MATFLEXEND NEWSLETTER January 2016

MATFLEXEND has achieved significant progress in the two main strands of the project, energy conversion and flexible secondary-battery. We are seeking discussion partners from industry and research.

1. Mechanical energy conversion

This part of the work currently addresses individual elements of the variable capacitor converter.

MATFLEXEND energy harvesting involves changing a capacitance by dynamically changing the surface of one of the electrodes of a capacitor, which is achieved by deforming said electrode, while it keeps contact with a high-k dielectric. The electrode´s maximum contact area on the one hand, the maximal useable voltage applied across the capacitor on the other hand, jointly determine the energy or power density available. The energy converter should be low cost, hence the project is focusing on designing polymer-based, printable dielectrics, as well as printable elastomer electrodes as described above.

A proof-of-concept for a liquid-electrode variable capacitor cell of ~0 – 500 pF was built, tested and presented at the April 2015 workshop by Univ. Vienna; it used mercury for the liquid-metal electrode instead of the Galinstan metal originally envisaged. This is because Galinstan oxidizes under any circumstances tested – including concrete chemical measures discovered on our own and suggested from outside. The latter included coating the Galinstan in HCl, which we found to necessitate the use of higher voltages, and which impaired the converter´s performance . Therefore, we believe that the original Galinstan design patented by Krupenkin can only be used in a completely airtight assembly such as a glass ampoule. However, in that hat design it would compete with other technologies such as MEMS devices which may do the job, but which unfortunately are incompatible with the low cost printing approach of MATFLEXEND. Moreover, such MEMS may raise packaging issues of their own.

Since we cannot use mercury (for the variable-area electrode) in a wearable, the project has refocused on high-conductivity-elastomer electrodes made of CNT-impregnated polyHIPEs, now being developed between IMPERIAL and Univ. Vienna. At Univ. Vienna, a polyacrylate polyHIPE elastomer has been prepared and characterized.

As for the dielectric layer of the variable-area capacitor, research into printable capacitor nanocomposite dielectric films is ongoing at Imperial College, with indicative breakdown strength of 100 MV/m. We´ve built STBO-C_{60} epoxy nanocomposites (7.6 nF cm^{-2}) and PVDF-SBTO-f where the SBTO-f was functionalised with PVDF for increased polymer compatibility, with more measurements pending.

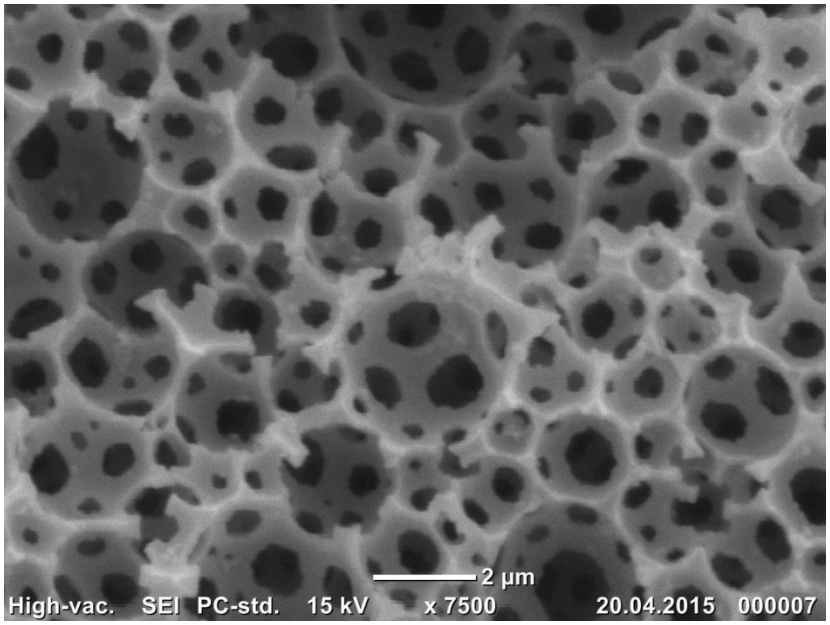
At Fraunhofer IZM converter prototypes have been tested which were produced with help of IMPERIAL´s STBO composite and commercial dielectrics. The measurement results and

corresponding numerical analysis shows, that the performance is limited by the elastomer electrode with up to one order of magnitude lower specific capacity in comparison to metal electrodes. C_{max} of ca. 0.5 and 2 nF/cm^2 was achieved and energy harvesting between 10 and 100 nAs/cm^2 per cycle.

Other issues like sticking between electrode and dielectric and material fatigue have to be solved as well.

2. Battery work

The second line of work in MATFLEXEND concerns miniaturized rechargeable batteries, inter alia aiming at Wearable Electronics applications. One major effort here is in developing printable electrolytes. Indeed, electrolyte filled polyHIPEs have been successfully prepared and characterized at Uni Vienna. 0.5M solutions of various Lithium salts ($LiBF_4$, $LiClO_4$, $LiAsF_6$, $LiPF_6$ and $LiN(SO_2CF_3)_2$) in the RT-IL 1-Ethyl-3-methylimidazolium tetrafluoroborate [EMIM][BF4] have been used as internal phase by a ratio of 85% in these polyHIPEs. Smooth and regular films of up to 70 microns thickness have been screen printed by Partner Eurecat (Barcelona) and photocured by UV.



PolyHIPE electrolyte, Uni Vienna

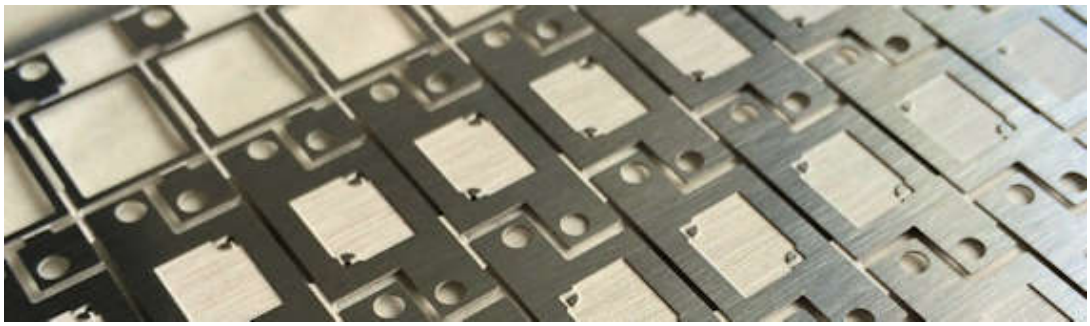
Work continues on printing LTO-fiber-doped anodes at Fraunhofer IZM. The fibers produced by PARDAM at low cost by means of force spinning now show similar electrochemical behavior in comparison to state of the art powders. Partner PARDAM´s production rates in force spinning are due to ramp up from 150 g/hr of fiber precursor.

Partner LAAS has successfully demonstrated battery electrode deposition using electrophoretic deposition (EPD) on LTO and LFP nano material.

The submicron-sized active battery electrode materials can now be EPD-deposited successfully, on their respective current collectors. Parameters such as the particle concentration, applied electric field and deposition time allow control over the thickness of the deposits. The obtained anode and cathode thick films also exhibit good electrochemical behavior in half-cells. Work is ongoing to achieve interdigitated-electrode batteries using this technology. Because electrophoretic deposition generates outliers, a masking step has to be developed to achieve clear patterning.

Patterned flexible electrodes have been screen-printed at VARTA, and a packaging scheme using hot-embossed metal-foil current collectors has been investigated.

In parallel to the inherently-flexible-battery package, arrays of small rigid batteries attached to a flexible substrate are being investigated. Such micro batteries have recently been redesigned by IZM for single chip reel-to-reel as well as substrate level assembly. Holes for adjustment pins enable both top-bottom assembly and electrolyte filling of single battery chips. The hole design was improved to function as a micro fluidic electrolyte fill adapter. A new design for a (ca. 3 mAh) miniaturized partially flexible rechargeable battery was made.



Micro battery housings, Fraunhofer IZM

3. Presentations, publications, workshops,

Presentations 2015, in reverse chronological order:

- EUROMAT, Warsaw
- YUCOMAT, Herceg Novi, MONTENEGRO
- 250th ACS Meeting & Exposition Boston
- International Symposium on Energy Challenges & Mechanics ISECM4 Aberdeen, Scotland; Fraunhofer IZM wins Research Image Competition for „Lithium micro battery with interdigitated electrodes"
- Paper published online RSC Advances no. 76, 2015 61502-61507: Nana Amponsah Kyerematen, Ty Mai Dinh, David Pech „Electrophoretic deposition of Li4Ti5O12 nanoparticles with a novel additive for Li-ion microbatteries" DOI: 10.1039/C5RA11039D

- Workshop on Energy Harvesting Systems-FlexTEG, Dresden, Germany
- IDTechEx Energy Harvesting and Storage Europe 2015, Berlin, Germany

The first of two industry workshops was conducted with 56 participants, in attendance in Berlin on April 26th, 2015. Of these participants, 26 were from industry including: Infineon (AT), STM (IT) +Solvay (IT, partial attendance); Albufera Energy Storage (ES); Continental Automotive (FR+DE); Coruna GmbH, Swatch Group (CH), Bosch, M. Braun, Junghans Microtec, Astro + Feinwerktechnik, Oellerking, Melexis, Nicomatic Deutschland (all DE), Tokyo Ohka (JP); LG (KR); one notable non-industry participant: RMIT from Melbourne.

A cluster workshop "energy materials", aiming to gather suggestions for the new H2020 Calls, cancelled because of the Brussels security clampdown end- Nov. 2015th; it is expected to be rescheduled to January 2016.

4. Seeking discussions and partners

We seek contacts and discussion regarding Partners´ generic technologies, as well as complementary technologies from outside.

4.1 Univ. Vienna has successfully deposited open-porous 2-D hetero-patterns where a plurality of individual open-porous patterns, each of which may involve a certain material and morphology, abut on each other, such that upon curing, the resulting hetero-pattern forms one single 2-D open-porous planar layer, in the manner of a slice deposited by rapid prototyping. This enables creating truly 3-dimensional open-porous polymer objects e.g. in a FDM RP process.

4.2 We seek partners for using electronic insoles (developed by Eurecat, relaying in-sole pressure to a mobile phone by Bluetooth) for gait analysis in conjunction with electrical rollators (developed by BEMOTEC, Reutlingen) as a medical application; as gait analysis has been mooted as a possible early diagnosis tool for neuro-generative disorders.

4.3 We had discussions about dental uses of EPD with an emphasis to measure local EPD parameters and processes: with Wolz Dental, Charité Berlin; and various parties interested in other aspects of ceramic EPD, e.g. methods to infiltrate nanofiber felts with ceramic particles.

4.4 We are interested in new materials susceptible to yield printable flexible batteries, such as the yolk-shell aluminium oxide materials recently mooted by MIT.

4.5 We seek to test new printing processes, such a „contactless" screen printing, where ink is transferred by surface tension forces, and where the screen does not touch the underlying substrate. This process will facilitate multilayer deposition of high-aspect ratio patterns by repetitive printing.

4.6 We are in preliminary discussions with Univ. Paderborn re. the detailed monitoring of complex fluids (such as HIPEs), in situ, in a screen-printing or (as in rapid-prototyping) extrusion process.