Dye sensitized solar cells

What is DSSC

- A **dye-sensitized solar cell** (**DSSC**) is a low-cost solar cell belonging to the group of thin film solar cells. It is based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a photoelectrochemical system.

- First version of a dye solar cell, also known as the **Grätzel** cell, was invented by Michael Gratzel.

Solar cell

- In a traditional solar cell, it is made from two doped crystals, one doped with n-type impurities (n type semiconductor), which add additional free conduction band electrons, and the other doped with p-type impurities (p type semiconductor), which add additional electron holes.

- When placed in contact, some of the electrons in the n-type portion flow into the p-type to "fill in" the missing electrons, also known as electron holes. Eventually enough electrons will flow across the boundary to equalize the Fermi levels of the two materials. The result is a region at the interface, the p-n junction, where charge carriers are depleted and/or accumulated on each side of the interface. In silicon, this transfer of electrons produces a potential barrier of about 0.6 to 0.7 V.

How it works

- When placed in the sun, photons of the sunlight can excite electrons on the p-type side of the semiconductor, a process known as photoexcitation. In silicon, sunlight can provide enough energy to push an electron out of the lower-energy valence band into the higher-energy conduction band . As the name implies, electrons in the conduction band are free to move about the silicon. When a load is placed across the cell as a whole, these electrons will flow out of the p-type side into the n-type side, lose energy while moving through the external circuit, and then flow back into the p-type material where they can once again re-combine with the valence-band hole they left behind. In this way, sunlight creates an electrical current

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- The dye-sensitized solar cells (DSC) provides a technically and economically credible alternative concept to present day p–n junction photovoltaic devices.

- In contrast to the conventional systems where the semiconductor assume both the task of light absorption and charge carrier transport the two functions are separated here. Light is absorbed by a sensitizer, which is anchored to the surface of a wide band semiconductor.

- Charge separation takes place at the interface via photo-induced electron injection from the dye into the conduction band of the solid.

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- Carriers are transported in the conduction band of the semiconductor to the charge collector. The use of sensitizers having a broad absorption band in conjunction with oxide films of nanocrstalline morphology permits to harvest a large fraction of sunlight.

- Nearly quantitative conversion of incident photon into electric current is achieved over a large spectral range extending from the UV to the near IR region. Overall solar (standard AM 1.5) to current conversion efficiencies (IPCE) over 10% have been reached.

- There are good prospects to produce these cells at lower cost than conventional devices. Here we present the current state of the field, discuss new concepts of the dye-sensitized nanocrystalline solar cell (DSC) including heterojunction variants and analyze the perspectives for the future developmentof the technology

Photovoltaic devices

- Photovoltaic devices are based on the concept of charge separation at an interface of two materials of different conduction mechanism.

  To date this field has been dominated by solid-state junction devices, usually made of silicon, and profiting from the experience and material availability resulting from the semiconductor industry.

  The dominance of the photovoltaic field by inorganic solid-state junction devices is now being challenged by the emergence of a third generation of cells, based, for example, on nanocrystalline and conducting polymers films

Low cost DSSC

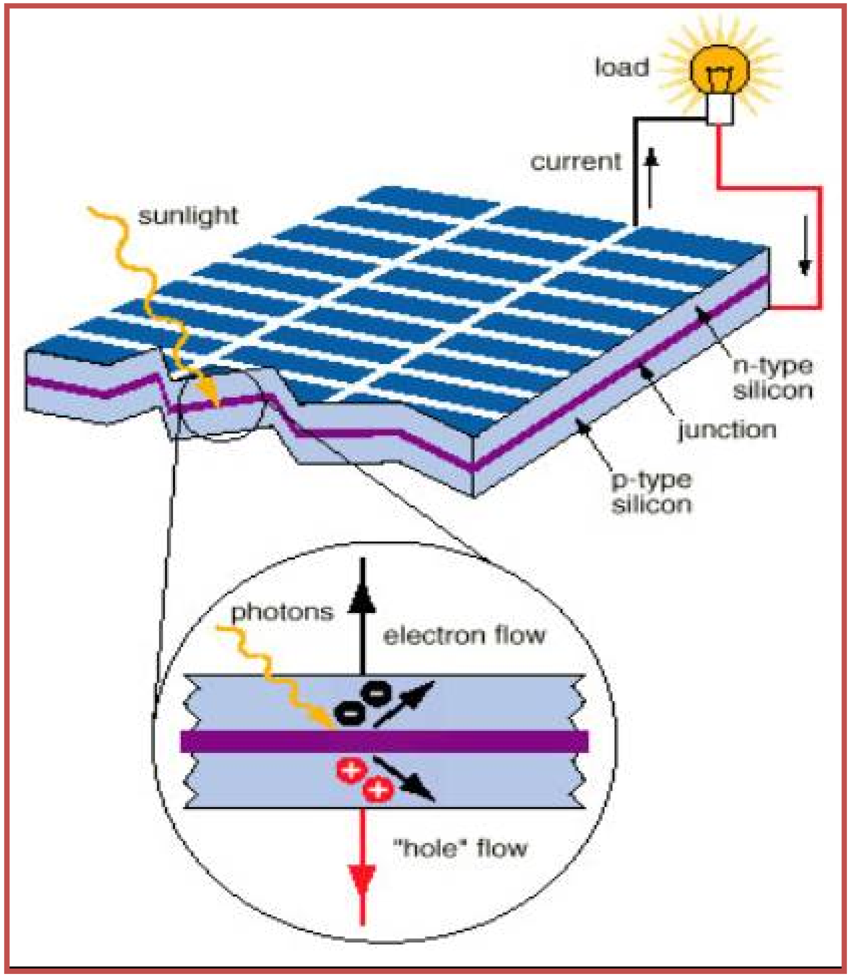
- These offer the prospective of very low cost fabrication and present attractive features that facilitate market entry. It is now possible to depart completely from the classical solid-state junction device, by replacing the contacting phase to the semiconductor by an electrolyte, liquid, gel or solid, thereby forming a photo-electrochemical cell.

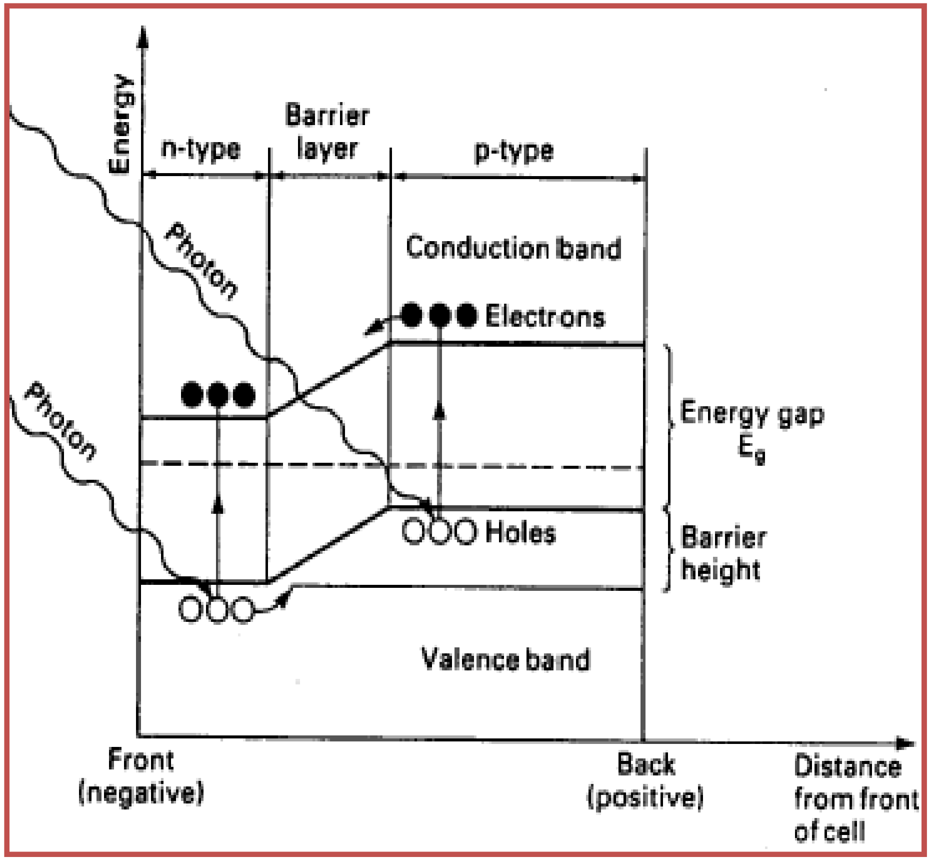
- The phenomenal progress realized recently in the fabrication and characterization of nanocrystalline materials has opened up vast new opportunities for these systems.

Operating details

- At the heart of the system is a mesoporous oxide layer composed of nanometer-sized particles which have been sintered together to allow for electronic conduction to take place. The material of choice has been TiO_2 (anatase) although alternative wide band gap oxides such as ZnO , and Nb_2O_5 have also been investigated.

- Attached to the surface of the nanocrystalline film is amonolayer of the charge transfer dye. Photo excitation of the latter results in the injection of an electron into the conduction band of the oxide. The original state of the dye is subsequently restored by electron donation from the electrolyte, usually an organic solvent containing redox system, suchas the iodide/triiodide couple.





The p-n junction under illumination (on the right). A photon induced hole-electron pair is separated by the local field of the junction.

How it works

- The regeneration of the sensitizer by iodide intercepts the recapture of the conduction band electron by the oxidized dye.
- The iodide is regenerated in turn by the reduction of triiodide at the counter electrode the circuit being completed via electron migration through the external load.
- The voltage generated under illumination corresponds to the difference between the Fermi level of the electron in the solid and the redox potential of the electrolyte.
- Overall the device generates electric power from light without suffering any permanent chemical transformation.

Typical Gratezel cell

- A modern DSSC, the Graetzel cell, is composed of a porous layer of titanium dioxide nanoparticles, covered with a molecular dye that absorbs sunlight, like the chlorophyll in green leaves. The titanium dioxide is immersed under an electrolyte solution, above which is a platinum-based catalyst .

- As in a conventional alkaline battery an anode (the titanium dioxide) and a cathode (the platinum) are placed on either side of a liquid conductor (the electrolyte).

- Sunlight passes through the transparent electrode into the dye layer where it can excite electrons that then flow into the titanium dioxide. The electrons flow toward the transparent electrode where they are collected for powering a load. After flowing through the external circuit, they are re-introduced into the cell on a metal electrode on the back, flowing into the electrolyte. The electrolyte then transports the electrons back to the dye molecules.

Dye sensitized solar cells

- Dye-sensitized solar cells separate the two functions provided by silicon in a traditional cell design. Normally the silicon acts as both the source of photoelectrons, as well as providing the electric field to separate the charges and create a current. In the dye-sensitized solar cell, the bulk of the semiconductor is used solely for charge transport, the photoelectrons are provided from a separate Photo sensitive dye. Charge separation occurs at the surfaces between the dye, semiconductor and electrolyte.

- The dye molecules are quite small (nanometer sized), so in order to capture a reasonable amount of the incoming light the layer of dye molecules needs to be made fairly thick, much thicker than the molecules themselves.

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- Dye-sensitized solar cells based on titanium dioxide (TiO_2) are promising low-cost alternatives to conventional solid-state photovoltaic devices based on materials such as Si, CdTe and $CuIn_{1-x}Ga_xSe_2$. Despite offering relatively high conversion efficiencies for solar energy, typical dye-sensitized solar cells suffer from durability problems that result from their use of organic liquid electrolytes containing the iodide/tri-iodide redox couple, which causes serious problems such as electrode corrosion and electrolyte leakage. Replacements for iodine-based liquid electrolytes have been extensively studied, but the efficiencies of the resulting devices remain low.

Use of Cs Sn I3

- Here it is shown that the solution-processable p-type direct bandgap semiconductor $CsSnI_3$ can be used for hole conduction in lieu of a liquid electrolyte. The resulting solid-state dye-sensitized solar cells consist of $CsSnI_{2.95}F_{0.05}$ doped with SnF_2, nanoporous TiO_2 and the dye N719, and show conversion efficiencies of up to 10.2 per cent (8.51 per cent with a mask). With a bandgap of 1.3 electronvolts, $CsSnI_3$ enhances visible light absorption on the red side of the spectrum to outperform the typical dye-sensitized solar cells in this spectral region.

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Inorganic solar cell system that consists of the p-type direct bandgap semiconductor $CsSnI_3$ and n-type nanoporous TiO_2 with the dye N719 (*cis*-diisothiocyanato-bis(2,2′-bipyridyl-4,4′-dicaboxylato) ruthenium(II) bis-(tetrabutylammonium)). We show that $CsSnI_3$ is well fitted for this purpose because of its energy gap of 1.3 eV and a remarkably high hole mobility of μ_h = 585 $cm^2\ V^{-1}\ s^{-1}$ at room temperature. We found that $CsSnI_3$ is soluble in polar organic solvents, such as acetonitrile, *N*,*N*,-dimethylformamide and methoxyacetonitrile.

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- Consequently, it is solution-processable and can be transferred into TiO_2 pores at a molecular level to make intimate contacts with dye molecules and TiO_2.

- The results show that doping of $CsSnI_3$ with F and SnF_2 dramatically improves the photocurrent density (J_{SC}) and power conversion efficiency (η). At an optimum molar concentration of 5% F and 5% SnF_2, the cell exhibits the highest efficiency so far reported for a solid-state solar cell equipped with a dye-sensitizer: η = 10.2% under the standard air mass 1.5 (AM 1.5) irradiation (100 mW cm^{-2}), and η = 8.51% with a mask. The observed value is close to that of the highest reported performance N719-dye-containing Grätzel cell ($\eta \approx$ 11%).

Natural dyes as photosensitizers for dye-sensitized solar cell

- The dye-sensitized solar cells (DSC) were assembled by using natural dyes extracted from black rice, capsicum, erythrina variegata flower, rosa xanthina, and kelp as sensitizers. The I_{SC} from 1.142 mA to 0.225 mA, the V_{OC} from 0.551 V to 0.412 V, the fill factor from 0.52 to 0.63, and P_{max} from 58 µW to 327 µW were obtained from the DSC sensitized with natural dye extracts. In the extracts of natural fruit, leaves and flower chosen, the black rice extract performed the best photosensitized effect, which was due to the better interaction between the carbonyl and hydroxyl groups of anthocyanin molecule on black rice extract and the surface of TiO_2 porous film.

Natural dye sensitized solar cells

- A food pigment (Monascus yellow) extracted from *Monascus* fermentations (red yeast rice) has been studied as a novel sensitizing dye for dye-sensitized solar cells (DSCs).

- The photocurrent action spectrum was in agreement with the absorption spectrum of the dye adsorbed on a nanocrystalline-TiO_2 electrode. The DSC fabrication process has been optimized in terms of the rinsing solvent used after dye adsorption and the dye-uptake duration. After optimizing nanocrystalline-TiO_2 electrodes and pH conditions, the resulting maximal photovoltaic characteristics were an open-circuit voltage of 0.57 V, a short-circuit current of 6.1 mA cm^{-2}, and a fill factor of 0.66, yielding an energy conversion efficiency of 2.3%.

- The blue-shift of absorption wavelength of the black rice extract in ethanol solution on TiO_2 film and the blue-shift phenomenon from absorption spectrum to photoaction spectrum of DSC sensitized with black rice extract are discussed in the paper. Because of the simple preparation technique, widely available and low cheap cost natural dye as an alternative sensitizer for dye-sensitized solar cell is promising.

Use of different natural source as dye

- The alcohol extracts of black rice, erythrina variegata flower, rosa xanthina flower, capsicum and kelp were obtained according to following step: The clean fresh of black rice, erythrina variegata flower, rosa xanthina, capsicum and kelp were dried at 40 °C in a vacuum drying oven; after crushed into a fractionlet, the raw materials were put into a 95 wt.% ethanol solution and kept in ambient temperature without exposing to direct sunlight for several weeks to extract natural dye in the solution adequately, solid residues were filtrated out and the natural dye solutions were concentrated to one quarter with a rotatory evaporator at 40 °C, then natural dye solutions were refined by chromatogram method. After that, the natural dye sensitizer alcohol solutions were prepared.