

## Absorbing infrared light in polymer solar cells

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# Absorbing infrared light in polymer solar cells

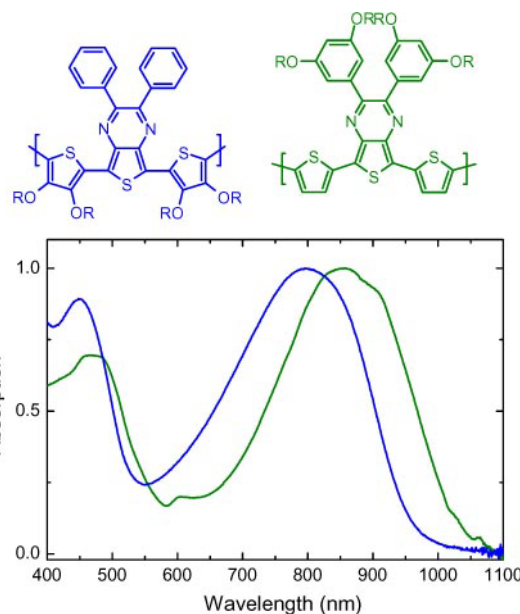
René Janssen

*New polymers absorb light from the ultraviolet to the infrared, extending the reach of organic-based solar cells.*

The use of photovoltaic solar cells that convert sunlight directly into electricity is increasing only slowly, due largely to the high cost of cell production. Hence, a worldwide search is on for new types of solar cells that can be produced at low cost, while still providing high conversion efficiencies. Polymer solar cells—in which organic molecules with semiconducting properties absorb light and generate electrical power—have emerged as a viable candidate from these efforts.

Solar cells are judged in terms of energy conversion efficiency and stability, which reflects both a cell's resistance to degradation in UV light and its lifetime under working conditions. At present, the best polymer solar cells are those based on a mixture of conjugated polymers and fullerenes ( $C_{60}$ ). These devices provide power conversion efficiencies of 4–5% in solar light.<sup>1,2</sup> This is lower than that achieved by commercial silicon solar cells, which typically average around 15% efficiency. The problem is partly caused by the negligible absorption of most semiconducting polymers in the red and near-infrared parts of the solar spectrum—the region in which the sun emits its maximum flux of photons (700 nm). Efficiency could be greatly improved by extending the range of wavelengths that a semiconducting polymer absorbs and converts into electricity. We have developed working photovoltaic solar cells comprising new, low-cost solution-processable polymers that cover a large part of the solar spectrum.<sup>3</sup>

Conjugated polymers have a structure with an alternating sequence of long single and short double carbon-carbon bonds along the polymer chain. This configuration enables delocalization of the extra electrons in the double bonds over the entire chain and endows the materials with semiconducting properties. The wavelength below which a polymer absorbs light—its optical band gap—is related to the extent of bond length alternation and can be shifted to the infrared by minimizing the differences in bond lengths between single and double bonds.

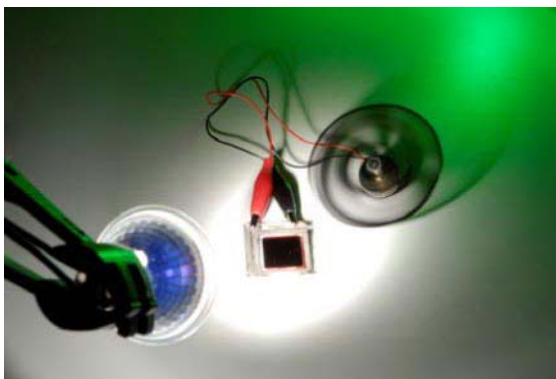


**Figure 1.** Shown are chemical structures of two new low-band-gap poly(di-2-thienylthienopyrazine) polymers (top) and their absorption spectra versus wavelength (bottom).<sup>3</sup>

One successful and versatile strategy for achieving such a configuration involves alternating the polymer's electron-rich and electron-deficient aromatic units, that is, alternating the single- and double-bond units. We used this concept to synthesize polymers consisting of electron-rich bithiophene and electron-poor thienopyrazine segments (see Figure 1). The newly synthesized polymers have high molecular weights and are soluble in a wide range of organic solvents, making them ideal for low-cost processing from solution. Most important, they absorb light from the UV up to 1000nm (see Figure 1).

Solar cells were constructed by sandwiching a thin (~100nm) layer of a blend of the new low-band-gap polymer and a soluble fullerene derivative between a transparent front electrode and a metal back electrode to collect the photocurrent (see Figure 2).

*Continued on next page*



**Figure 2.** A prototype polymer solar cell drives a small motor when illuminated. (Photo courtesy of DPI.)

The low-band-gap polymer solar cells exhibit an open circuit voltage of 0.56V and a short-circuit current of 3.1mA/cm<sup>2</sup> in simulated solar light of 100mW/cm<sup>2</sup>. They have an energy conversion efficiency of 1.1%. By measuring the monochromatic photoresponse, we confirmed that these cells are active up to a wavelength of 1000nm, with external quantum efficiencies exceeding 15% in the 700–900nm region.

Although the overall performance of the new low-band-gap polymer solar cells is still less than the 4–5% achieved by state-of-the-art solar cells based on polythiophene and fullerene, the lower performance is not due to a loss in open-circuit voltage, as might be expected of the longer-wavelength absorption. The minimal loss in voltage—less than 0.1V—compared with polythiophene cells is surprising because polythiophene has a much higher optical band gap (1.9eV) than the low-band-gap polymer (1.2eV). This demonstrates that photon energy can be used more efficiently in the new cells and suggests further improvements in charge generation and charge transport.

The new materials provide a significant shift of 350nm in the onset of light absorption to around 1000nm compared with most polymers used so far. Such broad band absorption is necessary to increase the performance of future polymer solar cells. In that sense, this result is an important step. Our next objective will be to increase the number of charges that are created and collected per photon to improve the photocurrent. We intend to do that by further optimizing the microstructure of the active layer and by creating new materials that provide improved charge transport. If we succeed, we are confident that polymer solar cells with energy conversion efficiencies of 10% or more can be achieved.

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René Janssen is a professor in chemistry and physics at the Eindhoven University of Technology. In 1999 he received the Pionier award from the Netherlands Organization for Scientific Research, and in 2000 he was co-recipient of the Descartes Prize from the European Commission for outstanding collaborative research. In addition, he has been a member of the program committees for SPIE conferences on organic photovoltaics and organic optoelectronics and photonics, and has contributed several papers to these meetings.

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