The cascade solar cell

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Fiber-optic waveguiding techniques yield a new photovoltaic device design.

Continued increases in energy costs and strained demand on world oil reserves are spurring development of new technologies and materials to meet global energy needs. Chief among these materials are silicon photovoltaic cells. But their poor power conversion efficiencies make them problematic. Improving this technology will require a cheaper alternative material, along with a fundamental change in solar cell design.

Over the last decade, we have explored using carbon-based nanomaterials such as pure polymer and fullerene (C_{60} and C_{70}) thin films instead of silicon as the active semiconductor layers in photovoltaic cells. Recently, we have employed both near-field optical and spectroscopic methods to make small-scale structural cell modifications and to develop new nanocomposites.

π-Conjugated polymers, or polymers with alternating single and double carbon bonds, have been a subject of great interest, particularly in the design of nanocomposites for applications such as solar cells.\(^1\) Given the potential of π-conjugated polymers for customized optical absorption, enhanced absorbance across the solar spectrum could be accomplished by creating blends and composites. We have experimented with a number of techniques involving π-conjugated polymers in search of a more efficient host for fullerenes.

The best combination we have found so far is a functionalized form of C_{60} (PCBM) and the π-conjugated polymer poly(3-hexylthiophene) (P3HT). It is now generally accepted that thermal treatment of these nanomaterials increases power conversion efficiencies.\(^2\) However, subtle variations in thermal treatment can have a dramatic effect. Using only a brief period of thermal treatment enables better fullerene dispersion. This has resulted in power conversion efficiencies of around 5.2%.\(^2\)

The flat-panel architecture of traditional photovoltaic devices derives from the need to maximize exposure to the sun: see Figure 1(a). Yet, despite advances in nanomaterials and nanocomposites, flat-panel designs still have many drawbacks, in particular regarding reflection and optical conversion. For example, an exciton generated by polymer-fullerene cells can travel no more than 50nm before it is trapped within the organic semiconductor layer.\(^1\) The problem of carrier mobility and resulting charge transfer increases with distance between electrodes.

We have begun to consider photovoltaic device design from an optical standpoint, focusing on ways of more efficiently coupling light into the active layer. We aim to waveguide light into a composite thin film, then confine it with optical fibers until all resonant energy is absorbed. For this purpose, fibers coated with indium-tin oxide are passed through a bath of organic nanocomposite and then coated with aluminum on the outside and woven together to form a bundle, or ‘fiber-weave’: see Figure 1(b) and (c). We envision that as many as 200 fibers can be woven together, although current devices have only 6 fibers, each 200μm in diameter. In our initial work, these ‘cascade cells’ operate at efficiency levels comparable to those achieved by traditional flat-panel devices.

Depending on the absorption coefficient of the materials used, it may be possible to extend the absorption range of the devices while shortening fiber length. Additionally, optical confinement of the light coupled with bundling and tapering of the fibers should result in greater efficiency, since reflection will not be an issue. Eventually, we expect to make devices measuring around 2cm (10 fibers) in diameter and less than 1cm long, with efficiencies that rival those of flat-panel organic photovoltaics.

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Figure 1. (a) Flat-panel and optical-fiber photovoltaic devices differ in structure. (b) ITO-coated fibers are drawn through a polymer solution and (c) woven into a bundle weave. Al: Aluminum. LiF: Lithium fluoride. PEDOT: Poly(3,4-ethylenedioxythiophene). ITO: Indium-tin oxide.

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References