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Efficient, large-area arbitrary shape solar energy

Rapports

Informations projet

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Final Report Summary - ARTESUN (Efficient, large-area arbitrary shape solar energy)

Executive Summary:
The European FP7 project ArtESun has realized several versions of organic solar modules demonstrating the potential of this technology for different application areas. Developments ranging from novel active layer and electrode materials in combination with coating and module interconnect techniques has led to small and large area demonstrators with a variety in shape and size. Application use cases ranging from indoor RFID-tags to outdoor building-integration (BI) have been successfully demonstrated.

In an RFID tag the battery pack is replaced by an organic solar module of the size comparable to that of a credit card to power the wireless communication between the tag and its reader and to power the integrated sensor device. In addition, auxiliary electronics including energy storage in form of a supercapacitor and overvoltage protection are integrated to the RFID tag to secure the operation up to one day during poor light conditions. The tag can sense the indoor surrounding temperature, which is monitored wirelessly with a hand held reader. Outdoors, a vehicle can be identified wirelessly with a fixed reader from a reading distance increased by a factor of 10 when utilizing the solar power compared to passive mode operation.
An aesthetically pleasing flower-like flexible organic solar antenna module was realized by gravure printing to power a radio and an environmental sensor in a distributed wireless sensor network. The module has been optimized to operate under low or varying light intensities like for remote, autonomous precise environmental monitoring in agricultural applications.
Thirdly, larger area modules have been realized and assembled in a glass-based facade element for use in building integration. The BIPV element was developed as a vertical fin as large as 1610mm x 380mm to be integrated as a ventilated façade within very well defined structural elements. Potential market acceptability, in terms of overall subjective properties (robustness, colour, design, reflection, etc.), was tested by means of a visual inspection experts' panel providing scores from 0 to 10. The result shows an overall excellent acceptance rating between 7-8 for this BIPV product.
Within the framework of the ArtESun project, VTT collaborates with imec (Belgium), Fraunhofer ISE (Germany), Imperial College (U.K.) IKERLAN S.Coop. (Spain), Corning SAS (France), ONYX Solar Energy S.L (Spain), Confidex OY (Finland), and Wibicom Inc. (Canada).

Project Context and Objectives:
Important advantages of OPV against other PV technologies include low cost and easy manufacturing on different flexible substrates using roll-to-roll (R2R) printing and coating technologies. High volume production technologies enable cost-efficient industrial production compared to vacuum processes. Moreover, the OPV technology does not present raw material abundance or toxicity problems at the same level as other PV technologies do. In addition, printing brings the advantage of large area arbitrary size and shape processing which increases the freedom of product design and its integration into various types of applications.
OPV's main application areas today are in low power electronic devices but there are visions of OPV entering into Building Integrated PV (BIPV) area as a high cell efficiency is not essential where there is a large area available, and further, when technology develops to energy harvesting for standalone stations and grid energy harvesting. Europe has a leading role in the development of OPV technologies and ArtESun combines the multidisciplinary and complementary competences of top-level European research groups and industries to generate new innovations in the field of OPV and to stay in the front line of development. The partners combined represent the capability to make break-through advances in the development of high performance innovative materials for multi-junction OPVs suitable for cost-effective non-vacuum production of arbitrary size and shape modules with efficiency over 15% in relevant environment and lifetimes relevant to its expected future applications. Application potential has been demonstrated in the field of BIPV as ventilated facade elements, as an energy harvesting element for RFID, and as a photovoltaic antenna for wireless sensor network nodes.
The main objectives for the project are:
Materials developments to increase the efficiency of multi-junction architectures, up to 15% PCE in

wavelengths up to 1000 nm. Novel material solutions for donor and acceptor materials will be developed as well as new solutions for interlayers and electrodes. For these novel compounds sustainable scale-up routes will be identified to clarify the potential for large-area processing of OPV modules with these materials on the longer term. Novel eco-friendly ink formulations for the photo-active layers will be targeted, avoiding the use of halogenated solvents.
Alternatives to the costly transparent IndiumTinOxide (ITO) electrode, especially processing technologies for ITO-free highly conductive transparent electrodes will be developed using two approaches, i) based on sputtered thin Ag layers (MO/Ag/MO), or ii) based on printing metal grids with metal nanoparticle inks and printing of Ag nanowires or conductive PEDOT materials on top of the grid structure.
Non-vacuum, low-cost multilayer printing, slot-die coating and self-patterning processes were investigated for the processing of the ITO-free transparent electrodes, photoactive layers and the ultra-thin interface and recombination layers, with a focus to produce OPV modules with arbitrary size and shape. In this project focus was on developing stable materials and device structures, including also the barrier layer required for shielding the solar cell, as well as processing technologies for all these materials. Internal and external degradation mechanisms were analysed and characterized for example using special indoor and outdoor testing facilities. In the project ultra-thin flexible glass to guarantee ultra-high barrier properties against external degradation has been introduced.
Work begun in parallel in all technical work packages described in the DoW. For Y1 an ITO free device with the benchmark material was demonstrated. Device geometries have been investigated and modelled and preliminary plans for the three demonstrator cases were determined. The designs define performance targets and processing and layout boundaries. This has enabled the simultaneous advance in both demonstrator development and material research for the purpose of the project.
The work on photoactive materials initially concentrated on the electron donor polymer and then moved on acceptor materials and interlayers. Donor and acceptor materials that are suitable for efficient upscaling, tuneable band-gap for tandem cells, and an increased efficiency in the target application was studied. Up-scaling potential for the polymers has been taken into account early in the synthesis development by applying Suzuki polymerization, which is more scalable and environmentally friendly than the more commonly used Stille polymerization which is favoured by development labs due to the mild reaction conditions. Low cost acceptors were developed to perfectly match the donors as alternatives to fullerene based materials that are costly and has potentially severe health issues.
Manufacturing process up-scaling is done using a state-of-the-art polymer available in multi-gram scale. A great number of interlayers have been screened, of which some are novel for the application and easily synthesized at low cost, thus very well suited for the target applications. Parallel work on 3-5 different electrode configurations is performed in order to find a balance between electronic performance, optical transparency and robust processing as an alternative to ITO based electrodes. The processing of materials into printable inks, printed thin layers and multilayers to form the layered structure of the device has been developed, targeting large area compatible manufacturing. The Hansen solubility parameter analysis has been utilized as a tool to develop environmentally friendly printing inks for the different materials. Thus, a process that excludes the use of halogenated solvents is developed. As the environmental and long term stability largely depend on the encapsulation of OPV cells, different encapsulation technologies have been evaluated. Encapsulation based on e.g. flexible glass, barrier adhesives, and flexible barrier film has been tested in order to find the best solution to device stability. The reel-to-reel printing and patterning process has been developed on pilot scale equipment while devices and modules for material and stability testing have been made on laboratory equipment. The main printing

techniques employed are flexographic, gravure and screen printing. For large area demonstrators and highest efficiencies slot-die coating is investigated.
The main outcome of the project is two-fold: first, the demonstration of materials and manufacturing techniques for OPV devices with efficiency up to 12% (>15% with typical indoor illumination) that avoid the use of halogenated solvents, fullerene acceptors and ITO; secondly, the demonstration of three quite different use cases for developed modules.
Novel interlayers have been incorporated into devices and different electrode structures have been demonstrated with different material "stacks". Functional OPV cells and modules have been produced using both established materials and techniques and combining with novel solutions developed in ArtESun. For practical applications the stability of devices over time is essential and environmental and lifetime testing of devices and modules has been performed.
The demonstrator cases produced are OPV based BA-RFID tags, which utilize the flexible glass, use friendly solvents and is ITO and fullerene free; the OPV antenna distributed sensor network node that show case the free form patterned printed OPV; and the ventilated facade OPV elements that are glass laminated large panels for building integration, demonstrating the large scale manufacturing capabilities.
The overall main objective and expected results of the project is two-fold: The demonstration of a 15% module efficiency OPV device as characterized in its relevant target environment and the demonstration of an arbitrary shape and sized module design. This involves advances in almost every aspect of the module, from active material and interlayer design and formulation, to process development, encapsulation and module implementation technology. In addition, the target is to demonstrate three quite different applications utilizing developed technology.
The expected impact in materials, the synthesis of novel donor and acceptor polymers with corresponding upscale routes, has been achieved. Several new donor and acceptor materials have been created and, more importantly, taking into account the economic and scalable manufacturing and tuneable band-gap for optimized device performance in different architectures. Novel interlayer materials have been identified and the manufacturing process has been developed for incorporating these in devices. Advanced electrodes have been developed and ultra slim flexible glass is employed as an encapsulation material with excellent barrier properties. These technical advances together with the environmentally friendly process, improved lifetime and device performance up to 18% for indoor applications efficiently improves the competitiveness of the products. Modelling together with stability data provide an effective tool for the development towards commercial OPV products. Design of arbitrary shape cells and modules enable direct integration into realistic end-use demonstrators according to specifications set by industrial players. Low carbon technologies through solution processing in air at low temperature save cost and the environmental impact, and the additive processing for low cost module processing enable faster industrial take-up as does the use of only non-halogenated solvents.
The demonstrator cases show that the technology can be used in real applications. The credit card sized BA-RFID has a range of up to 40 m and can be constantly ON thanks to the OPV - super capacitor combination. Thus, it could be readily implemented e.g. in vehicle identification and tracking. The arbitrary shaped OPV antenna sensor node is autonomous at illumination of various intensity; even low 500 lux illumination is sufficient to power the device using the 5 cm sized flower design that blends well with the environment. For the BIPV application rigid modules of a size compatible with building integration are manufactured for ventilated facade implementation.
The ArtESun project contributes to increasing the scientific and technological leadership of Europe in the fields of organic electronics and energy generation. The ArtESun project will enable the consortium

members and their European partners to benefit from the large potential market of Organic and Large Area Electronics. Moreover, the ArtESun results enable not only the European PV industry to become more competitive but will also improve the positions of related European industries, such as specialty chemical, substrate and encapsulation material companies, and equipment manufacturers. An objective of the ArtESun project is also to create new markets over the full OPV value chain, starting with materials for most layers of the device. Secondly, the organic photovoltaic devices will be new products that are introduced to the market as a clear result of this project. The environmental impact is important and the consortium has been able to make advances in all areas planned for reducing CO2 emission, produce sustainable chemistry and to reduce the use of halogenated solvents.
To ensure the impact of obtained results ArtESun publish scientific results, take part in conferences, fairs, trade shows and participate in organizing stakeholder meetings and seminars.

Project Results:
The project foreground has been documented and reported in Deliverable Reports throughout the project. However, most of the official reports have been restricted to the consortium and the EC. On the other hand, scientific achievements have been published in scientific journals, conferences, fairs and workshops, of which most are accessible to the general public.
One official deliverable report is a public technical report which contain in addition to the information below, several pictures and graphs to support the text.
Photo active materials development
The objective of WP1 is to develop high efficiency multi-junction OPV devices, exceeding 15% PCE, with novel donor and acceptor materials. In order to achieve these objectives, effort under WP1 were focused on the development of both low and wide band gap donor polymers with complimentary absorption properties and developing novel small molecule acceptors as replacements for fullerene based acceptors. Our efforts under WP1 to deliver photoactive materials capable of reaching 8% power conversion efficiency have been focused on three different classes of push-pull type medium-to-narrow band gap semiconducting polymers. Pleasingly, all three polymers have been optimised through synthetic modifications, polymer weight fractionations and OPV device optimisations to afford single-junction solar cells with efficiencies exceeding 8%.
A novel eight ring benzothieno[3,2-b]thiophene isoindigo acceptor unit was designed and a copolymer with thiophene was made to afford polymer TBTIT-h with a number average molecular weight of 152 kDa, an ionisation potential of 5.1 eV and an optical band gap of 1.6 eV (Adv. Mater. 2015, 27, 4702-4707). The single junction solar cell devices derived from TBTIT-h:PC71BM blends (1:2 weight ratio) exhibit power conversion efficiencies up to 8.7 % with a high Jsc of 17.08 mAcm2 and a high FF of 0.70 V for as-cast films without using any additives or post-solvent/ thermal annealing steps during the device fabrication.
Polymer BBTI-1 was synthesised by coupling benzo[1,2-b:3,4-b':5,6-d']trithiophene (BTT) as the electron-rich unit and 2,1,3-benzothiadiazole-5,6-dicarboxylic imide (BTI) as the electron deficient unit (Adv. Mater. 2015, 27, 948-953). BBTI-1 was obtained with a number average molecular weight (Mn) of 64 kDa and a polydispersity index (PDI) of 1.99. The photovoltaic properties of BBTI-1 were examined in an inverted OPV device architecture with PC71BM as the electron acceptor material. The photoactive layers comprised a 1:2 weight ratio of polymer to fullerene and were in the first instance solution cast from neat o-dichlorobenzene (ODCB). Using these conditions, BBTI-1 afforded a high power conversion efficiency (PCE) of 8.3% owing to a high short-circuit current (Jsc) of 16.45 mA/cm2, a high Voc of 0.80 V and a respectable fill factor (FF) of 0.63. Interestingly, when 1,8-diiodooctane (DIO) was employed as a solvent

additive, the performance of BBTI-1 significantly decreased (4.8% PCE) due to a loss in both current, voltage and fill factor.

In addition, we have also synthesised low band gap diketopyrrolopyrrole based polymer C3-DPPTT-T which affords a maximum power conversion efficiency of 8.8% resulting from a Jsc value of 23.5 mA/cm2, a Voc of 0.57 V and a fill factor of 0.66 (J. Am. Chem. Soc. 2015, 137, 1314–1321). Apart from medium and low band gap polymers we have also developed wide band gap polymer C2C6-NDT-BT with a band gap of 1.8 eV. A 1:2 (w/w) ratio blend of the polymer with PC71BM in an inverted device architecture gave PCE of 7.5% (Adv. Funct. Mater.2016 26, 6961–6969).

The donor polymers developed under WP1 have been optimised to give efficiency close to 9% with PC71BM, which have poor absorption in the visible region of the spectrum. Our efforts under WP1 to deliver photoactive materials capable of reaching 10% power conversion efficiency have been focused on developing non-fullerene based acceptors with better absorption as an alternative to fullerene based acceptors.

Solution processable novel small molecule electron acceptors bearing 3-ethylrhodanine flanking groups were synthesized as an alternative for fullerene based acceptor. These molecules were designed to be synthetically simple and versatile, with wide scope to modify the structural, electronic, and morphological properties through chemical design. Incorporation of benzothiadiazole extends the conjugation, thus improving charge transport, as well as affording electron deficient character to the outside of the molecule. To cap the ends of the molecule, 3-ethylrhodanine was chosen as an electron withdrawing flanking group. Furthermore, these molecules are highly absorbing in the visible region and the absorption can be tuned by changing the central aromatic core, offering the potential for enhanced photocurrent generation in OPV devices.

When fluorene was used as the central unit, the molecule gave relatively higher PCE of 4.1% with P3HT as donor with high open circuit voltage (VOC – 0.82 V) compared to PC61BM as an acceptor (VOC – 0.59V) (J. Am. Chem. Soc. 2015, 137, 898-904). The nonplanar molecular structure results in reduced tendency to crystallize, which helps to prevent large crystalline domains from forming in the bulk heterojunction blend composition over extended lifetimes. However, the inability to form pure domains results in highly intermixed donor and acceptor resulting in low short-circuit current (Jsc) in these devices. In addition, the large extent of spectral overlap of FBR with P3HT and lack of long-wavelength absorption reduced the ability to harvest photons across the spectrum, further limiting the generated photocurrent.

In order to address both the spectral overlap and morphological issues associated with FBR the central fluorene unit was replaced with an indacenodithiophene unit. This has the effect of planarizing the molecular structure and thus significantly red-shifting the absorption as well as increasing the tendency to crystallize on length scales commensurate with charge separation and extraction. Power conversion efficiencies of up to 6.4% were achieved, which is, to the best of our knowledge, the highest reported for fullerene-free P3HT solar cells (Nat. Commun. 7:11585 doi: 10.1038/ncomms11585 (2016)). The oxidative stability of these devices is also found to be superior to the benchmark P3HT:PC60BM devices demonstrating this to be a robust and highly promising new materials combination for OPV.

In order to improve the efficiency of binary OPV devices a third component, which is either electron donor or acceptor material, is usually added. The third component is often chosen to have complementary absorption with respect to that of the two components. Similar approach was applied to improve the efficiency of P3HT:IDTBR devices using our novel small molecule acceptors. The addition of IDFBR into P3HT binary devices increases the device efficiencies up to 7.7% by reducing the recombination, improving photo-voltage, charge carrier mobility and lifetime in the ternary blend (Nat. Mater.

doi:10.1038/nmat4797 (2016)). This is the highest efficiency value reported for P3HT based solar cells. Careful optimization of the third acceptor component in a P3HT ternary blend resulted in optimal phase morphology where the vitrification of the crystalline IDTBR phase, preservation of crystalline P3HT phase and a molecularly dispersed mixed phase creates an optimum energetic landscape for charge separation. This optimal phase morphology yields extended lifetime and reduced bimolecular recombination resulting in simultaneous improvement in Voc, Jsc and FF for P3HT:IDTBR:IDFBR devices.

Non-photo active materials and tandem architecture development

ArtESun also focus on the development of novel transport, barrier and recombination interlayers based on solution processing. In addition, also ITO-free alternative electrodes were studied; On one side transparent and semi-transparent structures comprising silver grids, silver nanowires and highly conducting PEDOT derivatives, and semi-metallic Cr/Al/Cr and AZO/Ag/AZO. In the other side, highly bottom reflective systems made of thicker Cr/Al/Cr layers were also investigated. In all cases, the main objective was to increase the PCE of resulting devices in comparison to traditional ITO based PEDOT-Ca structures for different active polymers. Finally, joining results for all material development, a task was dedicated to modelling single and junction tandem devices with the aim of achieving PCE over 15% under relevant illumination conditions.

In this way, the most important results from this WP are itemized below:

• Novel alternative transport and recombination interlayers for standard and inverted cell designs:

o Standard architectures: Novel interlayers based on C60-adduct pushed PCE to 6.7% in comparison to reference ITO/PEDOT-Ca devices (5.5%) made with ArtEsun reference polymer (ARP).

o Inverted architectures: Novel glycin and 5-ethyl-thipophene-2-carboxylic acid based interlayers equalized reference devices (5.5%).

• ITO-free alternative electrodes gave promising results:

o Ag grids/PEDOT structures yielded 3.5%

o Ag NW/PEDOT showed PCE of 2.7%.

o AZO/Ag/AZO resulted in 4.6% PCE devices.

• Highly bottom reflective systems also improved the efficiency of standard reference devices:

o Cr/Al/Cr devices produced 5.9% PCE.

• Combined optical and electrical modelling showed that ArtEsun tandem devices can yield PCE of 18.5% under indoor LED illumination conditions.

• The best experimental tandem device showed a PCE of 10.6% under AM1.5G illumination conditions.

Printing and coating materials and processing development for R2R manufacturing of OPV modules

The main objectives related to device processing has been to develop and optimise low cost R2R printing (direct patterning) and coating processes for novel materials developed in the project, thus highlighting the environmental impact in terms of material use efficiency and safety and optimisation of energy consumption. The upscaling of process capacity to R2R production was accompanied by work on the lab scale for determination of process parameters. Experimental work was carried out with VTT, Fraunhofer, IMEC, Ikerlan and, closely connected to the demonstrators.

Specific goals can be summarized as:

• Formulation of environmental friendly printing and coating inks

• Electrical modelling of arbitrary shape OPV cells and modules

• Direct patterning (printing) deposition development for OPV layers and structures

• R2R slot die coating process development

• Self-assembled patterning of OPV modules

• Upscaling of R2R processing of OPV module production including cost calculations

Environmental friendly printing and coating ink formulations from photoactive materials were developed with the main focus on using non-halogenated environmental friendly solvents. The inks were designed according to the Hansen solubility parameters and boiling points considering the ink requirements for specific printing and coating techniques. Non-halogenated solvents are one step toward industrially viable printing of solution processed TFPV and solvent systems were based on thiophene, tetralin, 1,2,4-trimethylbenzene, anisole, and o-xylene. The general five-step evaluation was based on screening of solvents, examination of wetting and Hansen solubility parameters as well as preparation of lab-scale coating trials and device tests. Furthermore, the feasibility of the inks containing novel photoactive materials and non-halogenated solvent was demonstrated as the upscaling of OPVs was realized in R2R process.

The output power of a solar cell is depending on the incident light intensity and spectrum thus, it is important to know the expected lighting conditions and real JV characteristics under these conditions. For low light intensities a low parallel resistance can severely limit the performance, while its influence may be negligible under a full sun illumination. In addition, one important source of light is artificial lighting with about 500 lux light intensity that has been utilized as printed, arbitrary shaped modules for demonstrator case has been design using novel materials developed by Imperial College. Different direct and indirect methods printing methods were examined in order to pattern modules namely by using flexographic printing, screen printing, gravure printing, inkjet-printing or aerosol printing techniques. Based on these results the free form OPV modules were fabricated using gravure printing and screen printing techniques.

Evaluation of lifetime, encapsulation materials and processes

A separate work package was set up in order to demonstrate device processing using willow glass, optimize encapsulation strategies and identify the dominant degradation mechanisms of the OPV devices. The integration of flexible willow glass allows for a perfectly tight highly transparent front barrier preserving a certain degree of flexibility. A first important finding was uncovered by comparing degradation of thin films of Calcium and Benchmark OPV devices in different packages, like state of the art flexible barrier films and willow glass laminated with different glues as pressure sensitive adhesive tapes or filled epoxy glues. It could be clearly demonstrated that the main ingress of water and oxygen takes place through the adhesive or at the interface between adhesive and substrates. A clear advantage of a filled epoxy over PSA glues was observed especially at 85°C and 85% relative humidity, which is one of the IEC 61646 standard tests for thin film PV module qualification.

The degradation of benchmark devices in the same packages was well correlated to the results of the Ca test. A large set of around ten photoactive materials and more than 15 different device stacks with and without ITO have been tested during the project, showing that each component influences the final device stability and that some materials are not compatible with certain device stacks, in which other function well and show best stability. The device optimization is therefore a highly complex task with a lot of interplay between materials and processing conditions. The goal was to identify a stable ITO-free device stack using a highly efficient organic photoactive layer which could be processed from non-chlorinated solvents in ambient atmosphere, to make the device compatible with low cost R2R production and suitable for real world applications. The best overall package was delivered by a novel non-fullerene acceptor ternary blend system which yields efficiencies above 5% even when processed in air from non-chlorinated solvents without using ITO and showed remarkable stability. Other photo-active materials yielded higher efficiencies but degraded significantly faster or where not compatible with non-chlorinated solvents or air processing while others did not work properly in ITO-free devices. Only the newly developed material fulfilled all requirements at once [B. Zimmermann: Efficient, large-area arbitrary shape solar energy, European Photovoltaic Cluster General Assembly, 25th - 27th May 2016, Barcelona; B. Zimmermann: Highly Efficient and Stable ITO-free Organic Solar Cells - EU-Project ArtESun, Oral presentation at 2016 International Summit on OPV Stability, October 14, 2016].

The second focus of the work package was to demonstrate processing of OPV devices directly onto Corning Willow glass. The handling of the thin glass needs a few precautions to avoid breakage, most importantly point impact must be avoided, but if this is carefully executed processing on the thin glass is reproducibly possible with the same quality as on thick glass. The smartcard size OPV module for integration into the active RFID tag of Confidex, which works well at low light intensities, utilizes Corning flexible glass [B. Zimmermann, (Organic) Solar Cells for Indoor Applications, invited presentation at MatHero Standardisation Workshop, 26.05.2016 Barcelona]. The device is built on Willow glass and also encapsulated with Willow glass, at a total device thickness of 200 µm only. Roll-to-Roll handling of Willow glass was also investigated showing that minimum roller diameters should be 100 mm and that with a machine equipped like this, R2R processing of the Willow glass is indeed possible.

The third main prototype related objective was to develop encapsulation strategies for the large scale BIPV Demonstrator. Two complementary approaches were developed. The first was to laminate a plastic film OPV module between two glasses to get a rigid and robust BIPV façade element as shown in Figure 9 left. Critical is the right choice of the encapsulant to ensure good adhesion. The second concept was to process the OPV directly onto a low cost flexible PV-Barrier Backsheet film and encapsulating with flexible Willow glass.

Demonstrator prototypes

One of the key objectives were to produce three types of prototypes based on the ArtESun OPVs, where the applications is quite different, to demonstrate the flexibility and versatility of the technology.

RFID + OPV

Within the ArtESun project, it has been shown that the small rectangular OPVs of size 40 mm by 30 mm can successfully be integrated into the RFID tag together with auxiliary electronics including energy storage and overvoltage protection. This enabled the utilization of solar power as a power source for BAP operation and for powering sensor. Real measurements were conducted with the RFID-OPV prototype to evaluate the adaption to application requirements. It was measured that the RFID-OPV tag could achieve market acceptable performance level when it comes to vehicle identification outdoors and temperature sensor application indoors. The power utilized from the OPV could increase the vehicle read distance dramatically and the sensor information could be used for monitoring the cold chain for food and pharmaceuticals.

The RFID-OPV device is essentially a flexible label (label dimensions of 59 mm (W) x 90 mm (L) x 3 mm (T)), ready to be attached on both opaque and transparent platforms.

The temperature is read with a hand-held reader. This could represent the RFID-OPV operation in indoor sensor applications where the temperature is monitored. The outdoor vehicle identification is demonstrated by reading the label through a piece of car window glass with a fixed UHF RFID reader. The reading distance could be increased by a factor 10 when utilizing the solar power for BAP mode operation compared to passive mode operation.

OPV + Antenna

It has been successfully demonstrated that an OPV having the shape of flower is directly integrated with a Bluetooth® low energy radio since the OPV is specifically designed to act as the antenna for the wireless device. The OPV antenna has a diameter of 10 cm and provides enough electrical energy to continuously power the electronic circuitry indoors at low light intensity. The system comprises an environmental sensor measuring ambient temperature, humidity, and pressure, aiming at applications where precise weather monitoring is needed, such as in greenhouses. The Bluetooth® radio connects to a smart phone via a mobile app where sensor data can be read in real-time. The OPV wireless device has a range of 30 to 100 m. The OPV Smart Flower module is very thin and flexible, thus it can be stuck to an object, such as a bottle, or on a window. It radiates in all directions and can be easily deployed. Not only can the OPV Smart Flower be used for wireless sensing, but also as a broadcast beacon sending notifications or alerts, and for precise location tracking. With a Bluetooth® to WiFi or Ethernet hub, multiple devices connect to the internet and data is stored on a Cloud getting access to historical data and data analytics. Using the WibiSmartTM mobile app from Wibicom, the OPV ArtESun device connects to a smart phone and sensor data are visualized and updated in real-time.

Large Format BIOPV elements

ARTESUN project has allowed to prove that OPV fabricated by R2R can be laminated as a double glazing BIPV element within typical large scale manufacturability conditions.

In this case, a decrease in the OPV efficiency when transformed from cell to module was observed. This finding could be explained by means of the different measurement equipment (lab vs. industrial simulator), but most probably is linked to the limited contact surface between Ag paint/Al ribbons leading to an increase in Rs. Nevertheless, BIPV market acceptable efficiencies of 1,23% were obtained.

The BIPV element was developed as a vertical fin as large as 1610mmX380mm to be integrated as a ventilated façade within very well defined structural system. Potential market acceptability, in terms of overall subjective properties (robustness, colour, design, reflexion, etc.), was tested by means of a visual inspection experts' panel providing scores from 0 to 10. The result shows that overall a good acceptability of the product with ratings between 7-8 over 10.

Cost of ownership, actual and projected, for a BIOPV-based ventilated façade was compared to those found in first and second generation PV technologies. Overall it was found that BIOPV solutions can offer a suitable CoO that can build up a business case to the final client, being a promising technology on mid-term basis.

Potential Impact:

The consortium members have sought to optimize the impact of the obtained results by gaining as much visibility as possible, through scientific publications and presentations at various fairs and conferences as well as by organizing share holders' meetings and workshops. The complete list of dissemination activities can be seen from the list below and a more detailed presentation is given in the corresponding deliverable reports. The total impact is the sum of all impacts listed by partner below.

VTT is a research institute positioned within the gap between fundamental academic research and commercial development or exploitation in industry. VTT aims to exploit the research results and gain expertise of the project for the generation of applications and profitable business such as flexible patterned printed solar cells and large area PV made by a printing compatible process on flexible substrate. As a research institute, VTT participates in the project to utilise the knowhow gained in the project to find new research and commercialisation opportunities in public and private sectors. VTT will have a more complete toolbox for printed electronics after the project, which enables VTT to offer high quality research services to European companies. By participating in the ArtESun project VTT keeps in touch with the forefront of research in the field of organic printed photovoltaics and assists in pushing the technology even further. In

addition, VTT seeks to generate new projects with the help of the knowledge and contacts acquired during the ARTESUN project. This will be possible since the methods developed in the project are well suitable for many areas of organic electronics, since they offer building blocks for numerous different applications. Also the R2R process as well as equipment and material development will be exploited in other projects after ArtESun is finished. VTT will also aim for promoting new business and considers the possibilities for enabling spin-offs within the field of the ArtESun research area, and to enable this it has been essential to play a central role in the execution of the project.
The objective of VTT is to build up value chains for OPV technology towards end-use areas by pushing further the up-scaling of materials and processes. Furthermore, the objective is to utilize the key advantages of OPVs such as ability to obtain custom shaped forms, flexibility and light-weight – the properties that are extremely applicable to R2R printing processes that have been one of the focus areas at VTT. Additionally, ArtESun provides an opportunity to utilize the unique pilot-scale facilities at VTT for the up-scaling of various fabrication processes. These aspects and environmentally sustainable materials and production phases together with cost-competitiveness are consistent with the OPV strategy. The work in ArtESun project strengthens the ability to understand the requirements of the fabrication chain from the materials to the prototypes. In particular, it will increase the understanding in the areas that are not the core competence areas e.g. electrical modelling, handling of new materials such as flexible thin glass in R2R, up-scaling of novel materials and end-use oriented system prototyping. While academic and basic research in the OPV area are diminished VTT sees great benefit in working close to the companies and their applications as in the ArtESun project. The close collaboration between partners generates a good starting point as future networking and opportunities takes place.
The identification of best performing materials, most feasible device structures and processes together with the main advantages of OPV technology plays the key role in the success of OPV/commercialization. The participation in ArtESun project provides an excellent opportunity to increase readiness of OPV technology by sharing the know-how between project partners. At VTT many aspects of the manufacturing process of flexible electronics based on liquid processing are being pushed forward, not only for OPV or solar cells in general, but for all functional printing and related processing. From VTT’s point, the main objectives that will be exploited are in:
• Development of inks for the printing processes
• Development of process phases in the printing of the novel materials
• Up-scaling of R2R process phases in printing
• Lamination concept for S2S and R2R
• Lamination concept of flexible thin glass for S2S and R2R
• Fabrication of arbitrary shape OPVs and specifications for the technical requirements
• Electrical interconnects between printed electronic materials, including vias through substrates or encapsulating layers
• Determination of the operating windows for process phases
• Aspects of system integration of photovoltaics, including circuit optimization for power management and system optimization for functionality
• Fabrication of OPVs for system prototypes
• Yield determination processes, including inline inspection and quality control
The development of proprietary roll-to-roll printing, online monitoring and testing, as well as production automation techniques for fabrication of large-area and arbitrary shape OPV can lead introduction of laboratory and pilot stage developments to commercial and industrial scale. VTT has a wide range of

intellectual property in the field of printed functional materials and related process technologies. Most of these technologies and processes have been ramped up to roll-to-roll pilot scale in order to better help companies to commercialize individual technologies and their applications.
In the near future, industrial product designers will gain greater design freedom, as arbitrary shape OPV and other forms of printed electronics develop towards more flexible, design-friendly, aesthetic and inexpensive forms of electronics. Combination of arbitrary shape OPV with hybrid electronics and 3D plastic integration enables new types of plastic-based electronics applications, particularly for the consumer electronics, home appliance and the automotive industries. In order to bring the component and system level technologies, such as large-area and arbitrary shape OPV, closer to commercial implementations, VTT is conducting intense applied research and having active industry collaborations in the field of printed electronics and hybrid manufacturing of integrated smart systems.
VTT's strength is in combining manufacturing technologies such as roll-to-roll-printed OPV, injection moulding and traditional component assembly so as to enable seamless integration of the new technologies into existing products and completely new types of products at a comparatively low cost. The logical route to market is to integrate arbitrary shape OPV first to small-area and high-volume applications such as energy autonomous sensors – and as efficiency, lifetime and cost of OPV materials improve, aim at large-area and high volume applications such as aesthetic building integrated photovoltaics.
As a research institute, imec has a long track record in development of photovoltaics technologies. Besides Si-PV this also comprises thin-film PV, including both organic and inorganic technologies. The multi-disciplinarity of OPV developments requires imec to team up with other institutes and companies to ensure joint successful progress. The ArtESun consortium clearly offers this broad range of interactions along the full value chain. As the goal of this project is to bring OPV into the thin-film PV marketplace, the results should bring the consortium to such a level that the processing of OPVs is understood from a broad point of view including technical aspects as well as assessments on application areas, cost breakdowns and reliability. The project should bring an accurate view on the position of OPV within the general PV market and a clear roadmap on how this new technology can evolve within the thin-film PV area for the coming years to become a mature player in this market.
As a research centre, imec will seek opportunities to validate its technological know-how in this field by engaging into partnerships with industrial players that focus on commercializing OPV products or related technologies. Therefore, this ArtESun project will enable imec to strengthen its position as a dedicated OPV research centre with strong knowledge on understanding and characterization of device architectures, deposition technologies, and lifetime mechanisms. In this way, ArtESun will give imec a privileged position and insight in the market potential of OPV, which it can use towards it potential industrial partners to ensure faster advancement of their OPV developments.
Imec is partner in the new Solliance initiative, with other research institutes among which ECN and Holst. For the OPV technology, in this initiative a research program is put up and currently industrial partners are attracted to participate which share the view that OPV will have added value for power generation markets where aesthetics, freedom of form and colour, and weight play a roll. Envisioned markets are the transportation sector (cars, busses, trains...) textiles, greenhouses, building integrated PV...
Solliance works in close relation together with industrial partners from the whole value chain with the aim to create a technology platform for the development of OPV from lab to fab and assist OPV industries (materials, equipment, integration) in their ambitions to accelerate the commercialization of their specific business. Solliance provides an OPV research program adaptable to the industrial needs by operating in a shared research environment and by offering the complete technology toolbox for the design, integration

and characterization of OPV cells and modules.
As a research institute partner, Fraunhofer ISE is currently active in the development of efficient, longterm-stable organic solar cells and large scale production processes with low cost materials using roll-to-roll coating and printing techniques.
Through participation in the ArtESun project Fraunhofer ISE can strengthen the competence on low cost, stable and highly efficient organic solar cells. Through interaction with Imperial College access to state of the art photoactive materials is granted. The exchange with Imec and Ikerlan broadens the perspective on device stacks and processing, resulting in the synergetic use of complementary competence.
In the field of large area roll-to-roll processing the exchange with VTT is important to efficiently tackle issues with coating and printing of organic materials.
Most importantly, the contact to the potential end users Onyx, Wibicom and Confidex allows understanding better the needs and expectations of such companies in terms of output parameters but also size and shape of the devices. With this knowledge the technological development can be focussed on addressing the real issues and thus avoid the optimization of parameters that are of low relevance for the final application.
The project allows us to make significant progress in terms of the efficiency of ITO-free low cost device stacks and their roll-to-roll processing to realise large area modules. Furthermore, we gather experience with new materials that are not yet commercially available.
The central result of the project will be the full roll-to-roll processing of ITO-free organic solar modules with significantly higher efficiencies than what has been achieved previously. The intermediate steps realised so far allowed to attract interest from a large German company, which resulted in the application for a nationally funded R&D project towards a specific OPV-product being different from the type of product being developed in the framework of the ArtESun project. The exploitation strategy is based on acquisition of R&D projects with subsequent technology transfer to the company and patent applications where it appears appropriate.
Another result is the improved ability to characterise and model single junction and tandem organic solar cells in detail. This enables us to deepen our understanding of the most relevant processes occurring in these devices and to accurately describe them in a quantitative manner. This will help us to be an attractive partner for the scientific part of future research projects. Also industrial partners are often interested to get estimations of the efficiency potential for new materials or cell stacks which can then be delivered by us. Especially for tandem solar cells adequate optical and electrical modelling is essential to restrict the number of necessary experiments.
The above mentioned strategy, if successful, leads to a strengthening of technical and scientific know-how and to a better networking with relevant industrial partners. It makes our institute to become an increasingly attractive partner for joint projects. In addition, the acquired skills can then also be applied in slightly different areas such as other solution-processable thin film solar cells (e.g. perovskite solar cells). Furthermore, even non-PV applications based on large area thin film coating.
At Imperial College the OPV research in the McCulloch group is focussed on three different areas.
1. Synthesis of low band gap donor polymers with efficiency greater than 10% in single cell lab scale devices.
2. Synthesis of complementary wide band gap polymers to extend the solar absorption for use in tandem cells
3. Development of alternative soluble acceptor materials as replacement for PCBM

High-efficiency photoactive donor polymers that afford single-layer bulk-heterojunction solar cells with power conversion efficiencies above 8% have been developed. Efforts are being made in designing new donor materials and to further improve the efficiency above 10%. In addition to development of low band gap polymers complementary wide band gap polymers to extend the solar absorption in tandem cells are also being developed.

While wide varieties of high performing donor material have been reported in literature, PCBM has been extensively used as the acceptor for BHJ solar cells. This is due to its ability to form small crystallites and improved phase separation into donor/acceptor nanoscale domains on spin coating from solution. However PCBM exhibits very poor absorption in the visible region of the spectrum and generates highly reactive singlet oxygen resulting in poor device stability under ambient conditions. Most high performing donor materials reported in literature use PC70BM as the acceptor material due to their better absorption profile compared to PC60BM. However the higher cost of PC70BM can be a deterrent for use in large area applications. In order to improve efficiency of OPV devices, high performance acceptors with LUMO levels optimised for the low band gap polymers are being developed and synthesized in the project. These materials will be designed to have acceptable electron transport properties, and facilitate optimal phase separation in BHJ thin films.

While material design and optimization may lead to better device performance, it should be emphasized that the power conversion efficiency of solar cell is more a device parameter than an intrinsic material parameter. This is because too many factors can affect the performance, i.e. the blending ratio with the acceptor, casting solvent, processing additive, thermal annealing of BHJ film and insertion of hole-transporting layer, device structure, and morphology control of BHJ film all play important role in device optimization. High-efficiency photovoltaic devices not only require material development, but also careful device optimization. The collaboration between partners and their input will enable us in developing in high performing materials and develop synthetic strategies for large scale production of these promising materials.

One of the biggest obstacles in commercialization of OPV is translating high performance laboratory-scale photovoltaic devices into large-area devices via solution-processable roll-to-roll (R2R) printing techniques. Spin coating is the widely used method for fabricating lab scale OPV devices from solution. The active layer morphology obtained using this method might be different from that achieved using R2R printing. As a result it is absolutely necessary for all researchers involved in the development and fabrication of organic solar cells to effectively collaborate with each other to elucidate the fundamental structure–property-processing relationships for high-performance devices, and push them for engineering scale-up in the end. The collaboration with device physicist within ArtESun will allow researchers at Imperial College to better understand the material requirements for commercialization and allow fine-tuning our benchmark materials for commercial application.

High-efficiency photoactive donor polymers that all afford single-layer bulk-heterojunction solar cells with power conversion efficiencies above 8% have been developed so far. Polymer BBT1 has shown to give a maximum efficiency of 8.3% without the use of any additives usually required to improve efficiency in solar cells. High molecular weight polymer TBTIT-h has shown efficiency as 9% without the need for additives or post annealing steps to improve efficiency. Both these results have been successfully published in high quality peer reviewed journals. The lack of post treatment steps makes both these polymers potential target for printed large area applications. Further device optimisation by using interlayers can enable these polymers to improve the device efficiency above 10%.

Solution processable novel small molecule electron acceptors bearing 3-ethylrhodanine flanking groups

were synthesized as an alternative for fullerene based acceptor. A simple synthesis route was employed, offering the potential for large-scale preparation of this material. Inverted OPV devices employing poly(3-hexylthiophene) (P3HT) as the donor polymer have been fabricated using these new acceptors. A high PCE of 6.38% has been achieved using C8-IDTBR as the acceptor in P3HT based solar cells. These materials have the potential to be used with other high performance donor polymers via electronic and structural optimization for low cost printed solar cells. Any Intellectual Property (IP) discovered during this research will be identified and protected by patent in accordance with the university guidelines. Significant research outcomes will be presented at international and national conference meetings to target both scientific and industrial audience.
The development of photoactive materials with high efficiency and good lifetime stability can lead to generation of intellectual property that can be of great significance to the OPV community. In addition materials developed can be used in other organic electronic devices like diodes, TFT for use in displays and sensors. These new applications can in turn provide opportunities for developing research in these areas and to generate new IP.
IKERLAN is a private non-profit research institution. Our mission is to help reinforce companies' innovation capacity to improve their competitiveness on the international stage through the generation of knowledge and transfer of technology, especially small and medium-sized enterprises (SME).

Results from the project will therefore be used in order to:
1. Continue researching on the field and participating in new related projects, both international and national.
2. Be aware of possible breakthroughs in order to transfer technology towards a potential application.
3. Consolidate and strengthen activities in Organic Photovoltaics and Smart System Integration.

In return from the project we expect to:
1. Be in the front line of knowledge in OPV to study our client´s demands and try to give them the best solution.
2.- Survey the market to identify new applications and clients.

As far as IK4-Ikerlan is concerned, this project will help increase the research and innovation capacities of the Centre and therefore its competitiveness in the technology transfer market.
IK4-IKERLAN defines its Strategic and Research Plans with the precise objective of helping our surrounding industry to improve its competitiveness. One of our Strategic Research Lines (L4) focuses on Smart Microsystems for Industrial Applications. The scope of this project therefore perfectly fits with our multiannual strategy in terms of developing smart energy harvesting and power generation elements. The successful development of this project will help us fulfill our objectives towards year 2020 in terms of growing i) our income to support our own research lines, ii) increase the technology transfer to industry, and iii) generate direct employment. With this regard:

i) The expected European turnover for the funding of our own research lines is expected to be 2.52M€ in 2015, a 39% of all of our public funding (6.53M€). Our objective is to grow at a yearly rate of 5% to achieve 4.08M€ in year 2020 from Europe to be this, the 49% of all of our expected public resources to support our own research activity (8.36M€)
ii) The technology transfer supported by private R&D contracts with companies is estimated to be 11.2M€

for 2015, the 60% of our total income. Our objective for year 2020 is 12.04M€, expecting in this way record levels even higher than those attained before the world crisis started.
iii) IK4-IKERLAN employs 236 people in 2015. For year 2020 we expect to recover the highest rates that we showed before we noticed the recession (276 people in 2012)

All these are very complicated economic and social challenges difficult to meet without the help of initiatives such as ArtESun.
The integration of organic photovoltaic modules and mini-modules as an energy harvesting and/or power generating element is a very promising approach to produce wireless and autonomous smart systems. Advances achieved within the project can be for example used to develop intelligent nodes in wireless sensor networks (WSN). These can be later employed in applications such as structural health monitoring (SHM) and predictive maintenance in industrial sectors like railway, windmill and automotive.
IK4-IKERLAN also participates in the development of our client´s roadmaps and portfolios. The domain of the project has been identified as strategic by some of our research departments, and as such, will be disseminated amongst our clients as a possibility to include the outcomes of the project in their future roadmaps and portfolios. The smart integration of OPV modules in systems with capabilities for energy harvesting, sensing and processing will allow our clients to fabricate more versatile, multifunctional and secure products that will take them to a better position in the market leading to increasing sales and generating direct and indirect employment.
IK4-IKERLAN is also a Technological Research Centre of Mondragon, the large cooperative group consisting of 260 autonomous and independent cooperative companies in very different industrial sectors like energy, health, household appliances, electronic components, and automotive.
This strategy of including OPV modules in smart systems has been supported by the participation of IK4-IKERLAN in the development of our clients' roadmaps and portfolios. Important companies such as Fagor Automation, Orona, CAF amongst others, have trusted this approach of providing intelligence to their products to gain a better position in the market over their competitors.
This domain has also been identified as strategic among IK4-Ikerlan research areas and so will have significant impact in several aspects oriented to increase IK4-Ikerlan competitiveness and density of added value and as a consequence new employment creation.
Corning is a diversified technology company that concentrates its efforts on high impact growth opportunities. With world-class expertise in glass, ceramic materials, polymers and the manipulation of the properties of light, Corning combines materials technology with strong process and manufacturing capabilities to develop and commercialize revolutionary innovations such as optical fiber for telecommunications; ceramic substrates for automotive catalytic converters; and specialty flat glass for handheld devices, computers, large-screen LCD televisions and photovoltaic high strength substrates. We work closely with customers and industry experts to understand critical market needs, develop keystone component solutions, and then bring those life changing solutions to commercialization.
Corning has been investigating thin and strong glass manufacturing processes for several years. Our intention was to continue leveraging this expertise and know how within ArtESun project to demonstrate the potential for combining latest-generation ultra-thin and flexible glass with existing OPV manufacturing tools to improve the performance and lifetime of OPV above the current state-of-the-art.
A thin flexible glass covers potentially a large spectrum of applications including flexible LCD for smartphones, digital smart watches, large area printed electronics etc. As an industry we are working always closely with our customers to develop the right solution for their needs. New technologies may

require significant amount of work to address product design and manufacturing approach. In addition, a value analysis requires an accurate evaluation of the incumbent products as well as a validation of the value assumptions of the new technology. Therefore they are risky. In these specific cases we believe that working within a consortium at early stage of the technology is very beneficial to get a direct access, knowledge and know-how of the entire value chain. More particularly our participation to the ArtESun project will be beneficial for getting a benchmark for OPV performance and lifetime improvements between OPV cells encapsulated with a commercial barrier layer and a thin flexible glass. The second benefit we expect to get is learning how to address potential issues of R2R processed OPV's on rolled flexible glass. This will help us accurately evaluate the value prop for the thin flexible glass for this particular application. Performance lifetime improvements are key arguments to convince potential customers to work with flexible glass. Data from R2R processed OPV's in one of the pilot lines of our partners would be essential to evaluate the potential of cost reduction and convince customers on the feasibility, opening those new market for this highly technical material.

The Global Flexible Glass market is an emerging market that is experiencing enormous changes and innovations. Flexible glass plays a key role in making electronic gadgets lightweight, attractive, handy, and of high quality. It also holds the key to the making of next-generation gadgets which are rollable, flexible, and wearable. The primer market we will foresee is flexible OLED's and OPV's both requiring a flexible substrate able to play a strong barrier role against humidity and oxygen and also provide the flexibility required by those technologies to deliver robust and reliable differentiate products.

The global market estimates for flexible glass forecast a grow at a CAGR of 50.21% over the period 2014-2018. The end use market includes PV Sector, and OLEDs (Display and Lighting).

The core business of the company Onyx Solar Energy S.L is the development of high efficient, cutting-edge and customized Building Integrated Photovoltaic (BIPV) solutions for buildings and urban furniture. The multifunctional products developed combine both active (energy generation) and passive properties (energy savings) and are used for easily replacing any non-active conventional building materials.

Among the existing PV technologies, Organic PV (OPV) offer several advantages that increase the number of options for its integration as a building component (transparency, flexibility, arbitrary shapes,...) and therefore, within ArtESun project, ONYX seeks to demonstrate the feasibility of using OPV modules in BIPV applications compared with traditional PV first and second generation technologies evaluating OPV behavior as a building electric generation part.

The bridge from OPV technology to BIOPV best design options is constructed by several requirements: electrical (I-V), energy production, size, shape, structural or mechanical, sealing requirements for real working conditions, materials and manufacturing knowledge, lifetime and costs. The interaction with the partners VTT and Fraunhofer is crucial to reach the best options for each parameter in order to get the optimal OPV module.

The future of architecture and construction is not understood without the integration of renewable energy sources that generates energy from the places where it is needed. Numerous PV technologies have already shown its feasibility to be a part of a building by replacing traditional materials and providing active and passive properties. OPV, as an emerging technology with electricity generation capacity, should consider this application as a main objective due to social future requirements and according to the market evolution of BIPV. From an architectural point of view, third generation PV and OPV in particular, offer several advantages that increase the number of options for its integration as a building component such as transparency, flexibility, color and arbitrary shape options. From an economical point of view, a dramatically cost reduction is expected due to material and manufacturing advantages and a lower cost in

transportation and installation due to lighter substrates.
Therefore, ONYX participation in ArtESun is crucial to be close to the OPV evolution for BIPV which is expected to show a considerable growth when OPV is ready to this market.
The main objective for ONYX is to demonstrate OPV device performance developed within ArtESun project in a BIPV application. The OPV performance will be tested in a BIPV demonstrator case together with PV first and second generation technologies. Taking into account this main objective, the major results expected are:
• Design of the prototype BIPV case
• Design of the OPV modules for the BIPV case and integration in a real façade.
• OPV module performance and stability testing in real environments with relevant conditions
• Balance of system (BoS) for BIPV demonstrator and comparison with first and second PV generation technologies
• Analysis of OPV developments from initial research tasks until a real application as a constructive element in buildings.
Despite the promising achievements obtained within ArtESun project, there is still a long way to go for OPV, especially in terms of lifespan and stability.
Recent reports ("BIPV Glass Markets.-2014 and Beyond". NanoMarkets Report and "BIPV Markets Analysis and Forecast 2014-2021". NanoMarkets Report) have established that BIPV market will grow from $823 million ($US) in 2014 to $2.7 billion in 2019 leading to BIPV glass shipped will surpass 7.6 million square meters by 2021. It means that the market will grow constantly around 30% every year. Robust technologies (first and second PV generations) will not satisfy the market needs by year 2021 considering a market growth of 30%. Thus, new solutions should be developed and force into market in a short time basis.
As mentioned in previous points, organic PV offer a number of advantages ranging from rapid and low-cost manufacturing to extremely thin, lightweight, and flexible form factors, which offers opportunities for advances in the acceptance and deployment of solar energy among the professionals of the building sector and to satisfy the BIPV market needs in the near future. In this sense, an exploitation strategy as explained above is vital for ONYX to be placed in the forefront of this market when OPV is ready to be industrially exploited for BIPV applications.
As a company partner, Confidex Ltd. is currently an active supplier of high-performing contactless ticketing and RFID tag solutions and services to make supply chains, transactions and authentication of goods and people more efficient and secure. By today, RFID is widely used in security applications such as access control in buildings, biometric passports for passengers, and contactless cards and tickets in public transportation. RFID is also becoming a vital part of supply chain management. Many retail companies have already integrated RFID to their processes to improve delivery capabilities and solve many of the common challenges in retail business processes caused by insufficient traceability of items. Confidex has mainly focus on the industrial and logistic side, providing RFID solutions for factory operations such as for Volvo.
RFID allows increased interconnectivity and automation and as such is one of the key enablers for the Internet of Things (IoT). The adoption of RFID technology is largely driven by our need to improve security, safety, and efficiency, and it is in these domains that IoT makes a difference. IoT solutions can help improve the way we manage traffic, public transportation, waste collection and logistics in Smart Cities. This project will both strengthen and expand our knowhow in development of smarter RFID tags, enabling IoT solutions to customers. This is possible through the activity on development of renewable and efficient

energy sources for active RFID solutions.
We expect to learn about the integration process of more complex RFID tag solutions. This covers both reliable manufacturability and exploitation of alternative solutions for developing smarter RFID tags. As a concrete example, the OPV module developed in this project will be investigated as an alternative solution for conventional battery in battery-assisted passive RFID tags. The OPV would be used to provide the necessary energy for the microchip, but also for providing energy for storage. Batteries are to be recharged and finally replaced, and for long-term use OPV based energy sources would provide a more or less maintenance free option and little waste. The role of Confidex in the ArtESun project is the integration of the OPV cell in the RFID tag. Confidex will also take part of OPV cell development by providing feedback about the suitability for RFID and by testing cells in real applications. Through this project we get access to status of state-of-the-art technologies, and we get the knowledge of whether the technology is mature enough to find a niche in the RFID market. On the other hand, we get a possibility to guide the research work in the direction where research targets and industrial demands meet.
As an outcome of this project, Confidex is demonstrating a small form factor and flexible OPV module as the energy harvester for active RFID, which potentially enables smart vehicle identification and solutions for sensor applications in the world of IoT. The utilization of OPV as an energy harvester in active RFID solution is currently envisaged through promotional samples to customers to map the target groups in the market and to communicate the mass production capabilities. Moreover, the outcomes of this project give valuable information on how to utilize the state-of-the-art technology in RFID solutions, and how this information can be used to differentiate us in the market. Promotional samples could be used as show cases in exhibitions to show that Confidex is capable of developing future products, which has a great market value.
Today, we are innovating and exploring with our customers how our solutions can help people and companies to address their problems and challenges by fusing strong combination of RFID tag design competence, RF engineering and customization to manufacturing experience. The integration of the IoT concept in our solutions will help retailers and manufacturers in their attempt to increase the efficiency and productivity. A RFID solution enabling IoT with newest technology, for example through an integrated OPV, gives better visibility, data analytics, and resource utilization. Consumers will as end users experience enhanced services and innovations. The exploitation of the results obtained in this project will support our vision as a leading short range wireless IOT solution provider for industrial markets and a leading platform provider for access and marketing in mobility markets.
As an SME partner, Wibicom is currently active in developing and commercializing state-of-the-art light energy harvesting devices for the wireless market. In particular, it develops unique photovoltaic antennas which combine both the photovoltaic properties of photon energy translating to electrical energy and electromagnetic energy reception and transmission by exploiting the various materials used in the photovoltaic module. By assigning a special design to the OPV module, the OPV module functions as a radio-frequency antenna. As the antenna is exposed, its performance is not altered with respect to other wireless systems that use a separate PV module and antenna element.
This project will strengthen our expertise and innovative approach to battery-free wireless systems. By using state-of-the-art technology, our role in photovoltaic antennas is strengthened.
The OPV antenna special design is possible through interaction with Fraunhofer ISE for determining the dc characteristics of the OPV cells and how to design such OPV module while respecting the constraints of the antenna design and VTT for fabricating such module and performing reliability tests.
We expect to learn about OPV technology and its performance, especially in low light conditions, and

reliability for short to medium life spans. Moreover, its fabrication process using R2R printing allows high volume production at a low cost.
As printed electronics evolve, OPV technology could be easily integrated with other electronics, such as sensors, radios, and energy storage devices. Hence, by participating in this project, Wibicom not only gets access to OPV technology know-how, but also achieves a step closer to innovation in flexible and lightweight electronics.
Enhanced performance of OPV technology in low light conditions, i.e. 200-500 lux, as compared with other PV technology, gives a great exploitation potential for indoor applications. New projects could be initiated following the results obtained in this project.
The OPV antenna's flexible, lightweight, and arbitrary shape features open up new product markets for systems that are required to be conformable to objects and thin, such as labelling tags.
Printed technology used in OPV will enable full printed electronics solutions. Further work is required to integrate and embed all electronic devices. This could be achieved through new partnerships and initiating new projects.
By adopting OPV technology, a new product position is created for light energy harvesting wireless devices. By showing OPV performance for indoors, as well as outdoors, our product portfolio of wireless systems incorporating PV antennas is broaden. This OPV unique design proves the feasibility of arbitrary shapes by using a R2R process, enabling custom designed PV antennas, hence eliminating the constraints imposed by a PV manufacturer.

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Documents connexes

final1-artesun-deliverable-d6-7-20161227095435.pdf

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