Turning Up the Power in Organic Solar Cells

Solar cells are an important component of renewable energy, and polymer solar cells are particularly attractive for some uses. They're lightweight and flexible, so they're easily integrated with architecture, and they can be manufactured on plastic surfaces using inexpensive roll-to-roll printing. Polymer solar cells, however, lag behind their silicon counterparts in their efficiency at converting sunlight to electricity. Now, based on experiments carried out at the APS, researchers have reported a new approach to boosting that efficiency, potentially making them more practical and cost effective.

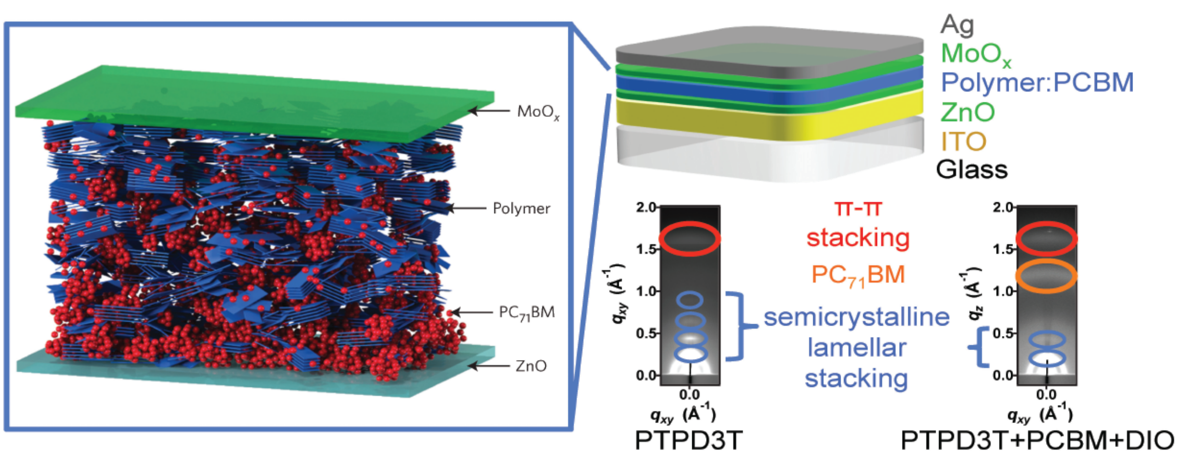


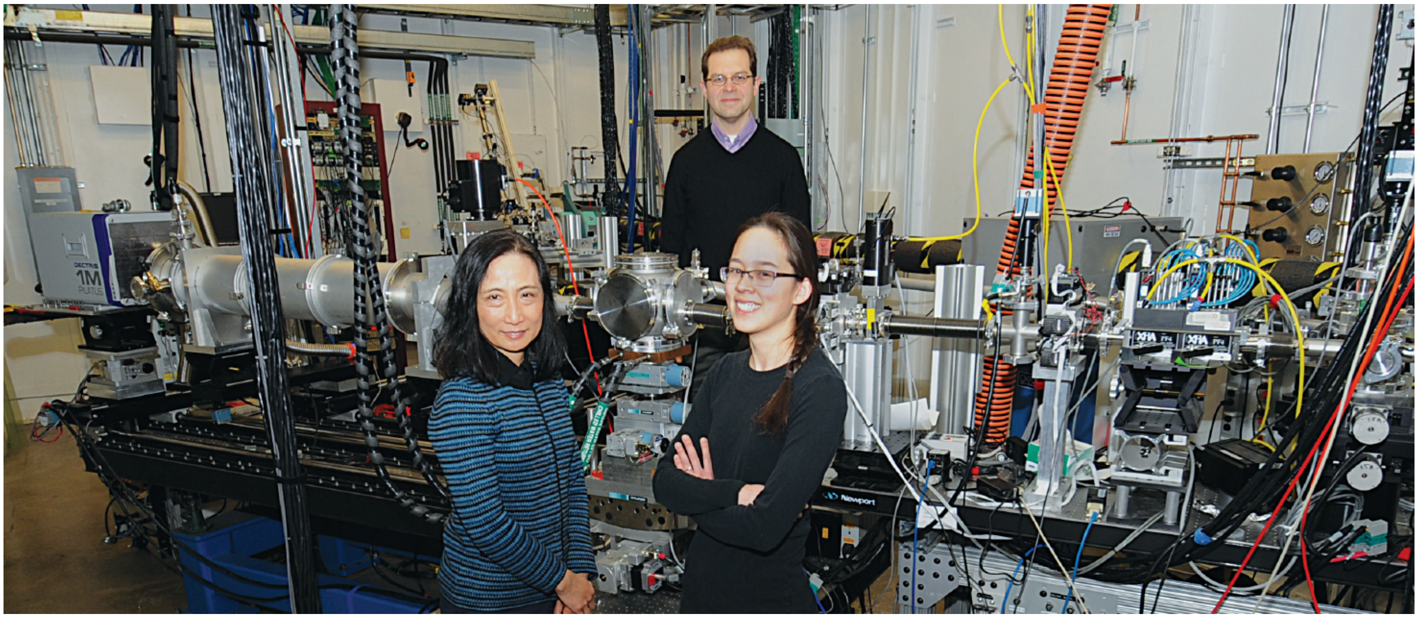
Fig. 1. A schematic of a solar cell (top right) shows a glass substrate coated with indium tin oxide, a layer of polymer sandwiched between zinc oxide and molybdenum oxide, and a silver contact on top. X-ray scattering revealed the organization of the polymer molecules (left) with the blue ribbons of PCBM arranged in stacks that, together with π-π stacking, allows charge to move more easily.

Three factors contribute to the power conversion efficiency of all types of solar cells, including polymer solar cells: the short-circuit current, the open-circuit voltage, and the fill factor. Fill factor is the ratio of the maximum power available from the solar cell to the product of the short-circuit-current and open-circuit voltage.

Although increasing conversion efficiency can be achieved by adjusting the polymer properties to improve either the short-circuit current or the open-circuit voltage, the two properties may compromise each other. Ultimately, raising the fill factor is a key to boost cell power conversion efficiency, but the best result researchers had been able to achieve in the past was 72%, with most polymers falling far short of that.

The team of researchers from Argonne, Northwestern University, South University of Science and Technology of China, the University of Malaga (Spain), and the Polyera Corp. developed polymers that enable the production of solar cells with fill factors of 76 to 80%, the highest ever achieved. That leads to a power conversion efficiency of 8.7%, but the researchers say further adjustments should bring that to above 10%. The eventual goal, they say, would be to create polymer solar cells with 15% power conversion efficiency.

The polymers the researchers created were poly[5-(2-hexyldodecyl)-1,3-thieno[3,4-c]pyrrole-4,6-dione-alt-5,5-(2,5-bis(3-dodecylthiophen-2-yl)-thiophene)] (PTPD3T) and poly[N-(2-hexyldodecyl)-2,2′-bithiophene-3,3′-dicarboximide-alt-5,5-(2,5-bis(3-decylthiophen-2-yl)-thiophene)] (PBTI3T). They combined these electron donating polymers with fullerene ("bucky ball") electron acceptors in films to create bulk heterojunction solar cells. In such solar cells, light striking the material creates excitons in the polymers, which can be split into positive and negative charges at the intersection between the polymer, acting as an electron donor, and fullerene molecules, acting as an electron acceptor. The positive charges in the polymers and the electrons in the fullerene clusters in the films then flow to the solar cell's respective electrodes



L. to r.: Lin X. Chen (CSE and Northwestern University), Joseph W. Strzalka (XSD), and Sylvia J. Lou (Northwestern University) in the 8-ID-E research station.

to provide power. Enhancing the ease with which excitons split and charge carriers transport through the material and reducing the probabilities for the positive and negative carriers to recombine will improve the fill factor, and hence the solar cell efficiency.

Using XSD beamline 8-ID-E at the APS, the team made grazing incident x-ray scattering measurements that allowed them to study the orientation and arrangement of the molecules in the thin bulk heterojunction films on an electrode substrate. Though the molecules of a polymer are not as ordered as those in a silicon crystal, they were found to be arranged in an orderly enough fashion in one dimension to have polymer aligned at the interface. The polymers, the researchers found, were arranged in ribbons, stacked flat on top of the electrode in an arrangement known as π-π stacking. The arrangement creates a periodic structure that allows positive charge carriers to move from ribbon to ribbon easily, thus improving the carriers' mobility and maximizing the contacts with the electrode to enhance the charge collection efficiency.

The fullerenes, however, tend to form big clusters and interrupt the polymer stacking, so the team looked at what happened when they added 1,8-diiodooctane (DIO) to the mix. The DIO caused the fullerenes to be dispersed more evenly among the polymer ribbons. Because the intersection between fullerenes and polymer is where the charge carriers are most likely to separate into positive and negative, dispersing the fullerene more regularly to create an optimal number of these junctions to allow more excitons to split into charge carriers effectively.

Many parameters of the materials that go into polymer solar cells can be adjusted to improve performance, and not all the mechanisms that work against high efficiency are fully understood, but the researchers say their demonstration that they can enhance the fill factor to record levels means that the devices, which have doubled their efficiency in the last five years, will continue to improve.

– Neil Savage

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