Transparent polymer films for capturing solar energy

Zhihua Xu, Hsinhan Tsai, Hsing-Lin Wang, and Mircea Cotlet

Honeycomb-structured conductive polymer films could lead to see-through solar panels with many useful applications, particularly in the building industry.

Solar cells, or photovoltaics (PVs), are emerging as one of the most promising technologies in the field of renewable energy. Organic solar cells (OSCs) are particularly attractive because of their cost-effective processing, light weight, and mechanical flexibility. As a thin-film PV technology, OSCs contain an active layer of organic (plastic) material with thickness of a few hundred nanometers that is usually deposited from a solution consisting of an electron-donating conjugated (i.e., semiconducting) polymer and an electron acceptor such as a fullerene (carbon) derivative. The structure of the thin film depends largely on the deposition procedure, which in turn determines the performance of the OSCs. Recently, we reported the deposition and characterization of transparent films based on a conjugated polymer and an emerald green fullerene derivative (EG-C$_{60}$) having an ordered honeycomb-patterned structure.$^1$ The transparency achieved offers great potential for application in building-integrated PVs, such as power-generating windows.

We fabricate the thin films using the so-called breath-figure technique (BFT):$^2$ see Figure 1(a). We dissolve the conjugated polymer P1—poly[2,5-bis[3-(N,N-diethylamino)-1-oxapropyl]-1,4-phenylenevinylene]$^3$—and its blends with different ratios of EG-C$_{60}$ in chlorobenzene. We then deposit the polymer solution on a water surface (which enables peeling of the film without disruption) and expose it to a flow of micron-sized water droplets from above. As the chlorobenzene solvent evaporates, the void space created by the water droplets allows the formation of a tightly packed honeycomb structure created by capillary (i.e., surface tension) forces. These P1 honeycombs show structural regularity over areas up to 1mm$^2$—see Figure 1 (b)—and consist of hexagons 3–4nm in size and with node and frame thicknesses of 0.6 and 0.25nm, respectively.

The polymer film located in center of the hexagons is extremely thin—a few nanometers high—which accounts for its transparency. The polymer concentration used for BFT plays a dominant role in determining the final structure of the honeycomb. The ideal concentration (4mg/ml) produces a highly uniform structure, while higher concentrations (>6mg/ml) result in thicker films with rounded holes.

The most intense photoluminescence (PL) signals emanate from the frame, or edges, of the hexagons and in particular from their intersection points (nodes) with adjacent units. These regions feature short PL lifetimes (0.43ns on average) and redshifted PL spectra, suggesting the existence of ordered polymer aggregates within the honeycomb framework. In contrast, the extremely thin center regions of the hexagonal rings show

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long PL lifetimes—see Figure 2(a)—and unstructured PL spectra similar to homogeneous regions of spin-casted P1 films. These center films form directly and very rapidly beneath water droplets by virtue of the thinness of the polymer solution as solvent evaporation occurs. The frame and nodes of the hexagon, on the other hand, develop between water droplets, and the thickness of the polymer solution at these regions is in the hundreds of nanometers. Hence, formation of the fully evaporated film is slower, which leads to more structured assemblies or aggregates of the polymer.

For the P1/(EG-C$_{60}$) blend, the PL signal from the honeycomb frames is nearly completely quenched, and the remaining PL shows a shorter lifetime—see Figure 2(b)—which indicates efficient charge separation between P1 and the fullerene. The structure of this blend is similar to that of pure P1 honeycomb. It is worth mentioning that the ordered packing of the polymer chains at the honeycomb frames can facilitate charge transport, which is a critical factor in determining the power-conversion efficiency of solar cells.

The near-future goals of our group are focused on scaling up the thin-film deposition method and on device fabrication. To this end, we are working on ways to spread the polymer solution more uniformly over the water surface and to control the size and distribution of the water droplets being condensed from above. We are also working to transfer the polymer films to a transparent substrate and to deposit electrical contacts onto them to produce actual solar cells.

This research was supported by the US Department of Energy (DOE), Office of Basic Energy Sciences, Division of Materials Science and Engineering. The research was carried out in part at the Center for Functional Nanomaterials of Brookhaven National Laboratory (US-DOE contract DE-AC02-98CH10886) and at the Center for Integrated Nanotechnologies at Los Alamos National Laboratory (US-DOE contract DE-AC52-06NA25396). We thank our colleagues who contributed to various stages of this project.

Author Information

Zhihua Xu and Mircea Cotlet
Center for Functional Nanomaterials
Brookhaven National Laboratory
Upton, NY

Zhihua Xu received his PhD in materials science and engineering from the University of Tennessee, Knoxville (2008). He is currently a research associate.

Mircea Cotlet received his PhD in chemistry from the Catholic University of Leuven, Belgium (2002). Following postdoctoral work at Los Alamos National Laboratory in New Mexico, he became a staff scientist and leader of research on single-molecule spectroscopy at the Center for Functional Nanomaterials.

Hsinhan Tsai and Hsing-Lin Wang
Chemistry Department
Los Alamos National Laboratory
Los Alamos, NM

References