HOCHSCHULE DER MEDIEN

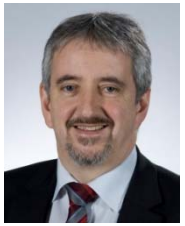
iad Innovative Anwendungen der Drucktechnologien

Printed Batteries
overview, status, recent developments, future perspectives

07th Sept. 2015

Prof. Dr.-Ing. Gunter Hübner

Authors



Gunter Hübner

HdM Stuttgart

Patrick Rassek

HdM Stuttgart

Martin Krebs

VARTA Microbattery

Agenda

- Introduction
- History
- Types of printed batteries
- Future perspectives

5 Segments of Organic and Printed Electronics

Presently the Organic and Printed Electronics Association OE-A divides the targeted market into 5 groups, see [OE-A 2013]

	Segment	Power/Storage Requirement
1.	Organic LED (OLED) Lighting	Power Source
2.	Printable, Organic Photovoltaics (OPV)	Storage
3.	Electronics and Components (printed memory and batteries, active and passive components)	Active comp. need power source
4.	Flexible Displays	Power Source
5.	Integrated Smart Systems (including smart objects incl. NFC/RFID, sensors and smart textiles)	Power Source Especially autarcic systems

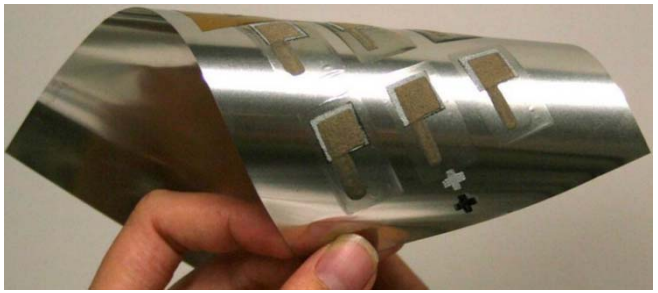
=> Most are suitable for printed batteries !

Advantages of printed batteries

- Freedom of design

Imagesource:
http://www.enas.fraunhofer.de/content/dam/enas/de/documents/Downloads/datenblaetter/PrintedBatteries_EN_web.pdf

- Thin and flexible (bendable)



Imagesource:
http://mashable.com/2014/07/21/printed-rechargeable-batteries/ or http://www.imprintenergy.com/

- Costly tools unnecessary, replaced by printing processes

Electrochemical Systems

electrochemical systems	**Nominal voltage**	**electrochemical reaction**
non rechargeable		
Zinc/Manganese Dioxide	1,5V	$Zn + 2\ MnO_2 + H_2O \rightarrow ZnO + 2\ MnO(OH)$
Zinc/Air	1,4V	$2\ Zn + O_2 + 2\ H_2O \rightarrow 2\ Zn(OH)_2$
Zinc/Silver oxide	1,5V	$Zn + Ag_2O \rightarrow 2\ Ag + ZnO$
Lithium/ Manganese Dioxide	3,0V	$Li + MnO_2 \rightarrow MnOOLi$
Rechargeable		
Nickel/Metal hydride	1,2V	$Metal\text{-}H + 2\ NiOOH \rightarrow Metal + 2\ Ni(OH)_2$
Lithium-Ion	3,7V	$Li_{1-x}Mn_2O_4 + Li_xC_n \rightarrow LiMn_2O_4 + nC$
Zinc/Air	1,45V	$Zn + 1/2\ O_2 \rightarrow ZnO$
Post Li	different	Different systems using Air-, Sulphur-Cathode or solid state components

Applicability for Printing

electrochemical systems	voltage	Electrolyte	applicability for printing
non rechargeable			
Zinc/Manganese Dioxide	1,5V	Zinc Chloride	++
Zinc/Air	1,4V	Alkaline	-- Cathode complicated,
Zinc/Silver oxide	1,5V	Alkaline	o
Lithium/ Manganese Dioxide	3,0V	Organic (aprotic)	- Humidity/Water sensitive
rechargeable			
Nickel/Metal hydride	1,2V	alkaline 25%KOH Potassium hydroxide (caustic potash)	o
Lithium-Ion	3,7V	organic	- Humidity/Water sensitive
Zinc/Air	1,45V	alkaline	-- Cathode complicated,
Post Li	different	organic	today impossible

Competition

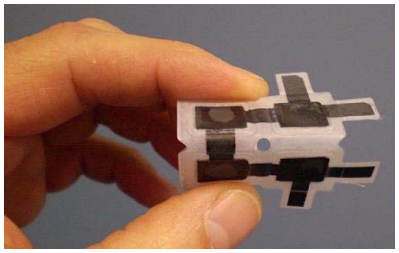
- Great variety of models
- Cheap!!
- But rigid housings

Disposing problem for any battery!

Imagesource:
https://upload.wikimedia.org/wikipedia/commons/c/c7/Coin-cells.jpg

Pioneers of printed batteries

- since about 20 years printed batteries appeared on the market and nowadays several research groups work in that field.
- easiest printable electrochemical system is Zn-MnO_2 closely related to the so called Alkaline-batteries
- Pioneer: "Power Paper“ Israeli company since 1997


medical and beauty applications (cosmetic patches)
from www.powerpaper.com resp. www.powerpaper.cn
Today they seems to be China based

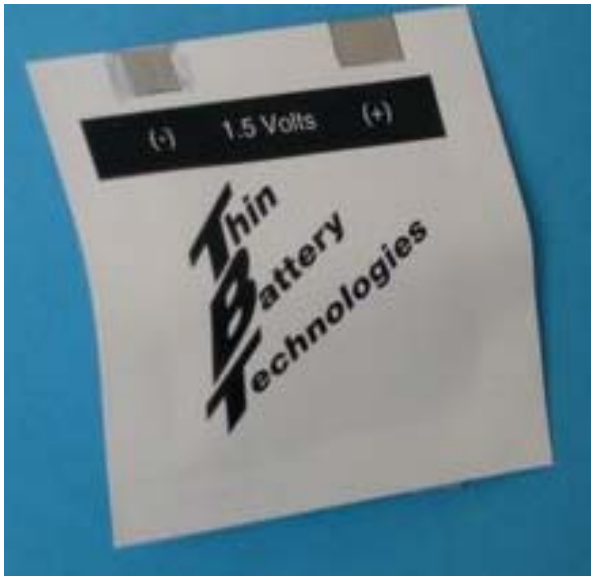
Pioneers of printed batteries

thin flexible battery by KSW-Microtec, Germany

source: www.ksw-microtec.de around 2007.

The website no longer refers to batteries

Pioneers of printed batteries



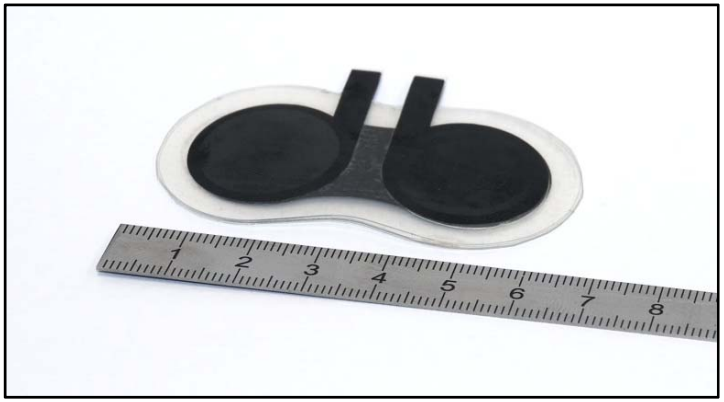
Thin Battery Technologies, Inc. (TBT)

source: www.thinbattery.com around 2007. The website now belongs to Blue Spark Technologies

Pioneers of printed batteries

thin flexible batteries SoftBattery by Enfucell
Imagesource: www.enfucell.com

Pioneers of printed batteries



Printed Battery: two cells in series connection

Imagesource: http://www.enas.fraunhofer.de/content/dam/enas/de/documents/Downloads/datenblaetter/PrintedBatteries_EN_web.pdf

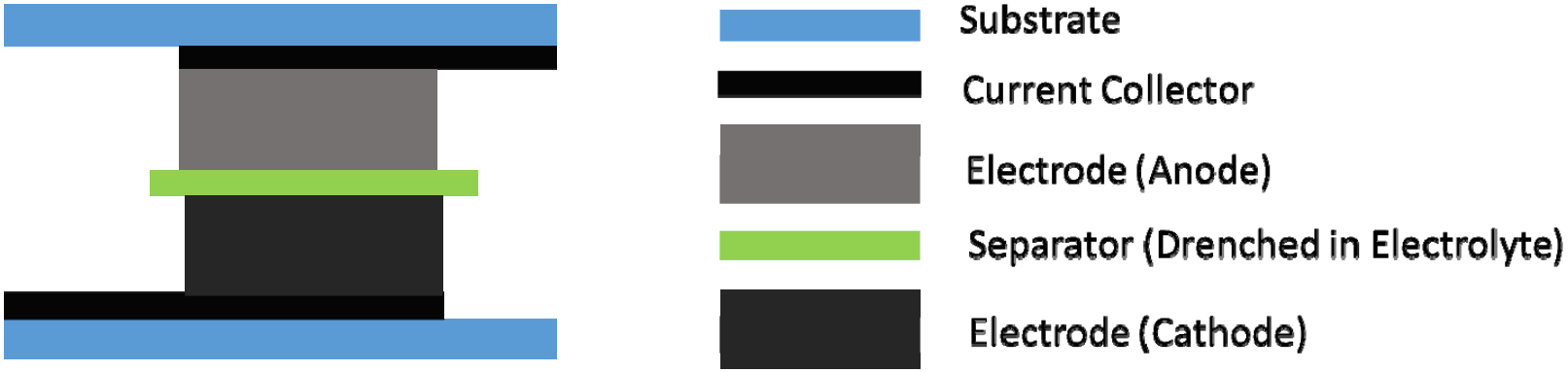
HOCHSCHULE DER MEDIEN
Innovative Anwendungen der Drucktechnologien

Pioneers of printed batteries

printed NiMH-Battery

source www.hdm-stuttgart.de/iad

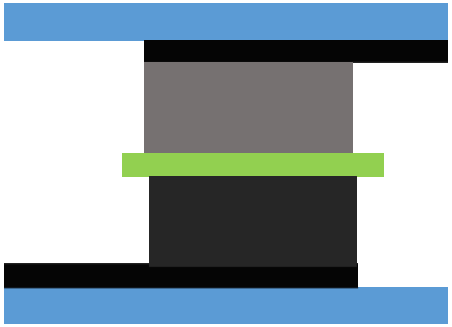
Basic Design of Single Cell

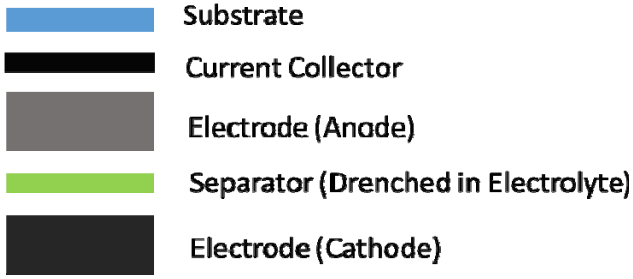


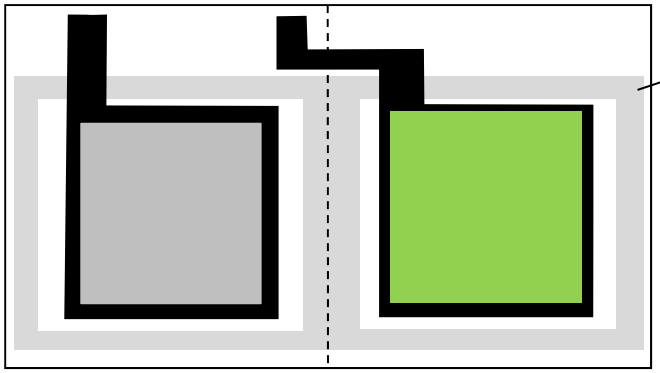
Stack or Sandwich design

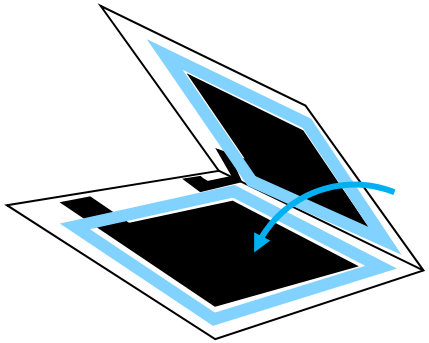
- layer thicknesses are as follows:
- Current Collector 10-15µm
- Electrodes 100-150µm
- The Separator/Electrolyte layer can either be a fleece soaked in electrolyte or it can be printed, too. Then the electrolyte must ideally be brought into a gum-like state. The electrolyte should penetrate a bit into the electrodes for better performance.
- Since the coarseness of the particles in the anode and cathode are in the range of 10 up to 50µm the only printing technique that is suitable for applying these materials is screen printing.

Assembly (HdM Style)



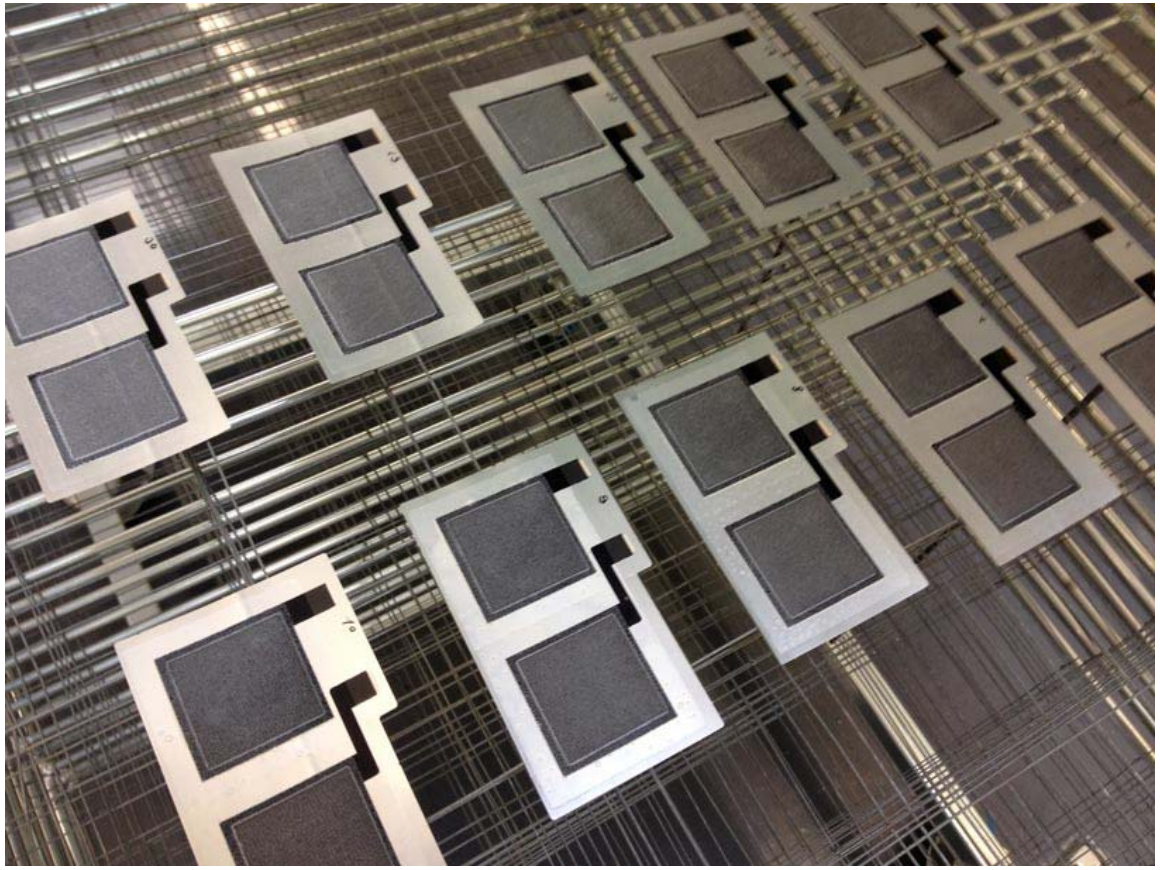




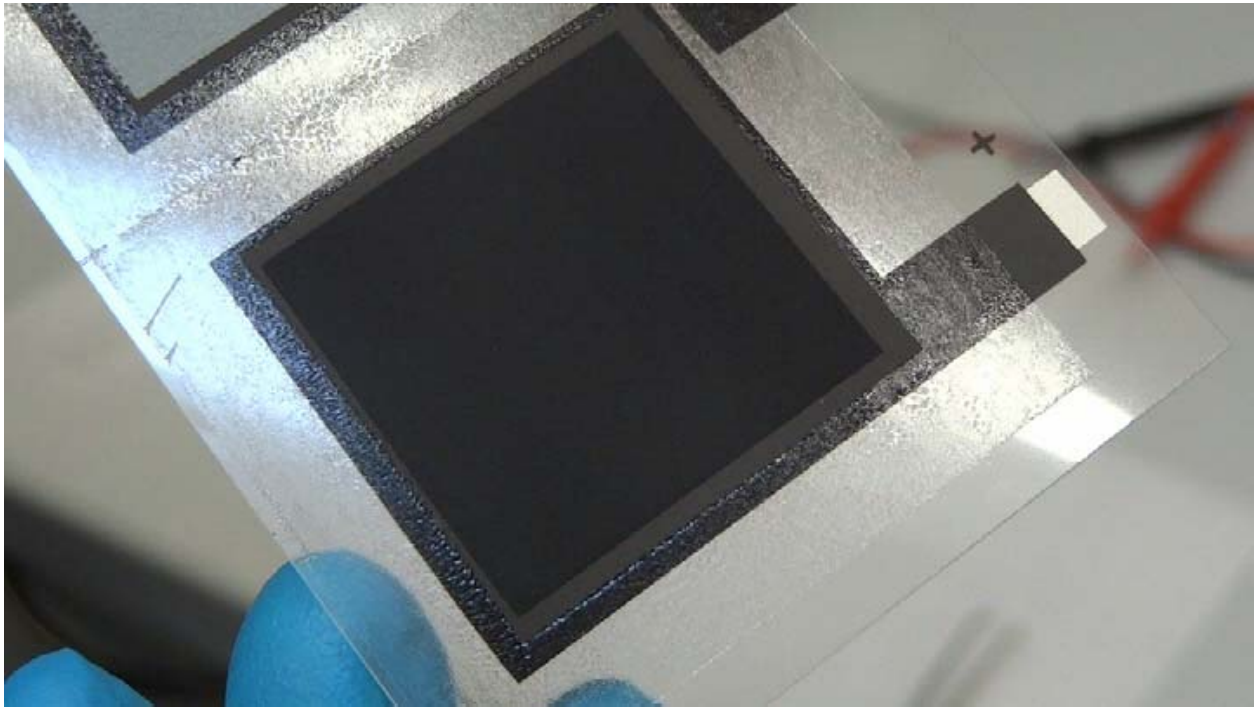


BatMat Video

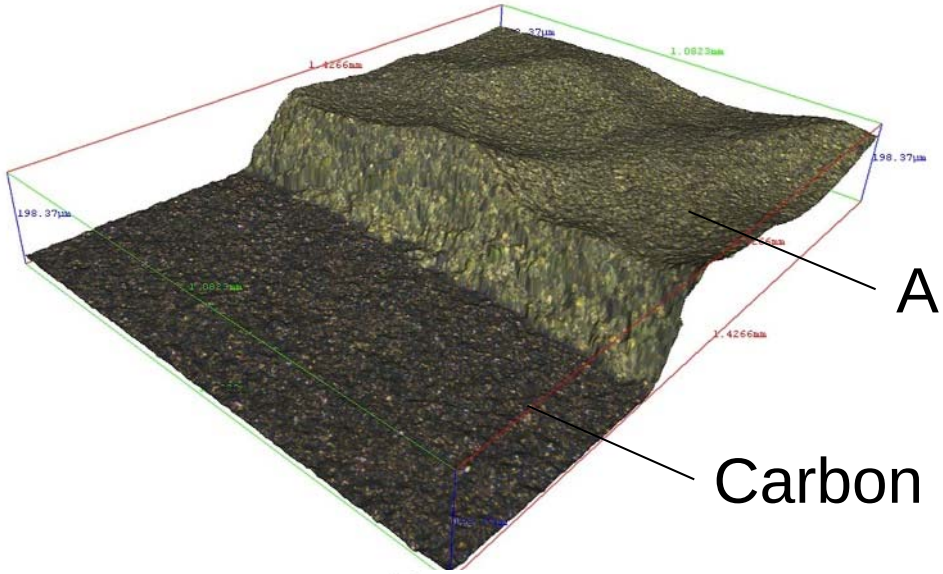
Screen Printed Batteries Air Drying



Challenges: Sealing

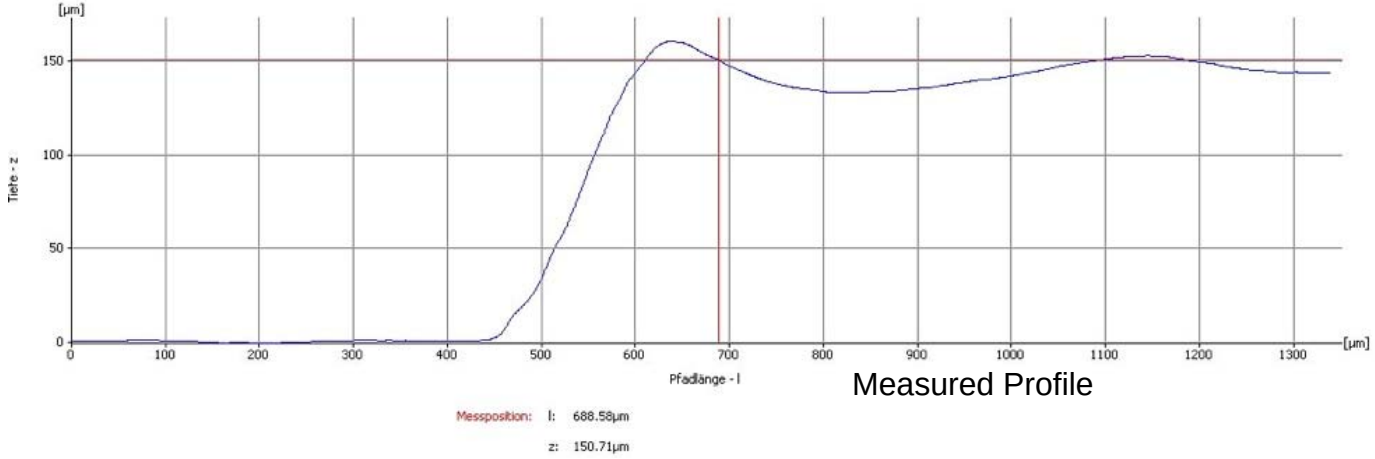


High Layer Thicknesses
Screen Printing (150µm in one stroke)



Anode Material

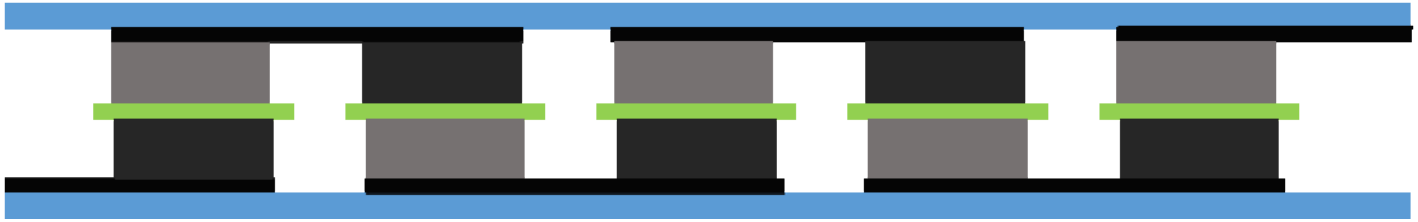
Carbon Black Current Collector

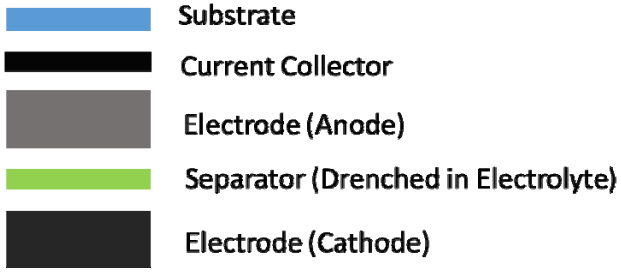


Measured Profile

Pre Printed Roll of Current Collectors

Easy Way of Series Connection for Higher Voltages



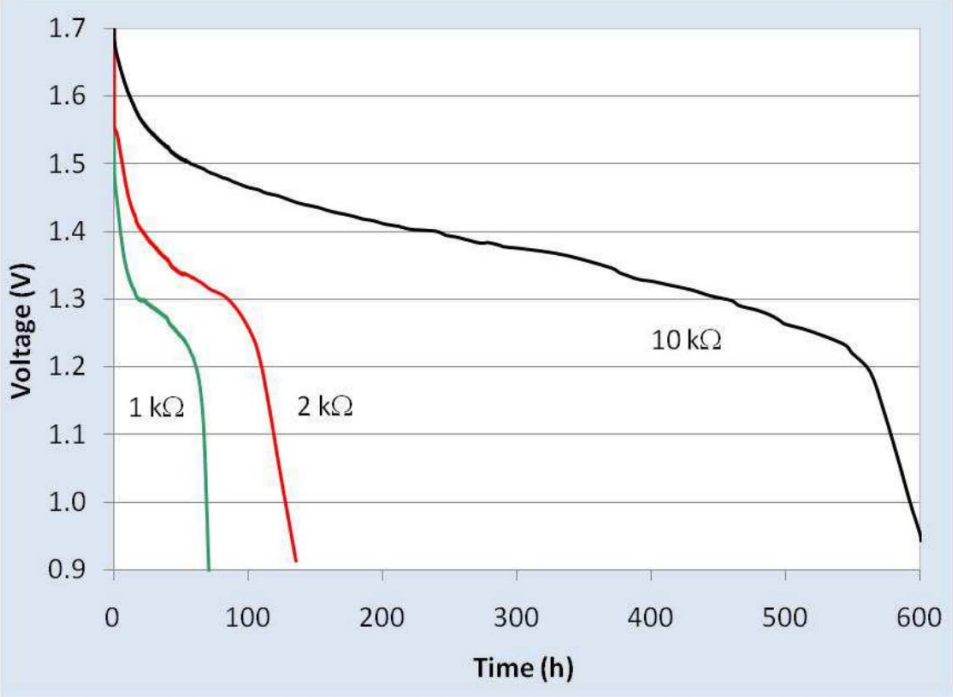


Present Commercial Applications of Printed Batteries

Iontopatch medical patches
source: http://www.iontopatch.com/

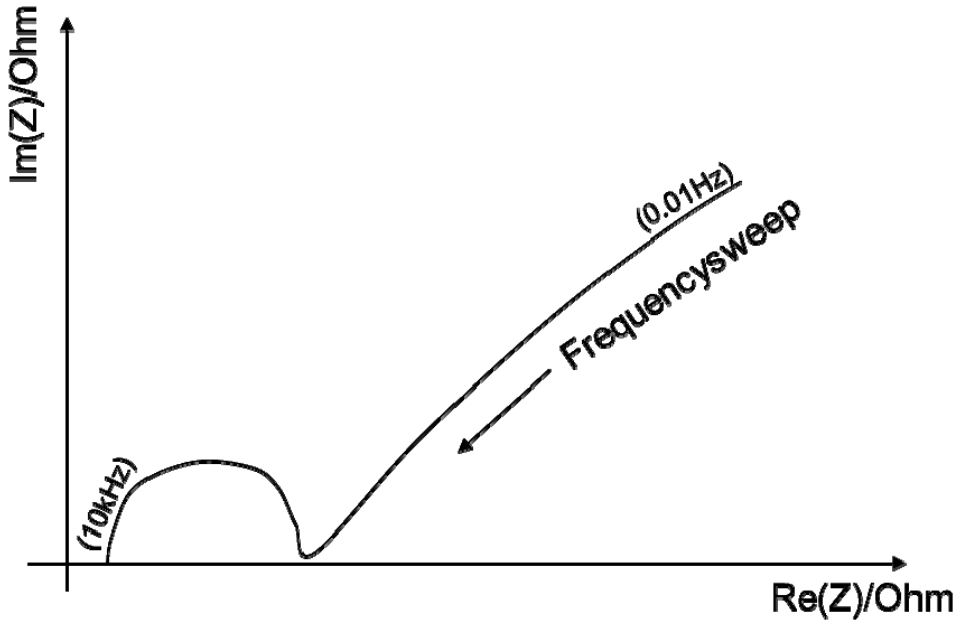
Beauty patch from VTT, Finland
source: http://www.oe-a.org/article/-/articleview/136419

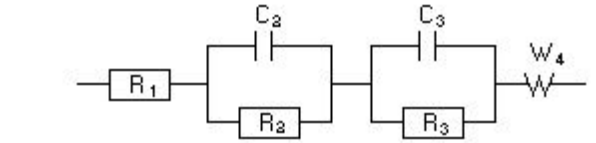
Electrical Properties of Printed Batteries



Discharge curves of SoftBattery® 1,5V with various loads at room temperature
Source: http://files.kotisivukone.com/enfucell.kotisivukone.com/tiedostot/discharge.pdf

Electrical properties of printed batteries





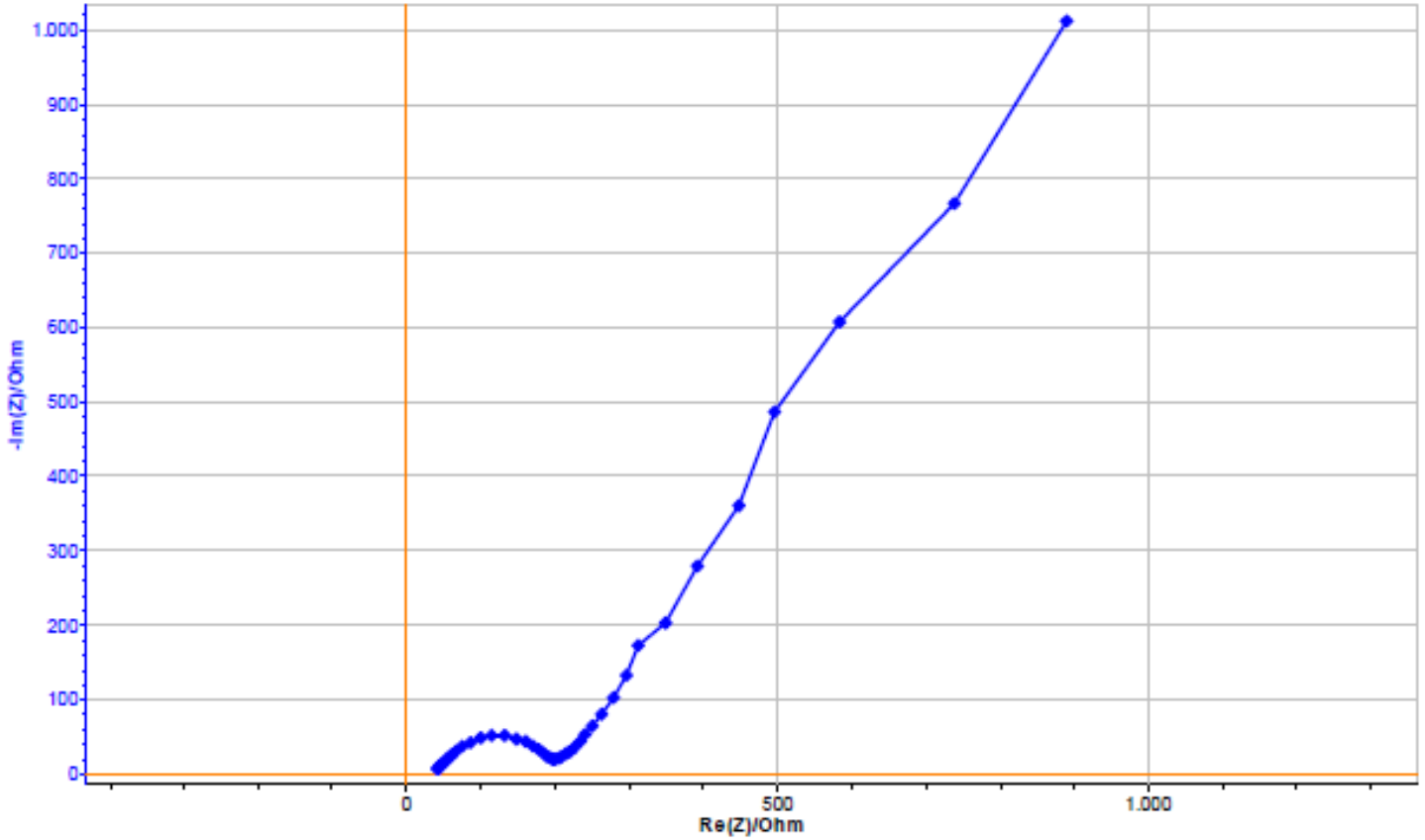
Impedance

$$Z(f) = R_1 + \frac{R_2}{1 + j2\pi f R_2 C_2} + \frac{R_3}{1 + j2\pi f R_3 C_3} + \frac{\sqrt{2}\,\sigma_4}{\sqrt{j2\pi f}}$$

Theoretical Nyquist plot of a battery

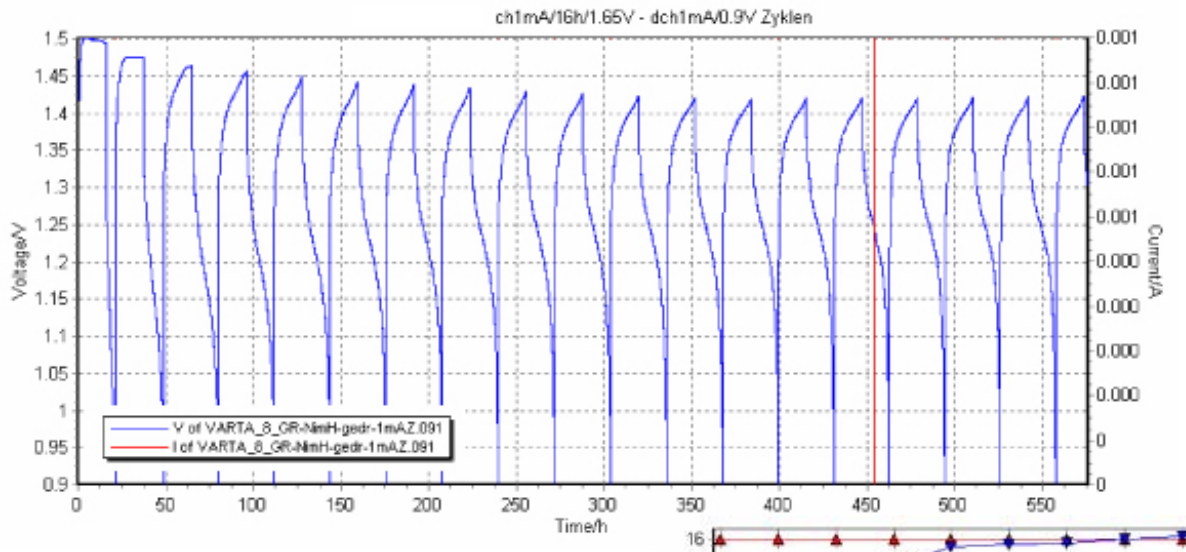
- For high frequencies (> 1 kHz) the current flows through C_2 and C_3 completely. W_4 is also not that important. If R_1 is low high currents are possible.
- For middle range frequencies (1 - 1000 Hz) the small capacitance starts blocking the current and the impedance increases. For low frequencies (0.01 – 1 Hz) both capacitances block and the impedance is determined by the resistors R_1, R_2 and R_3.
- For longer periods of time the Warburg-Impedance starts playing a role due to diffusion processes.

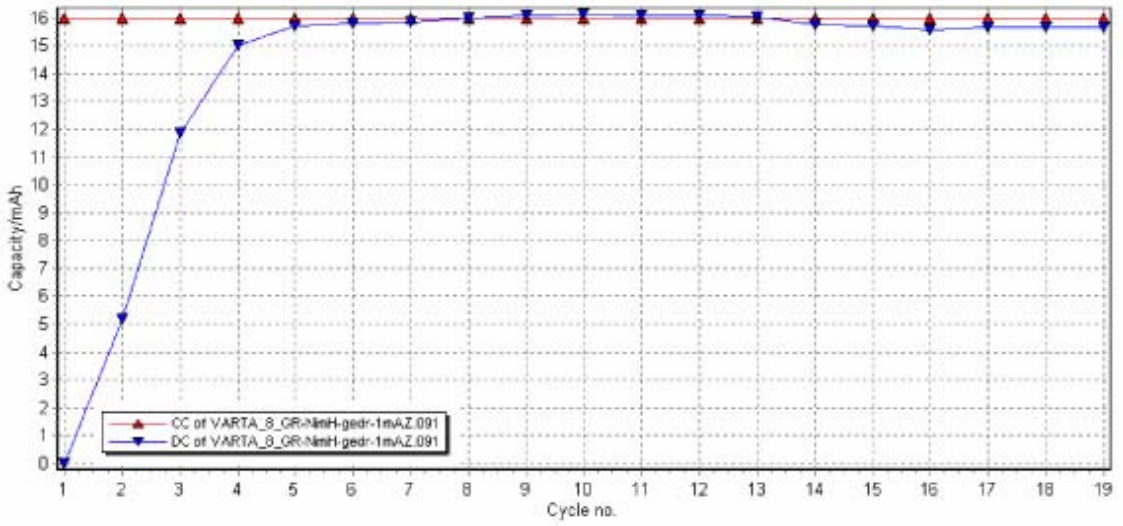
Electrical properties of printed batteries



Nyquist plot of a printed rechargeable battery

Cyclisation of Rechaergeable Battery





Roll to Roll Manufacturing Demonstration

- Single color screen printing press with large drying cabinet at Schreiner Group, Munich

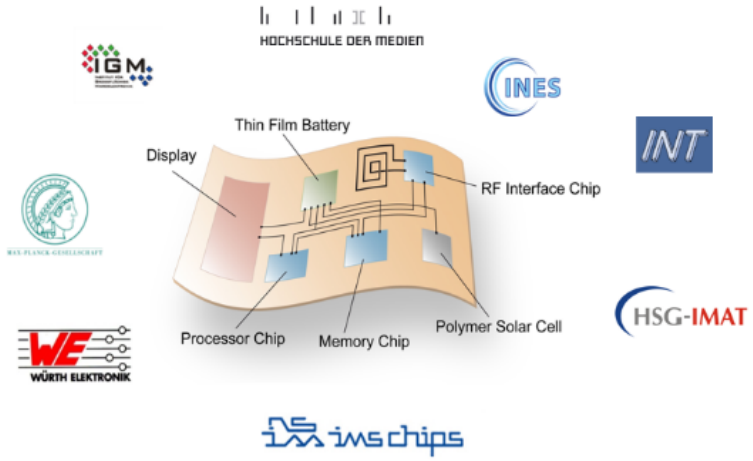
Roll to Roll Manufacturing Demonstration

- Two cells in series connection (3V) on both sides of the web

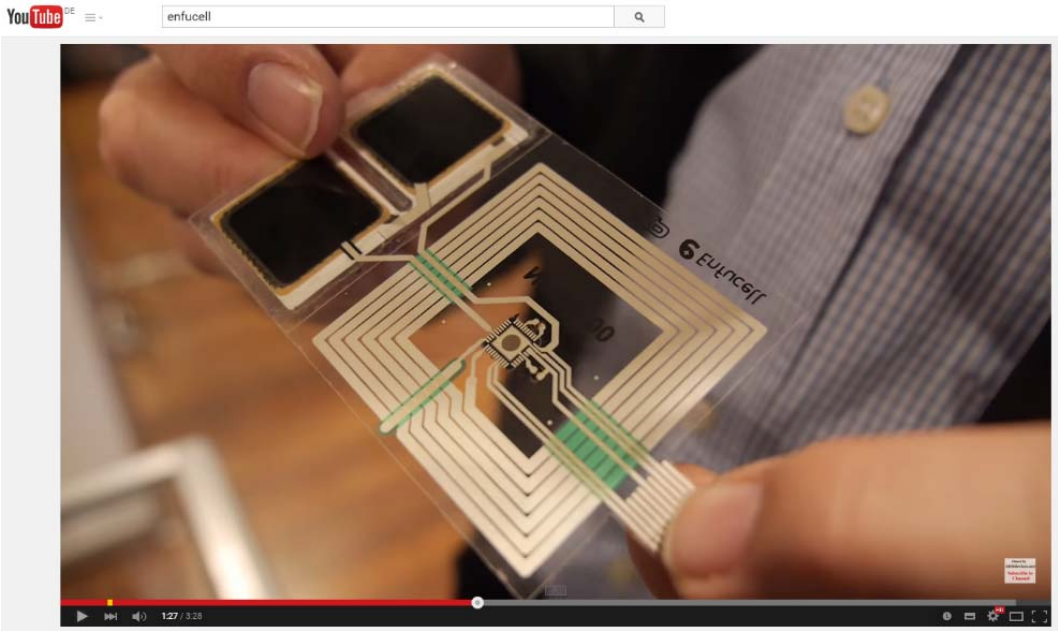
Applications

- Project KOSIF

  - ASIC
  - HF-Chip
  - Printed strain gauge
  - flexible Display
  - HF-Antennae
  - Printed batterie
  - Thin Film Transistors



New Applications



Disposable temperature logger

(screenshot taken from www.youtube.com/watch?v=HTXaa317P0s)

Quad Industries, NXP and Enfucell have showcased a cold chain monitoring system for biopharmaceutical products. Together with the Dutch electronics enterprise NXP, Enfucell has developed a disposable temperature logging foil demonstrator containing NXP's NHS3100 IC, Enfucell's printed battery and an NFC antenna.

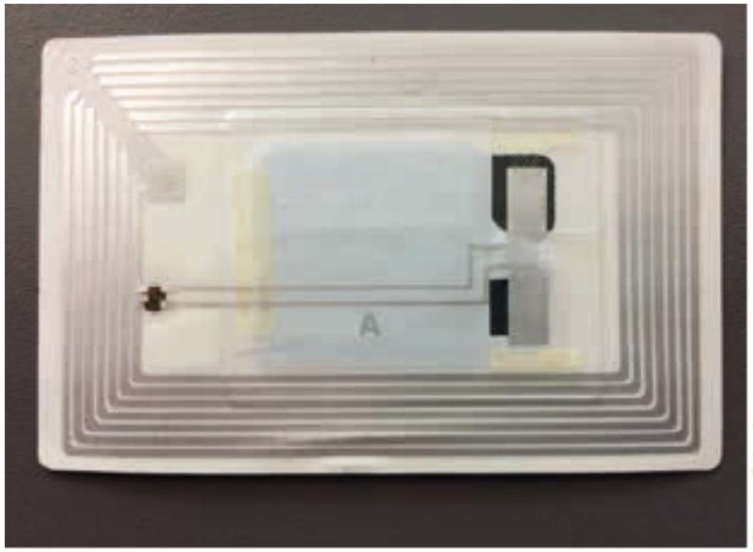
Applications

Golf sensor patch powered by Enfucell SoftBattery

Sensor patch for golf club by Enfucell

(screenshot taken from www.youtube.com/watch?v=3eQBKi7Vl-0)

New Applications



Zn-Mn battery and temperature logger by CZIPEI (Changzhou Institute of PrintedElectronics Industry)
Source: OPE Journal 12/2015

It has a many-layer structure consisting of two sealing materials, a separator layer, an anode collector, a cathode collector, and two active anode and cathode layers. The main features of the paper battery are: 1) thin – below 1 mm; 2) flexible like paper; 3) eco design; and 4) extremely low-priced due to its R2R printed.

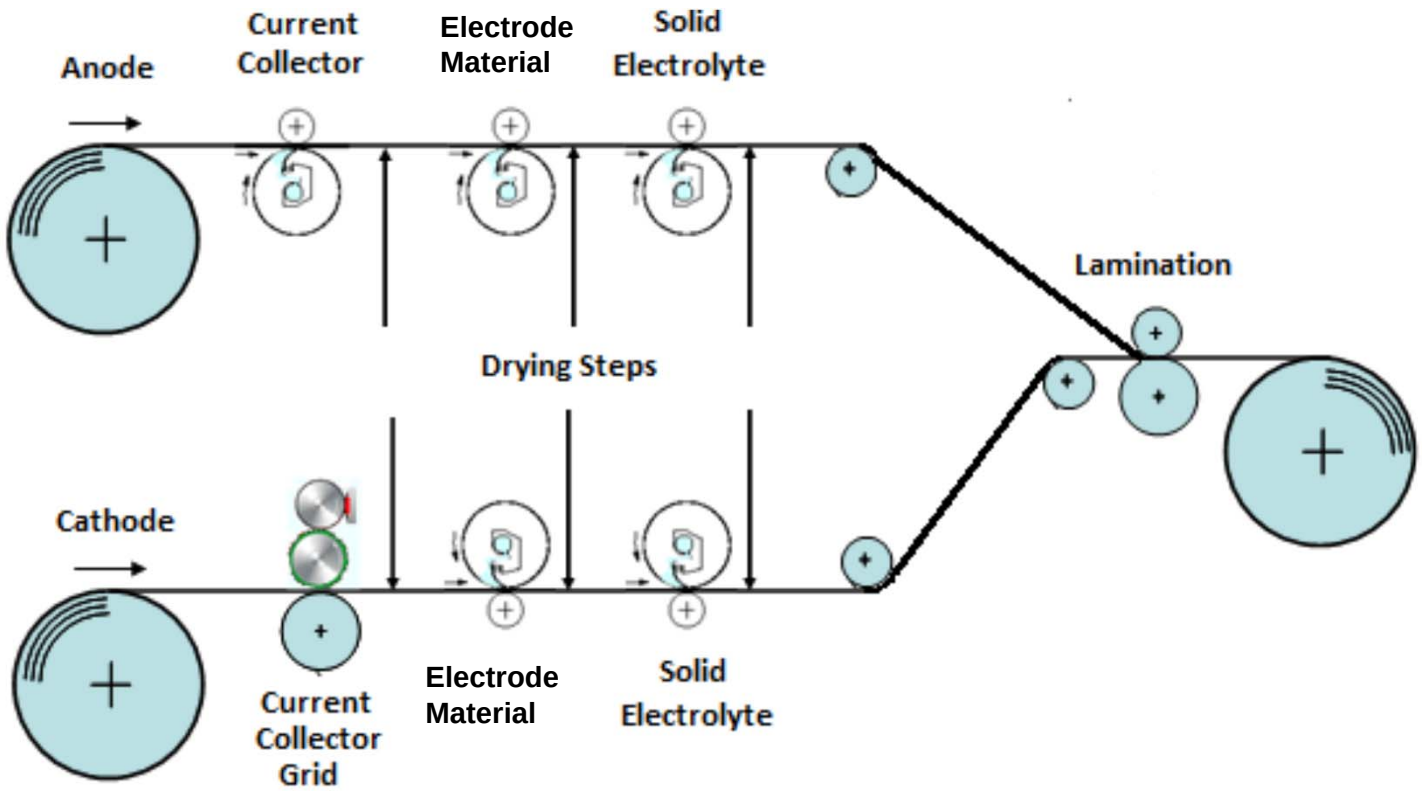
Also the power source can be produced in various sizes, thickness, and shapes, matching the customers' needs. A paper battery enables many new electronic applications,especially for printed and thin electronics. Those applications include, among others, wearable electronics and active packaging. The CZIPEI (Changzhou Institute of Printed Electronics Industry) has recently developed an active packaging application, which is powered by the paper battery.

The so called Temperature Data Logger communicates via the cloud system. The product is very thin, less than 1 mm, and flexible with and adhesive on one side. The size of the product varies from 10 cm^2 to a few hundreds of cm^2.

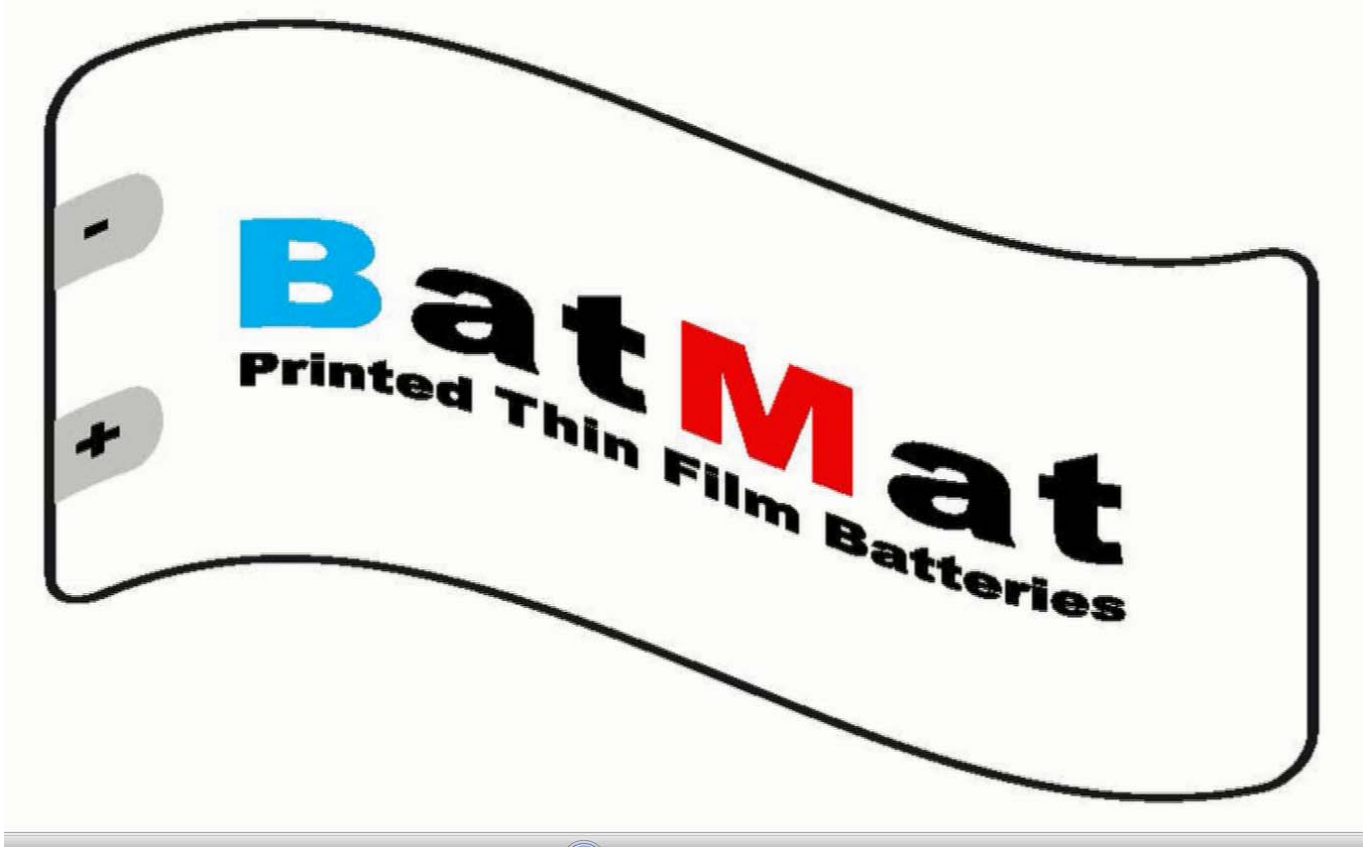
Future Perspectives

- Sophisticated series connections
  Demonstrated up to 24V
- New chemical systems: zinc/air rechargeable
- Power Storage
- Powercaps

Future Perspectives R2R Manufacturing



Videoclip BatMat Lab and R2R Manufacturing



HOCHSCHULE DER MEDIEN
iad Innovative Anwendungen der Drucktechnologie

Printed Batteries, overview, status, recent developments, future perspectives

Thanks for your attention

HdM Campus Stuttgart-Vaihingen

photo: D. Seydel

Prof. Dr.-Ing. Gunter Hübner