Polymers show versatility in organic solar cells

Chris McNeill

Long believed to exhibit either p-type or n-type conduction, a conjugated polymer is shown to have the ability to act as both an electron donor and acceptor in solar cells.

With the world facing a potential energy crisis, there is an increasing need to develop technologies that can supply clean, sustainable energy. The harnessing of solar radiation to provide electricity is an attractive solution, and it is expected to play a key role in lowering dependence on non-renewable energy sources. While efficient photovoltaic technologies based on inorganic semiconductors are available, high fabrication costs are limiting their widespread application. Organic semiconductors, on the other hand, have the advantage of being fabricated quickly and cheaply through processes such as roll-to-roll printing. They represent an attractive alternative to traditional inorganic technologies. However, these semiconductors have lower dielectric constants and charge carrier mobilities, which makes efficient charge separation and collection problematic.

Another limitation of organic semiconductors is their reported preference for the transport of positive charges, or holes, over that of electrons. This is a concern for the design of photovoltaic devices because, unlike field-effect transistors (FETs) that only need to transport one type of charge, solar cells must be able to transport both types. Recent work, however, has demonstrated that the poor operation of electron-transporting (or n-type) FETs was the result of charge trapping at the polymer/dielectric interface and not due to any intrinsic property of the polymer itself.\(^1\) However, as the mobility of charges is known to also depend on the charge density under operating conditions, it was still unclear as to whether the ambipolar (that is, exhibiting both p- and n-type conduction) nature of conjugated polymers extended to lower charge density environments such as that of solar cells. We have recently shown that a red conjugated polymer with energy levels located between those of typical electron donors and acceptors can act as an electron acceptor or donor in efficient solar cells.

Due to high exciton binding energy, polymer solar cells consist of a blend of two materials, one acting as an electron donor, and the other as an acceptor, to promote exciton dissociation.\(^2\) The acceptor functions as electron transporter, while the donor

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transports holes. Figure 1 shows the chemical structures and energy levels of a typical electron-donating polymer, poly-3-hexylthiophene (P3HT), and electron-accepting fullerene derivative, [6,6]phenyl-C₆₁-butyric acid methyl ester (PCBM).

Demonstrating the dual donor/acceptor character of a conjugated polymer in a solar cell requires a polymer with a moderate electron affinity such that, in one combination, it accepts electrons, while donating them in another. F8TBT is a polyfluorene co-polymer with highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) energy levels located mid-way between that of P3HT and PCBM, thus making it an ideal candidate for this study (see Figure 1). Studies performed on ambipolar FETs based on F8TBT unambiguously confirm that this material can transport both electrons and holes in an FET configuration (see Figure 2).

As for solar cell operation, Figure 3 shows that devices using F8TBT combined with either PCBM or P3HT display similar efficiencies, indicating that F8TBT is equally capable of acting as either electron donor/hole transporter or electron acceptor/electron transporter. Furthermore, Figure 3 presents the current-voltage characteristics of an optimized F8TBT/P3HT cell under simulated sunlight with a power conversion efficiency of 1.8%. While this value is low compared to inorganic solar cell efficiencies, it is one of the highest reported for all-polymer solar cells and demonstrates the potential of conjugated polymers for further development as electron acceptors in photovoltaic devices.

The demonstration that the electron affinity of a conjugated polymer determines whether it acts as an electron or hole transporter is reassuring since theoretical calculations show that, in the undoped state, they should not show any preference for the transport of one charge type over the other. This conceptual advance provides increased scope for the role of materials design in improving all-polymer solar cells, and it may help realize the long-standing dream of producing cheap plastic energy.

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Author Information

Chris McNeill
Cavendish Laboratory
University of Cambridge
Cambridge, United Kingdom

Chris McNeill is an EPSRC Advanced Research Fellow in the optoelectronics group at the Cavendish Laboratory, University of Cambridge. He completed his PhD at the University of Newcastle, Australia, in 2004 before moving to the Cavendish Laboratory initially as a post-doctoral research associate. His research interests include the device physics of polymer solar cells and structure/function relationships in organic optoelectronic devices.

References