

# Products 2017 / 18

Instrumentation for  
battery research





# We advance battery research.

EL-CELL® offers electrochemical test equipment and services for battery research at leading edge quality. Our products range from 3-electrode battery test cells through in-situ test cells for optical measurements to highly integrated battery test stations. The main focus of our ongoing product development is on the PAT (Parallel Test) family, which is being designed for high-throughput testing of battery material such as anodes, cathodes, electrolytes, and separators. The PAT system serves both aprotic and aqueous battery systems, with the focus on Li-ion batteries. The worldwide patented PAT-Core takes advantage of the single-use concept,

thus eliminating the need for cleaning and drying cell components, and increasing the productivity and quality of results.

The hardware is being completed by tools like cutting pliers and punching tools for a more productive and accurate experimentation process.

EL-CELL® provides a wide range of services. Our fully equipped electrochemical research lab is ready for almost any kind of battery related service measurement. Moreover, EL-CELL® offers seminars and trainings in order to support researchers in effectively utilizing our products.

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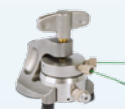
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# About the PAT series

## Our modular system for testing of battery materials

The novel PAT (Parallel Test) family is built around the PAT-Core, the single-use assembly comprising anode, cathode, reference electrode and separator. This PAT-Core is hermetically sealed inside the PAT-Cell, protecting the sensitive battery components against the outside atmosphere. Different versions serve different battery chemistries including aprotic and aqueous systems, with the focus on Li-ion batteries. Specialized PAT-Cells are equipped with sensors for the in-situ measurement of additional variables such as temperature and gas pressure.

The PAT family is completed by a variety of docking and test stations. The simplest docking station, the PAT-Stand-1, is for connection of a single PAT-Cell to an existing potentiostat. The PAT-Chamber is a temperature-controlled, 16-channel docking station for connection to an existing multi-channel potentiostat. Finally, the most advanced PAT test station, the PAT-Tester-i-16, integrates a 16-channel docking station, a fully featured multi-channel battery tester, and a temperature chamber into one single instrument.

## Why PAT?

### → Long-term tests

With the ring reference built into the PAT-Core, the half-cell voltages can be monitored throughout the whole battery life.

### → No cross-contamination

No cleaning, no cross-contamination due to single-use concept

### → Easy electrolyte filling

Easy and reliable electrolyte filling during assembly (defined electrolyte volume down to 50 µL)

### → Battery grade materials

Different from competing designs, the PAT-Core may be solely built from battery-grade materials: pure Al, Cu and polypropylene.

### → Saving time and space

Fast assembly and dismantling to accelerate experiments

### → Half-cell impedance spectra

With the ring reference built into the PAT sleeve, the half-cell impedances can be measured as easily as the full-cell impedance.

### → Good reproducibility

PAT series increases the reproducibility of battery test results.

### → Less cleaning effort

The single-use components of the PAT-Core eliminate the need for drying and cleaning cell parts.

### → Tight test cells

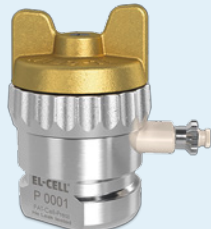
PE seals and double-cutting knives guarantee best tightness. All PAT series test cells are tested for helium leaks.

# PAT series overview

## PAT test cells



PAT-Cell



PAT-Cell-Press



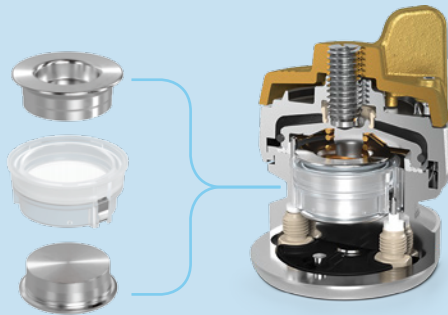
PAT-Cell-Press-Aqu



PAT-Cell-Aqu



PAT-Cell-HT



**PAT-Core**

Patent Pending, Publ. No.  
US 2017-0016844 A1



PAT-Stand-1



PAT-Stand-4



PAT-Stand-16



PAT-Heater-4



PAT-Chamber-16



PAT-Tester-i-16

## PAT docking and test stations

# PAT-Core

## Enabling ageing studies and impedance spectra of unmatched quality

The PAT-Core is the essential part of the PAT-cell holding in place and precisely aligning the electrodes being tested. The well-defined geometry of the PAT-Core enables high-quality two- and three-electrode tests of Li-ion and other battery materials as well as supercapacitors.

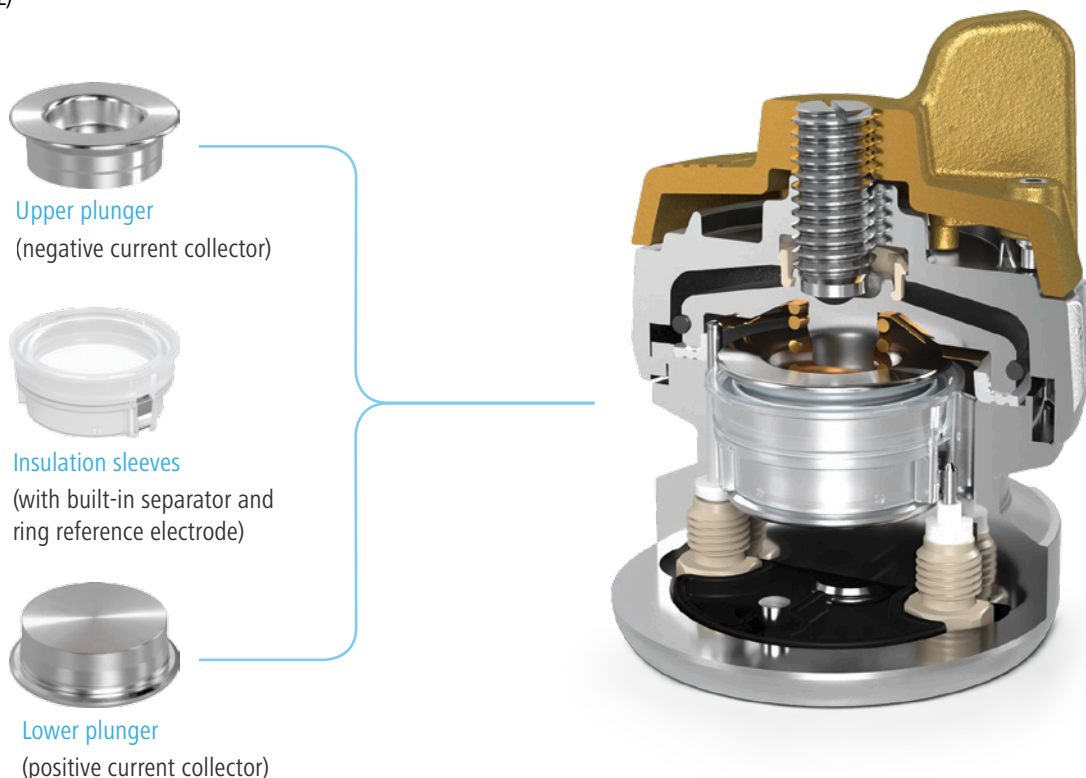
The PAT-Core comprises three components. The first part is a highly customizable insulation sleeve made of polypropylene with a built-in separator and ring-shaped reference electrode. Different reference materials like sodium or magnesium and various separator materials such as glass fiber or microporous polyolefine are available.

The single-use concept lowers lead times in the lab and minimizes the risk of cross-contamination. The insulation sleeve is pre-assembled under a protective atmosphere at the EL-CELL® factory to ensure consistent quality for reproducible battery tests.

The upper and lower plungers complete the PAT-Core. Plungers are made of aluminum, copper, or stainless steel, functioning as current collectors. This enables battery researchers to work exclusively with battery-grade materials. Aluminum and copper plungers are single-use parts, while the stainless steel plungers can be reused.

## Features

- High-precision 18 mm diameter sandwich geometry of cell stack with a ring-shaped reference located at the separator edge
- All battery-grade materials available: Al, Cu, polypropylene
- Optionally reusable current collectors made of stainless steel (316L)
- Long-term ( $\geq 1000$  hrs) half-cell measurements with three electrodes
- Minimal risk of cross-contamination or corrosion due to the single-use concept
- No need to clean and dry cell components







\* For customers using the older ECC-Std, ECC-Ref or ECC-Combi, the "ECC to PAT upgrade kit" is available to make these cells working with the PAT-Core.

# PAT-Core configurations




## The test cell core for characterizing battery and capacitor materials

The PAT-Core is available in different configurations for different test cases. The following examples give an overview only of the most common applications, LiB (Li-ion and Li-metal) and aprotic supercapacitors (EDLC). Several other solutions – other separator, reference and plunger materials – are available on request. We continuously expand the PAT system to include new chemistries.



### Insulation sleeves

① Inner clips ring ② Separator ③ Reference ring ④ Reed contact ⑤ Outer clips ring				
	Insulation sleeve with lithium metal ring reference	Insulation sleeve without ring reference	Insulation sleeve with activated carbon ring reference	Plain insulation sleeve, disassembled
	glass fiber			
	LiB	LiB and aprotic EDLC	aprotic EDLC	LiB and aprotic EDLC

### Upper plunger

			
Type	Copper, Cu 99.9 (E-CU 58), For single use	Aluminum, Al 99.5 (EN-AW-1050) For single use	Stainless steel, 316L (1.4404) Reusable
Stable potential range (vs. Li) in LiPF <sub>6</sub> based electrolytes	0 to 3 V	1 to 5 V	0 to 5 V
Field of application	LiB	aprotic EDLC, LiB with LTO as negative	LiB and aprotic EDLC

### Lower plunger

			
Type	Copper, Cu 99.9 (E-CU 58), For single use	Aluminum, Al 99.5 (EN-AW-1050) For single use	Stainless steel, 316L (1.4404) Reusable
Stable potential range (vs. Li) in LiPF <sub>6</sub> based electrolytes	0 to 3 V	1 to 5 V	0 to 5 V
Field of application	LiB "half-cell": graphite vs Li metal	LiB and aprotic EDLC	LiB and aprotic EDLC



# PAT-Cell

## High-throughput testing with the PAT-Core

The PAT-Cell is the test cell for reproducible testing of battery materials with high throughput. The PAT-Cell has no sockets for direct cable connections. The pre-assembled PAT sleeve greatly facilitates and speeds up the building of test cells. Due to the single-use concept, there is no need for cleaning or drying cell components.

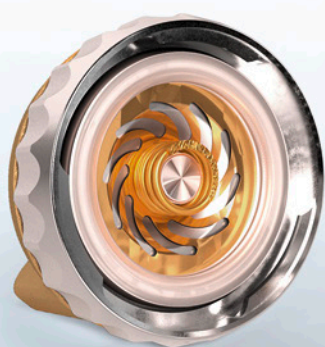
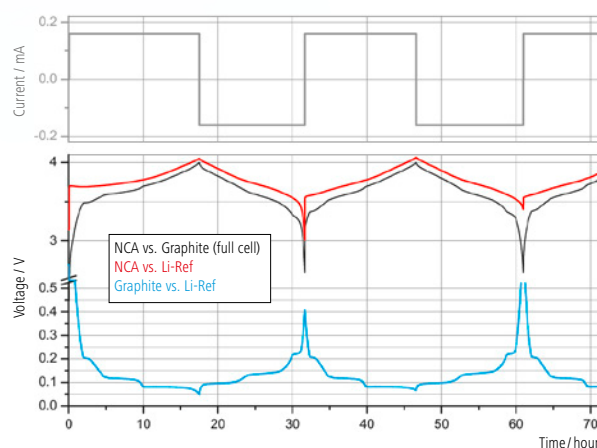
## Features

- Wireless test cell with all the advantages of the PAT-Core
- Suited for experiments with aprotic and aqueous electrolytes
- Leak-proof sealing with double-cutting knives and PE seal
- Reliable sealing due to LDPE seals with double-cutting rings
- Easy and reliable electrolyte filling upon assembly (defined volume down to 50  $\mu\text{l}$ )
- Almost no need for cleaning and drying of cell parts

With the PAT-Cell, the variation across experimental results due to varying experimentators is minimized. The PAT-Cell has been designed and is ready for the future automation of battery testing. EL-CELL® consults you about the integration into your assembly concept.

The PAT-Cell is the ideal cell for high-throughput battery testing.

Monitoring half-cell voltages during the initial cycles of  
NCA vs. Graphite





# PAT-Cell-Aqu

## The new test cell for aqueous electrolytes

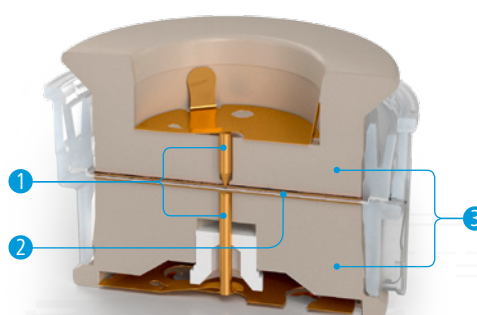
The PAT-Cell-Aqu is the newest PAT-series test cell dedicated to the characterization of aqueous batteries. Functionally, the PAT-Core-Aqu comprises three components: the insulation sleeve with a built-in separator and reference ring, and two 18 mm diameter current collectors, each contacted by a feed wire. By default, current collectors and feed wires are made of pure gold. The feed wires are held in place by plungers made of PEEK polymer.

As a result, the PAT-Cell-Aqu does withstands most aqueous electrolytes such as sulfuric acid (up to 50% concentration) or potassium hydroxide solution. Other metals such as Pt and Ni are optionally available as current collectors, and may be easily replaced by the user. While most appropriate for aqueous electrochemistry, the PAT-Cell-Aqu can also be used for aprotic systems beyond Li-ion with special demands on corrosion stability.

## Features

- PAT-series test cell specialized for aqueous electrolytes or non-lithium battery systems with special demands on corrosion stability.
- Superior corrosion resistance against aqueous electrolytes (e.g.  $\text{H}_2\text{SO}_4$ , KOH)  
Also applicable to aprotic battery chemistries with special demands on corrosion resistance
- Specialized PAT-Core with reusable plunger made of PEEK polymer and gold current collectors (optionally other metals such as Pt, Ni)
- Single-use insulation sleeves with or without ring-shaped reference electrode
- Fast assembly and dismantling and easy cleaning of cell components
- Electrodes are easily accessible for post-mortem analysis.

Specialized PAT-Core for aqueous electrolytes



① Gold feed wire    ② Gold current collectors (18 mm diameter)    ③ PEEK plungers



# PAT-Cell-Press

## Pressure test cell for the PAT series

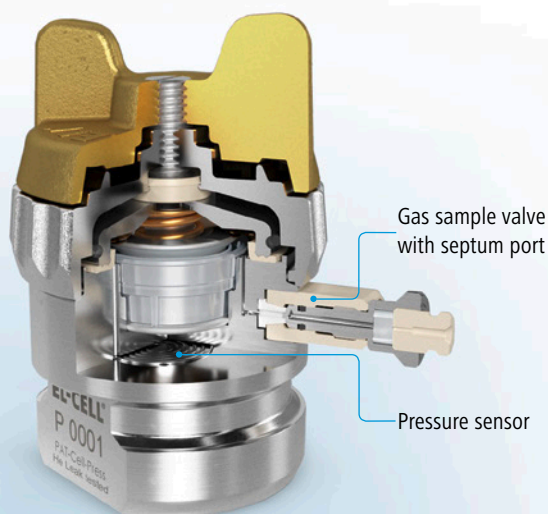
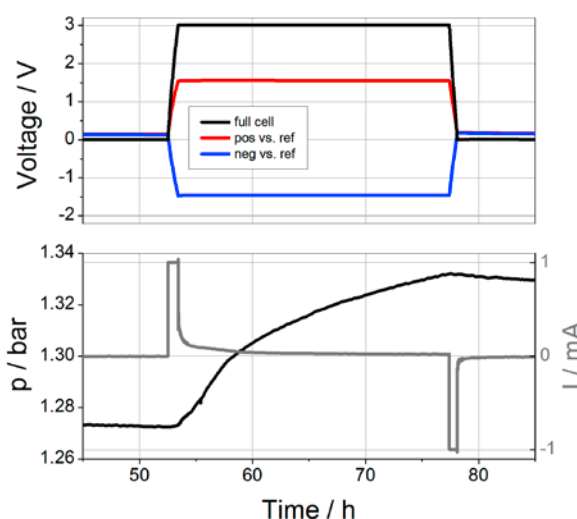
The PAT-Cell-Press is the PAT-Cell with an integrated pressure sensor and a sample port for drawing gas samples from the cell's head space. The PAT-Cell-Press can be operated in three different ways: either as part of the PAT-Press package, or plugged into the PAT-Chamber-16, or plugged into the PAT-Tester-i-16. The advanced design of the PAT-Cell-Press includes a laser-welded pressure sensor and glass-to-metal seals for the electrode feedthroughs.

## Features

- PAT-Core design with or without reference electrode
- Laser-welded pressure sensor, 0 to 3 bar abs.
- Optional gas sample port
- Electrode feedthroughs with glass-to-metal seals
- Tested for helium leaks
- Can be operated in three different ways: either as part of the PAT-Press package, inside the PAT-Chamber-16, or inside the PAT-Tester-i-16
- Temperature operation range: -20 to +70° C

The number of non-permanent seals is reduced to its minimum: a single PE seal between cell lid and base and a ferrule when the cell is ordered with the optional gas sample port. In order to ensure best testing results, every PAT-Cell-Press has been tested to be free of helium leaks before delivery.

Pressure response during cc/cv cycling of a supercapacitor\*



\* Test setup: PAT-Cell-Press, activated carbon electrodes, activated carbon reference, 1M TEABF<sub>4</sub> in acetonitrile, 25 µm polyolefine separator (2x), CCCV cycles, 1 mA, 0/3V, 35° C

# PAT-Cell-Press-Aqu

## New pressure test cell for aqueous electrolytes

The PAT-Cell-Press-Aqu is the aqueous version of the PAT-Cell-Press. The special design can withstand all common aqueous electrolytes such as sulfuric acid and potassium hydroxide solution. All current collectors and feed wires are made of gold. Other metals such as Pt and Ni are available as an option.

Due to its excellent corrosion resistance, the PAT-Cell-Press-Aqu can also be used for aprotic systems beyond Li-ion.

The PAT-Cell-Press-Aqu is our specialized pressure test cell for aqueous electrolytes and non-lithium battery systems.

## Features

- Superior corrosion resistance against aqueous electrolytes (e.g.  $\text{H}_2\text{SO}_4$ , KOH)  
Also applicable to aprotic battery chemistries with special demands on corrosion resistance
- Laser-welded pressure sensor, 0 to 3 bar abs.
- Tested for helium leaks
- Specialized PAT-Core with reusable plunger made of PEEK polymer and gold current collectors (optionally other metals such as Pt or Ni)

### Test setup examples



\* All available battery testers can be used with the PAT series



# PAT-Cell-HT

## New heat resistant PAT-Cell for up to 200°C

The PAT-Cell-HT is the new 2- and 3-electrode test cell equipped for high temperatures up to 200°C. The high temperature system

comprises the PAT-Cell-HT with the HT version of the PAT-Core, and a 4-channel docking station with temperature control.

### Specialized PAT-Core for the PAT-Cell-HT



### Specialized PAT-Core components

To meet the challenges of battery tests at elevated temperatures up to 200°C, we offer a HT version of the insulation sleeve. This reusable HT-sleeve is made of PEEK (rather than PP) and is especially useful for the investigation of solid state (ceramic) electrolyte membranes. Just like the standard sleeve, the HT-sleeve can be equipped with different reference materials such as lithium, sodium or magnesium. The standard current collectors (plungers) complete the PAT-Core. Available plunger materials are aluminum and copper (for single use), or stainless steel 316L (for reuse).

### Features PAT-Cell-HT

- PAT-series test cell for 2-or 3-electrode testing at elevated temperatures
- Continuous operating temperature: up to 200°C
- Demountable HT-sleeve for self-installation
- Single-use ring-shaped reference ring and reed contact
- Compatible with solid state electrolyte membranes





# PAT-Heater-4

## Heated chamber for four PAT-Cell-HT

The PAT-Heater-4 is a heated docking station connecting up to 4 PAT-Cell-HT to any potentiostat or battery tester. The working temperature is adjustable from 10°C above ambient temperature up to 200°C. The PAT-Heater-4 saves wiring effort, because it is not

necessary to renew the connection between cell and potentiostat for every battery test. However the easy-to-access banana sockets at the side of the docking station allow for flexible wiring.

The PAT-Heater-4 is the temperature controlled docking station for parallel electrochemical tests with high temperatures up to 200°C.

## Features

- Heated chamber from 10°C > ambient temperature up to 200°C
- 4x1 docking station for up to four PAT-Cell-HT
- Compatible with all of today's multi-channel potentiostats and battery testers
- Can be placed on the bench or inside a glove box
- Flexible wiring due to easy-to-access banana sockets
- Saves wiring effort and space in the lab

## Technical Data

- 400 mm x 265 mm (width x depth)
- Height: 230 mm



# PAT-Stand-1

## PAT-Cell docking station for individual battery testing

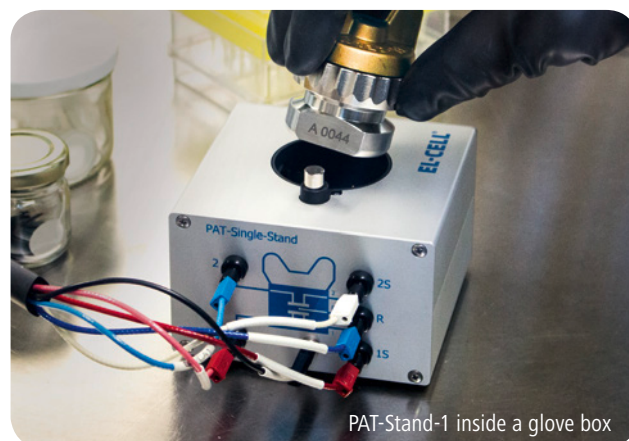
The PAT-Stand-1 is a docking station, that runs a single PAT-series test cell e.g. PAT-Cell-Press. It can be connected directly to a common potentiostat or battery tester using 4 mm banana sockets or a hardwired Sub-D socket. Therefore, the PAT-Stand-1 saves wiring effort, because it is not necessary to renew the connection of cell and potentiostat for every battery test.

The PAT-Stand-1 fits nicely into a normal climate chamber and is small enough to be placed inside a glovebox. This enables you to perform whole battery tests inside the glovebox.

The PAT-Stand-1 saves space in the lab and allows immediate functional testing of all PAT-series test cells.

## Features

- Compatible with all of today's multi-channel potentiostats and battery testers (e.g. Biologic MPG-2 or Maccor 4000)
- Charge/Discharge/EIS compatible with any PAT series test cell (Please refer to the table PAT-Compatibility for further details)
- Can be placed on the bench or inside temperature chamber
- Flexible wiring due to easy to access banana sockets or Sub-D connector
- Paves the way for high-throughput testing with multi-channel docking stations, e.g. PAT-Stand-16
- Saves wiring effort and space in the lab



PAT-Stand-1 inside a glove box

## Technical Data

- 105 mm x 113 mm (width x depth)
- Height: 80/110 mm (without/with PAT-Cell)
- Weight: ca. 0.56/0.96 kg (without/with PAT-Cell)



# PAT-Stand-4

## Scale up of individual battery testing

The PAT-Stand-4 is a docking station connecting up to four PAT-Cells to any potentiostat or battery tester. The PAT-Stand-4 saves wiring effort, because it is not necessary to renew the connection between cell and potentiostat for every battery test.

However, the easy-to-access banana sockets at the side of the docking station allow for flexible wiring.

The PAT-Stand-4 enables you to perform simultaneous battery testing on a small scale.

## Features

- 4x1 docking station for up to 4 PAT series test cells
- Compatible with all of today's multi-channel potentiostats and battery testers
- Charge / Discharge / EIS compatible with any PAT series test cell (Please refer to the table PAT-Compatibility for further details)
- Can be placed on the bench, inside the temperature chamber, or inside a glove box
- Flexible wiring due to easy-to-access banana sockets
- Saves wiring effort and space in the lab

## Technical Data

- 301 mm x 119 mm (width x depth)
- Height: 84 / 114 mm (without / with PAT-Cells)
- Weight: approx. 0.67 kg (without PAT-Cells)





# PAT-Stand-16

## High-throughput docking station

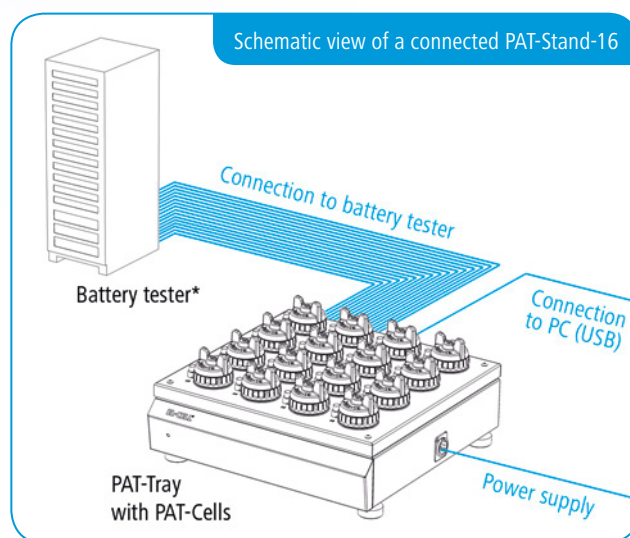
The PAT-Stand-16 is the docking station for up to 16 PAT-Cells in a 4x4 matrix. It has a built-in data logger recording full- and half-cell voltages, cell current, tray temperature and time. The PAT-Stand-16 can be operated with a usual multi-channel potentiostat (like the Biologic MPG-2 or VMP300) or battery tester (like the Maccor 4000).

This way, the PAT-Stand-16 saves wiring effort, because it is not necessary to renew the connection of cell and potentiostat for every battery test. Furthermore, it fits nicely into a normal climate chamber (such as Binder KB53), which saves space in the lab.

All of these features make the PAT-Stand-16 the optimum solution for high throughput testing when using an external battery tester.

## Features

- 4x4 docking station for up to 16 PAT-Cells
- Integrated data logger for recording of cell data (current, full- and half-cell voltages) and tray temperature
- Compatible with all of today's multi-channel potentiostats and battery testers
- Charge / Discharge / EIS compatible with any PAT-series test cell (Please refer to the table PAT-Compatibility for further details)
- Can be placed on the bench or inside temperature chamber
- Saves wiring effort and space in the lab
- Flexible wiring possible with optional PAT-Connect-16



\* All available battery testers can be used with the PAT series

## Technical Data

- 315 mm x 315 mm (width x depth)
- Height: 120 / 148 mm (without / with cells)
- Weight: ca. 6.9 kg (without cells)



# PAT-Chamber-16

## Temperature-controlled PAT series docking station

The PAT-Chamber-16 combines the high-throughput testing abilities of the PAT-Stand-16 with a temperature controlled cell chamber. The integrated Peltier device enables you to test at the exact temperature you need, without using an external heat chamber. The PAT-Chamber-16 is our first high-throughput docking station that is capable of utilizing both the PAT-Cell and the PAT-Cell-Press for in-situ pressure monitoring of up to 16 test cells at the same time.

Just like the PAT-Stand-16, the PAT-Chamber-16 comes with a built-in data logger recording full- and half-cell voltages, cell current, time, global temperature and individual cell pressure.

The PAT-Chamber-16 can be left connected permanently to all of today's multi-channel potentiostats or battery testers. This enables you to save a lot of wiring effort, because it is not necessary to renew the connection between cell and potentiostat for every battery test.

## Features

- Temperature-controlled docking station for up to 16 PAT series test cells
- Integrated Peltier-temperature-control with a temperature range of +5 to +80°C
- Ready for PAT-Cell-Press for pressure monitoring
- Charge / Discharge / EIS compatible with any other PAT series test cell (Please refer to the table PAT-Compatibility for further details)
- With data acquisition of cell current, cell voltage, half-cell voltages, global temperature, individual cell pressure
- Compatible with all of today's potentiostats and battery testers
- Flexible wiring possible with optional PAT-Connect-16
- Saves wiring effort



## Technical Data

- 380 mm x 640 mm (width x depth)
- Height: 375 mm
- Weight: approx. 24 kg (without PAT-Cells)



Image shows PAT-Chamber-16 with optional top-mounted PAT-Connect-16.

# PAT battery tester

## First fully integrated PAT-Tester-i-16

Until now, battery research solutions were modular systems built around wired test cells or test cells docked into a docking station. The cell and docking station needed to be placed into a temperature-controlled chamber and connected via cables to a potentiostat/galvanostat, which was connected to a desktop PC. Such modular and distributed set-ups are flexible, but have severe drawbacks such as a large foot print, an extensive cable harness, unconsolidated data management, and susceptibility to experimental mistakes.

This can be the past! The new PAT-Tester-i-16 integrates all functions of a 16-channels battery tester, a PAT docking station, and a temperature-controlled test chamber into one single instrument. The world-wide patented wireless connection between test cell and potentiostat saves space in your lab and eliminates any wiring effort. Plug the PAT-Tester into the main power and get full remote access from any host PC on a network!

The internal impedance analyzer is capable of simultaneously recording both half-cell impedances. The intuitive, easy to use, yet powerful experiment builder enables starters in battery research to setup all common tests such as CCCV cycling, voltammetry and impedance measurements. A powerful script language allows experienced scientists to set up almost any kind of battery tests. All test channels feature a switch-matrix for software-controlled switching between half- and full-cell measurements without reconnecting any cables. Most advanced graphing capabilities allow users to review and compare data of running experiments with any experiment ever stored to the database.

[The PAT-Tester-i-16 enables intuitive PAT series testing with the smallest possible footprint.](#)

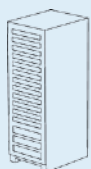
## Technical Data

- 380 mm x 640 mm (width x depth)
- Height: 375 mm
- Weight: approx. 26 kg (without PAT-Cells)



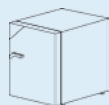
## Our single-device solution for all your needs.

The PAT-Tester-i-16 integrates all functions of a temperature-controlled cell chamber and PAT-docking station with a battery tester into one single instrument.



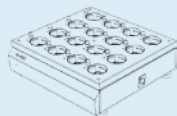
### Battery tester:

The PAT-Tester-i-16 is a fully featured multi-channel potentiostat/galvanostat/impedance analyzer



### Temperature controlled chamber:

Integrated Peltier temperature control for cooling and heating from +5 to +80°C



### Docking station:

The PAT-Tester-i-16 contains 16 independent channels for all PAT series test cells (adapters available for other test cell formats, e.g. coin cells)



## Features

### Hardware

- 16 independent channels for PAT-series test cells
- Each channel with fully featured potentiostat/galvanostat/impedance analyzer
  - Current: up to 100 mA, 4 current ranges plus autorange
  - Voltage:  $\pm 7$  V control range
  - Impedance: 10  $\mu$ Hz to 10 kHz
- Data acquisition
  - 24 Bit ADC
  - 1 ms sampling interval with intelligent data reduction
  - Simultaneous recording of both half-cell voltages
  - Simultaneous recording of sensor signals (e.g. temperature, pressure)
- Software controlled switching between control modes: full cell, cathode half cell, anode half cell
- Integrated Peltier-temperature-control with a temperature range of +5 to +80°C
- Built-in server with a solid-state hard disc for independent operation from the host PC



### Software

- Intuitive, powerful experiment builder for setting up common tests such as CCCV cycling, voltammetry, impedance tests
- Powerful, flexible script language for customization of nearly any desired experiment
- Batch mode for sequencing of experiments
- Most advanced graphing capabilities for viewing and comparing data
  - Single experiment and group reports
  - Multi-panel graphs
  - Built-in and custom graph templates

### Data management

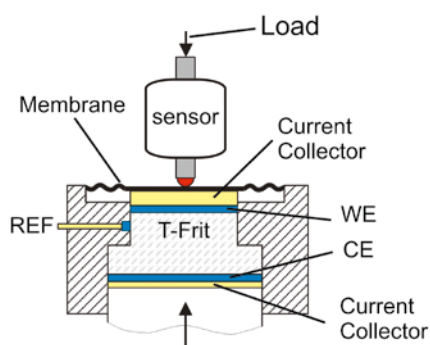
- Multi-user hard- and software with database and LAN connectivity
- Full remote access from any host PC on a network



# Electrochemical Dilatometer

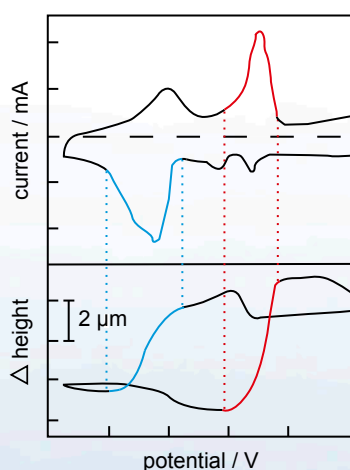
## Watch your electrodes breathing

Our new electrochemical dilatometer is available in two versions, the ECD-3 and the ECD-3-nano. The two instruments mainly differ in the resolution and drift stability of the displacement sensor system that is attached to the electrochemical cell. The electrochemical cell is identical for both versions.



## Working principle

The ECD-3 and ECD-3-nano electrochemical dilatometer measure the thickness change of a working electrode during the electrochemical cycle. The heart of the dilatometer is an electrochemical cell hermetically sealed against ambient atmosphere.

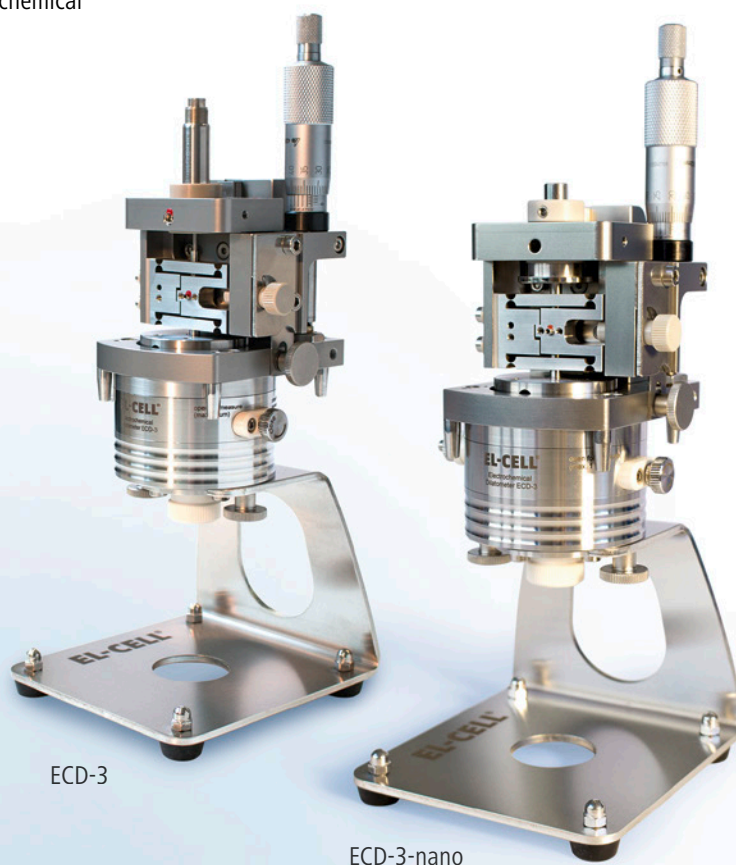


Current response and height change of layered ruthenium oxide in 2 M  $\text{H}_2\text{SO}_4$  during slow scan voltammetry. Courtesy of Prof. Wataru Sugimoto, Shinshu University, Japan.

The working electrode WE and the counter electrode CE are separated by a stiff glass frit soaked with electrolyte. The upper WE is sealed by means of a flexible metal membrane, through which any charge-induced thickness change is transmitted towards the sensor/load unit attached on top. The fixation of the glass frit ensures that only the thickness change of the working electrode is being detected, without interference from the CE. Optionally, a reference electrode REF can be placed at the edge of the frit close to the working electrode.

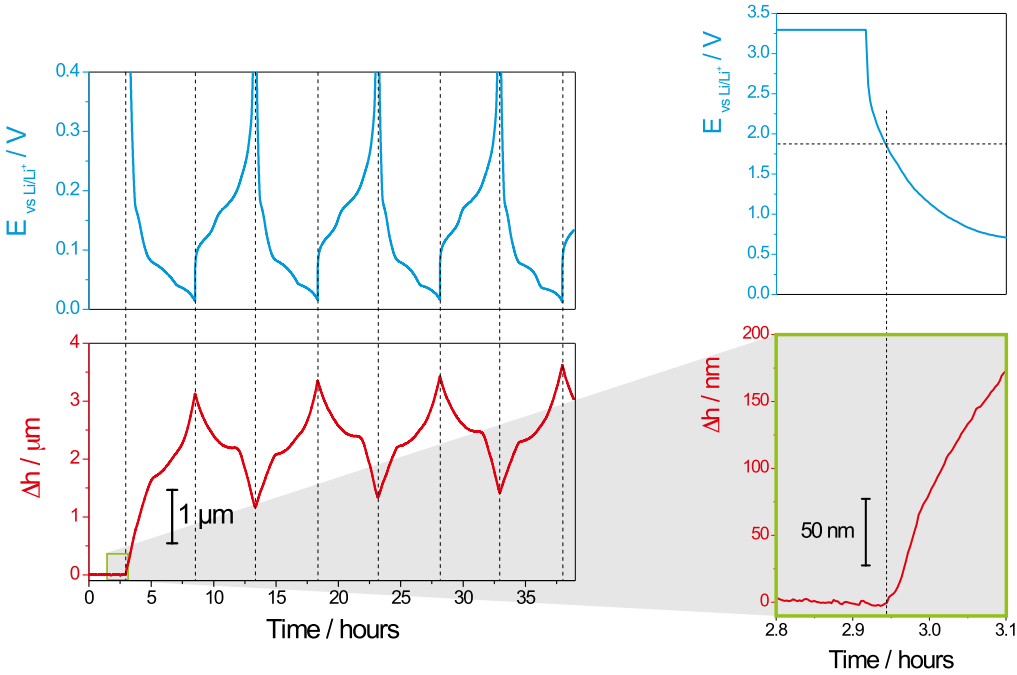
## Options

Various add-ons are available for special testing requirements, such as for using aqueous electrolytes, for using single grains or crystals instead of bound electrode films and for measuring the thickness change of the whole battery stack instead of only the working electrode.



ECD-3

ECD-3-nano



Expanding and shrinking of a graphite electrode during lithium insertion and extraction (figure left). The detailed view on the right shows the onset of expansion at 1.9 V vs. Li/Li<sup>+</sup> (figure right).

Technical data	ECD-3	ECD-3 nano
Displacement sensor system	LVDT	capacitive
Displacement range	500 $\mu\text{m}$	250 $\mu\text{m}$
Displacement resolution	$\leq 50 \text{ nm}$	$\leq 5 \text{ nm}$
Signal drift (sample-free)	$\leq 100 \text{ nm/hour}$	$\leq 20 \text{ nm/hour}$
Test specimen	Electrode films, optional single crystals/grains Diameter $\leq 10 \text{ mm}$ , thickness $\leq 1 \text{ mm}$	
Load on test specimen	approx. 1 N	
Chemical compatibility	Aprotic organic electrolytes; optional aqueous electrolytes	
Cell electrolyte volume	approx. 0.5 ml	

# ECC-Opto-Std

## Processes on your working electrode will become directly visible

The ECC-Opto-Std test cell serves to monitor the optical properties of an electrode material in the course of electrochemical charging. It is dedicated to the inspection of electrodes by optical methods such as light microscopy or Raman spectroscopy working in the reflection mode. Basically, the respective instrument looks through a transparent window onto the backside of the working electrode.

## Features

- 2- and 3-electrode cell with optical window for aprotic electrochemistry
- Full delivery scope for light microscopy
- Special kits for Raman-Microscopy and XRD optional available
- Materials in media contact are stainless steel 1.4404 and PEEK (other materials on request)
- Adjustable, reproducible, and homogeneous mechanical pressure on electrodes
- Reliable low-leakage sealing with PE washers and EPDM O-rings
- Easy and reliable electrolyte filling upon assembly
- Fast assembly and dismantling and easy cleaning of cell components
- Electrodes are easily accessible for post-mortem analysis

The ECC-Opto-Std is easily adapted by optional special kits (e.g. for XRD) to the respective battery system and optical instrumentation used.

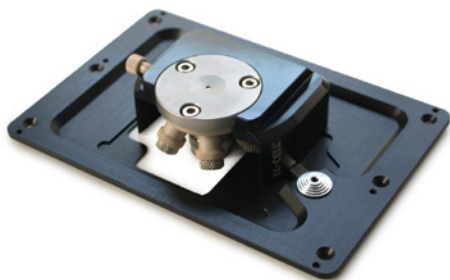
As a standard, the ECC-Opto-Std is equipped with a borosilicate glass window. Depending on your testing purposes, different optional window kits are available.








In this experiment, the ECC-Opto-Std test cell has been used to visualize the color change of a graphite electrode during electrochemical lithiation. The microscope "looked" through the 1 mm diameter hole in the copper foil onto the backside of the graphite electrode.







-  Polyimide (Cirlex) for X-Ray characterization
-  Beryllium for X-Ray characterization
-  Zinc Selenide for IR characterization
-  Calcium fluoride for IR characterization
-  Sapphire ( $\text{Al}_2\text{O}_3$ ) for Raman characterization

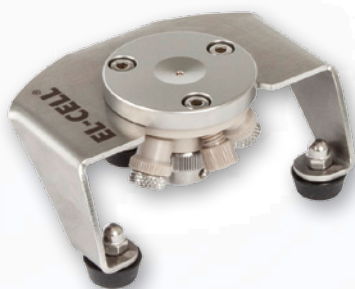
### Cell holder for ECC-Opto-Std

The cell holder is designed for the use of the ECC-Opto-Std in light microscopes. It fits nicely on sample stages of most manufacturers (e.g. Thermofisher or Renishaw) utilizing standard microscope slides (75x26 mm, ISO 8037-1).

The image on the left shows a cell holder for ECC-Opto-Std mounted on a Thermofisher sample stage.

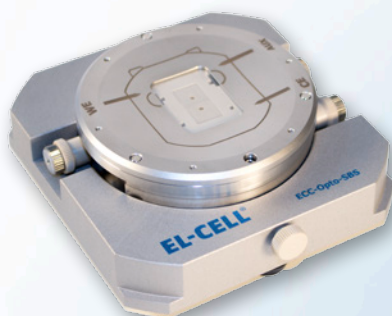
### Optional Window Kits

Every special kit (e.g. ECC-Opto beryllium window kit) includes one or more windows of specific material (e.g. beryllium) and one modified lid with inspection hole of specific shape and size (e.g. 10 mm inspection hole, min. viewing angle 8°). Further window materials like magnesium oxide, silicon dioxide, silicon nitride or PET (Mylar®) are available on request. Additionally, customization of the cell lids is possible.



### ECC-Opto-Std-Aqu

The ECC-Opto-Std-Aqu optical test cell is a variant of our popular ECC-Opto-Std, specialized for use with aqueous electrochemistry. Like the ECC-Opto-Std it is a 2- and 3-electrode test cell for optical characterization in the reflective mode with face-to-face arrangement of electrodes. Typical uses include optical and confocal Raman microscopy. Materials in direct media contact are made of gold, PEEK, and EPDM.

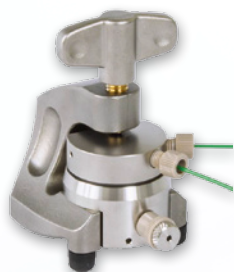


### ECC-Opto-SBS

With the ECC-Opto-SBS, the electrode can be observed in-situ in the reflective mode – just as with the ECC-Opto-Std. The special thing about the ECC-Opto-SBS is the side-by-side ("face up") arrangement of the electrodes which differs from the conventional sandwich ("face-to-face") arrangement of the ECC-Opto-Std.

## Special purpose test cells

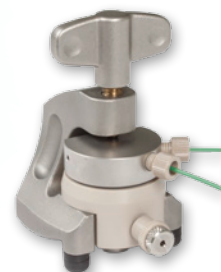
Here you can find test cells of the ECC series for different electrolytes and testing purposes. Our main focus is on lithium-ion batteries, but we also design test cells for other battery technologies. We can also customize our devices and tools according to your individual purposes and develop solutions for specific experiments – just ask.



### ECC-Air

The ECC-Air is a member of the ECC series dedicated to the electrochemical characterization of gas diffusion electrodes in aprotic electrolytes, e.g. for lithium-air batteries.

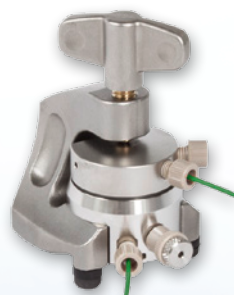
Basically, the upper diffusion type electrode is contacted by and “breathes” through the perforated stainless steel current collector on top. Two ports in the cell lid serve to connect the inside cell volume to the external gas supply and outlet. The design includes a reference electrode.



### ECC-Air-Ni

In contrast to the standard ECC-Air test cell, the current collectors of the ECC-Air-Ni are made of nickel instead of stainless steel. This way, the test cell is stable against corrosion in alkaline aqueous electrolytes.

The ECC-Air-Ni can be used with a reference electrode, which is located at the separator edge.



### ECC-DEMS

This test cell is dedicated to the in-situ gas analysis in aprotic Li-air and conventional Li-ion systems. The cell features a current collector with a spiral-shaped flow-field that is to be constantly purged with a gentle stream of inert gas. The flow-field is located at the bottom of the cell base. The composition of the outgoing gas can be analyzed by e.g. mass spectrometry. The ECC-DEMS cell provides almost perfect plug-flow of the purge gas, which is essential for quantitative time-resolved analysis.



### ECC-Press-Air-DL

The ECC-Press-Air-DL test cell is dedicated to the characterization of gas diffusion electrodes in aprotic electrolytes, in particular for lithium-air batteries. The attached pressure sensor serves to monitor the inside pressure in either a flow-through or in a dead-end pressurized set-up.

The provided low-dead-volume sampling port/valve serves to draw gas samples from the cell’s headspace. The cell hardware can be used with or without a reference electrode. The ECC-Press-Air-DL comes with a controller box for easy interfacing with an external potentiostat.

# Accessories & Tools

EL-CELL® offers useful tools and accessories for enhancing the work experience with our test cells and to make your life as a battery researcher easier. Find more information at [www.el-cell.com](http://www.el-cell.com).



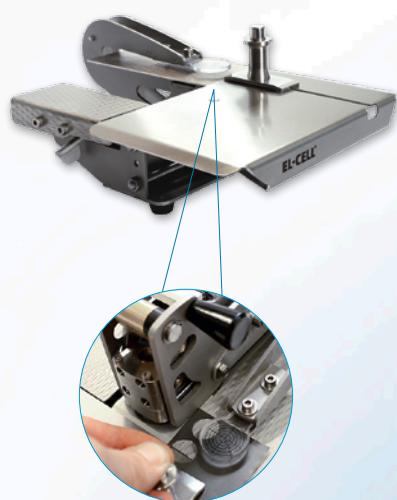
## EL-Cut

**High precision cutting pliers eliminate torn and chipped electrode edges.**

The proper cutting of the electrodes is often an neglected factor in battery testing. Torn and chipped electrode edges – although invisible to the bare eye – inevitably cause current inhomogeneity and are thus likely to affect experimental results. Life cycle and impedance results are especially vulnerable to such artifacts. Electrodes being cut (fine blanked) by the EL-Cut are produced in tools with a few microns of cutting clearance. The fine blanking process results in electrodes having clean cutting surfaces without torn or chipped edges and being almost perfectly flat.

## Features

- Perfectly cut electrodes
- Electrode thickness: max. 300 µm for coatings on Al and Cu foil (may vary for other support materials)
- Any size (diameter) from 6 to 40 mm. Different shapes (e.g. squared) are available on request.



## ECC-StopRail

**Cross hairs reduce cutting waste after mounting to the EL-Cut.**

The ECC-StopRail is an optional tool for the EL-Cut cutting pliers. When attached to the pliers, the ECC-StopRail helps to conveniently target the cutting area and to make effective use of the electrode sheet.

## Features

- Easily attached to EL-Cut, no tools required
- Compatible with any EL-Cut diameter up to 22 mm



## ECC-RefLoad

**Tool for loading reference materials such as lithium metal into ECC-Opto-Std, ECC-Opto-SBS, and ECC-Aqu test cells.**

The device is basically a small tube (cannula) containing with a knock-out pin inside. A tiny piece of lithium metal is first picked up by pressing the cannula onto a piece of lithium foil. The cannula is then inserted into the bore of the Ref sleeve, and the lithium inside the cannula is extruded into the Ref bore by pushing the knock-out pin.



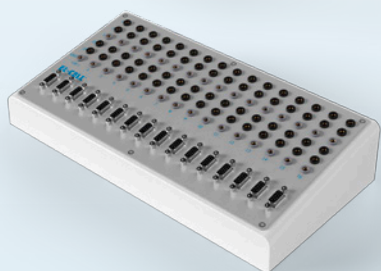
## ECC-LiPunch

**Punching tool for lithium foil**

The ECC-LiPunch is the perfect tool for smoothly punching lithium discs for PAT and ECC series test cells. The punching knife can easily be removed for cleaning.

## Features

- For punching precise and flat lithium discs
- Standard size for EL-CELL® test cells: 18 mm diameter
- Other sizes available:  
6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 16.6, 17, 18, 19, 20 mm



## PAT-Connect-16

**Adapter box for flexible wiring connections**

The PAT-Connect-16 is an intermediate box between the PAT-Stand-16/ PAT-Chamber-16 and your potentiostat/battery tester. It enables flexible rewiring in order to switch between operation modes (full cell, cathode half cell, anode half cell) without manipulating the cable connection the between adapter box and the stand / chamber.

## Features

- Easy-to-access banana sockets for cell signals: current, full-, and half-cell voltages
- Sub-D Connector for optional auxiliary signals: buffered half cell voltages, temperature, sensor signals
- Available as modular box (PAT-Connect-16) to be placed on the bench or fixed on the wall, or as an attachment on top of the PAT-Chamber-16 (PAT-Connect-16 C)

# Services

In addition to our hardware we also offer a wide scope of services like hands-on seminars or electrochemical service measurements in our own research laboratory.

## Lithium battery application lab

No time or equipment available to run battery tests yourself?  
We can help you to solve your testing problems in our own laboratory e.g.:

- Manufacturing (slurry preparation, casting, drying, punching) of electrodes from client's material; formulation and characterization of electrolytes
- Cycle life and impedance tests on half and full cells (to some extent materials can be provided by us)
- Round robin tests for validation and tuning up of client's test capabilities
- Testing of client's materials with EL-CELL® test equipment

### Equipment

Our professional research laboratory provides the following equipment to run different electrochemical experiments. With this equipment we are able to operate at the highest standard of academia and industry:

- All kinds of battery test cells of EL-CELL® (standard and reference electrode test cells, optical test cells, dilatometer, gas and air test cells and many more)
- Tools and handling equipment for electrochemical experiments (e.g. cutting and punching tools)
- Equipment for the preparation of electrode slurries and for casting or drying of electrode films
- MBraun glove box system for test cell assembly
- Helium-leak tester
- Temperature-controlled test cabinets
- Different kinds of potentiostats and battery testers:
  - Maccor 4000 series cycler
  - Biologic VSP multichannel impedance analyzer
  - Gamry Interface 1000
- All standard consumables such as lithium metal,  $\text{LiPF}_6$  based electrolytes, anode and cathode materials

## Hands-on seminars

EL-CELL® organizes seminars and trainings in its laboratory to impart knowledge about battery testing and to support researchers in effectively exerting our products.

### Learn more about:

- The latest devices and applications for battery testing
- How to run meaningful electrochemical tests by yourself (constant current cycling, voltammetry, impedance)
- The practical preparation and testing of Li-ion battery materials in the lab
- The pros and cons of different cell designs (EL-CELL® test cells, coin cells, pouch cells, Swagelok® cells)
- The benefits and limitations of 2- and 3-electrode test cells
- How to perform experiments with the latest in-situ test cells from EL-CELL® (dilatometer, gas analysis, Raman, X-ray and many more)
- Many other recent electrochemical research topics

### Facts:

- Duration: two days (8 hours per day)
- Location: Tempowerkring 8 - 21079 Hamburg, Germany
- Pricing: regular registration: 1,300 Euro (1,200 Euro\*)  
PhD-students\*\*: 650 Euro (600 Euro\*)

See website [www.el-cell.com](http://www.el-cell.com) for next dates.

\* Early bird (4 weeks before)

\*\* confirmation required

# What is the right test cell for you?

## Test cells

Test cells	Aprotic electrolytes LiPF <sub>6</sub> and R <sub>4</sub> NBF <sub>4</sub> <sup>2)</sup>	Aqueous electrolytes		Available current collectors
		alkaline	neutral + acid	
PAT-Cell	yes	no	no	Cu, Al, SS <sup>3)</sup>
PAT-Cell-Aqu	yes <sup>4)</sup>	yes	yes	Au, Pt, Ni
PAT-Cell-Press	yes	no	no	Cu, Al, SS <sup>3)</sup>
PAT-Cell-Press-Aqu	yes <sup>4)</sup>	yes	yes	Au, Pt, Ni
PAT-Cell-HT	yes	no	no	Cu, Al, SS <sup>3)</sup>
ECC-Air	yes	no	no	SS <sup>3)</sup>
ECC-Air-Ni	no	yes	no	Ni, SS <sup>3)</sup>
ECC-DEMS	yes	no	no	SS <sup>3)</sup>
ECC-Press-Air-DL	yes	no	no	SS <sup>3)</sup>
ECC-Opto-Std	yes	no	no	Cu, Al, SS <sup>3)</sup>
ECC-Opto-Std-Aqu	yes <sup>4)</sup>	yes	yes	Au, Pt, Ni
ECC-Opto-SBS	yes	no	no	SS <sup>3)</sup>
ECD-3-nano	yes	yes <sup>1)</sup>	yes <sup>1)</sup>	SS <sup>3)</sup> , Al, Cu, Au <sup>1)</sup>
ECD-3	yes	yes <sup>1)</sup>	yes <sup>1)</sup>	SS <sup>3)</sup> , Al, Cu, Au <sup>1)</sup>

<sup>1)</sup> with optional aqueous kit only

<sup>2)</sup> for organic super capacitors

<sup>3)</sup> SS = stainless steel 1.4404 (316L)

<sup>4)</sup> depends on current collector

## Test cells

	Purpose / testing						
	2-electrode	3-electrode	optical	Raman	X-Ray	dilatometry	gas analysis
PAT-Cell	yes	yes	no	no	no	no	no
PAT-Cell-Aqu	yes	yes	no	no	no	no	no
PAT-Cell-Press	yes	yes	no	no	no	no	yes
PAT-Cell-Press-Aqu	yes	yes	no	no	no	no	yes
PAT-Cell-HT	yes	yes	no	no	no	no	no
ECC-Air	yes	yes	no	no	no	no	yes
ECC-Air-Ni	yes	yes	no	no	no	no	yes
ECC-DEMS	yes	yes	no	no	no	no	yes
ECC-Press-Air-DL	yes	yes	no	no	no	no	yes
ECC-Opto-Std	yes	yes	yes <sup>1)</sup>	yes	yes <sup>3)</sup>	no	no
ECC-Opto-Std-Aqu	yes	yes	yes <sup>1)</sup>	yes	yes <sup>3)</sup>	no	no
ECC-Opto-SBS	yes	yes	yes <sup>2)</sup>	yes	no	no	no
ECD-3-nano	yes	yes	no	no	no	yes	no
ECD-3	yes	yes	no	no	no	yes	no

<sup>1)</sup> with glass window, sapphire optional

<sup>2)</sup> with sapphire window (standard)




<sup>3)</sup> with optional beryllium or polyimide window



# PAT compatibility

Docking / Test station	PAT-Cell	PAT-Cell-Aqu	PAT-Cell-Press	PAT-Cell-Press-Aqu	PAT-Cell-HT
PAT-Stand-1	C	C	C	C	C
PAT-Stand-1 + PAT-Press Box + Temperature Chamber	C	C	C T P	C T P	C
PAT-Stand-4	C	C	C	C	C
PAT-Tray / PAT-Stand-16	C	C	C	C	C
PAT-Chamber-16	C	C	C T P	C T P	C
PAT-Tester-i-16	C	C	C T P	C T P	C
PAT-Heater-4					C

**Supported features:** C: charge / discharge / impedance  
T: temperature control  
P: gas pressure

**Colors:**  all test cell features supported  
 some test cell features not fully supported  
 test cell incompatible

## What is the right tool for you?

Test cells	ECC-RefLoad (one size)	ECC-LiPunch (several sizes)	EL-Cut (+ StopRail) (several sizes)
All PAT series test cells	-	•	•
ECC-Air, ECC-Air-Ni	•	•	•
ECC-DEMS	•	•	•
ECC-Press-Air-DL	•	•	•
ECC-Opto-Std	•	• diameter = 10 mm	• diameter = 10 mm
ECC-Opto-Std-Aqu	•	-	• diameter = 10 mm
ECC-Opto-SBS	•	-	• 9.5 x 9.5
ECD-3, ECD-3-nano	-	• diameter = 12 mm	• diameter = 10 mm

• recommended; diameter for ECC series is 18 mm unless otherwise indicated

For further information about our products don't  
hesitate to contact us directly!



**Iris Zwanziger**  
Director of Marketing and Sales



**Susana Moreira**  
Sales Manager

EL-CELL® GmbH  
Tempowerkring 8  
21079 Hamburg  
Germany

phone: +49 40 79012-734  
fax: +49 40 79012-736  
e-mail: [info@el-cell.com](mailto:info@el-cell.com)  
web: [www.el-cell.com](http://www.el-cell.com)





electrochemical test equipment

EL-CELL® delivers worldwide directly and through its Japanese distributor. Please see our website [www.el-cell.com](http://www.el-cell.com) for further information.



EL-CELL® GmbH  
Hamburg, Germany