New polymers for plastic solar cells

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Thin-film blends of novel conjugated polymers with fullerene derivatives offer a promising route to improved power conversion efficiencies in photovoltaic devices.

Conversion of light to chemical energy through photosynthesis in green plants and certain bacteria is the basis of life on earth. It is made possible by conjugated organic molecules in the form of chlorophyll and bacteriochlorophyll, to name two. Current research investigates the prospects for using related molecules and polymers in artificial systems to create fuels and electricity from light. Progress continues with efforts to produce thin-film photovoltaics using organic conjugated polymers and molecules.

Large-area photovoltaic energy conversion requires cheap materials and deposition methods. Organic polymers and molecules in ∼0.1µm thin films offer possibilities for coating by standard coating methods on flexible substrates, to give highly absorbing films generating photocurrent. The films are sandwiched between electrodes, at least one of which is transparent. Typically, one is metallic and deposited by evaporation; the other may be a transparent metal oxide, such as indium tin oxide (ITO), or alternatively a transparent polymer electrode.

At present, the best materials give ∼5% power conversion efficiencies (PCEs) in AM1.5 solar illumination, a number that has increased dramatically over the last few years. Best performance is currently found with a polymer named poly(3-hexylthiophene) blended with a fullerene derivative, PCBM. Work in many laboratories aims to optimize the yield from this polymer. At the Center for Organic Electronics (COE), we focus on discovery of new alternative polymers and on the optical engineering aspects of these thin-film devices to enhance power conversion efficiency.

Molecular engineering can manipulate polymers and molecules to create desired properties associated with electronic structure and transport, optical absorption spectra and strength, chemical compatibility, and processability. Polymers in the form of alternating fluorene and comonomers offer a wide variety of optical properties, with absorption up to 1000nm. This is desirable for low-bandgap solar cells, where they are blended with fullerene acceptors and coated from solution onto electrodes. Such combinations can yield polymer solar cells of photovoltage ∼1V with optical absorption ending at 650nm. Lower-bandgap polymers can provide photocurrents up to 1000nm but lower photovoltage of 0.6V. External quantum efficiencies in these devices are in the range of 10–60%, and enable high-bandgap solar cells to achieve 3.5% and low-bandgap solar cells, 2.2% PCE. The nanostructure in these blends, which strongly impacts photocurrent collection, can be altered through solvent processing and thermal annealing. We have developed optical models and integrated electrical/optical models of these devices. With further work, assuming that current-limiting transport parameters can be sufficiently increased, we predict the upper limits of PCE at ∼9%.

Optical input is critical for collecting large photocurrents in the thin-film devices and can be enhanced by the use of gratings and microstructured reflectors. Transparent polymer cathodes and anodes can be used to fabricate semitransparent solar cells, while anodes help in making flexible polymer cells. We have recently demonstrated that substitution of a polymer anode with a metallic grid for the brittle and expensive ITO electrode is an attractive route for fabricating flexible cells at lower cost. The transparent, flexible electrode also allows easy assembly of tandem solar cells, necessary for raising overall PCE.

Polymer cell properties always represent a dynamic compromise. Competing aspects of optical absorption are affected by thickness and composition, while generation of charge reflects both composition and nanostructure. Transport properties for photogenerated charges are a function of composition and nanostructure. Electrical studies of these materials in diodes and on field-effect transistors are therefore helpful in generating input for electrical modeling. Transient photophysical measurements strongly argue that charge generation is efficient in blends with low acceptor concentration, but in agreement with results from electrical transport, charge transport is not effective.

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