

Electric Power from the Sun using Solar Cells

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As the world slowly realizes that our reservoirs of fossils and nuclear fuels are limited and rapidly running out, much attention has been directed towards renewable energy source. Of these, solar energy is by far the most abundant and accessible, clean energy source. On the other hand, in many parts of the world, solar energy is available in staggering amounts. Therefore, there has been an increasing interest in systems which enable the conversion of solar energy into electrical or chemical energy. In this article, solar cells are briefly discussed as one of the most attractive and important techniques of solar energy utilization.

Simply, a solar cell is a device which converts the energy of the sun's radiation directly into electrical energy. Such a device must therefore be able to perform the basic task of absorbing photons and in doing so create mobile charge carriers which can flow and generate an electric current in an external circuit. Solar cells are made of semiconductors (p-type and n-type) and the solar energy absorbed is used to promote the electrons from the valance band to the conduction band of the semiconductor, thereby causing an electron-hole mobile pair of charge carriers. These solar cells can be divided basically into two groups: solid state cells and the photoelectrochemical solar cells.

Solid Solar cells

Solid solar cells can be made in different ways by using p-n junctions, heterojunctions, n-n junctions *etc.* Typical examples of the materials used in fabricating these cells are mono- and polycrystalline silicon, amorphous silicon (actually a silicon hydride), GaAs, CuInSe₂, CuInS₂, CdS, Cu₂S *etc.* The best known semiconductor, silicon, as used in microelectronics, has been used to fabricate these cells with a conversion efficiency of over 20%. The first silicon solar cell was developed in 1954. Since then, the development of solar cell technology has been remarkable. Efficiencies have improved, manufacturing costs have decreased and production has increased. The best efficiency data for a single crystal silicon cell now exceeds 22%. However, such data have been achieved only in laboratories on small cells, using the highest quality silicon and experimentally made in very complicated ways. The efficiencies of the commercially available larger size cells are much less than that, namely, about 15%. Usually a number of such cells are assembled to make a so-called 'module'. For practical applications, several such modules are mounted on a stack and connected with wire to form the final output. This final setup is called an 'array'. The efficiency of a module is inevitably smaller than that of a cell, and the efficiency of an array is still less than that. With silicon cells it is the order of 10%. However, the total cost, not only the cost of solar cells alone but also including the inverter and storage batteries of these silicon-based cells is still quite expensive. In order to solve this problem

enormous effort has been made to find materials for solar cells which are cheaper than silicon. However, this has not yet been achieved.

The basic photovoltaic mechanism in these solid cells is the absorption of a sufficiently energetic photons, *i.e.*, the photons with energies higher than the band gap energy, strike the semiconductor, electrons in the valance band are excited to the conduction band. In the other words, “electrons” and “holes” are generated by the incident light. The generated holes and electrons diffuse in the semiconductor. The two charge carriers are then separated by an electric field. Therefore, a photocurrent flows. However, in order to avoid charge carrier recombination during the diffusion, the concentration of defects in the solid must be small. This imposes severe requirements on the purity of the semiconductor material making a solid state device of the conventional type very expensive.

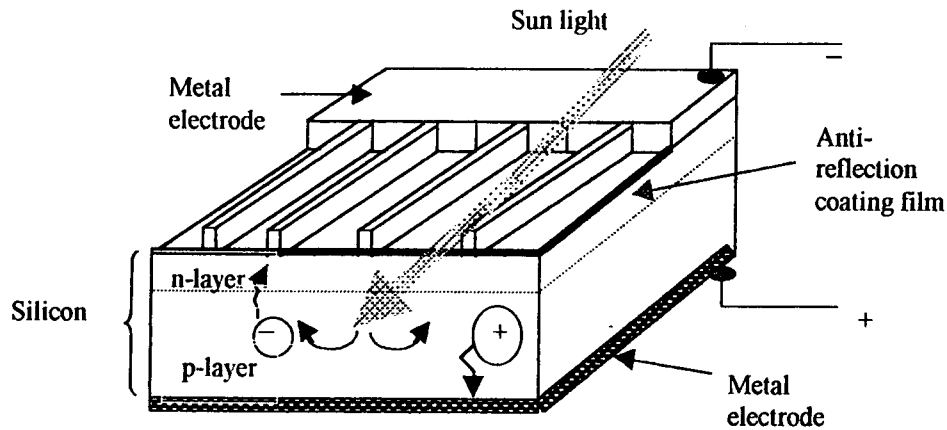


Fig. 1: Schematic view of a typical silicon solar cell.

Photoelectrochemical solar cell.

A photoelectrochemical (PEC) cell is defined as an electrochemical cell having photoactivity. In other words, a cell generating an electric potential or inducing electrochemical reaction by illumination. A typical PEC cell has a low band gap semiconductor electrode, a counter metal electrode and an aqueous solution containing redox couple such as I^-/I_3^- , as shown in the Figure 2. The redox species in the solution undergo rapid exchange of electrons with the electrodes so that an electronic equilibrium is established in the cell.

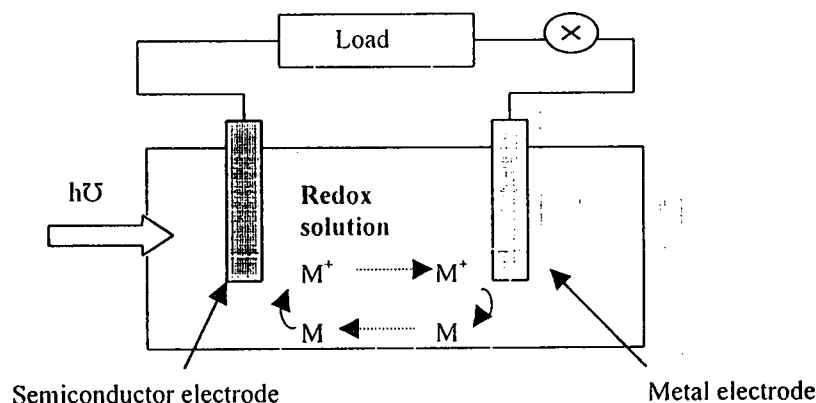


Fig. 2: Schematic view of a typical PEC cell.

These PEC cells can be constructed using both n-type and p-type semiconductors. However, the number of PEC cells studied having p-type semiconductors is much less than those of n-type semiconductors. For practical purposes, applications of PEC cells, especially those of n-type semiconductors, are often restricted by the instability of the semiconductor electrodes. The holes generated in the semiconductor electrode have strong oxidizing properties. They oxidize not only the reduced species of the redox couples but also attack the semiconductor itself. However, the decomposition of the n-semiconductor electrodes may be avoided by using redox species having fairly negative redox potentials but a paradoxical situation does however arise, in that as the redox potentials become more negative, the photovoltages become smaller. In many cases, the corroding reactions can be avoided by using non-aqueous solutions instead of aqueous ones. For example n-silicon is stable in pure, dry methanol or acetonitrile, and PEC cells of high conversion efficiencies are found with such a system. However, the choice of the semiconductor is restricted due the size of the band gap of the semiconductor too and therefore semiconductors with high band gaps cannot be employed in these cells. Therefore, in recent years, considerable effort has been diverted to develop a dye-sensitized photoelectrochemical cell based on nano-porous films of high band gap semiconductors.

Dye sensitized Photoelectrochemical cells

Some n-type semiconductors adsorb organic dyes (sensitizer) and the role of the sensitizer is the same as that of chlorophyll in the plants. Typical examples for the sensitizer are Ruthenium bipyridyl, Rose Bengal, Rhodamine B, Cyanadin, *etc.* In these cells the light harvesting is carried out by a sensitizer which initiates electron transfer events leading to charge separation. This makes the use of expensive solid state components in the system unnecessary. TiO_2 , ZnO , SnO_2 are the most widely used n-type semiconductors for these cells. The dye-sensitized cells differ from the conventional semiconductor devices in the sense that they separate the function of the light absorption from charge carrier transport. In the case of n-type materials such as TiO_2 , a current is generated when a photon absorbed by a dye molecule gives rise to electron injection into the conduction band of the semiconductor. To complete the circuit, the dye must be regenerated by electron transfer from the redox species in solution, which is then reduced at the counter electrode. Although many attempts to use dye sensitized photoelectrochemical cells in energy conversion have been made before, the efficiency of such devices have been extremely low and practical applications have seemed to be remote. In these attempts, Michel Gratzel and co workers, K. Tennakone and colleagues have fabricated and reported solar cells with possible ways to achieve remarkably high efficiencies, high current voltages based on TiO_2 and SnO_2/ZnO semiconductors respectively. Though these dye sensitized photoelectrochemical devices are cheap and the energy conversion efficiencies reasonable, practical application still requires resolution of fabrication problems and improvement of the long-term stability. The main problem is encapsulation of the cell with a liquid electrolyte. Completely foolproof sealing is difficult and the loss of volatile components in the electrolyte cannot be ensured. The problem is aggravated by the build up of pressure inside the cell due to gaseous degradation products of the electrolyte. The ideal solution to this problem would be the replacement of the liquid electrolyte by a high band-gap solid hole conductor. However, the choice of the hole conductor is highly restrictive and a fully solid state dye sensitized solar cells present different type of fabrication problems that are now being investigated. A suggestion has been made to use solid electrolytes instead of a liquid to avoid the difficulties of sealing. Obviously as ionic transport is diffusion limited, high short-circuit photocurrent, (and therefore reasonable efficiency) cannot be expected from a cell utilizing a solid electrolyte, because the mobility of ions in solid electrolytes are generally lower than that of liquids. Gratzel and co-workers and K. Tennakone and colleagues have also reported possible ways of fabricating dye sensitized cells without using liquid electrolytes, (dry cells) with high efficiencies, photo-currents and voltages with organic (2,2',7,7'-tetrakis (N,- di -p- methoxyphenyl-amine)9,9', spirobifluorene) and p-type inorganic materials (*e.g.*, CuI).

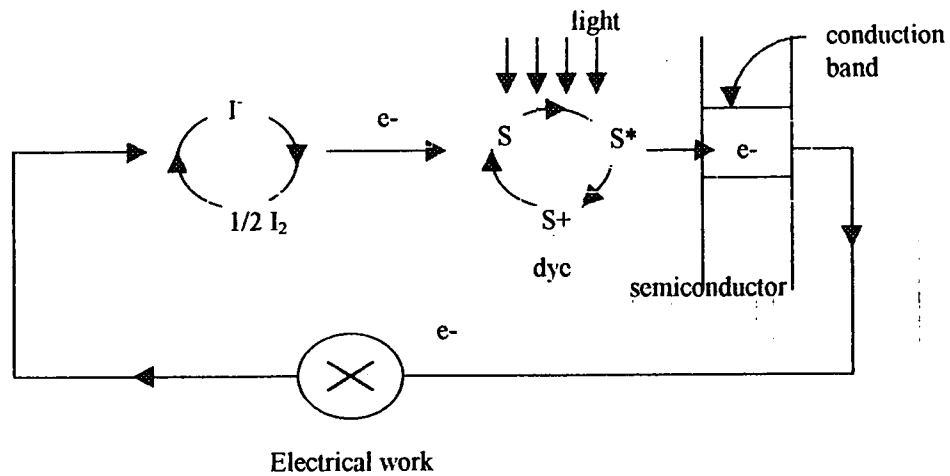


Fig. 3: Schematic view of a typical dye sensitized PEC cell.

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