

semiconductor film (described in Section 15.2.2) would improve the IPCE performance in the long-wavelength region. In addition, the energy gaps, ΔE_1 and ΔE_2 , as the driving forces for electron-transfer processes (Figure 15.6) are sure to result in energy loss. If we can construct good systems performing with smaller ΔE_1 and ΔE_2 because of molecular design of the photosensitizers, the efficiency can be improved. Improvement of V_{OC} is also important for achievement of higher efficiencies. As shown above, decreased V_{OC} is mainly attributed to recombination between the injected electrons and the redox mediator, I_3^- (dark current). Molecular design of the photosensitizers and/or blocking effect of dark current using adsorbate, such as TBP would improve the V_{OC} . Development of new semiconductor materials, whose conduction-band level is more negative than that of TiO_2 , and the new redox mediator, whose redox potential is more positive than that of the I^-/I_3^- redox, would also increase V_{OC} of DSSC. Presently, however, good semiconductor materials and redox mediators exceeding the combination between the TiO_2 electrode and the iodine redox have not been found.

(b) Long-term stability for outdoor applications

As shown in Section 15.4.1.2, satisfactory long-term stability of sealed cells has already been achieved under relatively mild testing conditions (low temperatures and no UV exposure). For outdoor applications, additional stability testing under more rigorous conditions will be required (e.g. high temperature at near $80^\circ C$, high humidity, and UV exposure).

(c) Solid electrolyte

As shown in Section 15.3.4, development of solid-state electrolytes in DSSCs is essential for developing a cell with long-term stability and is critical for commercialization. Several organic and inorganic materials, such as OMeTAD, polypyrrole, CuSCN, and CuI, have been investigated as solid electrolytes. Presently, however, performance of solid-state DSSCs using these materials are inferior to that of DSSC using liquid electrolytes. It is very difficult to form a good solid–solid interface, which will produce a high solar cell performance because of the large surface area of the nanoporous TiO_2 electrode. On the other hand, liquid electrolytes can easily penetrate into the nanoporous TiO_2 electrode. One of the factors determining high performance of DSSC is the easy formation of solid–liquid interface between the nanoporous TiO_2 electrode and liquid electrolyte. Therefore, electron-transfer processes can occur at most part of the interface. Low electron (or hole) conductivity of the solid electrolyte materials would also determine low performance of solid-state DSSC. CuI is one of the more attractive materials used for solid electrolyte in DSSC and 4% efficiency was attained using TiO_2 /dye/CuI system, as shown in Section 15.3.4. For commercial applications, improvement of the cell performance and long-stability testing of the cell are required because long term stability of the CuI system has not been clarified. Development of new solid electrolyte materials is also desired.

REFERENCES

1. Gerischer H, Tributsch H, *Ber. Bunsen-Ges. Phys. Chem.* **72**, 437–445 (1968).
2. Tributsch H, Gerischer H, *Ber. Bunsen-Ges. Phys. Chem.* **73**, 251–260 (1969).
3. Anderson S *et al.*, *Nature* **280**, 571–573 (1979).