Nanocomposite organic solar cells continue to improve

David Carroll and Seamus Curran

Ordering nanomaterial structures within a conducting polymer host provides a means of controlling the charge balance needed to create truly efficient plastic solar cells.

Charge-transfer nanocomposites (CTNs) are blends or composites of quantum-functional nanophase materials—such as carbon nanotubes, quantum dots, and fullerenes—with electroactive conjugated polymers. These materials exhibit distinctive properties over polymer-polymer blends, in particular enhanced electroactivity, photoemission, and photoabsorption. CTNs in their various guises have been extensively studied for over a decade. They have led to a number of interesting laboratory-based demonstrations of technologies, including highly efficient organic light-emitting diodes, highly conductive thin films, and, more recently, efficient organic photovoltaics.

Advances have generally been limited to laboratory devices because organic-based technologies can suffer from extreme sensitivity to the environment, including oxidation and delamination of contacts due to water. Moreover, performance levels of organic-based devices have traditionally been limited by carrier mobility and optical coupling.

Indeed, up until now, the performance of thin film polymer photocells lagged significantly behind that of commercially available silicon solar cells. Of the few conjugated polymers that show promise in their use as photocells, the best are thiophene-based polymers such as P3HT [poly(3-hexylthiophene)] and P3OT [poly(3-octylthiophene)]. These materials are well known for their robustness and processibility, although their band gap (~1.9eV) limits the absorption range of the solar spectrum. The active films are necessarily thin (~80nm) to allow for efficient charge or exciton separation. This permits removal of photogenerated charge in these low-mobility materials prior to recombination. So, for instance, in P3HT the theoretical limits of photovoltaic performance are set at about 14% by limited spectral overlap and the low mobility of the carriers.

But today’s polymer photovoltaic devices are closing the gap between potential performance and actual efficiency, in much the same way that silicon-based solar cells are also reaching their theoretical limit. In particular, organic solar cells created in our laboratory have achieved record photovoltaic conversion efficiencies: nearly double reported values of a year ago using an AM1.5g-calibrated standard light source, which simulates the sun’s radiation. From a product standpoint, these advances are both exciting and economically viable. They are due in large part to our ability to construct materials over different length scales. In fact, one of the ‘grand challenges’ of nanoscience is frequently identified as the ordered placement of nanostuctures into architectures that extend over many microns (so-called mesoscale ordering). This placement

Figure 1. Nanowhiskers can be seen in this micrograph as long white filaments (courtesy M. Reyes-Reyes).
of nanomaterials into three-dimensional arrays—referred to as ‘scaled structures’ or ‘hierarchical structures’— has long been thought to provide a route to engineering novel supermaterials. When applied to CTNs, mesoscale ordering has provided a powerful new tool for developing high-performance photovoltaics.

How did scaled CTNs help generate these more efficient devices? In our most recent work we begin with a disordered array of solubilized fullerenes dispersed in a P3HT thin film device. Such materials are known to produce devices that are ∼3% efficient. However, when annealed to a temperature approaching the glass transition of the polymer, two things happen. First, the polymer crystallizes, and hole mobilities within the polymer phase increase dramatically. Second, high-aspect-ratio nanocrystalline grains of PCBM (nanowhiskers) form in the matrix (see Figure 1). These can be aligned slightly in a temperature gradient across the active polymer film, thereby improving the electron mobility of the device to match the enhanced hole mobility. Using this forest of nanowhisker ‘trees,’ devices can be produced with 5.2% external conversion efficiency, nearly 45% of the theoretical maximum for this host material.

For some time, we have understood that polymer-based thin film photovoltaics (plastic solar cells) promise mobile and cheap sources of solar-derived electrical power. More important, they offer substantial advantages by being applicable to paints, building materials, and automotive coatings. This in turn reduces the barrier to market entry, because there is little market disruption in terms of infrastructural alterations. Meso-ordered CTNs lower the barrier just that much more.

Author Information

David Carroll
Department of Physics
Wake Forest University Center for Nanotechnology and Molecular Materials
Winston Salem, NC
http://www.wfu.edu/nanotech

Seamus Curran received his Ph.D. at Trinity College in Dublin, Ireland. His postdoctoral work was at Rensselaer Polytechnic Institute in Troy, NY.

References

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