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"Development of plastic dye-sensitized solar cells by printing technology"

By combining low-temperature deposition of titanium dioxide (TiO2) porous films with printing technology, the ability to produce low-cost dye-sensitized solar cells (DSSCs) on plastic substrate is now available. With energy conversion efficiencies up to 7%, these lightweight flexible plastic solar cells are now poised for large scale commercial production and will see extensive application to portable applications. DSSC technology is environmentally friendly because the fabrication processes are extremely energy efficient and the constituent materials can be easily recovered and recycled. An easy-to-assemble dye-sensitized solar cell kit was developed as a learning tool to teach school children about energy and the environment.

1. Fabrication of dye-sensitized solar cells by low-cost chemical processes

Dye-sensitized solar cells (DSSCs) have now reached practical efficiency levels that are high enough to compete with conventional solar cells, and can be fabricated inexpensively in open air conditions. The development of dye-sensitized semiconductors grew out of efforts to increase the sensitivity of photosensitive materials, and photoelectochemical research has a long history stretching back more than 40 years.

Recently, energy conversion efficiencies up to 11% have been achieved using very large sheets of dye-sensitized nanocrystalline porous titanium oxide (TiO2) film with a surface roughness coefficient of greater than 2000. Dye-sensitized porous TiO2 films are highly light absorbent, and are thus able capture diffuse visible light on overcast days outdoors and from artificial light sources indoors very efficiently. As the ubiquitous network society continues to evolve, these lightweight unbreakable and flexible photovoltaic cells show enormous promise for replacing the vast number of batteries that people use in the mobile devices that they carry around. In the deposition of semiconductor nanocrystalline porous TiO2 film— the heart of the DSSC fabrication process— typically a paste that consists of nano particulate TiO2 suspended in a resin binder is coated onto a substrate, which is then sintered by firing at a high temperature of 450°C or above.

This forms the photovoltaic layer that absorbs or is sensitive to the dye. Until recently, expensive transparent conductive glass coated tin oxide was used for the substrate, so the substrate alone accounted for close to half the manufacturing cost. If this glass substrate could be replaced by plastic film, this would greatly simplify the fabrication process and also permit continuous roll-to-roll manufacturing such as used to make textiles that would dramatically reduce the production costs.

2. Printable plastic dye-sensitized solar cells

With the goal of producing electrodes for DSSCs using plastic substrate, the authors developed an innovative new type of paste for the porous TiO_2 that is cured by dehydration drying at low temperatures below 150°C and thus doesn't require high-temperature firing. Not including the binder, the paste is a viscous composite that consists of nanocrystalline TiO_2 particles and titanium dioxide aqueous sol as a particle binder that is dispersed in branched alcohol-water. The paste is coated onto the substrate by screen printing, and the nanocrystalline porous film is cured by applying dry heat under 150°C and dehydration-condensation reaction. Using ITO transparent conductor coated PEN (polyethylene naphthalate) for the substrate, Ru complex dye N719 for the sensitizer, and iodine in 3-methoxypropionitrile for the electrolyte, we fabricated dye-sensitized solar cells with an active area of 0.23 cm^2 that yielded energy conversion efficiencies of 5.9% in strong light (1 sun = 100 $mWcm^{-2}$) and 7% in low light.

Next we developed a prototype practical module that interconnected the solar cells to investigate ways of fabricating grids for energy collection and sealing materials using similar low temperature processing. Using a deformable plastic substrate, we were able to dramatically reduce the thickness of the electrolyte (the amount of electrolyte used) to 1/5 the usual thickness, and because the light filtering effect caused by the coloring of the electrolyte was eliminated, incident light from both sides of the electrode could be effectively used. Photo 1 shows what the parallel-type large-area prototype module looks like. Photo 2 shows the large-area prototype plastic integrated modules (0.8 X 2.1 meters) that are made up of 10-cm-square submodules (6-cell arrays, 4.2 V each). The modules were exhibited at the 1st International Photovoltaic Power Generation Expo in 2008 (PV EXPO 2008) and efficiently generated 112 volts of electricity using the diffuse artificial light in the exhibition hall. This printable technology that doesn't involve high-temperature firing makes it possible to fabricate high-performance dye-sensitized solar cells at very low cost. The constituent materials can also be readily reused: the inorganic materials in the electrodes (TiO_2, ITO, and metal) and plastic can be stripped out and recovered by mechanical deformation, and the dye and electrolyte can also be recovered by washing.

3. Supporting environment and energy education

Photo 3 shows a DSSC kit developed by Peccell Technologies that can be easily assembled by students without any vacuum or high-temperature processing. In assembling these models, students can experience the entire process from application of the paste to assembly of the energy-producing cell. The solar cell kit can be easily put together from a handful of ordinary components. It has proven to be an effective teaching tool, and has been widely distributed to classrooms around the country.