X10D

Efficient, low-cost, stable tandem organic devices

Results of the European Project X10D – Efficient, low-cost, stable tandem organic devices

www.x10d-project.eu

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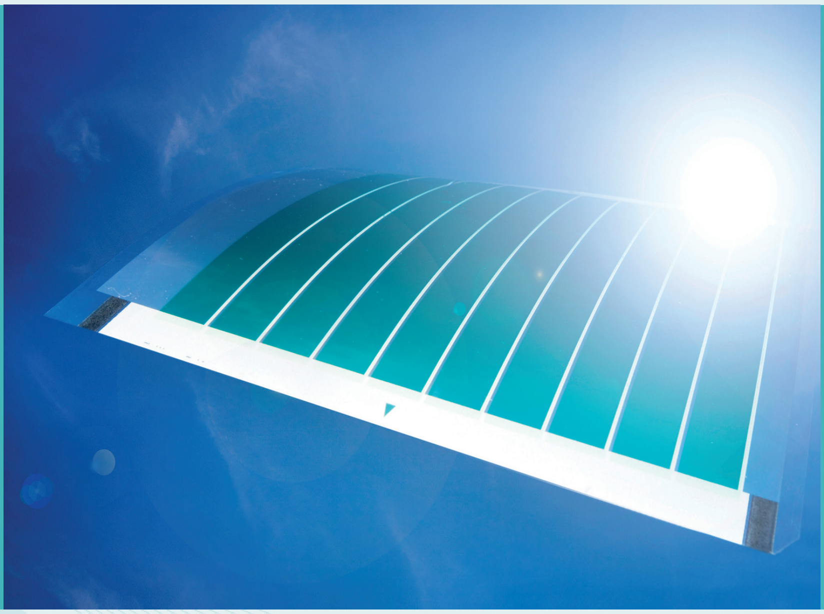

Opaque solar films
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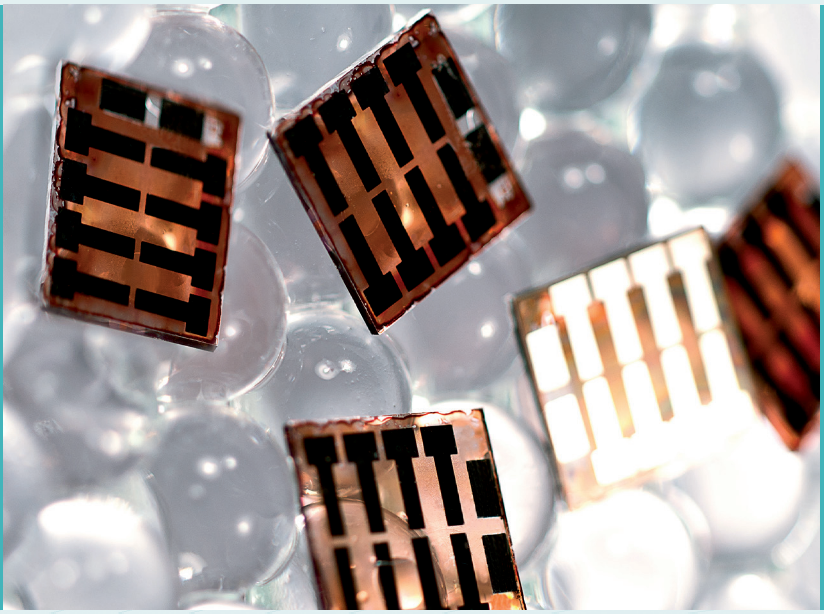
Coordinator:
Dr. Tom Aernouts
imec
Kapeldreef 75 – B-3001 Leuven – Belgium
R&D Teamleader - Organic PV
Phone: +32 16 28 16 89, Fax: +32 16 28 10 97
E-mail: Tom.Aernouts@imec.be
www.imec.be

Chief Technical Officer (CTO):
David Cheyns
imec
Kapeldreef 75 – B-3001 Leuven – Belgium
Phone: +32 16 28 2193
E-mail: david.cheyns@imec.be
www.imec.be

Chief Operating Officer (COO):
Johannes Rittner
VDI/VDE Innovation + Technik GmbH
Steinplatz 1, 10623 Berlin, Germany
Tel. +49 30 310078 230, Fax +49 30 310078 223
johannes.rittner@vdivde-it.de
www.vdivde-it.de

Website:
www.x10d-project.eu



Spraycoated active layer
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X10D – Efficient, Low-cost, Stable Tandem Organic Devices

New designs, material and manufacturing technologies for market-competitive organic photovoltaic modules

X10D was a three-year project sponsored by the European Union. 17 partners from six countries worked together to establish organic photovoltaics (OPV) on the competitive thin-film-market.

In order to realize this, the idea was to pool the knowledge and expertise of Europe's leading research institutes and start-up companies. It was the first project of its kind to leverage this knowledge irrespective of the processing technology. It made use of the strengths available in device efficiency and architectures regarding both: solution-processed as well as small molecule-based OPV.

17 partners, 6 countries

Chief Operating Officer (COO) Johannes Rittner and Coordinator Dr. Tom Aernouts in Interview

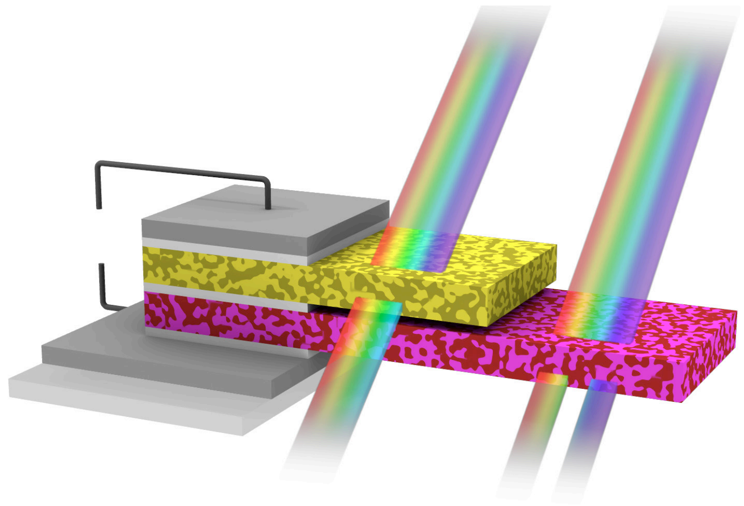
Objectives and Results

The objective for X10D was to develop efficient, low-cost, stable tandem organic solar cells by applying new designs, materials and manufacturing technologies to create market-competitive OPV modules. Therefore, X10D proposed to bring together partners that compose a complete and unique OPV research and development consortium, from academic partners, research centers, SMEs, and large companies. Together, the X10D partners cover each segment of the entire value chain: material development and up scaling, device development and up-scaling, large area deposition equipment and processes, novel transparent conductors, laser scribing equipment and processes, encapsulation technologies, energy, life-cycle and cost analysis, and finally end-users.

The project is divided into seven work packages (WP). Five of them are engaged in the development of organic tandem solar cells. These work packages will be introduced in the following.

The project partners were comparing their original objectives and the results after three years of networking, researches and developments.

1. Objective:
   To increase the power conversion efficiency to achieve at least a 12 % on cell level (1 cm^2), and 9 % on module level (100 cm^2)
   Result:
   In the labs of Heliatek the efficiency of 12 % on cell level was reached on January 2013.
2. Objective:
   To guarantee a minimum of 20 years life for OPV modules on glass, and ten years on foil
   Result:
   During the project, two rounds of lifetime testing are conducted, a third is underway. The results of these tests showed the crucial parameters to obtain long-lived OPV modules.
3. Objective:
   To reduce the costs to under 0.70 €/Watt-peak
   Result:
   From the cost of ownership calculations carried out by Holst Centre, it is concluded that OPV can cross the barrier of € 0.50 per Watt peak by consecutive technological improvements to the current standard designs.



Tandem solar cell absorbing light in different spectra

Introduction

Organic Photovoltaics (OPV)

Molecules for OPV use based on carbon: The molecules form larger structures are called polymers, and they can conduct electricity. These materials act like amorphous semiconductors, making them usable to build organic solar cells.
The manufacturing process is scalable just like industrial printing. The energy-consuming purification and crystallization of silicon is no longer needed.

Benefits:

- cheap to produce
- lightweight & flexible
- produce less waste

OPV benefits from one certain difference as compared to conventional PV technologies: It is embedded in the developing field of Organic Large Area Electronics (OLAE), which is a palette of interrelated photonics technologies, allowing cross-fertilisation between the technologies. Most intriguing is the similarity of demands for OLED lighting and OPV, but also interrelations with other parts of the OLAE sector exist. This will help the materials and equipment industry to step in and invest in this sector, since it will mitigate the risk if one of the technologies would fail.

Tandem Solar Cell

Typically, an organic solar cell absorbs only a small portion of the solar spectrum while the rest passes through unused. The additional polymer layer of the innovative tandem solar cell absorbs light in a different part of the spectrum, leading to a greater overall efficiency.

The research team developed new organic material that was tested in labs
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WP1 "High Performance Materials and Their Sustainable Up-scaling"

Objectives:

The work has evolved around the design, synthesis and testing of new light-absorbing donor and acceptor materials in order to ultimately produce tandem solar cells with a performance of 12 % power conversion efficiency in a device and 9 % power conversion efficiency in a module.

The objectives have been:

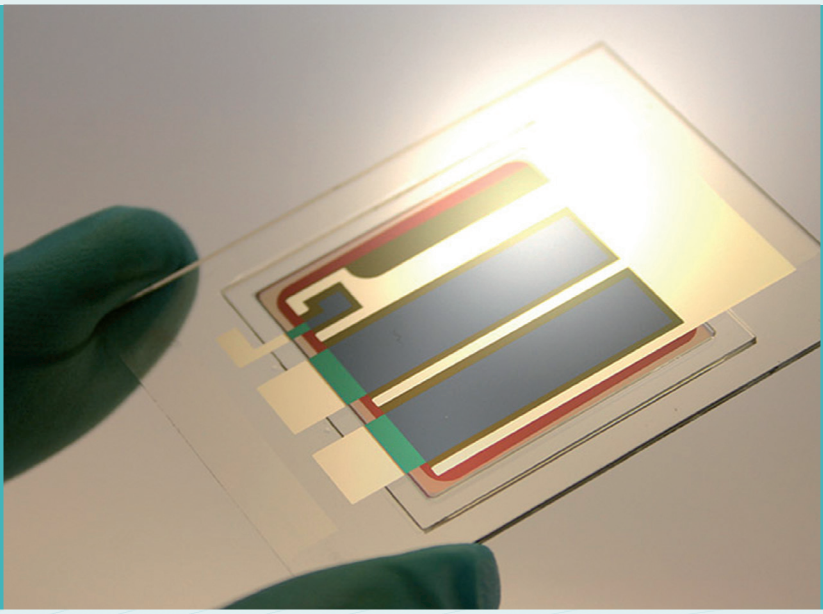
1. to develop and provide the required quantities of enabling materials for the active bulk heterojunction layers in high-efficiency tandem solar cells;
2. to provide up-scaled materials for process development and prototype manufacturing;
3. to explore the feasibility of large-scale synthesis of active materials and to promote and include sustainable chemistry in all synthetic routes, with an additional goal of developing environmentally friendly "green" materials by facilitating the use of commercially viable, non-halogenated solvents for active layer processing.

Realisation:

Aided by the development of highly efficient small molecule and polymer donor materials, giving above 6 % and 7 % power conversion efficiency, respectively, in single junction solar cells, we have to date produced multi junction solar cells with power conversion efficiencies approaching 10 %. We have clearly proven the practical feasibility of large-scale synthesis of photoactive materials and have, for example, synthesised more than 25 g of one of the promising donor polymers. This successful scale-up has moreover enabled the detailed study into commercially viable, non-halogenated solvents for active layer processing, which has resulted in achieving comparable solar cell device performance using non-halogenated solvents such as xylenes and mesitylenes. Additionally, acceptor components have been prepared for improved efficiencies. The compounds present self-organization capabilities, for improving charge transport capabilities through the organized layer and thermal and chemical stability to ensure the possibility of sublimation deposition onto substrates. Significant efficiency improvements (up to 8.4 % power conversion efficiency) have been achieved in sublimated planar heterojunction.

Results:

There has been much collaboration between the work package partners, sharing information on the best synthetic procedures as well as sending intermediates and monomers to each other. It has been stimulating to have some "crosspollination" between the small molecule and polymer approaches. For example, University of Madrid synthesised a requested monomer from Imperial College, who then successfully synthesised the polymer. As we reach the final part of the project, these collaborations are intensifying, with goal-oriented targets driving interactions. Currently we have polymers that have achieved over 7.5 % power conversion efficiency in single cells and similar results with small molecules. Moreover, non-fullerene acceptors have afforded power conversion efficiencies above 8 % in planar heterojunction solar cells.



Heliatek world record cells with 12.0 % efficiency on an active area of 1.1 cm^2

WP2 "High-efficiency Device Structures with Enhanced Light Incoupling"

Objectives:

The main objective of WP2 is the development of tandem device structures for high-performance organic solar cells, using new absorber materials from WP1 and new interlayer concepts. The work is divided into five tasks:

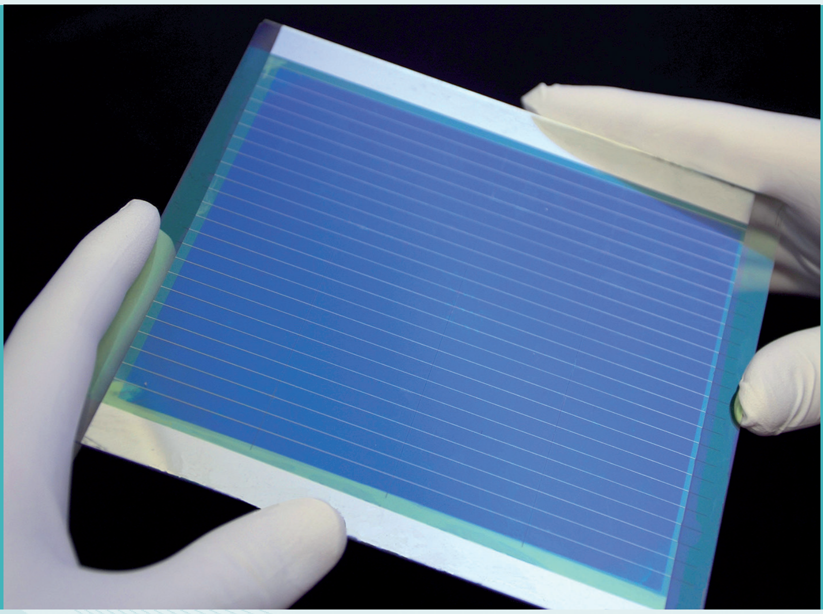
1. starting with the development of inter-electrode systems for solution-based tandem cells,
2. followed by the development of tandem devices made from wet processing, and
3. the development of tandem devices made from vacuum processing;
4. the next part studies the optical properties of tandem cells in nano and micro scale to define advantageous optical designs;
5. in addition, it is the aim of WP2 to get a better understanding of device behaviour by several in-depth characterization methods, including a round-robin study on tandem OPV efficiency, too.

Realisation:

As an important stepping stone, WP2 developed several approaches for loss-free charge conversion inter-layers and middle electrodes for solution-based devices, as they are one of the key challenges for making tandem devices from solution. After several studies, the approach of using zinc oxide turned out successful. ZnO nanoparticles were developed and deposited jointly with a polymer mixture (PEDOT:PSS). This material combination gave reliable inter-electrodes, which could be used by several partners in solution processed tandem cells. WP2 used such charge conversion interlayers in full solution processed devices, and combined them with newly developed absorber materials from WP1. Another key objective of this WP was the development of vacuum processed multi-junction devices, using mainly electrically doped charge conversion layers, which in part are developed within the project as well. The in-depth characterizations comprised, among others, the definition of agreed methodologies for tandem cell characterization, as well as a round robin study comparing the efficiency of tandem devices made at the different partner's labs.

Results:

As WP2 is responsible for making high-efficiency tandem devices, the progress in this field must be seen as the main result. Record multi -unction devices of 8.9 % and 9.6 % have been fabricated with the conversion contact and absorber materials from WP1. Moreover, a 12 % power conversion efficiency cell on 1 cm^2 has been made and externally certified.



Novel fullerene-free OPV cell concept was used to process an OPV module (156 cm^2) with a conversion efficiency of 5.3 %

WP3 "Large Area, Efficient, Low-cost Modules"

Objectives:

1. Large area alternative stable, high performing and low-cost transparent conductors to indium tin oxide (ITO)
2. Deposition techniques for up-scaling uniform films to large area
3. Design and construction of modules with optimal area coverage
4. In-line cell/module performance testing at 5 m/min

Realisation:

Holst Centre developed a technology to embed micron thick silver lines in the substrate to circumvent resistant losses for large area and high efficient solar cells. Agfa contributed with the synthesis of Ag and highly conductive PEDOT while SPG Prints focused on the printing process.

Large area coating has been studied by several partners in a patterned (inkjet printing) and full-area (sot die coating) fashion. Even the option of spray coating has been investigated by imec.

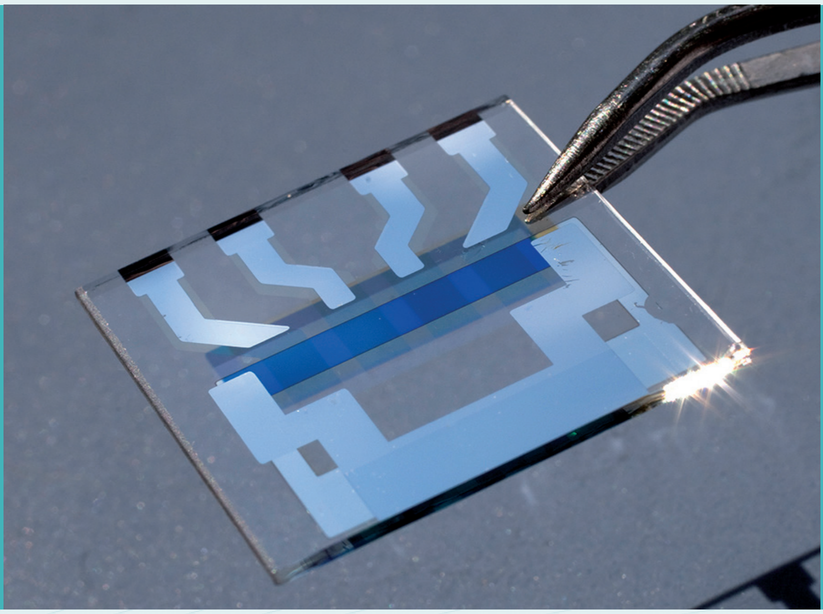
ECN developed a finite-element-model to define the most optimal module design based on properties of the stack and the electrodes applied. These calculations were performed taking into account a single-junction or tandem configuration and also studied the influence of the light intensity. For manufacturing of these models 3DMM, ZAE, and Holst Centre investigated patterning cells via laser ablation. Dead areas of less than 300 micron were achieved rendering geometrical fill factors of over 95 %. Solar Press is developing an in-line cell/module performance test unit with specific electrical contacts applicable to r oll-to-roll production of organic photovoltaics. A flash light system will illuminate the contacted module for a reasonable amount of time to measure the corresponding current density-voltage curve to extract all performance parameters at a speed of 5 m/min.

Results:

Heliatek realised a tandem cell of 7.5 % efficiency on 4 cm^2 area of transparent conductive electrodes from Holst Centre on glass. These cells showed a higher fill factor than the reference cell with ITO as electrode, but showed a slight loss in current density.

ZAE and Solar Press demonstrated large area modules up to 30cm^2 on glass and flexible substrates. Module efficiencies exceeding 4 % were manufactured on roll-to-roll or R2R compatible technology and patterned via laser ablation or during coating.

Holst Centre and ECN succeeded in manufacturing organic solar cells that, through inkjet printing, feature all layers applied on glass. ITO-free solar cells achieved reproducibly an o efficiency exceeding 1.5 % which is 70 % of a spin coated and vacuum deposited variant.



OPV solar cells from the R&D lab
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WP4 "Full Device Encapsulation and Accelerated Lifetime Evaluation"

Objectives:

The objectives of work package 4 are

1. to identify degradation mechanisms of materials, cells and modules;
2. to develop low cost encapsulating solutions, and to evaluate the lifetime of OPV modules coming from the X10D project.

Realisation:

At first, the intrinsic degradation mechanisms of cells have been identified. This enhanced the selection of the most stable materials (photo-active, transport, electrode and contact layers) as well as device architectures from WP1-3. Wet processed and small molecule solar cells' stability has been compared in different conditions and the most critical factors have been identified. This work also allowed making recommendations for the most appropriated lifetime testing conditions. Lifetime measurements on devices and modules based on benchmark materials and architectures have to be carried out in an inter-laboratory study with standardized test protocols. This study will soon be completed in a second round including outdoor lifetime testing and under complementary accelerated conditions. Finally, materials and architectures coming from the results of WP 1-3 will be tested in a third round and will result in determining acceleration factors and accurate lifetime extrapolations. In parallel of all aging studies, a low cost polymer flexible encapsulation system with high H_2O barrier properties has been developed. A better environmental impact, as compared to current technologies, has been proven. Current studies are particularly concerned with the transfer of this technology on to a roll-to-roll pilot line and the quantification of all improvements. Furthermore, in order to consider the fully encapsulation process, characterization tool to measure lateral permeation from the edge (through the adhesive) has been developed and some adhesive materials have been tested. New adhesive materials will be evaluated in the final period of the project.

Results:

This work package is strongly linked to WP 1-3 concerning stability and lifetime studies. The combination of WP4 and WP5 studies is also crucially important due to the fact that the encapsulation is identified as one of the main contributors to environmental and cost impacts.

The transparent solar films for windows can be integrated between two glass sheets. These "tinted" windows will provide shading and green energy at the same time
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WP5 "Costs, Environmental Impact and Market Analysis"

Objectives:

1. Cost of Ownership calculation of a commercial plant with the aim to define the conditions to achieve module costs below 0.7 €/Watt-peak;
2. Environmental profiling of investigated OPV technologies by life cycle assessment (LCA) studies;
3. Investigation of the market needs and developments for potential applications of OPV, like BIPV and grid connected outdoor; specification of requirements for product integration.

Realisation:

- A market analysis report: The report is based on information gathered from literature, external reports and X10D (industrial) partners;
- An initial life cycle assessment of a pre-commercial OPV processing line of Heliatek (confidential);
- Cost of ownership calculations of the manufacturing.

Results:

The market analysis report describes the current situation in the PV landscape and sketches the current technological status and future market potential of OPV for specific targeted applications like BIPV, automotive and various fast deployable applications. These targeted applications were selected after identifying unique selling points like flexibility, semi-transparency, freedom of design, beauty to give OPV a competitive advantage over other flexible PV technologies. The performed LCA studies are confidential, but have been realised after an intensive exchange of information and data between ECN, who carried out the LCA calculations, and Heliatek, who provided the input data for the assessment. It has been demonstrated that the energy payback time of Heliatek's pre-commercial flexible OPV module technology is already competitive with commercial thin-film PV module technologies that are typically produced as rigid glass-based laminates. Further significant reduction of energy payback time is expected as soon as scale effects from large-volume OPV production reduces the environmental footprint of OPV. Thus, OPV has the potential of becoming the first truly green PV technology. From the cost of ownership calculations carried out by Holst Centre, it is concluded that OPV can cross the barrier of € 0.50 per Watt peak by consecutive technological improvements to the current standard designs. The effects of going from single junction to tandem modules and laser structuring of OPV modules have been explored in this project. This projection says that OPV may become a competitive PV technology once it is up-scaled to large volume. Still, the costs are not significantly below PV costs. This means in other words, that the main difference of OPV to conventional PV technologies will not be costs, but performance.

The robust and ultralight solar films are especially suitable for energy harvesting applications in transportation. Transparent solar glass roofs could be integrated into cars to harvest green solar energy
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Market Chances for Organic Photovoltaics

Organic Photovoltaics should not be seen as a replacement for current PV technologies. Instead, OPV is a disruptive technology that opens access to completely new markets, where energy scavenging so far has not been exploited. This may have different reasons like e. g. aesthetic considerations, or more practical ones, as weight or form factor. OPV opens completely new design options, for example due to its ability to be adapted in colour, transparency or shape. As one of the first PV technologies, with OPV it is possible to produce large semi-transparent devices with full area coating. Structuring of these devices can be carried out either by additive technologies (as printing) or by subtractive ones (like laser ablation). Each of these approaches has its own upsides and creates chances in different applications. All these properties make OPV an interesting option for applications in the automotive sector, as well as in the building integration market. And these markets are enormous: World-wide, each year 20 million car roof windows are used. The use of facade glass is 20 million square meters annually, within the EU only. All these markets become accessible, once a certain threshold of device performance is reached. The project X10D has this topic in focus: The efficiency of OPV cells could be increased to 12 % within X10D, which is the current world record for OPV devices. OPV lifetime has been studied in detail as well, and the durability of OPV devices could increase further, which is another prerequisite for a widespread application of OPV. In summary, OPV is a truly green technology, giving access to so far non-developed markets. To reach this goal, however, continued research and development will be required before a commercial breakthrough can be expected.

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