paios

Electro-Optical Characterization of LEDs & Solar Cells

swiss made software

All-in-One

DC, AC & Transient Analysis

Over 15 Different Experiments

Fully Automated Routines

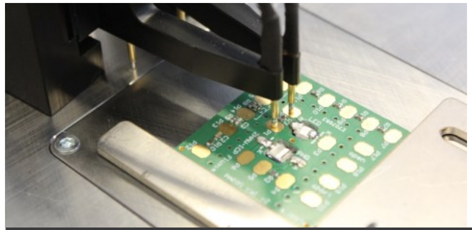
www.fluxim.com

FLUXiM

Verify Your Hypothesis Quickly With Paios

Paios performs a large variety of electrical and optical characterizations on organic, perovskite, and quantum-dot LEDs and solar cells with one click. Get consistent and precise measurement data, directly compare your results in the measurement software and speed up your R&D.

- Current-Voltage-Luminance
- Transient Photocurrent
- Transient Photovoltage
- Transient Electroluminescence
- Charge Extraction
- Dark Injection Transients
- Dark/Photo-CELIV
- DLTS
- Impedance Spectroscopy
- Capacitance-Voltage
- IMPS/IMVS
- MELS
- Emission Spectrum
- User-Defined Signals



AC, DC & Transient

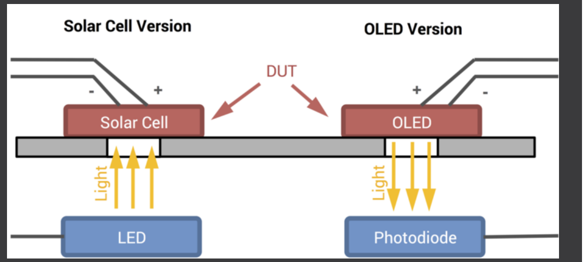
The combination of opto-electrical measurements in steady-state, frequency and time domain provides deeper insight into the device physics.

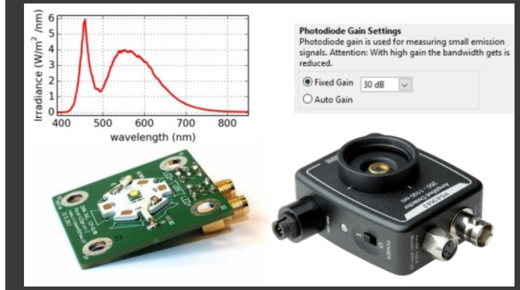
Paios Research Fields

- Perovskite solar cells
- Organic, quantum dot & hybrid solar cells
- CIGS, CdTe , CZTS solar cells
- Dye sensitized solar cells
- Solid state thin film batteries
- Organic light-emitting diodes (OLEDs)
- Perovskite-LEDs and QD-LEDs
- Light emitting electrochemical cells (LECs)
- Unipolar devices
- Metal Insulator Semiconductor (MIS) devices

LED & PV Characterization

Paios is available in a solar cell and an LED version. The versatile Combined Version is suitable for research and development on both LEDs and photovoltaic devices.





SOLAR CELLS: the main hardware is equipped with a suitable LED illumination system. A multi-LED board can be employed for External Quantum Efficiency (EQE) measurements.

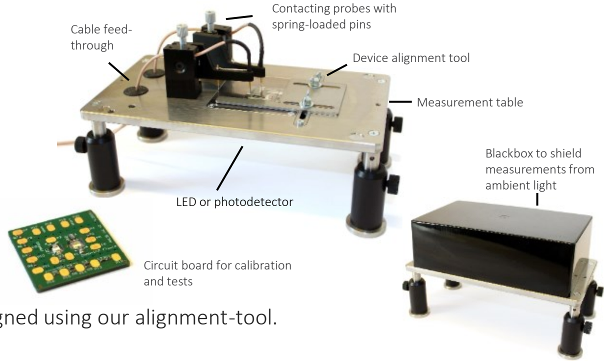
LEDs: an amplified photodetector with autogain is included in the version for LED research.

PV

LED

Flexible Probe Station

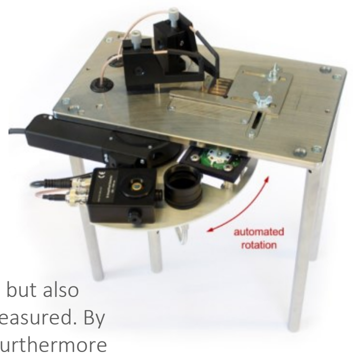
Paios is delivered with a probe station to provide a fully calibrated system down to the contacting pins. Our contacting probes are designed to create a low parasitic resistance and reproducible contact to your device. The magnetic feet are adjustable to accommodate different sample layouts.



- The device can be easily aligned using our alignment-tool.
- The measurement table comes with a black cover to ensure the reproducibility of dark measurements.

Paios Modules

Automated Measurement Table



- Photodetector
- Spectrometer
- Multi-LED board
- Empty space for existing sun simulator

For Solar Cell Research
With the fast LED light pulses can be applied to solar cells, but also steady-state IV-curves with varied light intensity can be measured. By switching to the photodetector or spectrometer you can furthermore analyze the electroluminescence properties of efficient solar cells

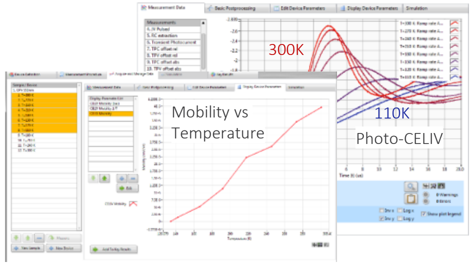
For LED Research
Measure the LED spectrum and transient electroluminescence without changing manually the measurement setup. By using a blue or UV LED, Paios can also measure the LED photo-response.

Peltier Cryostat

- Perform all Paios experiments at low and high temperature.
- Automatic temperature control and data acquisition.
- Peltier cooling system.
- Customized sample holder included in the standard product.
- Temperature range: -50°C to +80°C.
- Compatible with the automated measurement table.
- Multiplexing: Measuring 4 solar cells or LEDs in sequence automatically.
- The chamber can be evacuated or flushed with inert gas.

Liquid Nitrogen Cryostat

- Perform all Paios experiments at low and high temperature with this liquid nitrogen cooling and heating system.
- Automatic temperature control and data acquisition.
- Temperature range: -150°C to +200°C.
- Maximum temperature ramp: 40 K/min.
- Samples are stored under an inert atmosphere.



Spectrometer Module

- Measure the emission spectrum of your LED or solar cell
- Calibrated spectrometer
- Automatic dark-spectrum correction
- Most powerful in combination with the automated measurement table
- Different spectrometers available

Spectral range :	360 – 880/1100 nm
Integration time :	1.1 ms to 10 min
Postprocessing quantities :	luminance, radiance, EQE, lm/W, CRI, CIE coordinates

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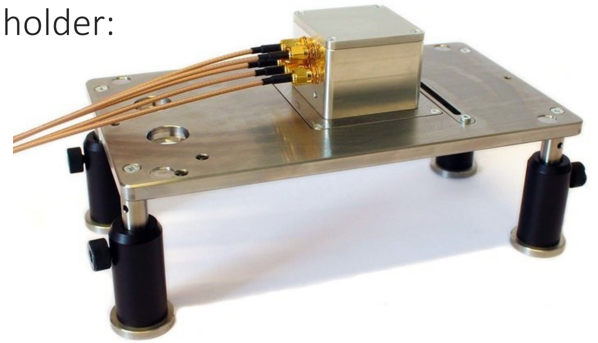
Paios Modules

Custom Sample holder: Multiplexing



With the Paios multiplexing module up to 4 devices can be connected simultaneously. Paios measures the devices automatically after each other. This saves a lot of time for the operator.

Combination with Customized Sample Holder

We also offer customized sample holders on request. The sample holder is compatible with the regular and automated measurement table.

Source Measure (SMU) Module

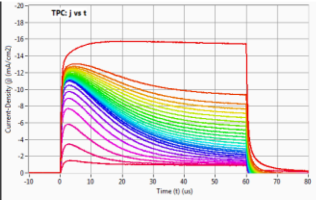
The SMU module is an extension to Paios that allows to apply and measure voltages up to 60 Volt.

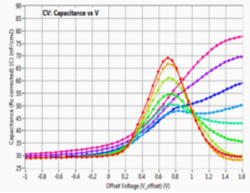
- Choose for each experiment whether to use the SMU mode or the regular Paios.
- Increase your current resolution.
- Measure impedance spectroscopy, IV-curves and transient experiments with high voltages.
- Can also be used for stressing and long-term measurements.

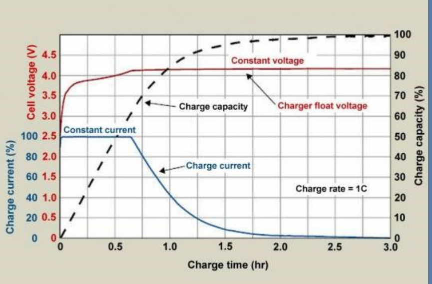
- Voltage range : ±60 V
- Min measurable current : 1 pA
- Frequency range impedance : 10 mHz to 1 kHz
- Sampling frequency : 100 kS/s

Stress-Test Module

- Monitor device degradation.
- Stress by constant current, voltage and/or under illumination at Isc, Voc or MPP.
- Fully automated stressing, characterization and data acquisition.
- Get highly consistent datasets.
- Understand the origin of degradation of your device.







Battery Module

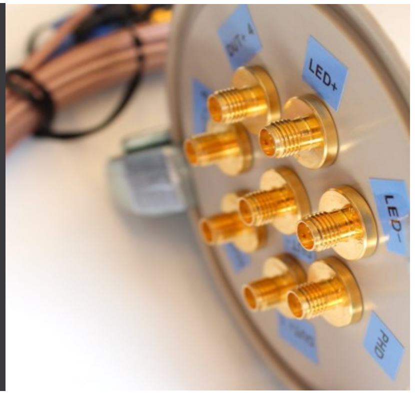
The Battery module uses the SMU and the Stress-Test module for characterization of solid-state thin-film batteries and other electrochemical devices.

- Impedance
- Cyclo-voltammetry
- Impedance

Glovebox Feed-Through

Paios can also be used in combination with a glovebox. Upon request, we provide customized cable feed-through for your glovebox.

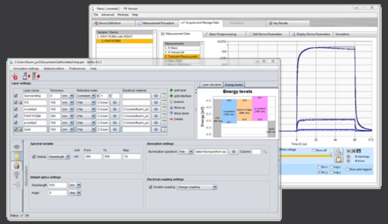
Paios is placed outside the glovebox and the measurement table (or the sample holder) can be used inside.



Numerical Simulation Module (Setfos-Paios Integration)

Numerical simulation helps to understand your measurement results.

So we integrated our simulation software Setfos seamlessly into the Paios software.



- Perform simulations of all Paios experiments
- Simulate LEDs and solar cells
- Use our global fitting routine to extract device and material parameters
- Compare simulation and measurements directly in the Paios software

Parameter Extraction

Use the Setfos-Paios Integration to extract device and material parameters:

- electron and hole mobilities
- recombination coefficients
- charge injection barriers
- built-in voltage
- doping densities
- mobile ions
- trap parameters
- permanent dipole moments
- series resistance
- parallel resistance
- electrical permittivity
- ....

How Does a Material Parameter Influence an Experiment?

Use drift-diffusion simulation to analyze the influence of certain material parameters on an experiment. Easily sweep a simulation parameter to understand its influence.

Distributed Computing

With the Setfos-Paios Integration calculations can be distributed on different computers over the network.

Save time by running simulations in parallel on different computers.

What is Parameter Correlation?

When two simulation parameters are correlated, it means they have a very similar influence on the simulation results. In this case the extracted parameters are not unique and therefore not reliable.

For each fit Paios automatically calculates a **correlation matrix**. The matrix shows the correlation between all parameters involved.

With the correlation matrix the user can judge how unique the fit is. By adding further experiments to the global fit the parameter correlation can be reduced.

	Electron-Mobility	Hole-Mobility	Opt Gen Eff	Epsr	Ref Eff	Built-In-Voltage	Anode Barrier	Cathode Barrier	N0	Polymer - Acceptor Doping (p-type)
Electron-Mobility	1.00	-	-	-	-	-	-	-	-	-
Hole-Mobility	-0.41	1.00	-	-	-	-	-	-	-	-
Opt Gen Eff	-0.01	0.30	1.00	-	-	-	-	-	-	-
Epsr	-0.25	0.21	0.04	1.00	-	-	-	-	-	-
Ref Eff	0.45	-0.92	-0.24	-0.04	1.00	-	-	-	-	-
Built-In-Voltage	-0.71	-0.08	0.10	0.17	0.10	1.00	-	-	-	-
Anode Barrier	-0.67	-0.13	0.05	-0.12	0.08	0.95	1.00	-	-	-
Cathode Barrier	-0.69	-0.20	0.06	0.17	0.22	0.97	0.92	1.00	-	-
N0	0.68	0.19	-0.05	-0.03	-0.18	-0.97	-0.97	-0.98	1.00	-
Polymer - Acceptor Doping (p-type)	-0.21	-0.03	-0.01	0.57	0.21	0.16	-0.03	0.31	-0.15	1.00

What is Fitting?

Fitting is a process where simulation parameters are adapted such to bring measurement and simulation result in agreement.

Fitting is used to extract parameters from experimental results. If more than one experiment type is fitted simultaneously, this is called global fitting.

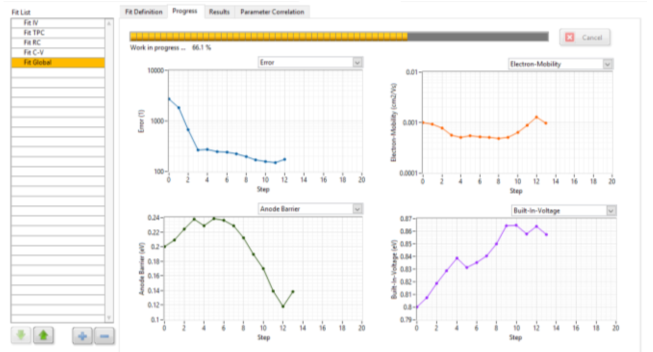
Global Fitting of Experimental Results

The Paios software optimizes parameters in order to fit several experiments.

The user defines the targets (what to fit) and the parameters to optimize.

The software does the rest.

Use global fitting to extract device and material parameters reliably and with increased accuracy.



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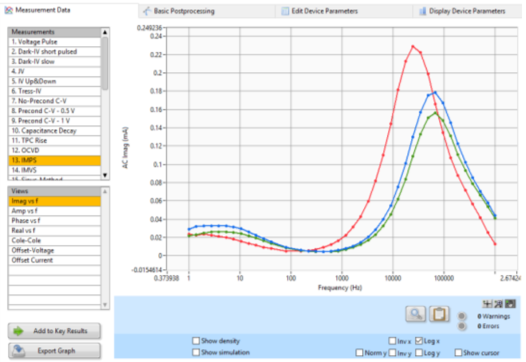
Paios Software Features

Data Management & Comparison

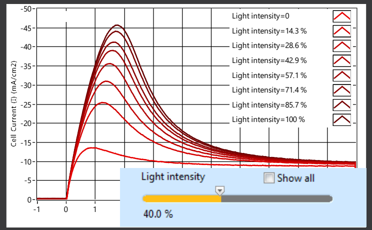
Paios is more than a measurement tool. Paios acquires systematic data of dozens of devices and lets you compare them in the Paios software.

- Internal database stores all measurement data
- Multi-select devices of interest and compare all measurement results
- Structure and organize your data
- Name and store key-results

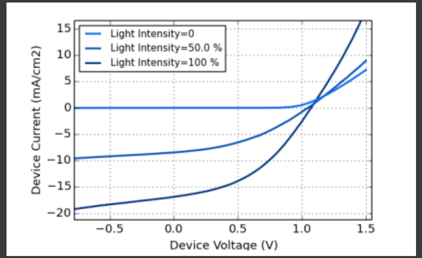


Parameter Sweeps

- Sweep measurement parameters
- Sweep types: linear, logarithmic, user-defined list
- Graphically inspect your dataset

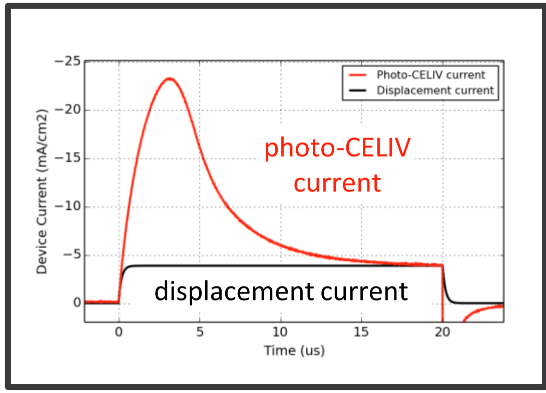


Export Data



- Create beautiful, publication-quality plots.
- Export single plots as eps, pdf or png files.
- Automatically create measurement reports and export to PDF.

Correct RC-effects

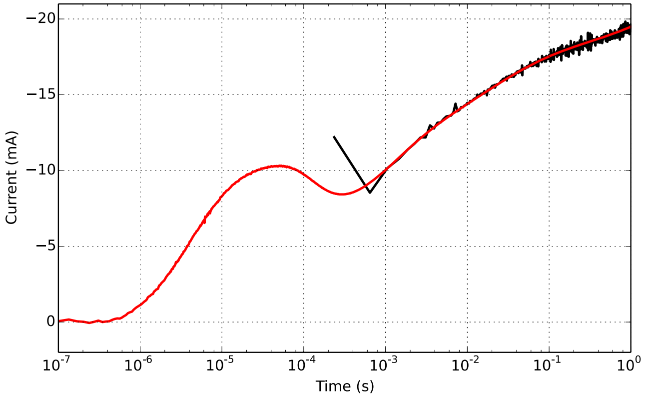


RC-effects are superimposed on the device current and can significantly disturb transient experiments.

Paios provides routines to extract the series and paralell resistance and the geometric capacitance of the device. With these values the displacement current is calculated, and the current can be corrected for the RC-effects.

Flexible Time-Resolution

Paios optimizes the time resolution for each experiment, allowing it to resolve up to 7 orders of magnitude in time in one shot. This helps to analyze Perovskite solar cells that can exhibit a broad dynamic range from microseconds to minutes.



Preconditioning:

To better understand hysteresis and obtain reproducible results each experiment can be performed after a specified preconditioning step (voltage, current, and/or illumination).

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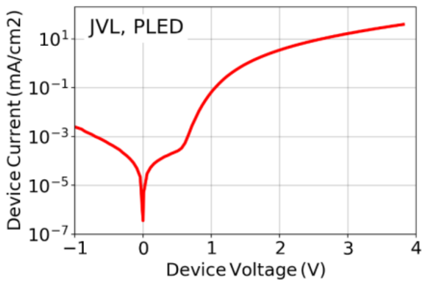
Experiment Techniques

IV(L) – Current-Voltage(-Luminance) Characteristics



For solar cells Paios automatically calculates the light ideality factor from the slope of the open-circuit voltage versus the light intensity.

- Voltage range -12 to +12V
- Current resolution < 100 pA
- For solar cells and OLEDs
- Extracting the emission onset voltage of an LED
- Extracting the mobility of a monopolar device from Mott-Gurney analysis (SCLC)
- Extracting the parameters of the one/two-diode model
- Extracting Isc, Voc, FF and MPP of a solar cell

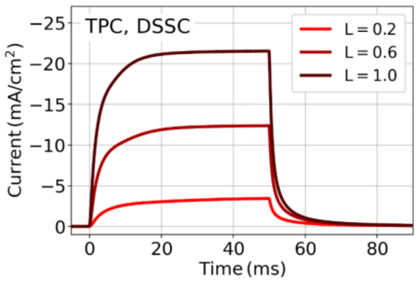
TPC – Transient Photocurrent

In this technique the transient current in response to the light pulse is measured.

The shape of rise and decay provide information about charge carrier mobilities, their ratio and the dynamics of trapping.

This technique can also be employed with bias illumination in a small-signal mode to determine the charge density.

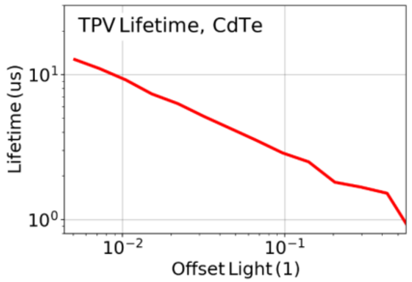
- Pulse length: 1 µs to 1000 s
- Offset voltage -12 to +12V
- For solar cells



TPV – Transient Photovoltage

In this experiment the solar cell is kept at open-circuit under illumination. A small additional light pulse is applied that leads to a rise in voltage.

After light pulse turn-off the voltage decays back to its previous value. From this decay-time the charge carrier recombination lifetime is calculated. The large-signal Open-Circuit Voltage Decay (OCVD) can also be performed with this measurement technique.

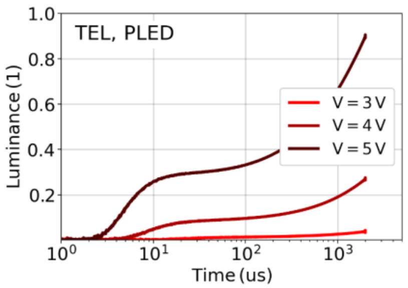


- Pulse length: 1 µs to 1000 s
- Device voltage -12 to +12V
- For solar cells

TEL – Transient Electroluminescence

A voltage pulse is applied to an perovskite LED and the transient EL signal is measured. Analyzing the delay time between voltage turn-on and emission turn-on the average mobility can be calculated.
By studying the decay of the EL signal the phosphorescence lifetimes can be determined.

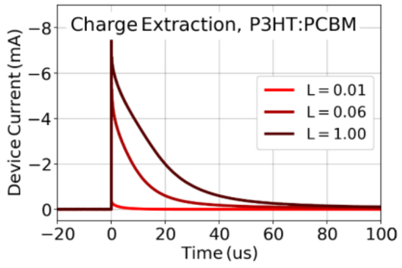
- For LEDs and highly efficient solar cells
- Extracting the average charge carrier mobility
- Extracting the EL lifetime



CE – Charge Extraction

The solar cell is kept at open-circuit under illumination. Then simultaneously the light is turned off and the device is put to short-circuit to extract charge. Paios integrates the extraction-current to get the total charge carrier density that was in the device prior to the extraction.

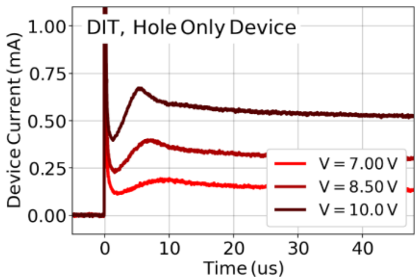
- For solar cells
- Extracting the recombination coefficient from charge extraction with varied delay-time similar as in OTRACE.



DIT – Dark Injection Transients

A voltage step is applied to the device and the transient current response is measured.

In monopolar (only one charge carrier type can be injected) devices with good Ohmic contacts the charge carrier mobility can be determined from the current peak.



A space-charge effect leads to a current overshoot. Therefore, this technique is also called transient space-charge-limited current (T-SCLC) in literature. The time of the current overshoot is related to a transit time and allows the estimation of the charge carrier mobility and its field dependence. The occurrence of the current overshoot is a confirmation of good electrical contact for charge injection.

- For monopolar devices, solar cells and LEDs
- Extracting the series resistance and geometric capacitance

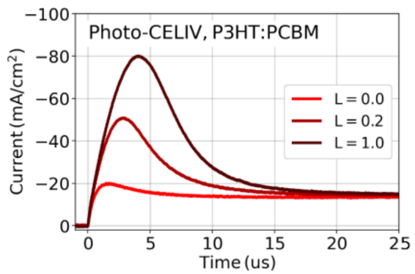
CELIV – by Linearly Increasing Voltage

Photo-CELIV is a powerful technique to extract charge carrier mobility, the recombination coefficient and the doping density.

CELIV is a commonly used characterization technique for organic solar cells but can also be applied to perovskite solar cells or LEDs.

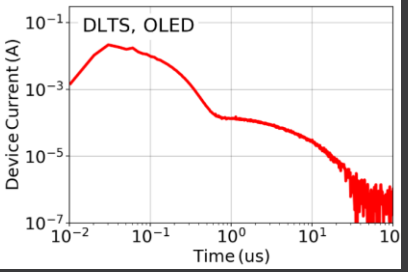
A voltage ramp is applied in reverse to extract charge carriers. The current-peak is related to the charge carrier mobility.

Paios uses the technique OTRACE to accurately determine the recombination coefficient of solar cells from photo-CELIV measurements with varied delay-time.



- For solar cells, MIS and LEDs
- Extracting the charge carrier mobility
- Extracting the doping density from dark-CELIV measurements
- Extracting the geometrical capacitance and the series resistance from dark-CELIV
- Extracting the recombination coefficient of solar cells from OTRACE CELIV

Deep-level transient spectroscopy (DLTS)



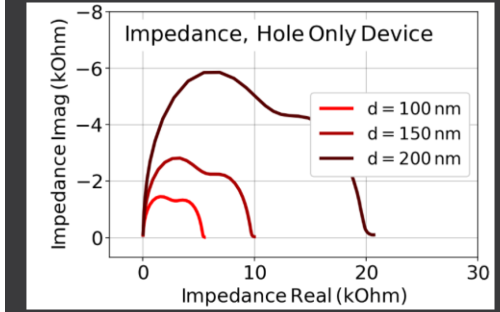
Deep-level transient spectroscopy (DLTS) is a measurement to characterize traps inside a diode.
In Paios the current-DLTS method is implemented, where the filling and release of traps as a response to a reverse voltage pulse is recorded. An exponential current decay is a signature of a single trap level, and the temperature dependent decay time can be used to determine the trap energy.

- for solar cells, MIS and LEDs

Experiment Techniques

IS – Impedance Spectroscopy

In impedance spectroscopy a small sinusoidal voltage is applied to the device and the complex impedance is measured according to amplitude and phase-shift of the current. The technique is widely used to study solar cells and LEDs. Charge carrier dynamics at different frequencies can be studied.



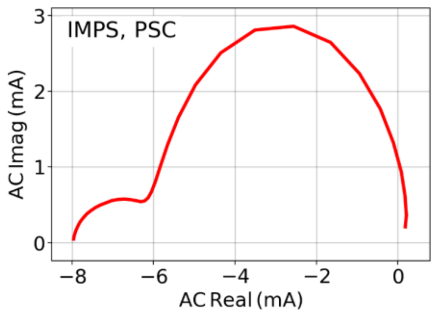
- Frequency range: 10 mHz - 10 MHz
- Impedances up to GΩ
- Offset voltage -12 to +12V
- For all devices
- Fitting with Equivalent-Circuits
- Extracting series resistance, parallel resistance and the geometric capacitance

IMPS – Intensity-Modulated Photocurrent Spectroscopy

A solar cell is illuminated at short-circuit with a constant light intensity. On top of the constant light intensity a small modulated light signal is added.

The amplitude and the phase-shift is measured between short-circuit current and input light.

This technique is applied to investigate charge transport in solar cells.

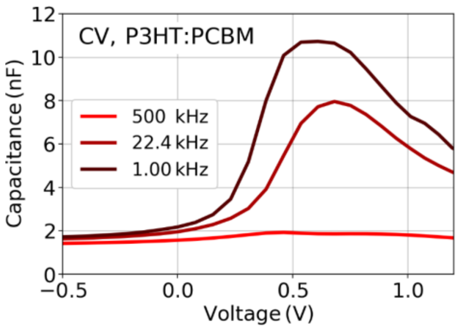


- Frequency range: 10 mHz to 1 MHz
- Offset voltage -12 to +12V
- For solar cells
- Extracting the charge transport time from the IMPS peak

CV - Capacitance-Voltage

The impedance of a device is measured for varied offset voltage at constant frequency.

Capacitance-voltage curves reveal information about the built-in field and the charge injection barriers.

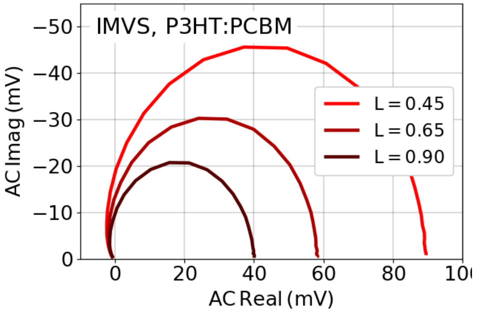


- Offset voltage -12 to +12V
- For solar cells and LEDs
- Extracting the doping density by Mott-Schottky analysis

IMVS – Intensity-Modulated Photovoltage Spectroscopy

IMVS works like IMPS (above) but instead of keeping the solar cell at short-circuit, the solar cell is kept at open-circuit.
This technique is applied to extract the charge carrier lifetime in solar cells.

- Frequency range: 10 mHz to 1 MHz
- For solar cells
- Extracting the recombination time from the IMVS peak

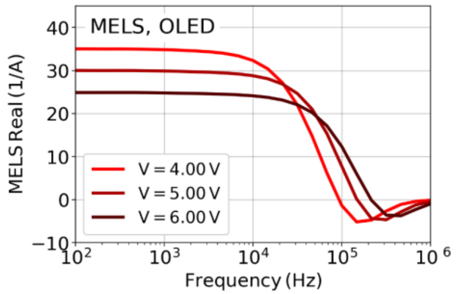


MELS – Modulated Electroluminescence Spectroscopy

As in impedance spectroscopy a sinusoidal voltage is applied to the device on top of a constant offset voltage.

The amplitude and the phase-shift of the EL signal are measured versus various frequencies.

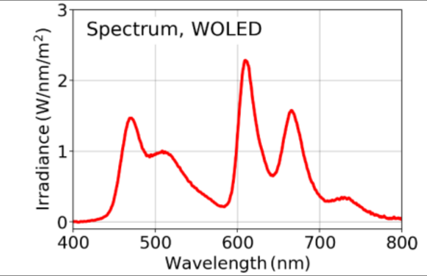
MELS is used to study the charge transport in LEDs.



- Frequency range: 10 mHz to 10 MHz
- Offset voltage -12 to +12V
- For LEDs

Emission Spectrum

The electroluminescence spectrum of an LED is one of its most important characteristics and can be obtained with the Spectrometer Module. The spectrum can be measured under constant voltage/current condition in DC, pulsed and pulse-width modulation modes.



The use of a calibrated spectrometer allows to quantify the absolute spectral and integrated irradiance, luminance and current efficacy as well as CIE and color temperature.

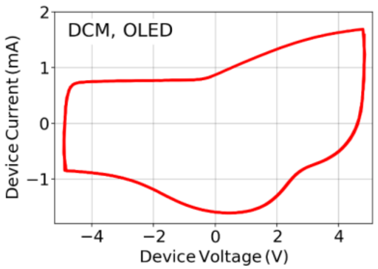
- for light-emitting devices (OLED, PLED, OLEC) and perovskite solar cells

User Defined Signals

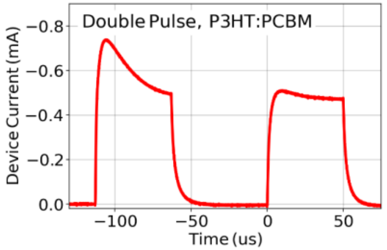
The custom signal editor allows to generate an arbitrary transient voltage and illumination signal and to measure the resulting device current. By defining relevant time intervals the signal can be cur and plotted conveniently.

- for solar cells, LEDs, unipolar devices

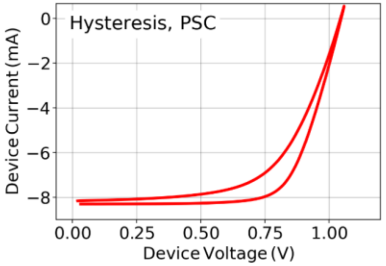
Some (predefined) examples are:



- Displacement current measurement (DCM) with cycles of up and down voltage ramps



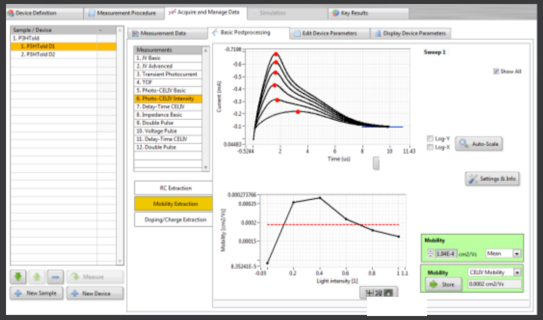
- Double transient photocurrent pulses with varied delay times to analyze traps



- IV-curves scanning up and down to investigate hysteresis

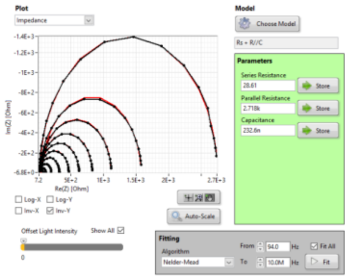
Postprocessing for Parameter Extraction

Paios comes with flexible and user-friendly post-processing routines included. Even novice users can easily analyze experimental results and extract parameters.

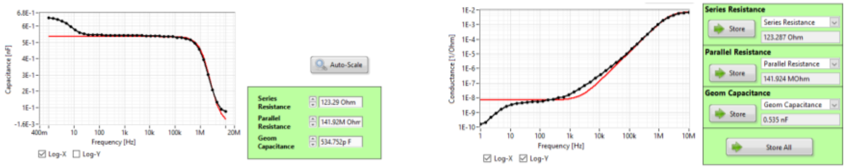


Equivalent Circuit Fitting

The most popular way to analyze impedance spectroscopy data is equivalent circuit fitting. Paios has integrated a routine for such fits. User-defined or pre-defined circuits are available.



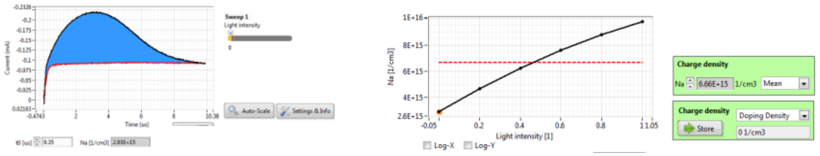
Series Resistance & Geometric Capacitance from Impedance



A very reliable method to extract the series resistance and the geometric capacitance from impedance spectroscopy data.

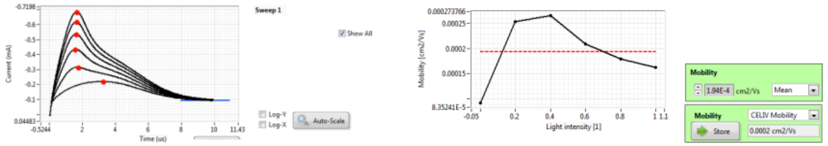
Doping Density from CELIV

The dark-CELIV current overshoot (shown in blue) is integrated to obtain the doping density.



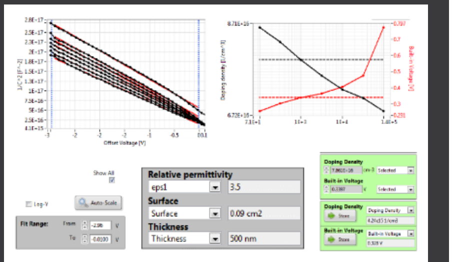
CELIV – Mobility

Extract the charge carrier mobility from CELIV experiments. The user can choose between several formulas to evaluate the mobility.



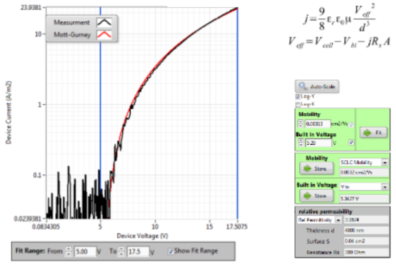
Mott-Schottky Doping Density from CV

With a Mott-Schottky analysis the doping density of a semiconductor can be extracted from CV-measurements (provided the device is thick enough).



Charge Carrier Mobility from Mott-Gurney Fit

In monopolar devices the charge carrier mobility can be extracted from an IV-curve using a SCLC-fit.



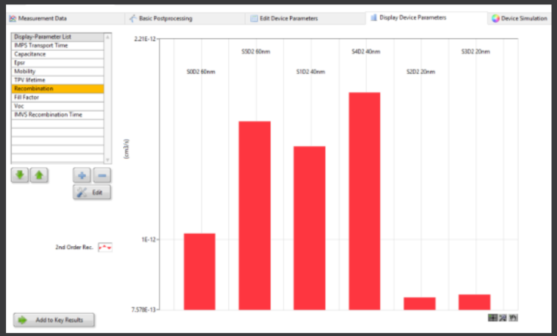
paios

Electro-Optical Characterization of LEDs & Solar Cells

FLUXiM

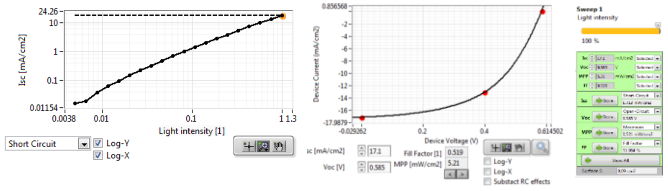
Postprocessing for Parameter Extraction

Compare the parameters you have extracted in Paios, create and export bar-plots or xy-plots.

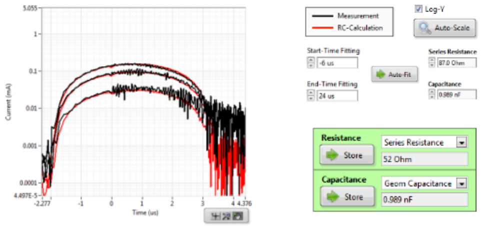


Basic Solar Cell Parameters

Extracts short-circuit current, the open-circuit voltage, the fill factor and the maximum power point of a solar cell.



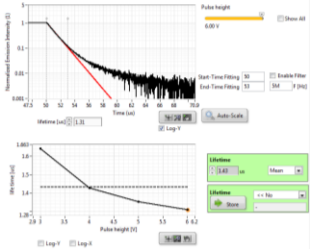
Series Resistance and Permittivity from Voltage-Pulse



Determine the permittivity/ capacitance and the series resistance from a small voltage pulse in reverse.

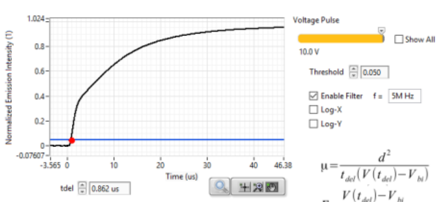
Luminescence Lifetime

From the electroluminescence decay after voltage turn-off the luminescence lifetime of the emitter can be extracted.



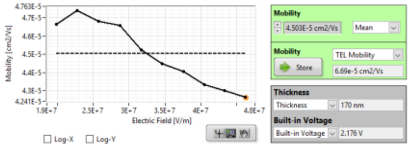
Mobility from Transient Electroluminescence

Extract the charge carrier mobility from CELIV experiments. The user can choose between several formulas to evaluate the mobility.



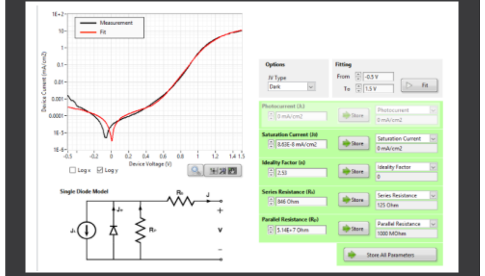
$$\mu = \frac{d^2}{t_{del}\left(V(t_{del}) - V_{bi}\right)}$$

$$E = \frac{V(t_{del}) - V_{bi}}{d}$$



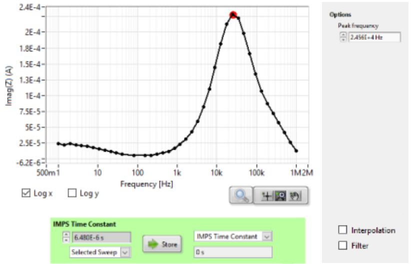
One-Diode Model Fit

Extract the parameters of the one-diode model for solar cells: ideality factor, dark saturation current, series resistance and parallel resistance.



Transport-Time from IMPS Lifetime from IMVS

Easily determine the transport time from IMPS that describes how fast charges reach the contacts. From IMVS the charge carrier lifetime is determined.



Paios Specifications

Sampling-rate	60 MS/s
Time resolution	16 ns
Voltage range	± 12 V
Extended voltage range *(SMU module, up to 1 kHz)*	± 60 V
Frequency range impedance spectroscopy	10 mHz to 10 MHz
Minimal resolvable current	< 100 pA
Maximum current	100 mA
Measurement resolution	12 Bit
Spectral resolution (Spectrometer module)	2.5 nm
LED rise/fall time *(PV version)*	100 ns
Illumination area *(PV version)*	1.7 cm^2
Computer Connection	PXI and USB
Dimensions / Weight	40 x 30 x 20 cm^3 / 18kg

Paios Optional Modules

- Liquid Nitrogen Cryostat
- Peltier Cryostat
- Spectrometer Module
- Automated Measurement Table
- Multiplexing Module
- Glovebox Feed-Through
- Source Measure Unit (SMU)

Paios Technical Support

Full technical support is included with every purchase of Paios. Our team of R&D Scientists will also be happy to discuss how we can help.

Contact us today to discuss how Paios can advance your R&D.

hardware@fluxim.com

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