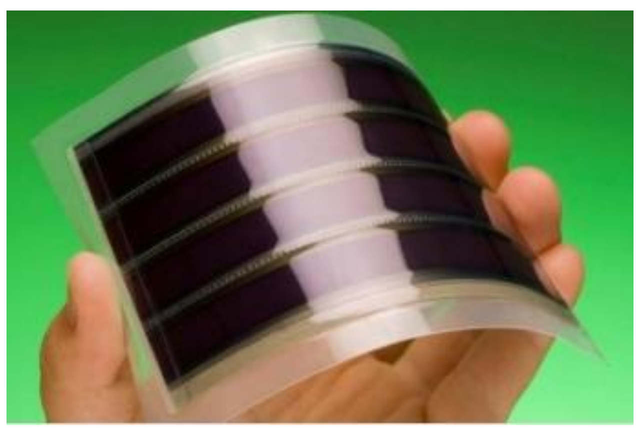
“Dye Sensitized Solar Cells and Porphyrins”

In today’s world, there are many major environmental problems such as pollution, climate change, global warming, waste disposal, etc. One of the main problems is the reduction of natural resources, which has been forcing some of Earth’s inhabitants to plan for several alternative energy sources such as energy based on wind, solar, geothermal, and biomass. Unfortunately, the largest energy source is fossil fuels (oil, coal, and natural gas) which are not renewable. Fortunately, though, the sun is a renewable resource – we will never run out of solar energy. Sunlight is the most abundant, cheapest, safest, and cleanest energy source. This energy can be used directly for electricity as well as for heating. Because of this, there is potential with solar-to-electric energy to replace fossil fuels. The best tool for this is with photovoltaic cells. Many of these solar cells function with the use of dyes, thus creating dye sensitized solar cells (DSSC’s).

Dye sensitized solar cells were invented in 1991 by Professor Michael Graetzel and Dr. Brian O’Reagan at Ecole Polytechnique de Lausanne, Switzerland. At this time, they were known as Graetzel cells, or “gcells”. In these cells, dye molecules were used to absorb light on a nanocrystalline film of titanium dioxide (TiO_2). This process is compared to photosynthesis with the mimicking of nature’s absorption of light energy[1]. DSSC’s have been more attractive than the conventional photovoltaic cells due their flexibility, transparency, and low production costs[2]. Another striking feature is how they can convert natural as well as artificial light into energy to power extensive ranges of



electric devices – they can be used indoors and outdoors. These cells also have a higher temperature performance, meaning it does not degrade with amplified temperature therefore they will continue to work efficiently in direct sunlight. The manufacturing process is low-energy and high efficiency with the use of abundant, inexpensive, and eco-friendly nanomaterial.

These DSSC's can be incorporated in a variety of devices. They can potentially power consumer electronics (eReaders, smart watches, Bluetooth keyboard, remote control, tablet accessories, etc.), sensors and actuators (smoke detectors, motorized blinds, wireless sensors, location sensors, etc.), and retail (electronic price labels, powered smart cards, etc.). Products that are actually currently available are the Leia Media solar powered eReader, Argus Security solar powered smoke detector, solar power keyboard Folio for iPad Air 2, and solar powered real time location sensor (RTLS). The eReader is an environmentally-friendly method of delivery for newspaper content. The mentioned smoke detector is a wireless device that requires 8-10 hours a day of indoor light and can continue to operate in the dark. The solar powered keyboard can be charged with ambient light, removing the need to change batteries or the use of a powered charger. The RTLS is the first self-powering wireless indoor tracking system that offers the capability to track positions in hospitals and care homes[1].

These solar cells are relatively easy to create. In fact, there are advanced undergraduate laboratories that perform experiments creating and incorporating dyes for DSSC's. They are made up of several layers. First, there is a glass layer, which is transparent and allows light to pass through the cell. Then there is a tin dioxide coating that is a transparent, conductive layer. Next there is the titanium dioxide layer which holds the dye in place. There needs to be a photoactive dye that can be sensitized by light. This dye will collect photons of light and produce excited electrons to cause a current in the cell. This acts like chlorophyll in photosynthesis. Next there is an iodide electrolyte layer that is a source for electron replacement. This closes the circuit so electrons are returned to the dye. Finally there is a graphite layer that is coated on the bottom. It acts as a conductor and does not allow light to pass through the bottom layer. This movement of electrons creates energy that can be harvested in some kind of storage device such as a rechargeable battery or super capacitor[1, 2].

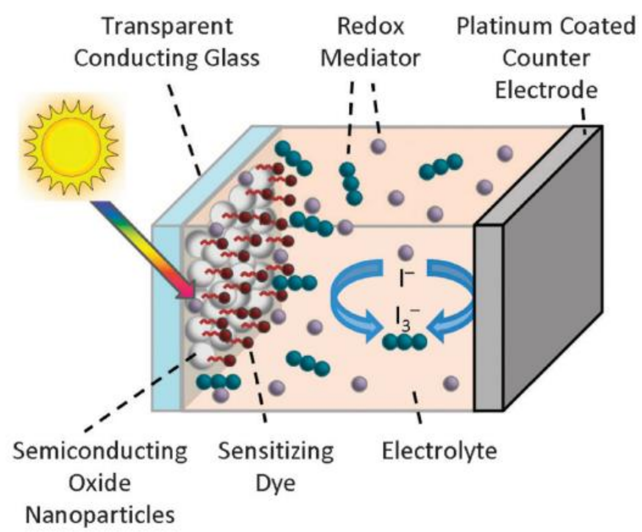
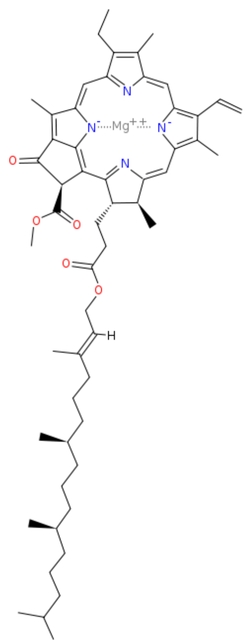


Fig. 1 Schematic illustration of a typical dye-sensitized solar cell (DSSC).

The most important component is the dye sensitizer. The structure of this is extremely imperative for achieving high photovoltaic performance. Many of these dyes are inorganic containing a transition metal in the structure. In order for the dye to be suitable, it must have certain properties such as high photo and thermal stability, strong absorption in the visible range, good solubility, and nontoxicity, bonds strongly to the semiconductor surface, and a suitable high redox potential[3, 4].

The most efficient sensitizers have been found to be polypyridyl ruthenium complexes, having a light to electric power conversion efficiency of up to 11%. Unfortunately, ruthenium is a rare metal which makes it expensive[5]. Because of this, scientists are constantly working on creating different inexpensive dyes for these solar cells. In photosynthesis, chlorophyll is responsible for creating energy by converting light absorbed into a plant. Chlorophyll is made from a porphyrin ring that holds magnesium as its center. Because of this, many dye sensitized solar cells are sensitized by porphyrin dyes. Porphyrins are highly conjugated macrocycles that consist of four pyrole rings fused together. These dyes are suitable because of their thermal, electronic, and photovoltaic properties[6]. They are also cheap, stable, less toxic, metal-coordinating, easy to synthesize and modify, etc. They absorb in the visible and the near infrared (NIR) region[7].



While porphyrins have all these attractive features, there are some drawbacks. Unfortunately, there are usually low yields when synthesizing the dyes and they do not have long term stability. In order for future industrial application, the devices need a long lifetime[8]. Because of this, scientists are very interested in modify the structures to incorporate into DSSC's. They can do this by placing different metals in the center as well as adding different functional groups that can help stabilize and preserve the dye. When it is metal free, the photovoltaic conversion efficiency is lower than when it has a metal such as zinc. Other reasons they show lower performance is due to the light limitation for absorption, low short circuit value, and reduced solar light distribution matching. To increase their performance, scientists experiment with either elongating the Π system or by changing the symmetry. These changes can affect absorption bands.

Once a DSSC is functional and efficient, the next step is for the generated electricity to be stored in some type of storage device. The company that created the previously mentioned solar powered products also has engineers that design Energy Harvesting (EH) systems. These systems are particularly capable of pairing solar powered modules to energy storage devices. Products that have heavy energy use usually use Low Self Discharge Nickel Metal Hydride (LSD NiMH) batteries. These batteries have a "low self-discharge" rate so they are ideal for electronic products that need long term storage. They also provide standby and light usage. For products with a light energy load, Lithium Manganese Coin Cells (ML) is more preferred. These batteries have a good self-discharge rate which helps keep energy from being lost from the battery. These are more for wireless communication products that need a fast discharge current when transmitting and receiving sequences such as Bluetooth. For many medium to light load usage applications, Lithium Ion Phosphate (LifePO4) batteries are used. These have a higher life cycle and "maximum instantaneous discharge current rate". These batteries are nice because they use more environmentally friendly materials and they have a greater stability and safety compared to other lithium batteries. Another type of battery is the flexible FPC Lithium-Ceramic Battery (FLCB). These batteries are ultra-thin, flexible and bendable, and can be used with flexible solar powered products. A more recent battery technology is with solid state batteries which use a solid state electrolyte. These batteries can be charged in low light conditions and also have a very high life cycle; because of this they are relatively expensive. Supercapacitors are also suitable to harvest energy. They have a high life cycle which is a good use for devices that require a continual charge and discharge cycle[1].

With the abundance of fossil fuel resources decreasing, it is important to have an alternate plan for energy. The other popular renewable resource is wind, but it is harder to install a wind system in a residential area. Solar energy has been gaining popularity due to its size and convenience. There are none out there, though, that are 100 % efficient. Because of this scientists are constantly trying different ways to increase the efficiency of solar panels and devices. With the knowledge and efficient solar products increasing and fossil fuel resources decreasing, homes will likely be shifting their energy sources.

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