Impact Objectives

- Investigate new materials for energy harvesting that are fleixble and durable, as well as solution-processable into printable inks
- Enable mass-producible energy harvesters, which integrate mechanical-to-electrical energy conversion and storage in a single device
- Support mass fabrication of such harvesters in a printing process

Harvesting energy and reaping the rewards

***Drs Robert Hahn** and **Wolfgang Bock** are part of a team working on MATFLEXEND – a project that investigates new materials for harvesting energy. Below, they discuss their hopes and ambitions for the project, the benefits of collaboration, and some notable achievements*

Dr Robert Hahn

Could you begin by giving an overview of your research interests and ambitions? What do you hope to achieve through this particular project?

RH: I am a Team Leader at the Fraunhofer Institute for Reliability and Microintegration IZM (Fraunhofer IZM), and the main research interest in my group is rechargeable microbatteries. These batteries should be thinner than existing solid state thin film batteries, have a long life, high cycle stability and low self-discharge to enable energy-autarkic sensors in many fields. In addition, such batteries should have a low-to-medium cost for consumer electronics, be mechanically flexible, and be suitable for integration into energy harvesting systems.

A second research interest concerned the energy-harvesting concept which will result in fully energy-autarkic systems in the future. Previously, Fraunhofer IZM only used commercially available energy transducers in its energy-autarkic wireless sensor systems. Here, for the first time, we have been able to design and fabricate capacitive harvester prototypes based on the material inventions of MATFLEXEND. This will strengthen Fraunhofer IZM's position in the wearable electronics sector.

You have many partners involved in MATFLEXEND. What different skills and expertise have they brought to the project?

RH: The most important contributions have probably been from Imperial College London and the University of Vienna. The former developed printable high-k dielectric and elastomer electrodes, while the latter developed printable spacer polymers to implement the required restoring force of the harvester and printable electrolytes for the battery. In addition, the Czech Republic company PARDAM – though small – made a really significant contribution with their custom-made nanofibres for high-k dielectric, conducting elastomers, battery electrodes and separators. VARTA directed the battery research towards mass production, while the rest of the partners have been involved in end-use and potential applications – which are important in any project.

How critical were the industry workshops you hosted and the team's attendance at other industry conferences to developing the technology?

WB: Our own workshop critically identified certain production technologies, such as depositing a battery paste in a substrate

cavity, as being of wider relevance. Similarly, we were able to verify – from peer interaction – that a critical feature in our technology, namely the use of a liquid-metal electrode in a capacitor, had no obvious solution. This led to a major reorientation of the entire project.

Participation in external conferences and exhibitions such as IDTechEx led us to an appreciation of the connector problematic for power and data in flexible wearables – something that was brought to our attention by a French connector specialist that visited our booth. Another significant moment was making contact with a major dielectric supplier, leading to development of improved high-k doped-polymer materials.

What have been the main challenges you have faced throughout the course of the project?

WB: One major challenge has been the materials science. I have already alluded to the liquid-metal oxidation problem, but other problems included the barrier materials for such soft, essentially planar devices that are placed under continuous mechanical stress – whilst being subjected to humidity and ageing. On the practical side, we needed textile-type wearables that can be easily disinfected – boiling them is currently unfeasible. We also needed connecting technologies that are extremely reliable and cheap – something of a contradiction until a mass market arises.

Finally, which results from the project are you particularly pleased with and consider will significantly contribute to harvesting energy?

WB: We are pleased with the progress we have made in RTIL-imbibed polymer separators, which are helping develop battery technology. Also, our highly conductive elastomers; the progress we have made on subminiature discrete batteries enabling flexible battery arrays; and also our inter-project communications. In terms of off-project influences, even over the short time span of this project we have seen major improvements in the availability of data and publications, which might significantly benefit energy harvesting, owing to its interdisciplinary nature. We therefore welcome EU initiatives to push further in this direction.

Developing durable devices and benefiting multiple sectors

The MATFLEXEND project is an exciting collaboration focusing on the development of novel, durable materials to facilitate effective energy harvesting. Technological developments so far include flexible electrical conductors and rechargeable microbatteries, which have applications in the growing wearable electronics sector

The technological developments of the past few decades have given rise to a global society capable of storing vast amounts of information. The fact that this trend continues to grow each year has led some to refer to contemporary to contemporary life as an information society, where the creation, distribution and use of information is an important economic and cultural activity.

As technological innovations have enabled more and more storage of information, they have also facilitated the creation of devices that allow individuals to collect and exchange data for a wide variety of reasons. A 2014 study by Forbes estimated that some 71 per cent of 16–24 year olds desired wearable technology. While this burgeoning technology is still in its infancy, it is set to grow as researchers around the world find improved means of incorporating computer and advanced electronic technologies into clothing and accessories.

MAKING THE MUTUALLY EXCLUSIVE A THING OF THE PAST

One of the most important considerations for those attempting to find cost-effective means of facilitating wearable technology is how to harvest energy in a practical, reliable and cheap way. While this has historically proved extremely difficult – not least because reliability and cost have often been mutually exclusive properties – a project co-funded by the European Commission is advancing the development of flexible and durable materials that boast very real potential to transform energy harvesting.

MATFLEXEND (MATerials for FLEXible ENergy harvesting Devices) is a three-year project composed of a consortium of 10

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partners from several European countries. Led by the Fraunhofer Institute for Reliability and Microintegration IZM (Fraunhofer IZM), MATFLEXEND began in 2013 and is set to end later this year. Dr Robert Hahn is a Fraunhofer IZM Team Leader who supported the project's approach to separating the work out into different packages. 'The project features three important work packages: materials development; fabrication and printing technology; and device development,' explains Hahn. 'It is critical to have basic materials development and functional demonstrators and prototypes in a three-year project such as this.'

The work package structure ensured that progress was quickly made. As the project ran deeper into its three-year duration and novel materials became available, many of the issues surrounding the design of their energy harvester, batteries and packaging were already solved.

ADVANCING SEVERAL FIELDS AT ONCE

One of the key concepts of MATFLEXEND has been microenergy harvesting, something that enables two key features: wireless and service-free operation. These features ensure that sensor networks require no cabling, no change of battery, and can operate autonomously for many years. 'There are many possible applications of microenergy harvesting,' explains Hahn. 'For example, energy-autarkic sensors for the Internet of Things and home automation.'

Additionally, such technology advances the field of wearable electronics as improved energy harvesting relieves each user of the burden associated with managing batteries – whether that is repeatedly charging them or replacing them. However, in the case of medical devices, either worn or implanted, changing the batteries is often practically impossible, so energy harvesting is essential. MATFLEXEND is developing technology that can convert mechanical energy into electricity at low frequencies and low forces.

IMPROVING THE MAGNITUDE OF EXISTING TECHNOLOGIES

Three of the most impactful developments of the project so far are high-k dielectrics that can be printed; flexible electrical conductors; and microbattery prototypes based on dispense-print technologies. High-k dielectrics were developed by researchers at Imperial College London and increase the energy density of capacitive harvesters. Ultimately, this enables electrical energy to be generated from mechanical motion. As the capacity of the harvester is changed through a deformation of the flexible electrode, charges are supplied and released at different voltage levels. The flexible electrical conductors were co-developed with researchers based at the University of Vienna and Imperial. 'The researchers developed flexible composite conductors based on an open porous PolyHIPE polymer doped with conducting particles,' explains Hahn. 'Conductivity was improved more than two orders of magnitude over existing state-of-the-art technology.'

The development of flexible rechargeable batteries is of equal importance, as they are essential for the buffering and smoothing of the harvested energy. Two battery configurations have been tested: the conventional configuration with stacked electrodes and a coplanar electrode arrangement that offers advantages in processing and mechanical flexibility. The fabrication of these different battery configurations has been simplified by novel printable electrolytes and separators that were developed as part of the project.

Importantly, Fraunhofer IZM recognised the huge market potential of microbatteries and micro energy harvesting, and invested off-project money in a new microbattery prototyping line that was dedicated to the final assembly of the microbatteries. This culminated in the opening of a laboratory in April 2016 and will be used in the final phase of the project.

BOUNDLESS APPLICATIONS FOR THE FUTURE

With the project set to be completed in September 2016, the team are now looking for partners in a range of sectors to ensure the best use of their technologies. Potential applications for the future include the use of ultra-small batteries for medical use, and a range of wearable technologies including footwear. While proving the long-term stability of their technologies is necessary before any production partnerships can be formed, the future for the technologies MATFLEXEND has developed is virtually limitless.

The final results of the MATFLEXEND project will be presented at the workshop on September 19th 2016 in Vienna (A). The workshop will offer a platform to discuss with materials researchers for micro batteries and harvesters, developers of miniaturized power supplies and wearable electronics, product and applications designers.

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Project Insights

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PARTNERS

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PROJECT LEADER BIO

Dr Robert Hahn is head of the micro energy storage and smart power group at Fraunhofer IZM in Berlin. He received the M.S. and the PhD degree in electrical engineering in 1986 and 1990 respectively from the Technische Universität Dresden. He has taken over the coordination of several national and European research projects for the development of new batteries and integrated power supplies for micro systems, energy autarkic and medical electronics