Period 2: Publishable Summary

Summary of project objectives

HIFLEX aims to develop a cost-effective **Highly Flexible Printed ITO-free Organic Photovoltaics (OPV) module technology** that matches the particular requirements of mobile and remote ICT applications, delivering the required efficiency under different light conditions, sufficient lifetime, acceptable cost structure, appropriate power-to-weight ratio and fit-to-purpose mechanical flexibility. The project intends to accelerate the exploitation of this OPV technology for a wide variety of ICT products in the mobile electronics market.

An application-driven research approach will be followed by developing large area, solution processable ITO-free OPV using scalable, reproducible and commercially viable printing and coating techniques enabling the **low-cost** production of **highly flexible** and **lightweight** OPV products. At the same time it guarantees the technological compatibility with other printed electronic ICT components and systems. The high flexibility and low costs will be addressed by the **solar cell module design** we intend to bring into production.

Description of the work performed since the beginning of the project

Approach:

HIFLEX aims to develop materials, device architectures and manufacturing procedures for large scale fabrication of OPV modules with increased power conversion efficiencies and lifetimes that are sufficiently long for the first commercial mobile applications in the low-power market segment (mobile telephones, PDAs, laptop computers).

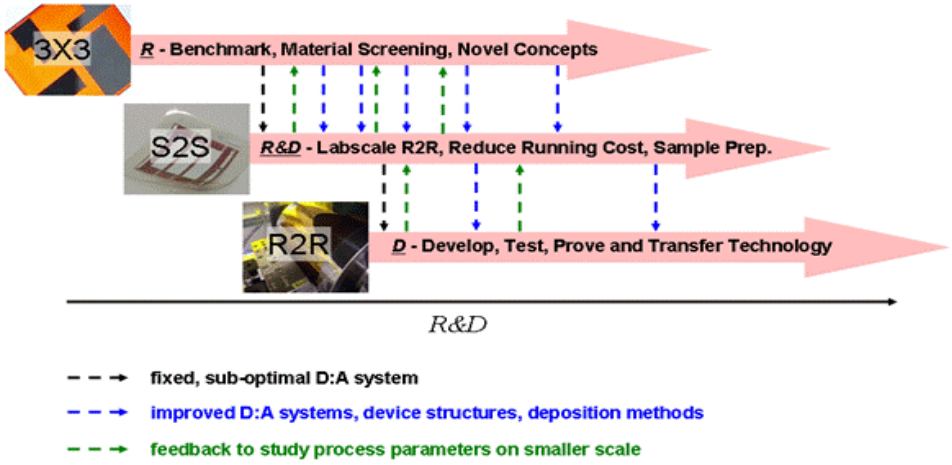
In order to reach the targets, the Hiflex consortium had developed an operational approach schematically shown in scheme I.

In the so called **R**esearch line, substrates with sizes up to 3x3cm2 will be used. These substrates consist of a few single cells with active areas up to 1cm2 and will be used to screen and optimize new available materials and explore novel ITO free device architectures. The performance of these lab scale devices, based on a particular set of materials and device architecture, will subsequently function as the benchmark for experiments that will be carried out on a Sheet-to-Sheet (S2S) and Roll-to-Roll (R2R) basis.

The final objective is to produce low cost polymer solar cells on a R2R basis. It is important to build up a knowledge base concerning the influence of process conditions on the performance of polymer solar cells. R2R experiments will give results that are most relevant for a final production line; however experiments on R2R scale are typically more laborious, consume significant amounts of materials and are therefore more expensive. To collect the required data, experiments

will be performed both on R2R scale (designated as **D**evelopment-line) as well as on sheet-to-sheet (S2S) scale (designated as **R&D** line). The S2S coating technique will be chosen in such a way that the basic physical and chemical processes are similar to those in R2R model. Different module designs and ink formulations will be compared based on a limited set of "fixed" materials combinations which are selected from the research line. It will be important to select the proper substrate and deposition method for experiments on S2S scale in order to be able to translate these results to the deposition method used for R2R production The S2S experiments in the **R&D** line thus form a stepping stone in the process from lab scale devices in the research line towards the production of R2R processed modules in the **D**evelopment line.

The general aim of the experiments in the **D**evelopment line is to develop and prove the technology, and more specifically they will be used to formulate the right research questions for the experiments that will be carried out in the **R**esearch and **R&D** line. This feedback loop is important and essential to accelerate the development of OPV to a fully mature PV technology for the first generation of products in the mobile ICT market.



The work that has been performed since the beginning of this project in the **R**esearch, **R and D** and **D**evelopment line can be summarized as follows:

- Design, fabrication and a comparative performance evaluation (efficiency and lifetime) of ITO benchmark and ITO-free device structures (WP 1)
- Development of fabrication technologies for optimal S2S and R2R processing of OPV (WP2)
- Electrical modelling to design optimal cell and module structures for ITO-free device concepts (WP2) and experimental validation (WP1,3)
- First evaluation of large Area characterization methods (optical inspection, LBIC) for process control (WP2,4)

- Development of low resistance and flexible ITO-free substrates composed of current collecting printed grids and highly conductive PEDOTs (WP3) as input for device fabrication (WP1,2)
- Development of robust R2R production routes for ITO-based and ITO-free module structures (WP4)
- Exploratory routes towards solution processable barriers (WP3)
- Inventory of public available life cycle analyses (LCA"s) for OPV and first LCA and cost assessments based on device concepts presently under investigation in Hiflex (WP5)
- Dissemination activities (WP6)

Description of main results so far

- A power conversion efficiency of 6.0-6.3 % at Standard Test Conditions (STC, 1kW/m2, AM1.5G, 25oC) was obtained for an ITO-reference device with an active area of 1 and 0.33 cm2 using a photoactive layer consisting of a commercial polymer from Plextronics (XP300) and C70-PCBM.
- An extensive performance evaluation of five different ITO free device concepts has been performed in terms of efficiency and lifetime. Power conversion efficiencies measured at STC, range between 1 and 2.5 % for the different ITO free device concepts using P3HT:C60-PCBM as the photoactive layer. Continuous light soaking tests were carried out at different illumination intensities (0.1-1 sun) and at various temperatures (From 25 to 85oC).
- A maximum power conversion efficiency of 3 % at STC was obtained for the ISE Wrap through device concept.
- Fraunhofer ITO free inverted S2S type modules achieved 2.2% aperture area efficiency using P3HT:PCBM, implying > 70% of small cell efficiency.
- An optimized PEDOT:PSS (Gen 6) version has been prepared with a transparency of 99% for a 100 nm thick layer while keeping the same conductivity as previous versions (Gen 5).
- Current collecting substrates with surface resistivity of silver grids + PEDOT:PSS $\leq$ 60 Ω/□ with $\geq$ 90% transparency and sufficient flexibility were demonstrated
- Detailed characterization and analysis of aged cells has been made after a continuous accelerated lifetime test. An extensive study of aged cells with imaging techniques (laser beam induced current (LBIC), dark lock-in thermography (DLIT), electroluminescence (ELI) and photoluminescence (PLI)) has been done and degradation mechanisms for two types of ITO-free devices have been proposed.
- New coating/printing processes have been explored on the R2R line resulting in improved processes that should lead to an efficient and robust all solution processed ITO free OPV system. In addition, an inexpensive, highly conductive and semi-transparent ITO free electrode was developed that will serve as input for the manufacturing of ITO free OPV modules.
- An optical inspection tool for process and quality control was developed and installed on the new R2R line of DTU. A full demonstration will follow soon. As a complementary method, LBIC has shown to be extremely useful for off-line inspection. The LBIC system will soon be upgraded to R2R for inline characterization.

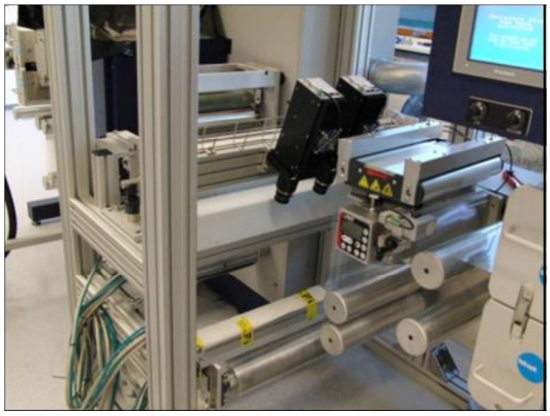
- Production of LCA report – in particular the finding that replacement of ITO has little benefit to the embodied energy of the system but that a still a strong driver for the replacement of ITO due to Indium supply issues.
- Dissemination activities: A number of events were attended and scientific publications produced in the second period, while networks with industry and scientific community have been strengthened.

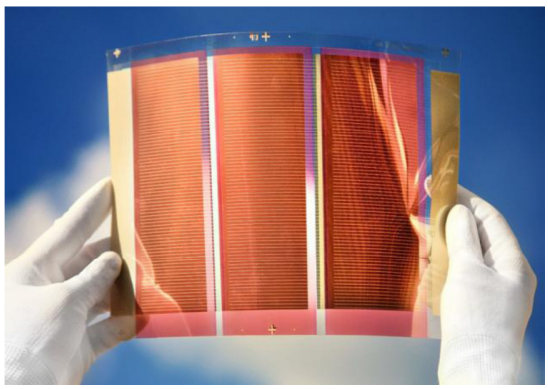
Expected final results and potential impact and use

We anticipate that this project will result in the demonstration of a new scalable, low cost, solution processable photovoltaic technology. It will therefore form the basis of a potentially substantial business opportunity aiming at developing a new solar cell product with cost and payback characteristics which are more advantageous than existing technologies. This will benefit the entire European community in creating economically accessible PV technology and significant industrial activity by demonstrating viable production procedures for OPV.

Project website information

http://www.hiflexopv.eu





R2R IV characterization setup (upper left) and optical inspection tool from Dr. Schenk (upper right) assembled on R2R line of DTU. Lower left: S2S and R2R processed Current Collecting Grid OPV module (Holst)