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## Progress in Dye-Sensitised Photovoltaics

The 12th International Conference on the Conversion of Solar Energy into Photovoltaic Power and Storage, IPS-12, was held in Berlin from 9th to 14th August. This is the principal technical conference on photovoltaics and solar energy storage worldwide, and is held every two years. This year there were over 400 delegates, with most coming from academic institutions. The major surprise of the conference was the growth in activity in dye-sensitised photovoltaics (DSPVs), with over half of the presentations and posters being related to this topic.

The basic science behind dye-sensitised photovoltaic cells is well known (1). Cells are typically constructed from a glass/ITO electrode coated with a thin layer of dyed titania ( $\text{TiO}_2$ ). The  $\text{TiO}_2$  is dyed with ruthenium-based compounds, such as  $\text{Ru(II)(2,2'-bipyridyl-4,4'-dicarboxylate)}_2(\text{NCS})_2$ , and then impregnated with a liquid electrolyte containing the  $\text{I}^-/\text{I}_3^-$  couple as a regenerative redox shuttle between the dye and the counter electrode (platinum-coated glass/ITO). The cell power-conversion efficiency can be remarkably high, with figures of > 10 per cent under AM1.5 conditions being quoted, due to the broad absorption spectrum of the dye (extending into the infrared region for some dyes (2)) and the absence of significant charge recombination in the (*n*-type) semiconducting  $\text{TiO}_2$ .

While the complex photophysics and chemistry of this system are still challenging, some consensus emerged as to what makes these cells work as well as they do:

- The more advanced ruthenium-based dyes show evidence for long-term stability, provided that proper sealing of the cell is achieved to prevent ingress of oxygen and water (which initiate free-radical attack of the dye).
- Electrons move primarily through  $\text{TiO}_2$  by

diffusive processes, although under some conditions this is likely to be field-assisted.

- The extraordinarily slow time-constants (typically hundreds of ms) of the cell in response to chopped illumination is almost certainly due to extensive trapping of electrons in surface states on the  $\text{TiO}_2$ .
- Increased cation (for example  $\text{Li}^+$ ) penetration into the pores of the  $\text{TiO}_2$  probably improves the efficiency of the electron transfer process and certainly assists the ionic (iodide) current in the liquid phase. The net benefit is an increase in cell current, although the type of cation also affects the cell open-circuit potential in ways that are not yet clearly understood.
- The electron-hole recombination may be retarded by virtue of the fact that the iodide 'hole-carrier' is negatively charged.
- The electron-injection kinetics (not the efficiency) are relatively insensitive to the dye type and very sensitive to the surface condition of the  $\text{TiO}_2$ .

Perhaps the highlight of the conference was a 'live' demonstration of DSPV technology by Dr K. P. Hanke, Institut für Angewandte Photovoltaik, Gelsenkirchen, Germany, who used a prototype module to turn an electric fan, during his lecture on issues involved in cell scale-up.

In summary, the work presented at this conference has shown that dye-sensitised photovoltaic cells are continuing to show promise as practical devices, and may, in the longer term, open up a new market for ruthenium and platinum-based materials.

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