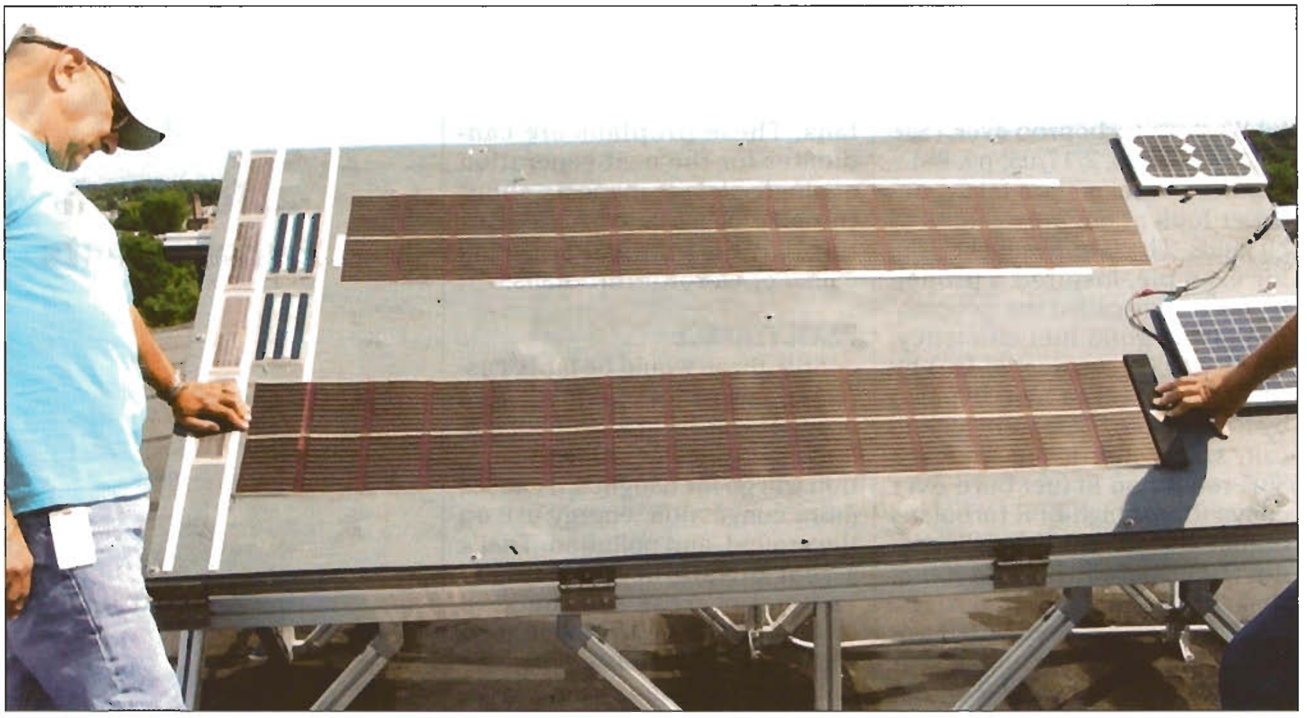
On a roll with plastic solar cells



PowerPlastic solar cells on a test bed: Continuous roll-to-roll fabrication techniques yield solar cells that roll up if need be. The first applications are in portable electronics and as a "power skin" for temporary military structures in the field.

Roll-to-roll processing techniques are poised to make plastic cells high-volume items.

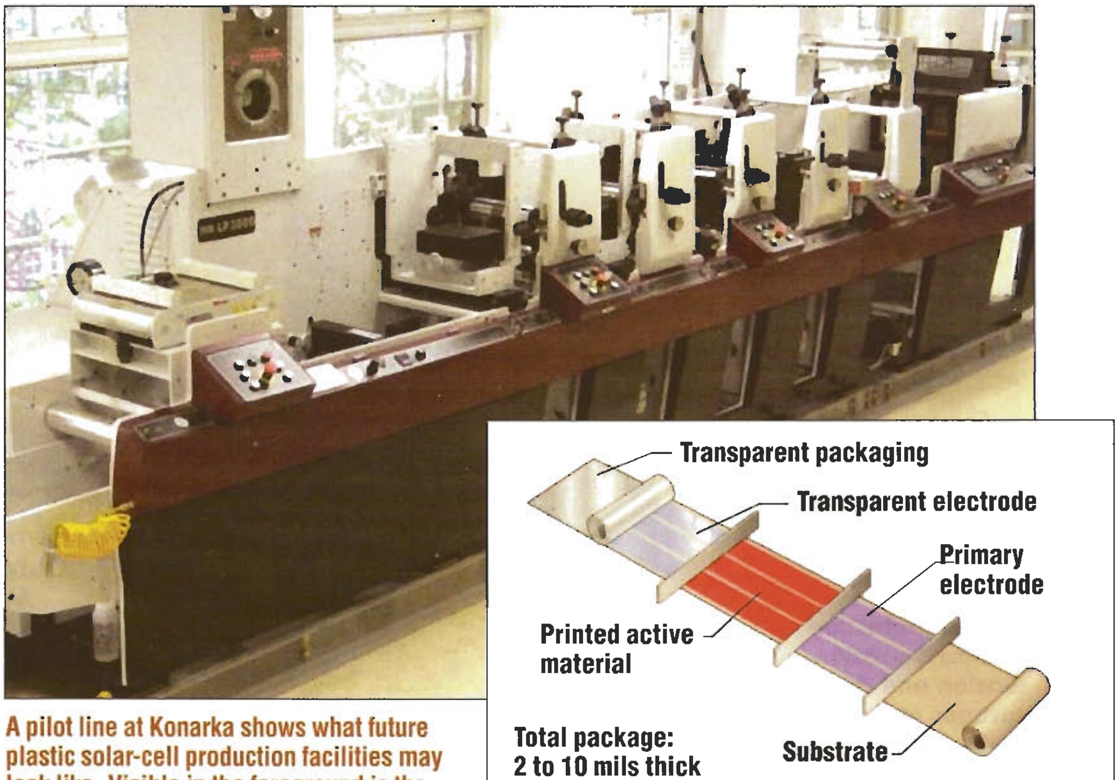
Leland Teschler
Editor

Picture an ordinary plastic soda bottle with solar cells inked onto its surface. That image comes close to the goal of work now underway at a number of start-up companies all trying to produce solar cells made from inexpensive plastic.

The substrates of choice for many of these efforts include polycarbonate (PC), polyethylene (PE), and polyethyleneterephthalate (PET), the same kind of polymer used for ordinary soft-drink and food containers. The light-sensitive material goes on via processes that are analogous to ink jetting or other printing techniques. Cell fabrication typically takes place on substrate material that is spooled from rolls. These continuous roll-to-roll manufacturing procedures can be inherently fast and economical.

Contrast roll-to-roll methods with those for conventional solar cells. Conventional cells use silicon substrates resembling those of integrated circuits. And as in ICs, cell features take shape through chemical-vapor deposition and etching steps in vacuum chambers at relatively high temperatures. The resulting material can convert sunlight to electrical energy more efficiently than plastic. Cell maker **SunPower Corp.**, for example, claims its cells are 21% efficient, compared to the 3 to 5% efficiency of today's plastic cells. But just

Production scheme for bulk-heterojunction technology



A pilot line at Konarka shows what future plastic solar-cell production facilities may look like. Visible in the foreground is the unwind station in which blank rolls are loaded. The four stations in the middle apply functional coatings. The right side has a spool at the top and one below (not visible) that are part of the apparatus for laminating and encapsulating cells. There is a via created through the lamination film through which contacts are added for electrical leads.

as with ICs, conventional solar cells get manufactured in batches. The batch processes are fundamentally less economical than techniques that are continuous.

The economies of roll-to-roll methods can make plastic cells inexpensive enough to be practical in a number of uses where low price is more important than a high conversion efficiency. **Konarka Technologies Inc.,** Lowell, Mass., for example, says its Power Plastic material can go into laptops and PDAs, can power sensor networks, or even be a power-generating skin for tents, awnings, and roofs.

Though many firms are pursuing plastic cells, Konarka may be among those that are the farthest along to large-scale commercialization. It has worked with the German firm **Leonhard Kurz GmbH & Co.** to devise a high-speed press capable of producing Power Plastic cells. According to Konarka officials, Kurz presses are expected to be able to print solar material on wide webs of plastic substrates at high rates. Konarka says samples from this line are now in the hands of customers for evaluation.

An appreciation for the promise of roll-to-roll cell making comes from a at look at Konarka's process. According to Konarka Director of Electronic Printing Technologies Eitan Zeira, many of its details are proprietary, but the overall sequence of steps involved are not. The semiconducting polymers that make up the photosensitive layers of the cell (called conjugated polymers in industry parlance) are created in batches of several liters each. Their final form is that of a fluffy powder. When manufacturers are ready to use the material, they combine it with standard industrial solvents common in printing to

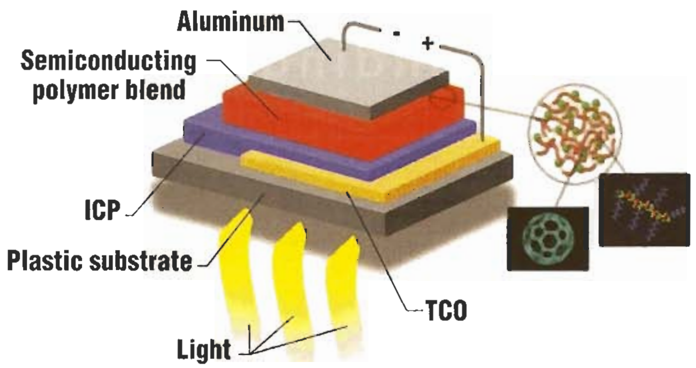
Inside a polymer solar cell

For its plastic solar cells, Konarka starts by creating batches of semiconducting polymers that also contain fullerenes. This material combination gets deposited in what's called a bulk heterojunction cell structure.

The cell is built on an ordinary plastic substrate onto which a transparent conductive oxide (TCO) electrode is first deposited. A layer of intrinsically conductive polymer (ICP) then goes on to serve as a buffer to the TCO and as a source of charge injection for the next layer, the semiconducting polymer blend. This latter layer undergoes annealing to create crystalline islands that facilitate light-induced charge separation. When exposed to light, electrons automatically go to the lower work function contact, holes to the one with the higher work function.

The structure diagramed here is about 3% efficient. Konarka is also working on a modified structure that includes an optical spacer between the conjugated polymer blend and the aluminum contact which boosts conversion efficiency to about 5%.

Organic bulk-heterojunction cross section



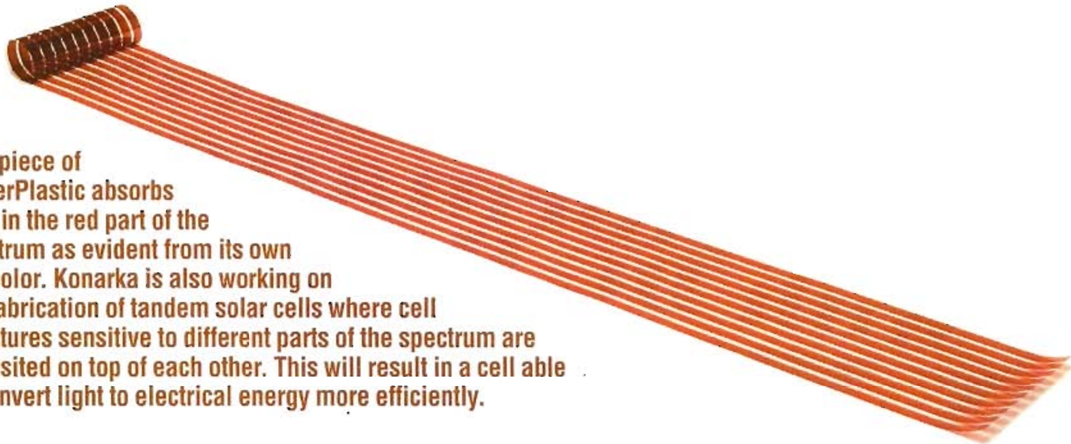
create an ink or coatable liquid.

The semiconducting polymers can be applied through any of several deposition methods. These methods are still evolving. But Zeira says that many printing techniques are candidates for solar-cell fabrication. Offset printing is the only method that doesn't look promising, he says, because the conjugate polymer inks are just too runny.

A roll-to-roll pilot line at Konarka, upon which the Kurz cell fabrication equipment is based, contains five stands. Each stand corresponds to a layer of the solar cell. The coating technology used is analogous to that of a slot die (extrusion) or slide coater. First to go on the substrate is a semitransparent electrode, typically a transparent conductive oxide layer (TCO). Next comes a patterning step that separates the cells from each other so they can later connect in series. Active layers deposit next followed by a top electrode to complete the active stack. The completed cells are cut apart and laminated to produce voltage outputs dictated by customers.

All of these layers are quite thin. The base TCO layer, for example is about 100-nm thick. Some of the active layers of semiconducting polymers are only tens of nanometers deep. Such shallow layers dry quickly and thus promote use of fast web speeds.

Key to making the process practical is in the quality of the application process. Pin holes in the applied material, for example, introduce shorts between layers. Zeira says Konarka has tweaked its printing methodologies to ensure the critical middle layers are pinhole-free.



This piece of PowerPlastic absorbs light in the red part of the spectrum as evident from its own red color. Konarka is also working on the fabrication of tandem solar cells where cell structures sensitive to different parts of the spectrum are deposited on top of each other. This will result in a cell able to convert light to electrical energy more efficiently.

Another strategic step in fabrication consists of heating that creates islands of crystals within otherwise amorphous polymer. This annealing process happens at about 110°C and once took about 10 min. But Konarka says it has found a way to get the right nanostructure with just a few seconds of heat.

Cleanliness during deposition is also important. But rather than encase the whole production line in a clean room to keep out dust, Konarka seals off only the coating stations themselves. This lets the entire line reside in an ordinary factory environment so long as the air isn't filthy.

The cells coming off Konarka's roll-to-roll line today are about 3% efficient. The company has devised a new cell structure that is over 5% efficient and intends to use it future products. But high efficiency isn't paramount in many of the applications envisioned for plastic cells.

"Customers don't care about efficiency, they care about total power," explains Eitan Zeira. "If you need more power from a plastic cell, you just make the footprint longer." **MD**

MAKE CONTACT

Konarka Technologies Inc., ***konarka.com***