Let there be light on plastic solar cells with the right interface and cathode size

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Polymer-based solar cells should soon reach a suitable performance level to offer a feasible alternative source of energy.

Low-cost clean alternative-energy sources have become a necessity to sustain the growth and quality of life on our planet. This poses a challenging scientific problem, requiring us to explore energy-harnessing ideas beyond conventional concepts and materials. Production of photovoltaic cells employing carriers originating from thin polymer films, manufactured by reel-to-reel printing and coating techniques, and packaged using lamination methods, is not only a novelty but also attractive from a commercial-environmental design perspective.

A prerequisite for photo-induced charge generation and separation in these active layers is the presence of donor-acceptor interfaces that form bulk heterojunctions where charge transfer occurs from a photoexcited donor to an acceptor on ultrafast timescales. The power-conversion efficiency of bulk-heterojunction-polymer solar cells based on a blend of poly(3-hexylthiophene) and [6,6]-phenyl-C61-butyric-acid methyl ester (P3HT-PCBM) has thus far reached approximately 5%. The morphology of these polymer-blend films—which form essentially an interpenetrating network—plays a crucial role in enabling efficient carrier transport.

Ongoing research efforts in this field include development of photovoltaic devices based on appropriate donor-acceptor combinations that provide suitable energy-level differences in the photoexcited state and phase-separation length scales. This ultimately results in morphologies leading to efficient performance parameters such as short-circuit current, open-circuit voltage, $V_{OC}$, and fill factor to the incident-light power density. The donor-acceptor setup can be tailored to have a graded donor system, where efficient energy transfer takes place within conditions, as well as device engineering (e.g., tandem-cell approaches) to enhance the optical-path length in photonic structures.

We recently demonstrated the promise of some of these strategies. The donor-acceptor setup can be tailored to have a graded donor system, where efficient energy transfer takes place within conditions, as well as device engineering (e.g., tandem-cell approaches) to enhance the optical-path length in photonic structures.

Figure 1. Scaling behavior of solar-cell efficiency (defined as the ratio of the product of short-circuit current, $J_{SC}$, open-circuit voltage, $V_{OC}$, and fill factor to the incident-light power density) as a function of active calcium/aluminum (Ca/Al) cathode area for a P3HT-PCBM solar cell under flooded uniform white-light illumination of 80mW/cm². $V_{OC}$, the fill factor, and the incident-light power density are independent of cathode size. ITO/PEDOT: Indium-tin oxide glass treated with a layer of conducting polymer, PEDOT:PSS.

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the donor system itself prior to charge transfer to the acceptor. This is possible by controlling the conjugation length in poly(paraphenylene vinylene)-based systems and using internal conversion processes to enhance the higher-energy end of the solar spectrum. The generally poor performance of these devices compared to their inorganic counterparts is largely due to the low fill factor and concave (S-shaped) light current density-voltage characteristics in the fourth quadrant (where the voltage, $V$, is given by $0 < V < V_{OC}$ and $V_{OC}$ is the open-circuit voltage). This is generally attributed not only to lower mobility but also to differences in hole-carrier and electron mobility, leading to carrier accumulation and space-charge behavior. Realistic deposition conditions of the cathode lead to a variety of interfacial features, of which some are current-limiting and detrimental. We realized that the additional factor contributing to these low fill factors can also originate from charge accumulation at the cathode-semiconductor interface. The shape of the current-voltage characteristics in the power-generating fourth quadrant strongly depends on the quality of the polymer-cathode interface and does not always bear the imprint of bulk-material properties.

The importance of this popular research area can be gauged by the growing number of peer-reviewed research papers in this interdisciplinary field where researchers routinely report power-conversion efficiency values and performance parameters. Unfortunately, in the absence of uniform standards and normalization procedures these estimates are difficult to compare across the board. We recently addressed this by studying the efficiency scaling as a function of electrode area and incident-beam size. The increase in efficiency for smaller active areas (see Figure 1) can be explained by reduced electrical-resistive losses, enhanced optical effects, and the finite additional fraction of photogenerated carriers in the vicinity of the perimeter defined by the metal electrode. Our results also suggest routes to design higher-performance large-area solar-grid structures that will take these effects into account. It is therefore expected that future polymer-based solar cells will reach a suitable performance level to offer a feasible alternative source of energy.

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References