Innovative materials for efficient, stable, and affordable organic photovoltaics

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The combination of solution-processable photoactive materials and high-throughput printing techniques will help to sidestep problems of traditional photovoltaics.

For many years, the ability to turn light into electricity has been an important human aspiration. The growth in power consumption—around five times greater than petroleum extraction—along with the inevitable exhaustion of conventional sources of energy has made this aspiration a necessity. The sun is the most powerful and inexhaustible source of energy available, at least for the duration of our solar system. Since green plants exemplify solar energy conversion, there have been many efforts to gain a deeper understanding of the process in order to reproduce it in scientific labs. Photovoltaic solar cells are the best artificial mimic of the natural conversion process that takes place in green plants. With the cost of electricity from fossil-fueled power stations rising unpredictably and fuel resources depleting, photovoltaic electricity represents an alternative energy source that is both clean and abundantly available.

It is estimated that 95% of commercially available solar panels are fabricated from the same material that also serves the enormously active microelectronics industry, namely, crystalline silicon. Novel materials for solar cells have emerged to help cut the dependence on fossil-fueled electricity, and to offer customized solutions for new markets whose demands are insufficiently addressed by silicon-based cells. The prospects of cost reduction, more appealing aesthetics, and versatile fabrication processes that are not restricted to wafer use are the prime motivators for this area of development. Building-integrated photovoltaics (BIPVs), for example, are installed in indoor environments. Used by architects and interior designers, these colored, arbitrary-shaped modules are integrated into façades, windows, awnings, or used for decorative multifunctional applications (see Figure 1). They are also readily customized for use in power generator units for consumer electronics, radio-frequency identification (RFID) systems, and microsystems where easy integration is a must.

One type of alternative material that has emerged for solar cells is organic semiconductors, particularly in the form of conjugated polymers. Solar cells made from conjugated polymers offer many benefits: their electro-optical properties can be chemically engineered to suit the application, color tuning is possible for aesthetic reasons, and their absorption spectrum can be tailored to the solar spectrum (thereby maximizing the efficiency of the module). The choice of materials for conjugated polymer-based solar cells is practically endless, and device manufacture is considerably easier than that for semiconductor-grade silicon because they are simply produced from solution. Additionally, organic conjugated polymer-based solar cells are light,
transparent, and flexible. Most important, the use of traditional printing techniques to deposit the photovoltaic material has the potential to reduce costs substantially. For instance, the yearly processed area outputs in a typical wafer production plant could be achieved in as little as 1–10 hours with a printing press operating at a standard speed of 15m/s.

The performance of conjugated-polymer solar cells is improving day by day through the development of new chemicals and device fabrication strategies. The chemical design of novel donors for polymer-based organic photovoltaic (OPV) cells has led to a step change in achieving sufficiently high and appealing power conversion efficiencies (PCEs) that allow OPVs to compete in the photovoltaics market.2–4 Stable materials that combine low-bandgap light absorption, adequate energy-level positions, and reasonably high carrier mobilities are considered to be the ultimate goals for commercializing OPV technology. However, improving the efficiency of a solar cell is not only a matter of the active material. Non-photoactive layers such as electrode interlayers and/or optical spacers also play a crucial role in overall efficiency.5, 6 Alternative cell designs can further enhance the conversion of light to electricity.7

In our labs, we are working on creating non-toxic, halogen-free ink formulations of OPV materials that can be printed straightaway on large-area substrates using high-throughput printing techniques as part of the ARTESUN project. ARTESUN specializes in the research and development of new photoactive and non-active materials and architectures with the aim of creating OPV modules with PCEs greater than 15%. Many organizations are involved in different aspects of the project (see Figure 2).

Our focus is on the cost-effective processing of OPV modules. We base our methods strictly on non-vacuum additive roll-to-roll processing-type printing and self-structuring of the active area. Such a technique enables considerable geometrical freedom in size and shape, and guarantees more efficient material usage. We hope that our work will convincingly demonstrate the cost-effective production of industrial modules since it avoids any subtractive steps such as laser or mechanical scribing.8 In addition to providing more stable materials, we are working toward innovative packaging solutions based on flexible glass that will lead to a substantial improvement in the lifetime (by a factor of 10) of current OPV cells and modules.

In the future, we plan to demonstrate the application potential of these technologies in BIPVs by integrating arbitrary shape and size modules into smart façades, awnings, and windows. Furthermore, we plan to implement our technologies as energy harvesting elements in RFID tags, and as photovoltaic antennae for wireless sensors.

The ARTESUN project is funded by the European Union’s Seventh Framework Programme (FP72007–2013) under grant 604397. The organizations involved in the project are the VTT Technical Research Centre, the Interuniversity Microelectronics Centre, the Fraunhofer Institute, IK4-IKERLAN, Imperial College London, SAFC Hitech Ltd., Corning, Confidex, Wibicom, and Onyx Solar.

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Figure 2. The different work packages (WP) that make up the internal structure of the ARTESUN project. Close interactions between the work packages guarantee that all the important issues for ensuring cost competitive and efficient OPV devices are properly addressed. The names in brackets indicate the organization responsible for the associated work package.
References


