W ith energy prices and concerns over global climate change rising, there is great interest in using solar cells to capture sunlight and generate electricity. If solar cells were price-competitive with grid electricity it would radically change the way the world’s population obtains its energy (Fig. 1). Some researchers hope to reduce solar cell costs by depositing solar cells in roll-to-roll coaters, similar to the ones used to print newspapers or photographic film. Semiconducting polymers are a good candidate for these solar cells because they can be dissolved in common solvents and printed like inks. The key to making efficient polymer solar cells is interpenetrating electron donating and accepting polymers at the nanometre length scale so that electrons and holes can be separated from each other and then transported towards electrodes. The spatial details of how the two polymers separate from each other in a thin film and how this affects charge separation are critically important but hard to study because the polymers interpenetrate at a very small length scale. On page 735 of this issue, Coffey and Ginger introduce time-resolved electrostatic force microscopy (EFM), a novel scanning probe technique for studying organic-blend solar cells, which uses an AFM cantilever in non-contact mode to image surface potentials and measure how they change with time. With this technique the authors were able to measure how rapidly photoinduced charge accumulates in different regions of a polymer-blend film in response to a short light pulse. Their initial results provide important information on the question of which locations are the most efficient at generating charge.

A polymer solar cell can be made by sandwiching a thin film of polymer between two metallic conductors such as indium tin oxide (ITO) and aluminium. Because in the two conductors the highest occupied energy levels of the electrons are different, electrons will flow from the conductor with the highest energy electrons to that with the lowest energy electrons (that is, from the aluminium to the ITO in our example) until they reach the same chemical potential. The charge that builds up in the two electrodes generates an electric field across the semiconductor. When the semiconductor absorbs light, the electric field pulls electrons to the positive electrode and holes to the negative electrode (Fig. 2a). The resulting current and voltage can be used to do work or charge a battery.

In practice, organic solar cells with only one semiconductor do not work well because the photoexcited electron is electrostatically bound to the hole left in the valence band — together they constitute an exciton. Because excitons are charge neutral, they do not drift in an electric field and rarely reach an electrode. More often than not, the electron recombines with the hole instead of being collected by the electrodes. This problem can be avoided by incorporating a second semiconductor with a lower-energy conduction band (Fig. 2b). If the exciton is formed near the interface, the electron can transfer to this second (electron accepting) semiconductor. The hole can then travel in the donor...
The polymer film typically needs to be at least 100-nm thick to absorb enough light. However, the excitons cannot diffuse across a film this thick to find the interface, as they typically decay within about 6 nm when diffusing in a polymer. A useful strategy is to interpenetrate the two polymers throughout the film so that there are more-extensive interfaces, and it is likely that most excitons will be formed near an interface (Fig. 2c). This can be done simply by dissolving both polymers in the same solvent and then casting a blend. When one considers how these blends could function in a solar cell, several important questions come to mind. To what extent do the two polymers phase separate from each other? Are the domains so large that excitons cannot reach the interface? Or is there enough of each polymer in each domain that the excitons do not even need to reach a domain interface? In what region of the cell is recombination of electrons with holes the fastest? Coffey and Ginger addressed these questions for a series of blends of the polymers F8BT and PFB with different mass ratios of the two polymers. Cells made with these two polymers had been studied extensively over the past few years, and a variety of high-resolution scanning probe microscopy techniques have been used to shed light on the spatial details of charge generation and separation in organic solar cells, but there has still been uncertainty as to where most of the charge is generated.

The authors apply their time-resolved EFM to measure the spatially averaged rate at which the surface potential builds up in all of the blends, and showed that it correlates extremely well with the measured quantum efficiency of the blends in solar cells. Then they analysed maps of this charging rate. One might expect that the surface voltage would build up near the interface between the two polymer domains because electron transfer from the donor to the acceptor is what generates current. Surprisingly, Coffey and Ginger find that the voltage builds up faster in the centre of polymer domains. The authors point out that excitons can be split in the centre of the domains because they are not pure domains; there is some PFB in the F8BT domains and vice versa. It is still an open question, however, why charge reaches the top of the film more quickly from the center of the polymer domains. Higher spatial resolution will be needed to answer this question.

In the future we expect that time and spatially resolved studies of nanostructured solar cells will be widely used to see how film morphology affects charge separation and transport. With further improvements in spatial resolution, it should be possible to study the processes that occur in a wide variety of solar cells with exquisite detail. Without a doubt, this information will bring us closer to the dream of rolling out low-cost solar cells on our rooftops.

REFERENCES