Organic solar cells

PROFESSOR SIR RICHARD FRIEND (BOTH IMAGES)

Solar cells can now be manufactured by roll-to-roll printing

How can the cost of solar cells be reduced enough to make them a feasible source of large-scale renewable energy? The answer is to make them thin.

Prototype solar cell panel

Research that began at the Cavendish Laboratory in the Department of Physics, and now draws in departments from across the University, has discovered how to make lightweight, flexible and cheaper photovoltaic ('solar') cells. This technology unlocks new potential to deploy vast areas of solar cells that will be needed as part of the renewable energy portfolio when we move away from fossil fuels.

Converting light energy to electricity

Solar cells use semiconductors to capture light. Each photon of light that is absorbed raises an electron in the semiconductor material to a high-energy state. The electron then drifts away from the net positive charge left behind (termed a 'hole') and this generates a current, which is drawn off as electricity.

Silicon makes excellent solar cells – it's the right colour, absorbing across the visible and near infrared parts of the solar spectrum, and makes reasonably efficient cells. However, its efficiency has limitations: for silicon to absorb enough light, relatively thick slabs (typically 0.2 mm) need to be used. Semiconductor-grade silicon is an expensive material, too expensive to make the scale-up of silicon-based solar panels a feasible prospect.

New materials roll up

A worldwide search has been under way during the past decade to find other semiconducting materials that may provide cheaper solar cells. If we are to reduce the cost of deployment, we need to bring down the cost not just of the semiconductor materials used in the solar cell itself, but also of all the other materials used in the solar cell assembly, such as the substrate and how it is encapsulated in the panel.

The best solution might be to print the entire apparatus – the active semiconductor layers, metal electrodes and tracks – directly onto a plastic film. And the fastest way to do this would be to use continuous roll-to-roll printing, in much the same way that newspapers are printed. Solar cells manufactured in this way would be lightweight, flexible and, crucially, much cheaper and easier to deploy than current systems enclosed within glass sheets.

Roll-to-roll printing sets us some big challenges. It requires scientists to develop a completely new materials set, re-design the solar cell semiconductor architecture and build up the manufacturing skills that allow precise control of printed film thickness. Within the University, we now have a broad programme of science and engineering to cover this full set of research tasks: Professor Sir Richard Friend, Professor Neil Greenham, Professor Henning Sirringhaus, Dr Chris McNeill and Professor Ulli Steiner in the Cavendish Laboratory; Professor Wilhelm Huck in the Department of Chemistry; Professor Mark Welland and Dr Andrea Ferrari in the Department of Engineering; and Professor Judith Driscoll in the Department of Materials Science and Metallurgy.

Persuading electrons to leave home

Roll-to-roll printing requires semiconductor materials that can be handled as 'inks' and printed at room temperature – a very different world from the traditional high-temperature and high-vacuum processing world of silicon technology. One very attractive set of materials are the polymeric organic semiconductors that Professors Friend, Greenham and Sirringhaus have developed for use both in light-emitting diodes (exploited through the University spin-out company Cambridge Display Technology Ltd) and in printed transistors for electronic paper displays (under development by another spin-out, Plastic Logic Ltd). There is however a catch. While silicon readily liberates electrons from holes when a photon is absorbed, the excited electron generated in an organic semiconductor is very reluctant to leave its positively charged hole.

Nature has already solved this problem in plants: in photosynthesis, the excited electron is generated at the interface between two semiconducting molecules that have different electron affinities. This causes the electron to move to the adjacent molecule, leaving the hole behind. Subsequent steps in photosynthesis use the reducing power of the electron and the oxidising power of the hole to complete the chemistry.

For solar cells, we have the simpler task of arranging that the separated electron and the hole can be collected at their respective electrodes to either side of the device. Although it was discovered some time ago by the researchers at the Cavendish Laboratory that single interfaces (or heterojunctions) seem to function reasonably well, the electron would often move no further than to the adjacent site across the heterojunction, bound by its electrostatic attraction to the positively charged hole. Although this creates a current, the efficiency of energy conversion is limited.

The Cavendish group, together with Professor Huck in the Department of Chemistry and colleagues at Imperial College London, are just beginning work to tackle this problem, funded by a major Engineering and Physical Sciences Research Council (EPSRC) Programme Grant (£6.8 million over five years). A significant programme of chemical synthesis, materials processing and semiconductor physics measurements aims to develop more-controlled heterojunctions that will be better at moving the two charges away from one another. The goal is to raise energy conversion efficiencies from current levels of around 5% to at least 10%, making the technology competitive with other solar cell technologies – a big challenge but one that the multidisciplinary group of researchers believes is attainable.

Grand challenges at the nanoscale

We face a second challenge: the excitation produced by the absorbed photon needs to find its way to the heterojunction before it decays. It is usually short-lived (about 1 nanosecond) and cannot therefore travel very far, typically about 10 nm (i.e. 20 or so intermolecular spacings). However, we need much greater thicknesses of semiconductor to absorb all incident light. The solution that is being investigated worldwide is to arrange that the electron-accepting and hole-accepting materials form an inter-penetrating network with dimensions at this nanometre lengthscale. Not only does this need to give efficient charge separation, but it also needs to allow the electrons and holes to move along continuous pathways to the electrode – a by no means trivial set of requirements!

One very promising route is to use polymers composed of two blocks of chemically distinct polymers (diblock copolymers). When the two blocks are selected so that they repel one another, they form very specific ordered structures with regions of one block tied to regions of the other block by the chemical bond that links them. The researchers are developing these nanostructures in a programme supported by a £1.3 million EPSRC grant under the Nanotechnology Energy Grand Challenge programme, which draws on Professor Steiner's polymer expertise, together with Professor Huck's synthesis expertise and continuing developments in solar cell research at the Cavendish. This and related approaches are facilitating the use of inorganic semiconductors such as titanium dioxide and zinc oxide to form nanocrystalline frameworks that can be subsequently filled with organic semiconductors; these structures are being developed by Professors Welland and Driscoll in their respective research groups.

Towards manufacturing

The programme of work on the process engineering of the printed solar cell has been positioned to provide the best interface between research and its move to industry. Cambridge's EPSRC-supported Integrated Knowledge Centre has been used to start the printing project. This has also brought in Dr Ferrari's work in Engineering on conducting carbon nanotube and graphene electrodes. Together with the technology and product development company The Technology Partnership, the researchers bid for and won a competition run by the Carbon Trust in 2007 to set up an industrial activity to prove the manufacturability of new solar cell technologies. With a commitment of £5 million from the Carbon Trust, the printing activity is growing rapidly, and large-scale solar power has now become a possibility that is within our grasp.

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