IOP Institute of Physics

Photovoltaic technology looks ahead to a bright future

Solar energy conversion

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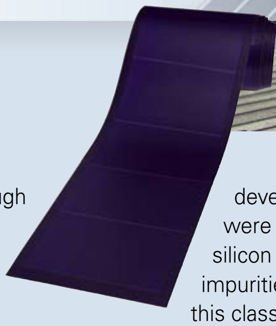
Power from sunshine



A thin-film amorphous silicon PV array integrated into a roof. Inset: a flexible PV roll
United Solar Ovonic

The Earth soaks up enough sunlight in just half an hour to satisfy world energy needs for a whole year. So tapping into this CO_2-free and limitless power supply is an obvious route to countering global warming, as well as reducing dependence on non-renewable energy sources. However, although the basic technology has been around for several decades, harnessing solar energy efficiently and cheaply has proved challenging. Nevertheless, the market for solar power generation is now growing at more than 40 per cent a year.

Capturing solar radiation relies on the photovoltaic (PV) effect, whereby light interacts with certain materials to produce an electric current. Although discovered nearly 150 years ago, it was not until the 1950s that the first practical PV cells were developed. These were based on silicon 'doped' with impurities that made this classic semi-conducting material sensitive to light. Today, the UK company, PV Crystalox Solar, is one of the world's leading suppliers of silicon for solar cells.

A simple solar cell consists of a thin silicon wafer with two layers, one doped to be electron-rich and the other electron-poor, so that an electric field is set up across the layer junction. Attached to the layers are conductors connected to an electrical circuit. When light hits the cell, it releases negative electrons, leaving behind positively charged 'holes'. Separated by the field, the negative and positive charge carriers travel through the circuit in opposite directions to create the electric current. The cell is coated with an anti-reflective material to maximise light absorption and covered with a protective glass plate. A commercial module will consist of an array of connected cells.

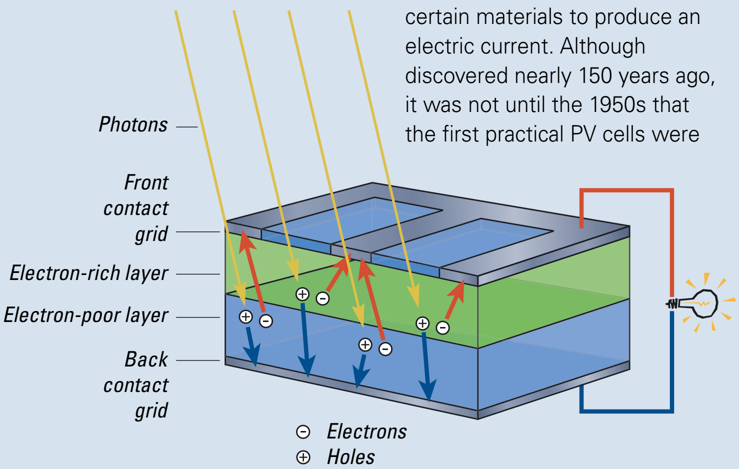
Today, 95 per cent of PV units are made of silicon. They convert sunlight into electricity with an efficiency of up to 17 per cent. The maximum efficiency that could be achieved is only about 25 per cent because only the light with more energy than that required to generate the charge carriers (the 'bandgap') is absorbed.

Silicon has other drawbacks. Currently, there is a shortage of electronic-grade crystalline silicon, which is expensive to manufacture and rather fragile. Most PVs are now based on cheaper polycrystalline silicon, although it is less efficient.

Thin layer cells

Other solutions are being sought, however, in the form of PV cells based on layers of semiconducting compounds just a few micrometres thick. Cadmium telluride combined with cadmium sulphide (CdTe/CdS) is a good light absorber with a bandgap well matched to the energy of normal sunlight. It is considered the best-performing PV material to date in terms of cost effectiveness and efficiency (up to 16.5 per cent). Several UK research groups, including those at the Universities of Durham and of Wales Bangor, have been

HOW A SOLAR CELL WORKS



THANKS GO TO KEITH BARNHAM AT IMPERIAL COLLEGE LONDON, KEN DUROSE AT THE UNIVERSITY
LAURIE PETER AT THE UNIVERSITY OF BATH, HARI REEHAL AT LONDON SOUTH

working on improving their efficiency and stability. Meanwhile the US company, First Solar, has already committed to supplying CdTe solar modules for a new 40-megawatt solar power plant in Saxony, Germany. Although cadmium is toxic, it remains tightly bound in the material so can be easily recycled.

Another competitive PV technology, also heading for the marketplace, exploits the more complex combination of copper indium diselenide (CIS), often with added gallium and sulphur (CIGS) to widen the bandgap and increase light absorption. A laboratory efficiency of nearly 20 per cent has been achieved at the US National Renewable Energy Laboratory (NREL), and several companies around the world are now manufacturing modules. However, one of the drawbacks is the high cost and limited supply of indium and gallium for large-scale use. Researchers at Northumbria University have been trying to minimise the amounts of these materials used by reducing the layer thickness. They are also looking at substituting more common elements – for example, replacing gallium with aluminium. A team at the University of Bath is exploring cheaper fabrication methods using electroplating.

An alternative is to re-visit silicon. Although crystalline silicon is a poor light absorber so does not perform well in thin films, the amorphous (non-crystalline) version is much better, but has tended to be unstable. Nanocrystalline films combining the best attributes of the crystalline and amorphous forms have potential. A group at Heriot-Watt University is employing low-power plasma technology to coat polyester sheets with silicon nanocrystals, which can be integrated into roofs or used for awnings. Luminescent dyes could be used to concentrate the light which is transmitted through the plastic sheet to PV cells placed around the edges. Researchers at London South Bank University are exploring how to grow layers of larger silicon crystals on glass starting from the amorphous material. The cell design could be engineered to trap light so that its absorption is maximised.

To achieve a higher energy conversion, layers of materials with different bandgaps (such as crystalline and amorphous silicon), each responding to a different light-energy range, can be stacked to form a multijunction cell. A US company, United Solar Ovonic, makes highly efficient triple silicon junction modules for roofing. Multijunction cells, based on gallium arsenide films combined with other semiconductors and optimised to trap solar radiation in space, can reach nearly 40 per cent efficiency but they are too expensive for more general use.

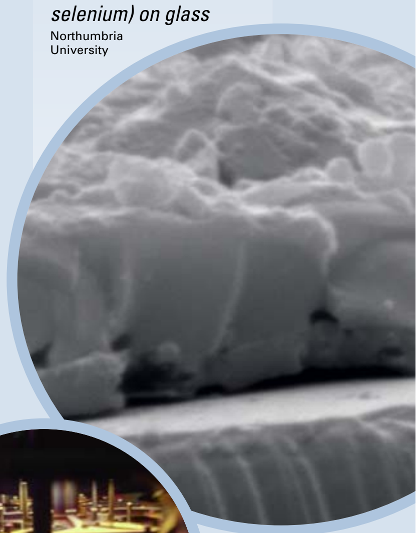
Future technology

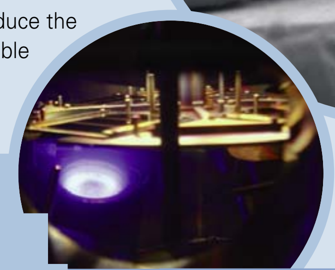
An alternative to the multijunction cell is being pioneered at Imperial College London. Exploiting quantum wells – ultra-thin nanostructures which absorb light over a wide energy range, result in efficiencies as high as 27 per cent, when the sunlight is concentrated by cheap lenses to reduce the overall cost. One application of these small, highly efficient cells, is in smart window blinds which will cut out direct sunlight, generate electricity and allow diffuse light for internal illumination.

The Imperial researchers are also working on even more exotic structures called quantum dots, which can be tuned to absorb light of a required energy. They may eventually replace dyes in a completely different type of solar cell: in these devices, light is captured by an organic dye which releases electrons into titanium dioxide nanoparticles coating one of two electrodes sitting in an iodine electrolyte. A UK university consortium (Bath, Cambridge, Edinburgh, Imperial and Warwick) is working on these dye-sensitised and other organic-based cells, which can achieve about 11 per cent efficiency – good enough for commercial exploitation. Konarka, a US company, already exploits the technology in portable battery chargers for laptops and mobile phones. Under licence, the UK company, G24 Innovations, has just built a factory in Cardiff to produce the cells mounted on a flexible plastic substrate, using an inexpensive 'roll-to-roll' process.

Sputter deposition of solar cell layers (copper, indium, aluminium and selenium) on glass

Northumbria University





THE FUTURE

Solar energy research is expanding rapidly, with many new ideas being explored – some using exotic nano-materials combined with ingenious engineering approaches. PVs look set to contribute significantly to future power generation. They can readily be adapted to suit the diffuse light conditions found in northern climes as evidenced by their widespread use in Germany. There is a strong research effort in the UK but to benefit fully from this vitally important technology, investment in the underpinning science needs to improve considerably.

of Durham, Ian Forbes at Northumbria University,
Bank University and John Wilson at Heriot-Watt University for their help with this paper

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Front cover:
A new CIGS solar array at St Asaph in North Wales – the largest CIGS array in the world

Inset:
A record-efficiency (16.5 per cent) cadmium telluride cell fabricated at NREL
DOE/NREL/Warren Gretz

Left:
Silicon PV wafers
PV Crystalox Solar

Editor: Nina Hall, Design: Peter Hodkinson