Making the most of sunlight

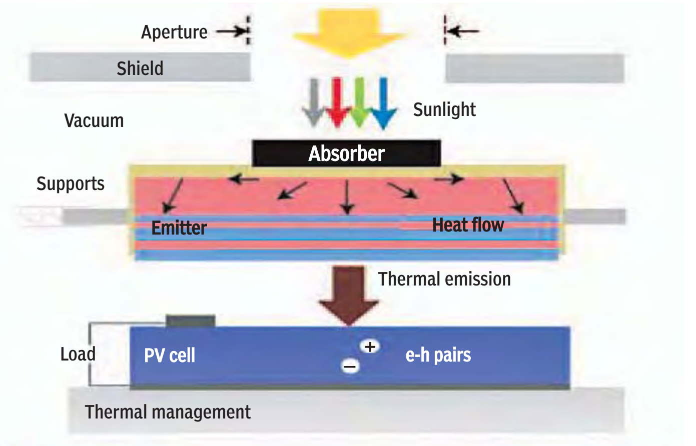
A WAY AROUND A 'BUILT IN' SPEED LIMIT IN SOLAR POWER IS BEING WORKED OUT, SAYS **S ANANTHANARAYAN**

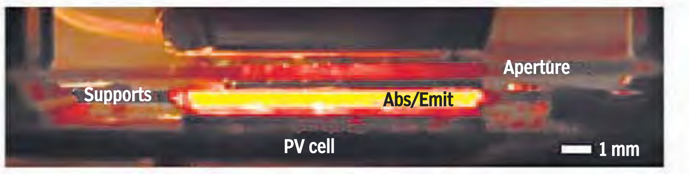
As photocells get cheaper and photocell panels come within reach, generating green power from sunlight is being looked at as the answer to the problem of meeting growing power needs and yet avoiding the pollution of conventional generation methods. In this context, improvement in the efficiency of the cells themselves amounts to multiplying the benefits that come from the fall in cost and increase in numbers.

The mechanism of the photocells' working itself creates a limit, no matter how well they are crafted, to how efficiently they can convert sunlight to electricity. While workarounds have been devised to improve the overall efficiency of conversion, in combination, a team of researchers working in the Massachusetts Institute of Technology, USA, report in the journal *Nature* an arrangement using *carbon nanotubes* and special crystals to capture sunlight and convert it, before passing it on the photocell, to a form that the photocell can use more efficiently.

The photocell is bit of a material from which electrons can be knocked out by sunlight and then the cell has an arrangement that the electrons cannot directly go back to the metal — which means the electrons can drive an electric current. In the atoms of metals, which are good conductors of electricity, the outer shells are not tightly fixed to the atoms but can "float" about in the assemblage of atoms that form a crystal. These "free" electrons can then help the metal carry an electric current. This property is the opposite of the case of insulators, where the electrons are securely bound. But in the case of semiconductors, like silicon, the electrons are halfway free and can be nudged loose by a photon of light. This is particularly so if traces of another atom, which has one more electron in the outer shell, are added to the crystal of the semi-conductor material. Now, if a crystal treated like this is placed in contact with another crystal where the atoms of the impurity added have not one electron more, but one electron less than the others, then, the "extra" electrons would cross over, but the "shortage" of electrons on the other side could not do the same thing and the boundary would be "one way".

Now if sunlight were to fall on this junction, a good number of electrons would get freed and cross over, but cannot return, and the result would be that the two sides would get electrically charged. The discharge could then take place through a normal conductor, which could work machinery, boil an egg or charge a battery. We can see that this could go on so long as a source of light is in action and also provided the photons of the light shining are energetic enough to supply the minimum, or threshold push that the semi-bound electrons need. Solar cell panels consist of thousands of such junctions grown on large sheets, to catch sunlight and generate electricity. There are no moving parts to wear out and there is no cost of fuel to be provided and the arrangement is economical once the photocells and the panels have been built.





Limitation

The limitations in efficiency arise from the manner of working itself. We have seen that all frequencies of light falling on the photocell cannot be knock electrons out. In the case of silicon, the threshold energy is in the range of the energy of photons in the red part of the spectrum. This means red light and light of the colours, like yellow, green and blue, can help produce power, but not infrared light or radiation in microwaves or radio waves. Now in the case of sunlight, about 19 per cent of the energy is in this low energy area. This means that this 19 per cent of the energy falling on the photocell is no good for producing electricity. On the other hand, it would go to heat up the photocell, which gives rise to its own inefficiency.

Another effect comes into force with the photons of energy higher than the threshold. Blue light has energy about twice that of red light and all the energy cannot be captured by a single photo-junction. The extra energy goes to excite or heat the crystal. This loss accounts for about 33 per cent of the incident sunlight and the overall loss, on account of mismatch of frequency, is about 48 per cent.

Another loss of energy in the photocell is because the cell warms up. The fact that the photocell is absorbing energy from the sun is really because the sun is a lot hotter than the photocell. The photocell is also a radiator of heat energy, which could go to heat other objects, or environment, that are cooler than the photocell. Hence, on the one hand energy corresponding to temperature below the temperature of the cell cannot be captured and at the temperature of the cell itself there is loss of energy by radiation. In the case of a photocell working at about 20° Celsius, about seven per cent of incident energy cannot be used. And then the cell warms up and usually works at about 75° Celsius. There is, hence, more energy that cannot be used and more energy that is radiated.

Yet another source of energy loss is because the electrons knocked out by photons sometimes combine with another atom from which an electron has been removed and release energy to the crystal.

This again represents photon energy that has not been tapped and is a source of heat.

These effects place a limit, called the Shockley-Queisser limit, of 33.7 per cent on the efficiency of a photocell. In the case of a silicon cell, this limit is only about 29 per cent.

Solution

The solutions attempted to get over these limitations are generally to capture the solar energy before it strikes the photocells and convert the energy into a radiation-tuned band of energy that suits photocells, using "hot absorber-emitters". In practice, this has proved challenging — to efficiently capture solar energy and then to have spectral control in the emission.

The absorber needs to capture energy and hold on to it so that the emitter reaches high temperatures. And then the distribution of wavelengths of the emission needs to be controlled, at the high temperature.

So far, this has been managed with specially designed cavity geometry of the absorber, with a very high degree of optical concentration. The combined requirement entails a degree of transmission and reflection losses, with efficiency at about 65 per cent. For the emitter, materials such as the metal, tungsten, have been employed, with no notable success in selecting a narrow band of emission. The result is that the conversion of solar energy to suit photocells has been poor.

The MIT team of Andrej Lenert, David M Bierman, Youngsuk Nam, Walker R Chan, Ivan Celanovic, Marin Soljacic and Evelyn N Wang report that for the absorber, they employ an array of multi-walled carbon nanotubes. And for the emitter they use a silicon/silica crystal. The layout of the arrangement is shown in the picture.

The absorber-emitter ratio was varied from one to 10 to achieve the best results. As the ratio was increased, the temperature of the emitter was kept high by increasing the concentration of sunlight and also by tuning the nanotube array. The communication from the absorber to the emitter was via the silicon material in which both were embedded. The emitter consisted of five alternating layers of silicon and silica, chosen to match the frequencies of emission that suited the photovoltaic cell and also for compatibility with the silicon material in which the arrangement was held.

The results of the arrangement are a threefold improvement over what has been achieved so far and the design is scalable and adaptable. An efficiency of 80 per cent is considered feasible. "The efficiency improvements demonstrated in this work, as well as the promising predictions using a validated model, suggest the viability of nanophotonic solar thermophotovoltaics for efficient and scalable solar energy conversion," the authors say in the paper.

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PLUS POINTS

Nano carriers

Research by an Indian team could provide an important breakthrough in finding a cure to Alzheimer's disease. It has successfully ferried curcumin, a natural compound found in turmeric, to rat brain by trapping it inside polymer nanoparticles. Curcumin has shown promise as a potential cure for neurodegenerative ailments such as Alzheimer's, but delivering curcumin to the brain has been a challenge.


Curcumin is found in turmeric.

Studies have shown that only 15 per cent of curcumin consumed reaches the brain. A major part of it fails to cross the blood-brain barrier or the protective shield around the central nervous system. To overcome this, the researchers synthesised curcumin-loaded nanoparticles using a drug-releasing polymer, poly (lactic-co-glycolic) acid.

They then studied the ability of these nanoparticles to release curcumin in rat brain. They also tested its biocompatibility and accumulation. The efficacy of the nanoparticles in helping regenerate Neural Stem Cells and in improving memory of rats was also studied. Neurodegenrative disorders rob the brain of its ability to regenerate nerve cells. NSC can help in such a scenario as they have the ability to form any type of nerve cell in the brain. In the experiment on NSC collected from rats, curcumin-loaded nanoparticles triggered a proliferation of nerve cells.

When injected into an adult healthy rat, the nanoparticles slowly released curcumin, increasing bioavailability of curcumin in the brain. This suggests that the nanoparticles helped curcumin cross the blood-brain barrier. The researchers induced Alzheimer's disease in rats by treating them with amyloid-beta proteins, known to cause the ailment. Curcumin-loaded nanoparticles inhibited beta amyloid-induced nerve degeneration in the rats, boosting their memory and learning. However, nanoparticles without curcumin showed no significant effect on learning and memory.

The study was conducted by researchers at the Indian Institute of Toxicology Research, Lucknow, the Academy of Scientific and Innovative Research, New Delhi, and the Institute of Genomics and Integrative Biology, Delhi. They found that curcumin-loaded nanoparticles were 500 times more powerful in boosting nerve cell growth than pure curcumin, suggesting that polymer encapsulation helped curcumin stimulate cell growth. The study was published online in the journal *ACS Nano* on 4 December 2013.

BIPLAB DAS/CSE-DOWN TO EARTH FEATURE SERVICE

Ants in space

A colony of ants has set up home in the International Space Station as part of an experiment to see how their behaviour changes in an environment of low gravity. Scientists are hoping to observe how they adapt their foraging ways under changing circumstances and use the data to help develop smarter robots.

The 800 common ants (*Tetramorium caespitum*) — the type we're used to seeing on pavements and picnics — are living in eight compartments with about 100 ants in each. Engineers on the ISS have erected and taken down barriers within the compartments, so the ants have gone from high-density areas to ones of lower density. They have evolved collective behaviour, or what is known in robotics as "distributed algorithms", to move around during foraging, and the experiment should shed some light and how this evolves under varying ant densities in microgravity.


A colony of ants has set up home in the International Space Station as part of an experiment to see how their behaviour changes in an environment of low gravity.

"When ant densities are high, each ant thoroughly searches one small area in a circular, 'random' walk," said Stefanie Countryman, programme director. "When ant densities are low, each ant searches by walking in a relatively straight line, allowing it to cover more ground."

It's hoped the data can be used to build robots that can "forage" for themselves — perhaps by searching for people in a building too dangerous for people to enter. Professor Deborah M Gordon of Standford University, an expert on animal collective behaviour who helped devise the experiment, told Space.com that some really interesting biological changes occurred in microgravity, for example, the way nutrients circulated around cells or the way genes were expressed. "We have a lot to learn about how collective behaviour changes in space," said Professor Gordon. The behaviour of the ants is being beamed back to earth, allowing schoolchildren to take part in the experiment.

THAIR SHAIKH/THE INDEPENDENT

AN ELABORATE ARRAY

TAPAN KUMAR MAITRA EXPLAINS 'INTRACELLULAR COMPARTMENTS'

A full appreciation of eukaryotic cells depends on an understanding of intracellular membranes and the functional compartmentalisation these make possible. Especially prevalent within most eukaryotic cells is the endomembrane system, an elaborate array of membrane-bounded organelles derived either directly or indirectly from the Endoplasmic Reticulum. The ER itself is a network of sacs, tubules and vesicles that separates the ER lumen (interior space) from the surrounding cytosol. The rough ER is studded with ribosomes and is the site of the synthesis of proteins destined for incorporation into various organelles — the nuclear envelope, Golgi complex, endosomes, and lysosomes — or for secretion from the cell.

Both the rough and smooth ER synthesise lipids for cellular membranes and the smooth ER is the site of other processes, including drug detoxification, carbohydrate metabolism, calcium storage and steroid biosynthesis. Before proteins leave the ER in transition vesicles, they undergo the first few steps of protein modification. A host of ER-specific proteins catalyse glycosylation and the folding of polypeptides, elimination of misfolded proteins and the assembly of multimeric proteins.

The Golgi complex plays an important role in die glycosylation of proteins and in the sorting of proteins for transport to other organelles and the plasma membrane. Transition vesicles that bud from the ER fuse with the cis-Golgi network, delivering lipids and proteins to the Golgi complex. Proteins then move through the Golgi stack toward the trans-Golgi network.

During their journey, proteins are further modified as oligosaccharide side chains that are trimmed or glycosylated. Transport vesicles that bud from the trans-Golgi network convey the proteins to their final destinations.

Among the proteins processed by enzymes of the Golgi complex are those intended for secretion from the cell by exocytosis. Secretory vesicles and secretory granules release their contents to the extracellular medium by fusing with the plasma membrane.

Exocytosis, which adds lipids and proteins to the plasma membrane, is balanced by endocytosis, which involves the ingestion of extracellular substances through invagination of the plasma membrane. Receptor-mediated endocytosis is highly specific because it depends on die binding of ligands to receptors on the cell surface. The receptor-ligand complexes are concentrated in clathrin-coated pits and brought into the cell by clathrin-coated vesicles. Once inside the cell, vesicles lose their protein coats and fuse with intracellular membranes, typically membranes surrounding early endosomes, which are sites where ingested material is sorted.

Receptors and membrane lipids are often recycled to the plasma membrane for another round of endocytosis, while material destined for degradation is carried along as early endosomes mature to form late endosomes and lysosomes.

Late endosomes are organelles containing inactive acid hydrolases. ATP-dependent proton pumps in the membrane lower the pH of the endosomal lumen and help to transform the late endosome into a lysosome.

Alternatively, a late endosome may fuse with and deliver its contents to an existing lysosome. In both cases, latent acid hydrolases capable of degrading most biological molecules become active. Phagocytic vacuoles acquire lysosomal enzymes by fusing with early endosomes or forming temporary connections with endosomes. Autophagic vacuoles generally fuse with late endosomes or active lysosomes.

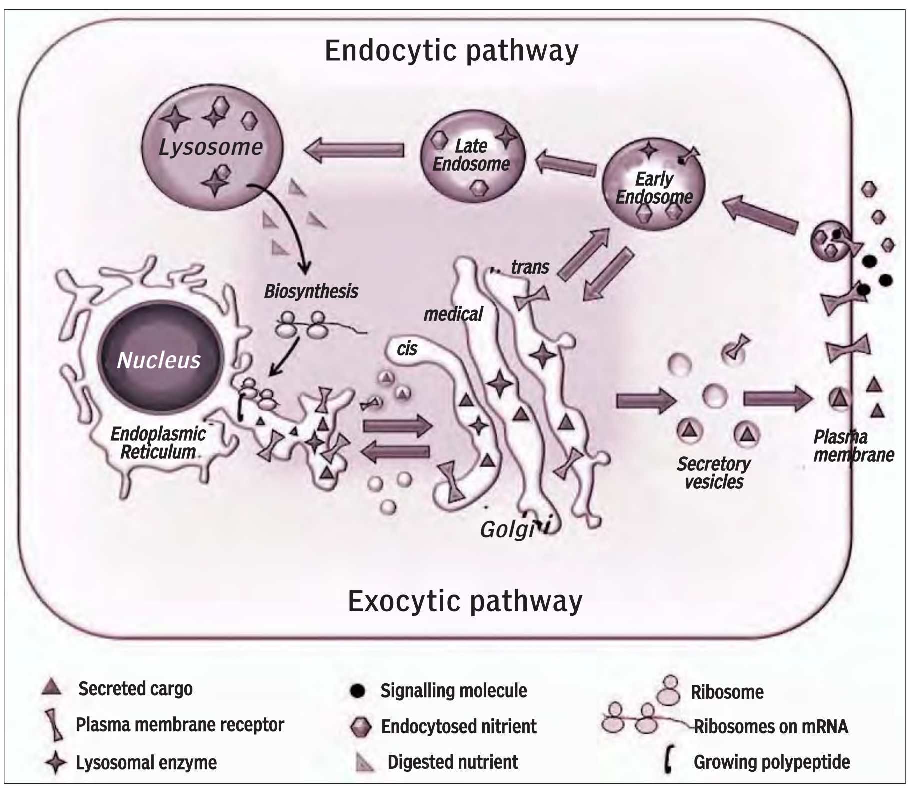
Autophagy is important for recycling cellular structures that are damaged or no longer needed. Transport vesicles carry material throughout the endomembrane system. Coat proteins — which include clathrin, CopI, CopII and caveolin — participate in the sorting of molecules fated for different destinations, and also in the formation of vesicles. The specific set of proteins covering the exterior of a vesicle is an indicator of its origin and its destination within the cell. Once a transport vesicle reaches its destination, it is recognised and bound by tethering proteins attached to the target membrane.

At this point, several additional proteins catalyse fusion with the target membrane. Two families of complementary receptor proteins, the v-Snares and t-Snares, interact physically once the vesicle has reached its target. A third family of proteins, Rab GTPases, locks complementary v- and t-Snares together prior to vesicle fusion. And finally, NSF and a group of Snaps catalyse Snare dissociation following fusion of the vesicle membrane with the target membrane.

Peroxisomes, which are not part of the endomembrane system, appear to increase in number by the division of pre-existing organelles rather than by the coalescence of vesicles. However, there is currently a debate concerning the existence of protoperoxisomes, vesicles that some researchers believe bud off from the ER and develop into new peroxisomes. Some of the peroxisomal membrane lipids are synthesised by peroxisomal enzymes; the rest are conveyed from the ER to peroxisomes by phospholipid exchange proteins.

Most peroxisomal proteins are synthesised by cytosolic ribosomes and are imported post-translationally. Others are believed to travel via a proposed sub-domain of the ER known as the peroxisomal ER (pER). The defining enzyme of a peroxisome is catalase. This enzyme degrades hydrogen peroxide that is generated by various oxidases before the chemical can harm cellular components.

In animal cells, the reactions occurring in peroxisomes are important for detoxification of harmful substances, oxidation of fatty acids and metabolism of nitrogen-containing compounds. In plants, peroxisomes play distinctive roles in the conversion of stored lipids into carbohydrate (glyoxysomes), and in photo-respiration (leaf peroxisomes).



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