qualitative investigation of **trapping dynamics**

Transient Photocurrent: Technology Comparison

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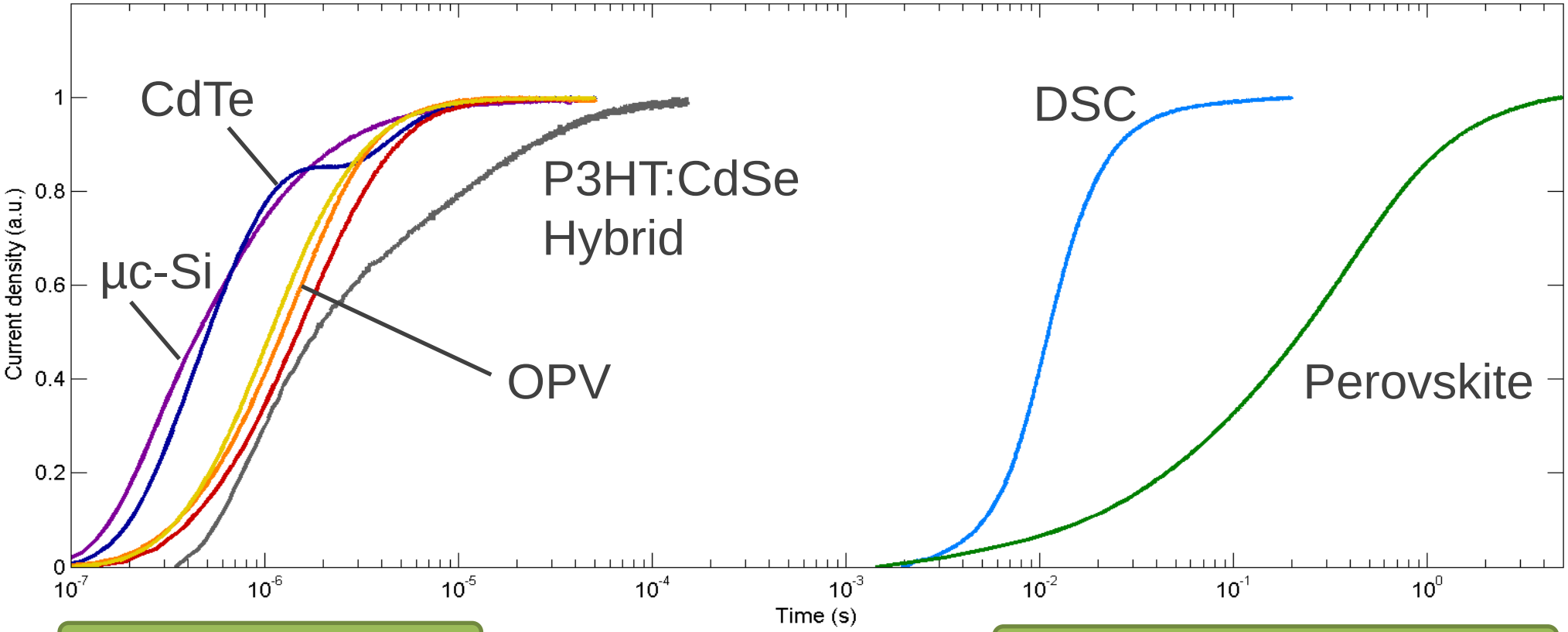

Drift & Diffusion

Ionic movement

Traps

Other slow effect?

Space-charge effects due to doping

Stress-Test Module

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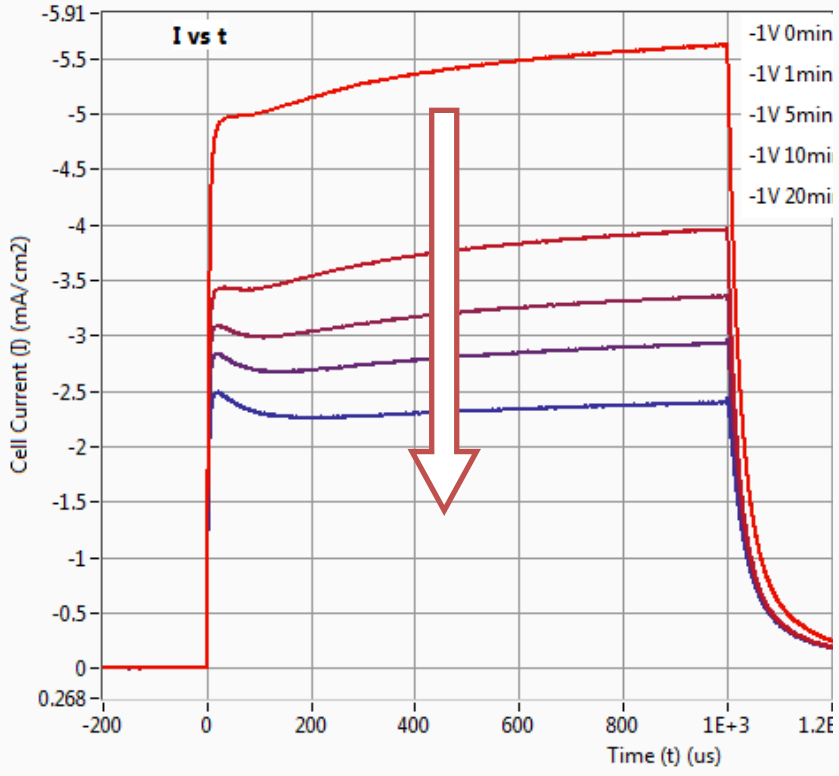
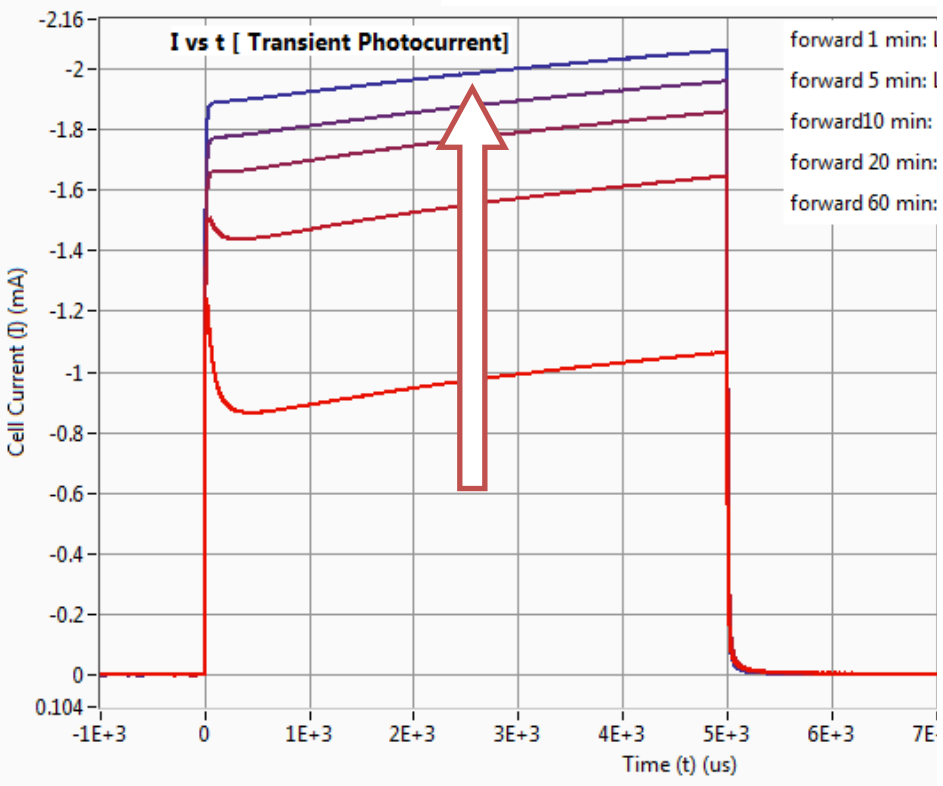
Repeated Transient Photocurrent on Perovskite SC





Preconditioning -1V

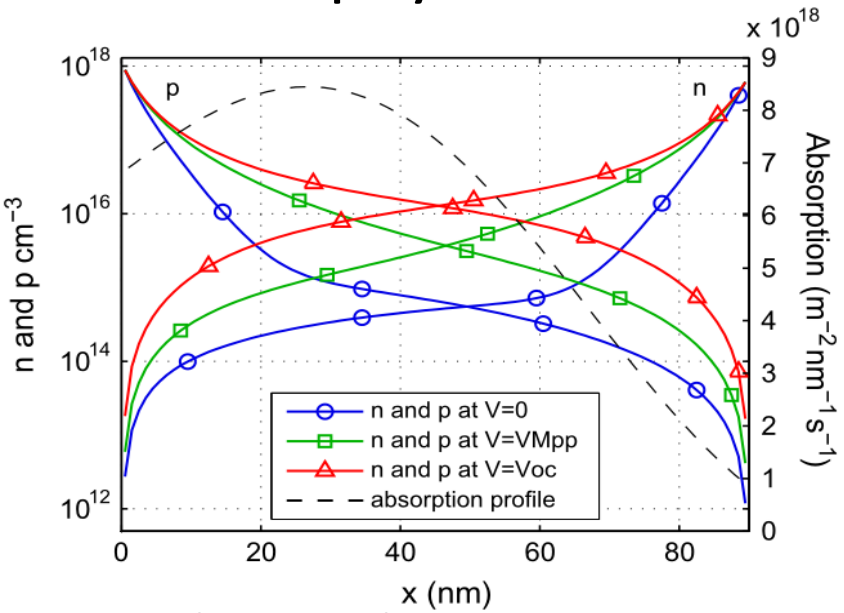
Preconditioning +1V

→ Evidence for movement of ionic charges

Modeling

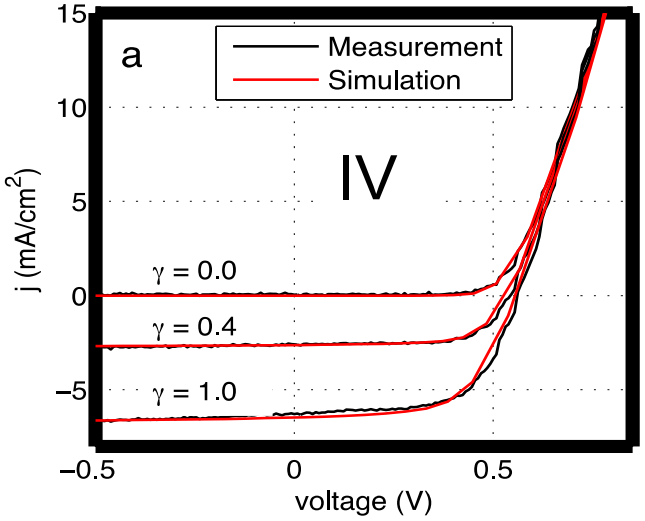
- Drift-Diffusion Simulation
- Simulate all experiments with one set of parameters
- Modeling helps to understand device physics
- Get further insight into device

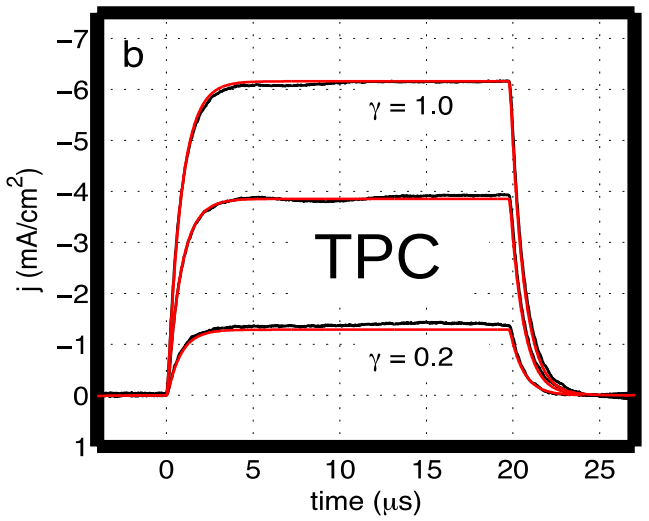
setfos
semiconducting thin film optics simulation software

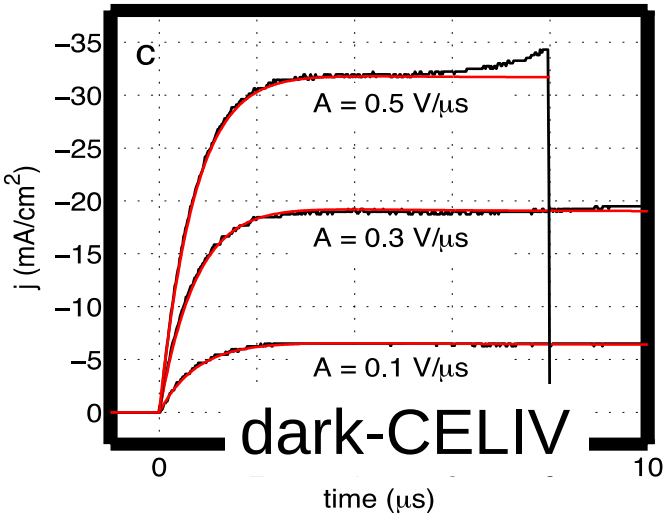


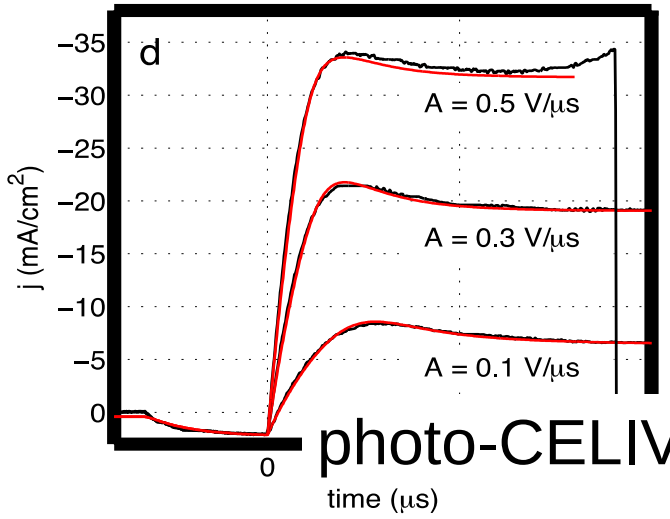
Neukom et al.,
Org. El. 13,2910 (2012)

Advanced Characterization Example









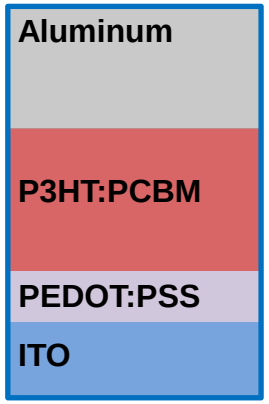
Measurement and simulation of an organic solar cell

Global fit with one set of parameters!

Neukom et al.,
Org. El. 13,2910 (2012)

Accelerated Ageing Study

- Standard unencapsulated P3HT:PCBM organic solar cells with PEDOT:PSS as hole transport layer (unstable)
- In climate chamber at 45°C, 85%RH
  → investigate influence of humidity



- Automated repetition of measurement routine
  → Highly systematic data!

Steady-State Measurements

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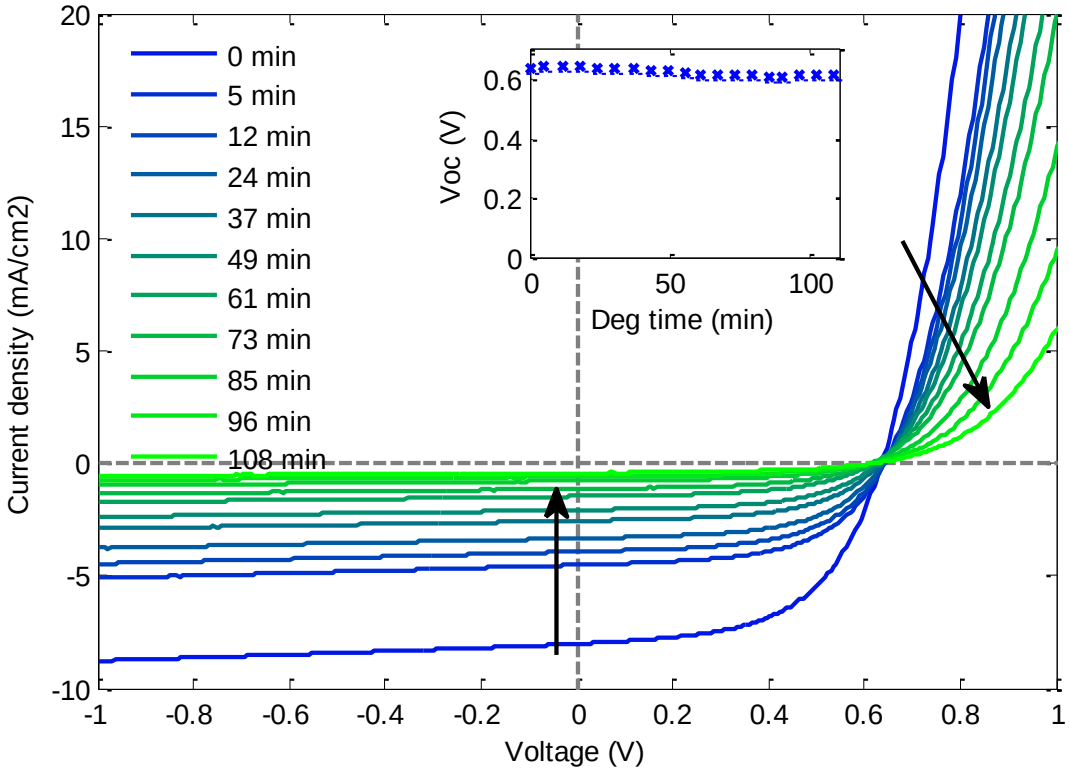
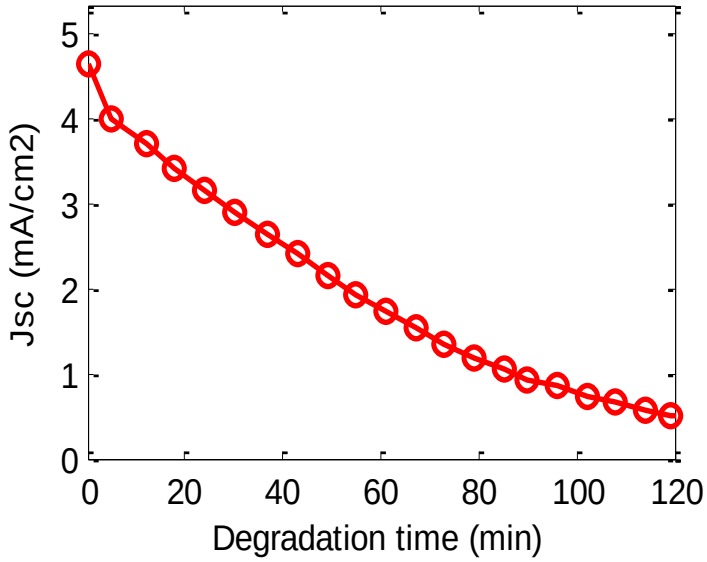
Current-Voltage

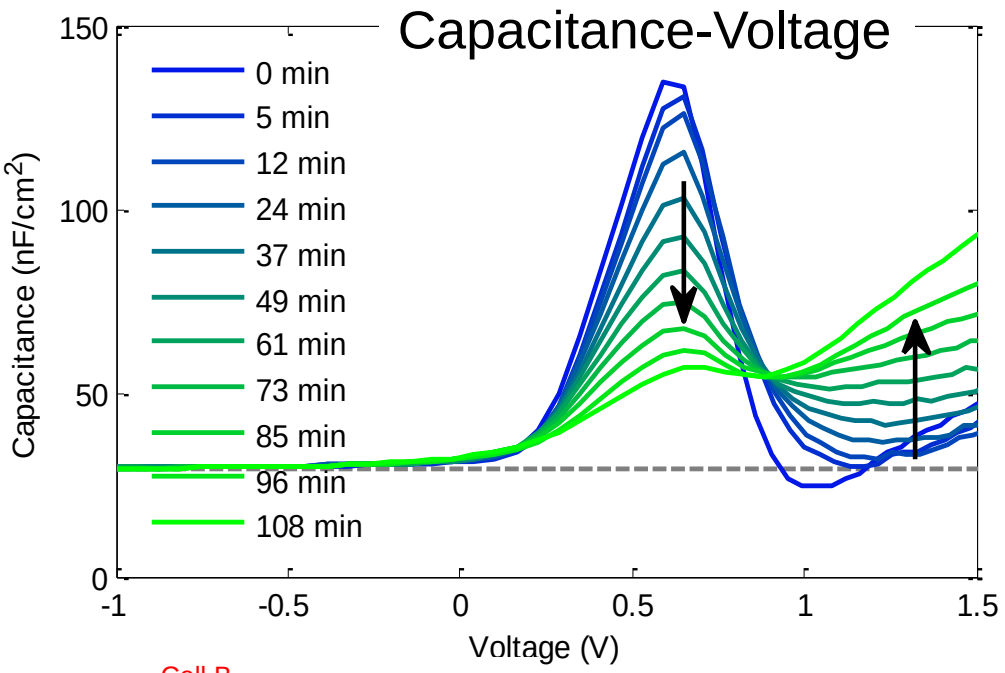


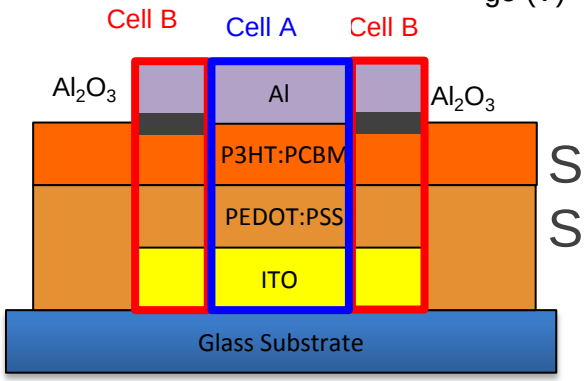
Short-circuit current



No conclusions about degradation mechanism possible!

AC Measurements

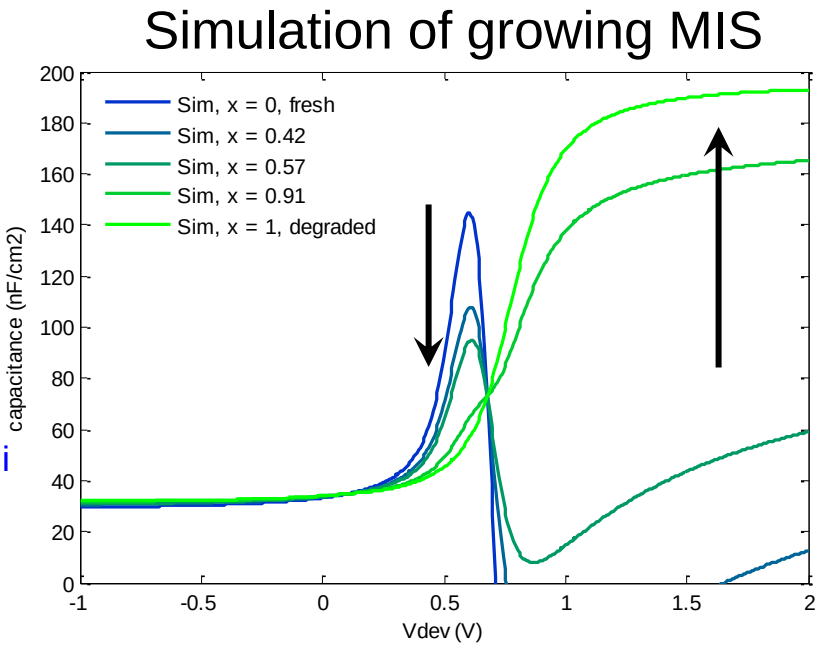




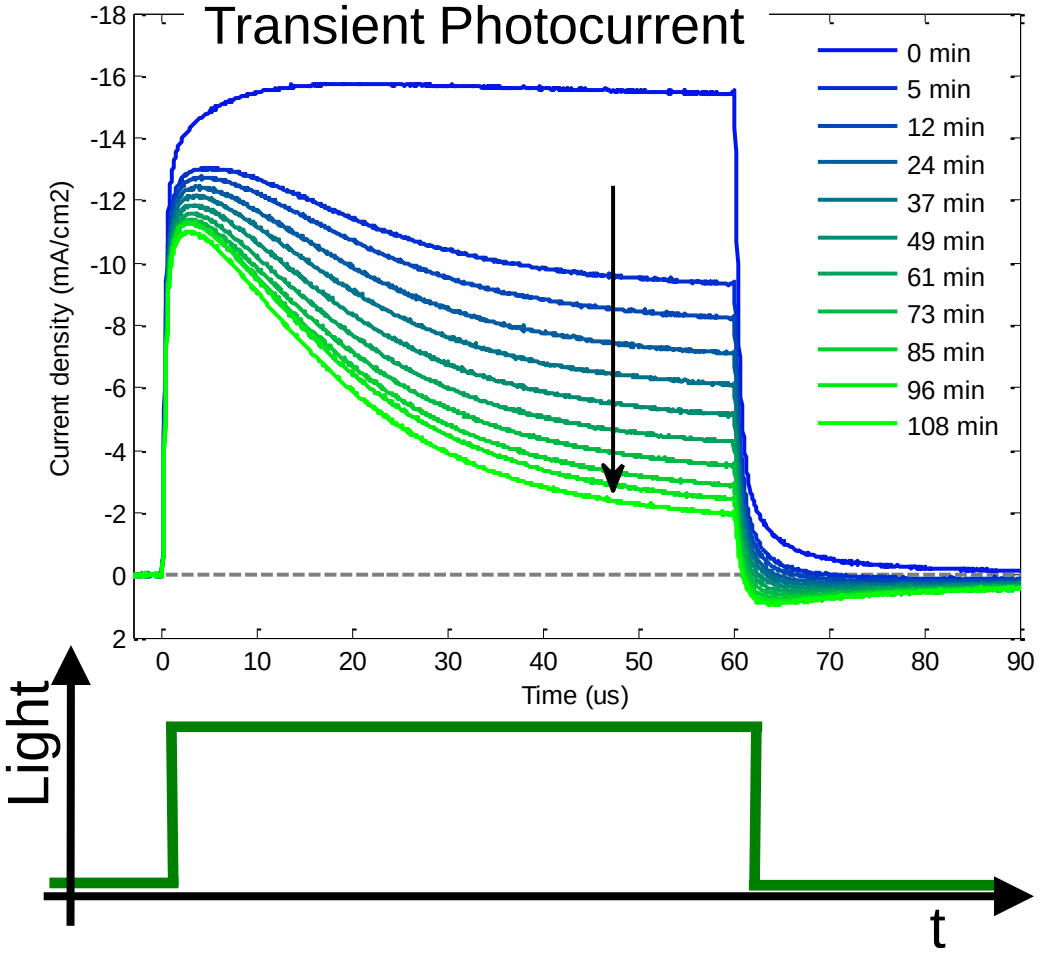
Surface A: $(1-x)\cdot S_{ini}$

Surface B: $(x)\cdot S_{ini}$

Hypothesis: Insulating Al_2O_3 interface layer grows, leading to MIS structure.



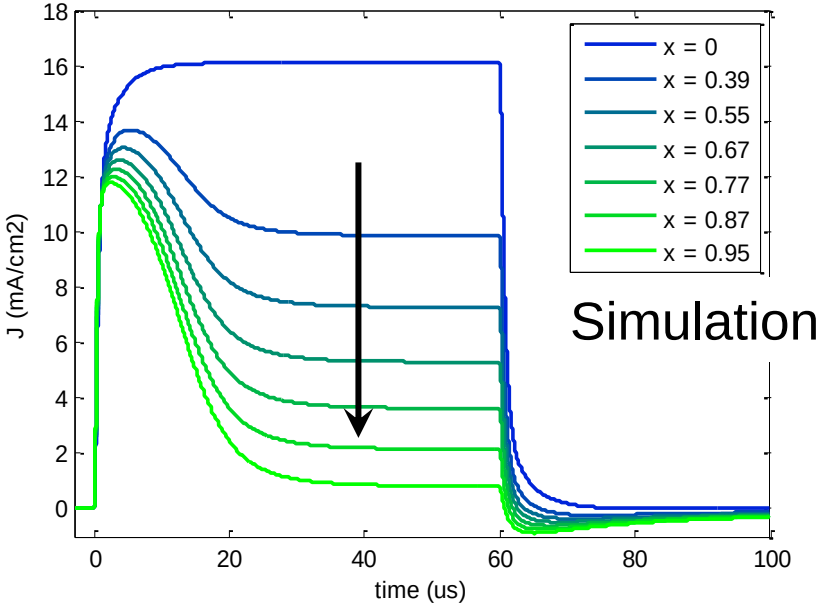
Transient Measurements



«There is life after death!»

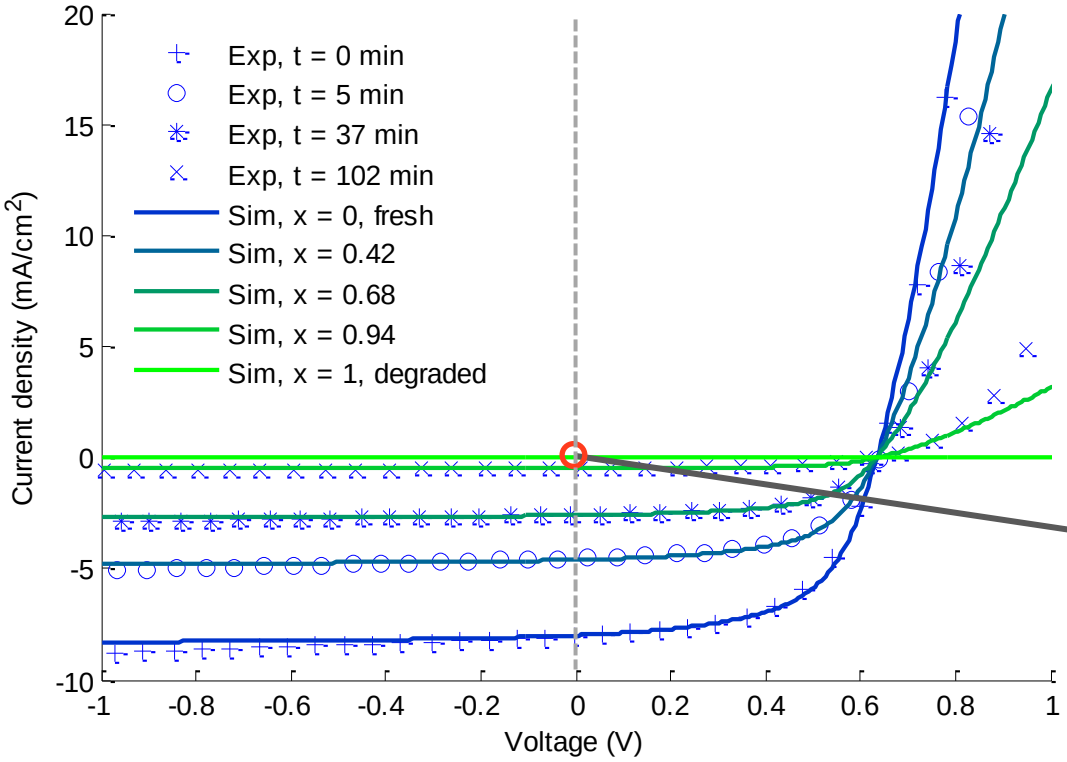
Charge extraction is hindered:

→Blocking Al2O3 layer

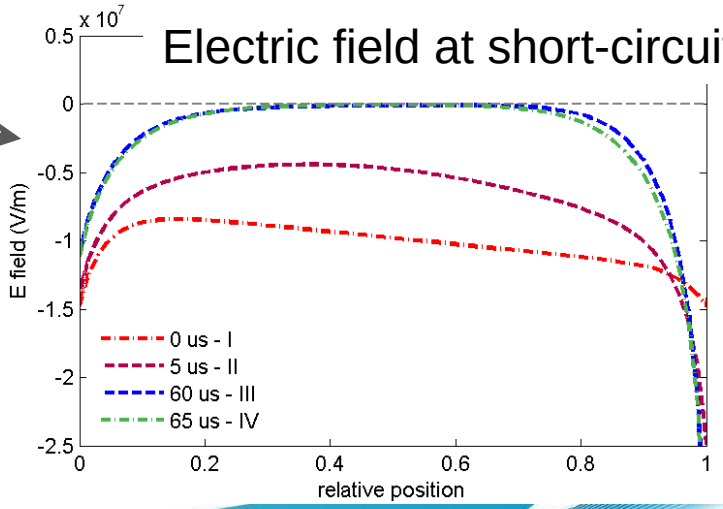


Comparison

IV: Paios Measurements + Setfos Simulations



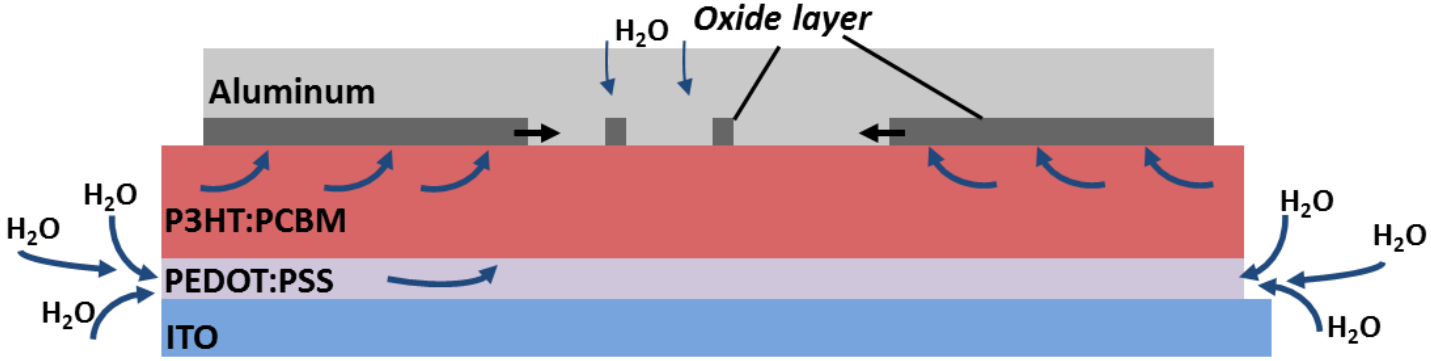
Model-based analysis helps to quantitatively validate the postulated degradation mechanism!



x describes effective area vs time, in agreement with a 2D diffusion model

Conclusions

- Hypothesis: Al_2O_3 layer acts as insulating interface resulting in a **local** complete loss of current



→**Lateral** instead of homogeneous degradation process!

This conclusion is possible without time-consuming, expensive and destructive methods!

Züfle et al., Adv. En. Mater., 2015, in press, 10.1002/aenm.201500835

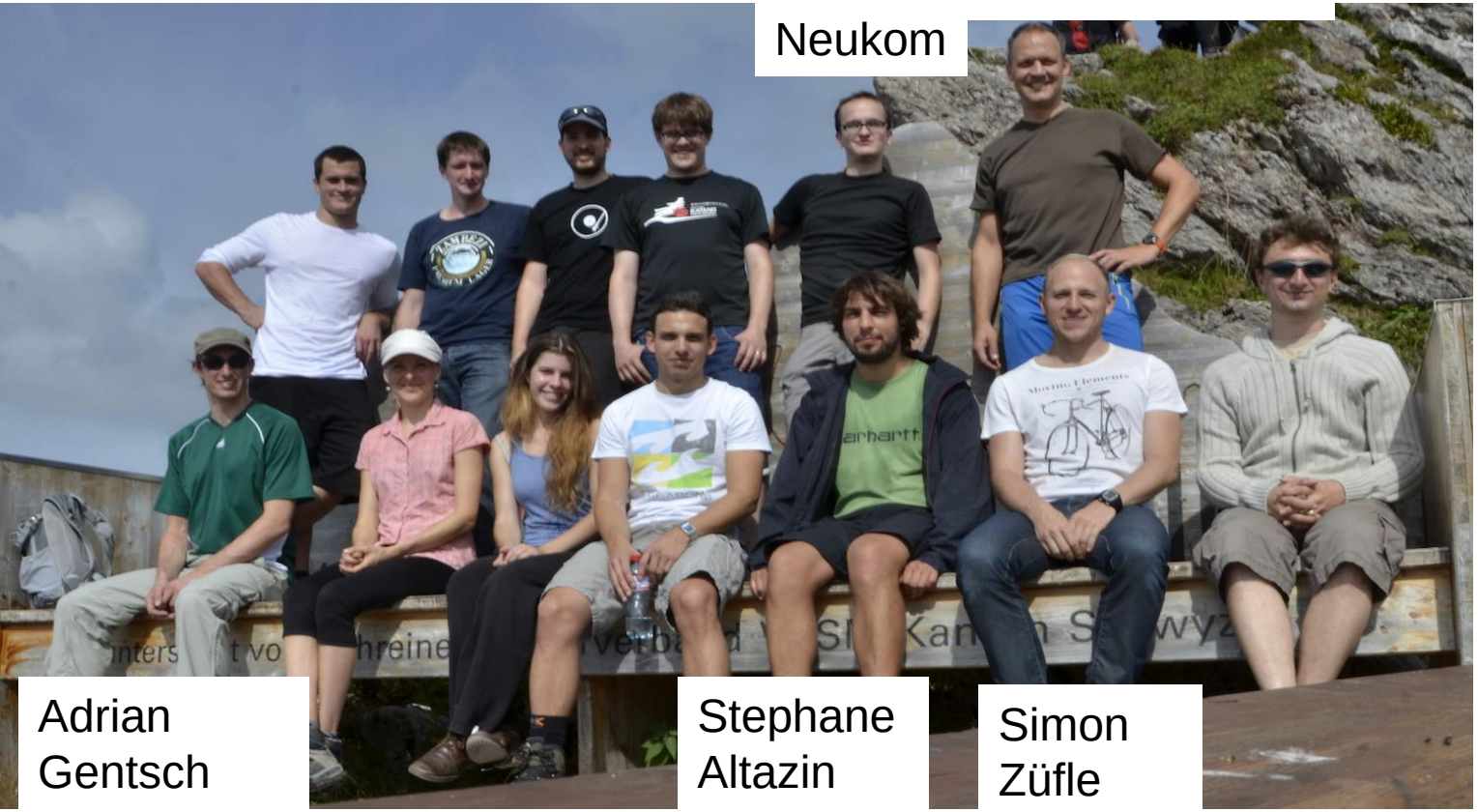
Summary

- IV-curves alone are not enough to understand degradation processes
- Transient and impedance techniques reveal valuable information
- Systematic measurement data allows for combinatorial analysis
- Advanced Modeling helps to validate hypothesis and gives additional insight into the device

Acknowledgement

Martin Neukom

Beat Ruhstaller



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csem swisselectric

BELECTRIC Sunflower

Thank you for your attention!

Transient Photovoltage

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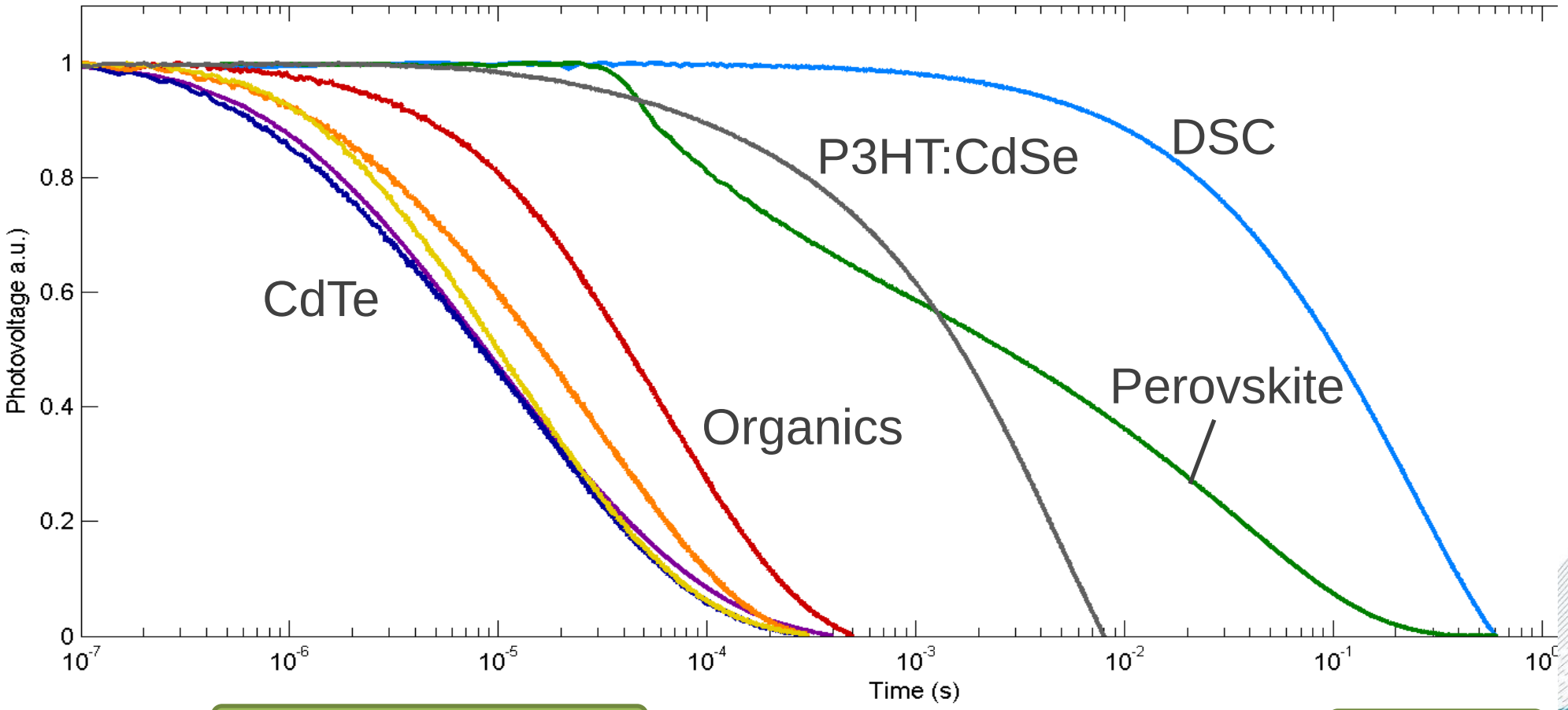


Recombination

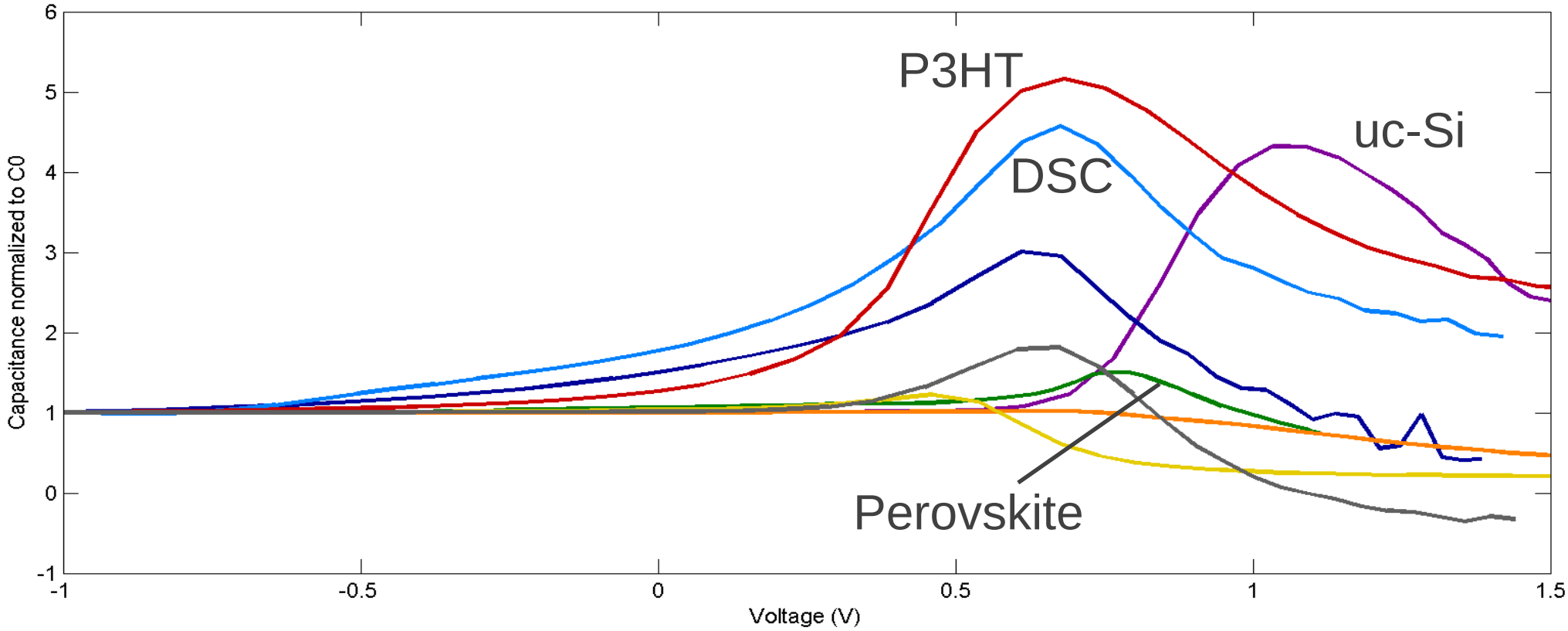
Drift & Diffusion

Traps

Ions?

Leakage Current

Capacitance-Voltage



Doping

Injection barriers

Built-in voltage

Low Temperature Module

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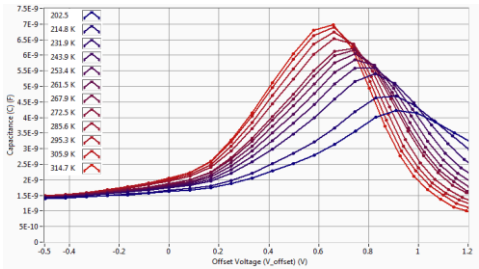
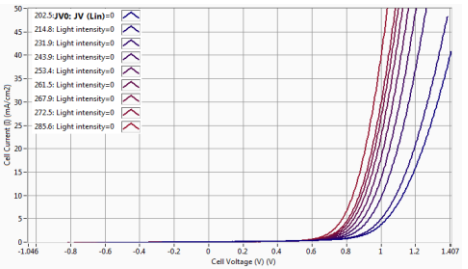
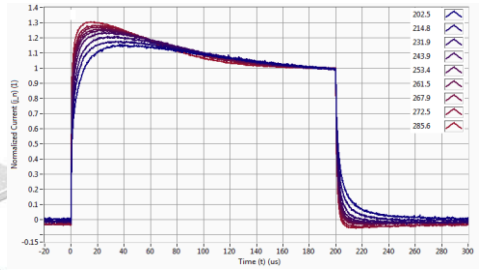
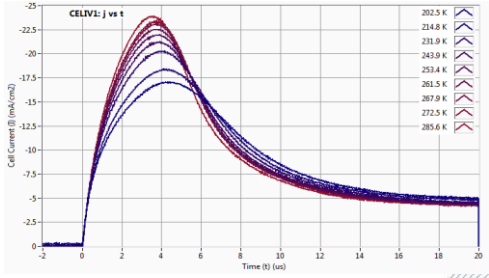
Perform all experiments at temperatures from 150 to 350 K









Transient and ac Measurements

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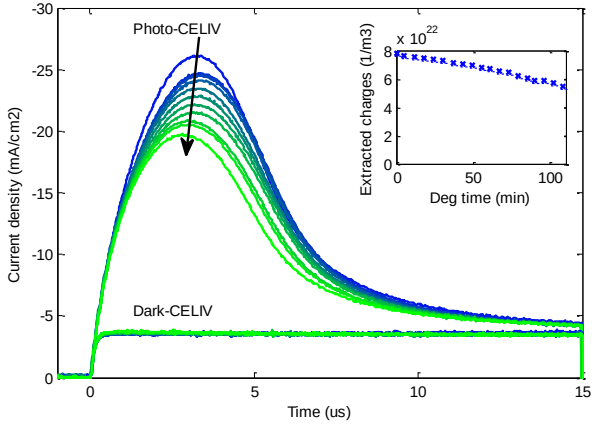
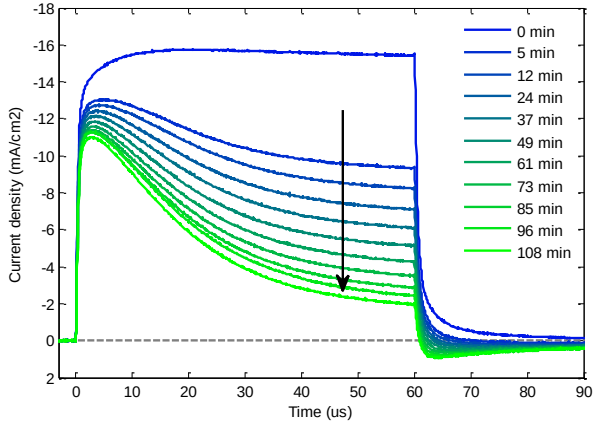
CELIV

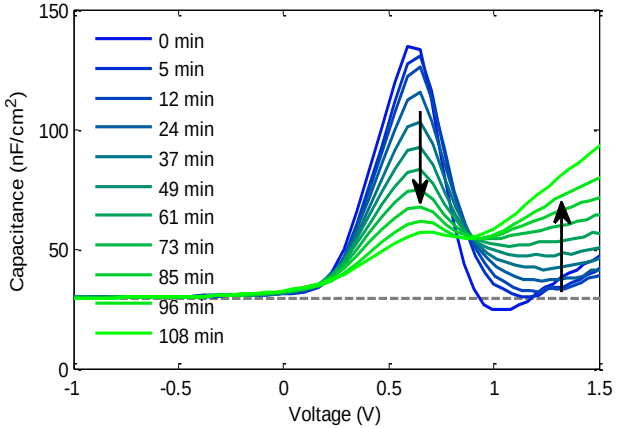


TPC

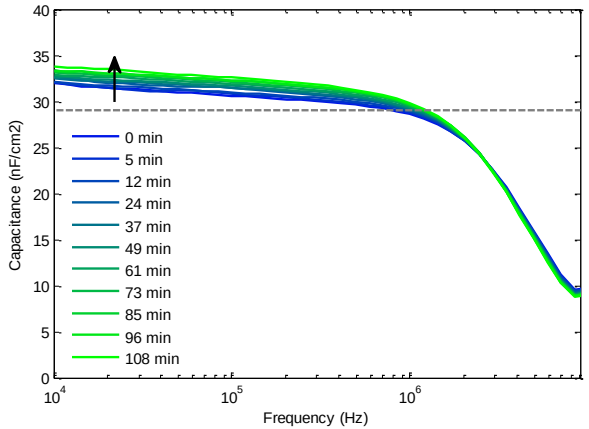


Systematic data of the same device during degradation!

C-V



C-f



Combinatorial Analysis

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- Electrode workfunctions are constant
- Electrode resistance is constant
- Layer thickness is constant
- No doping is present
- Traps cannot be dominant mechanism
- Absorption loss cannot be dominant mechanism
- Decreased mobility cannot be dominant mechanism
- Space charge due to hampered extraction

→ There is life even in dead cells!