Crystalline exit pathways enhance efficiency in organic solar cells

Marisol Reyes-Reyes and Román López-Sandoval

The ordering of carbon nanotubes in polymer hosts can significantly increase charge mobility in photovoltaic devices.

Organic solar cells fabricated with conjugated polymers and carbon nanostructures represent promising devices for inexpensive solar energy conversion. During the last few years, the use of conjugated polymers in micro- and nanoelectronic device technologies has led to a sustained rise of power conversion efficiencies. However, methods for producing a bulk, space-filling nanophase within thin-film devices still require development. This is primarily due to an inefficient charge extraction procedure that strongly depends on film morphology. Hence the high level of interest for novel alternatives to transport the available free charges to the electrodes.

Several approaches have been used to achieve efficient charge separation in organic photovoltaic devices. However, the low mobility carriers limit their performance. A recent development, however, has shown that an ordered crystalline nanophase extending over many microns could provide a way to remove charge in electroactive conjugated polymers. These 3D arrays can be ordered with organic nanomaterials that can provide high-mobility exit pathways.

Progress in bulk heterojunction devices has already resulted in several efficiency breakthroughs. These advances have recently been related to the crystallinity of both phases, i.e both constituent polymer and carbon nanomaterials, a factor now understood to play a role in maintaining charge balance while lowering internal resistance. The result is that the transport of charges (electrons/holes), a crucial efficiency parameter in these devices, can now be improved by controlling the formation and morphology of pathways that are well dispersed throughout the crystalline matrix. When the crystalline pathways are ordered correctly, it is expected that the charge will not be extracted through hopping conduction (as for example, from fullerene to fullerene) and that recombination losses will be avoided in such materials. A recent example is provided by the formation of crystalline 1-(3-methoxycarbonyl)propyl-1-phenyl-(6,6)C_{61} pathways. Inset: magnification showing their crystallinity.

Figure 1. Polymer host with arrows showing crystalline 1-(3-methoxycarbonyl)propyl-1-phenyl-(6,6)C_{61} pathways. Inset: magnification showing their crystallinity.

A perpendicular alignment to the substrate of such PCBM nanostructures would, however, be highly desirable to further enhance efficiency.

In photovoltaic devices, mobility can also be modified by engineering the electronic structure with a nanophase of carbon, such as carbon nanotubes (CNTs). They are interesting candidates because they can provide crystalline exit pathways for charge-transfer in organic solar cells when they are used as acceptor materials. They also have other attractive features, such as ho-

Continued on next page
Figure 2. Device architecture showing that the morphology of the film depends on CNT ordering (top) and the desired CNT orientation (bottom). SMU: source-measure unit; PEDOT/PSS: poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate); ITO: indium tin oxide; PDDA: poly(diallyldimethylammonium chloride); CNT: carbon nanotube.

mogeneric electronic properties that are easily tuned. However, they disperse poorly into the polymer, which leads to agglomeration across the film and shorting of the contacts. Recently, we have shown that multi-walled CNTs and nitrogen-doped CNTs could improve their solubility into the polymer by attachment of surface functional groups with the subsequent adsorption of a cationic polyelectrolyte (see Figure 2).

Even though this approach significantly enhances CNT manipulation or solubility, the crucial and most challenging factor still remains the ordering of the crystalline exit pathways. Our most recent work has shown that the CNT electron exit pathways must be oriented in a direction perpendicular to the substrate to further increase device performance (see Figure 2b).

This research was funded at the Autonomous University of San Luis Potosi by FAI grant no. C05-FAI-10-17.38, PIFI grant no. C06-PIFI-03.6.6 and by CONACYT J48897-Y. At the San Luis Potosi Institute of Scientific Research and Technology, support was provided by CONACYT-Fondo Institucional under grant FDO. INSTIT. 67554 Dr. R. Lopez S-3125 (2007-2008).

Author Information

Marisol Reyes-Reyes
Autonomous University of San Luis Potosi
San Luis Potosi, SLP, Mexico

Marisol Reyes-Reyes received her PhD at the National Autonomous University of Mexico and did her postdoctoral work at the Wake Forest University Center for Nanotechnology. She became a Professor of Physics and Materials Science at the Autonomous University of San Luis Potosi, where she is currently directing the laboratory of nanomaterials and organic devices.

Román López-Sandoval
Advanced Materials Department
San Luis Potosi Institute of Scientific Research and Technology
San Luis Potosi, SLP, Mexico

Roman Lopez-Sandoval received his PhD at the Paul Sabatier University in Toulouse, France, in 2000. He has been a researcher in the Advanced Materials Division of the San Luis Potosi Institute of Scientific Research and Technology since 2001.

References