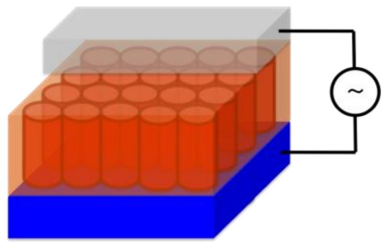
Supra-hierarchical nanostructured cells for the next generation OPV

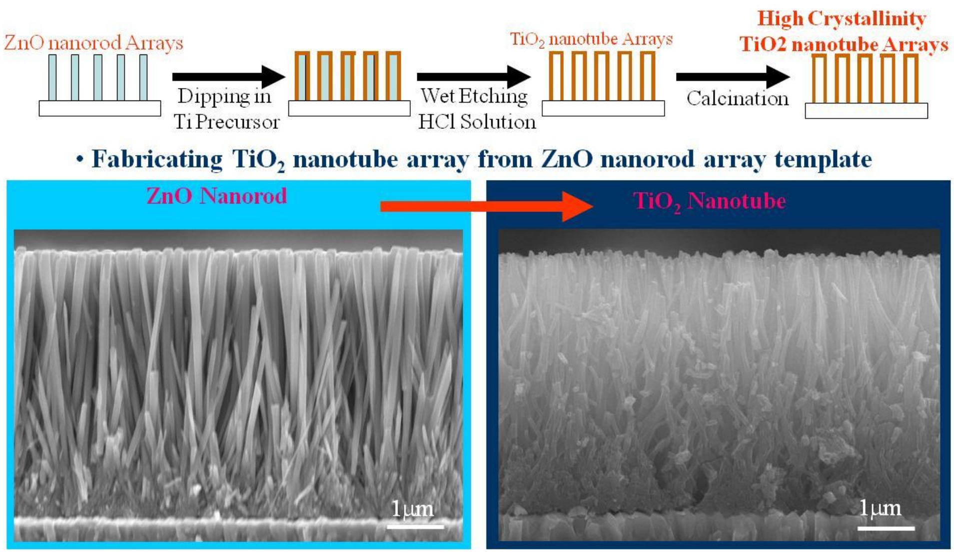
Susumu Yoshikawa,*'

Institute of Advanced Energy, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan

s-yoshi@iae.kyoto-u.ac.jp

Abstract The maximum PCEs of DSSCs (11%) and organic thin-film solar cells (10%) are still lower than those of silicon-based solar cell. For the higher efficiency, bulk heterojunction solar cells with highly ordered one-dimensional (1D) nanostructured components of semiconducting conjugated polymers, dyes, and metal oxides, are expected as the very promising cell structures for the next generation OPVs. We developed various materials of self-assembling 1D structure for a donor-acceptor active layer as well as an electron and hole-transporting layer in organic solar cells. We proposed "Supra-hierarchical nano-structured cell" as an ideal cell structure, with 1D nanostructured semiconducting materials that are vertically phase-separated with respect to a transparent conducting electrode, facilitating efficient carrier and exciton transportation and collection, where the barrier of short diffusion length will be soleved.





Key words organic solar cell, bulk heterojunction solar cell, dye-sensitized solar cell, radial p-n junction, ordered bulk hetrojunction, supra-hierarchical nanostructured cell

1D Nanostructured Electron and Hole-Transporting Layer. Novel hybrid solar cells have been made from a combination of both organic and inorganic semiconducting materials.

To rectify electron flow to the ITO side, ZnO and TiO_x are particularly suitable as electron-transporting layers (*viz*. hole-blocking layers) considering the large band gaps and good energy level matching. In this context, various types of inverted polymer solar cells with nanostructured ZnO and TiO_x have been developed and evaluated. Hayashi *et al* applied 1D ZnO to "dye-sensitized bulk heterojunction" solar cell with zinc porphyrin and fullerene (C_{60}-acid), possessing characteristics of both dye-sensitized and organic thin-film devices.[1] Despite a large surface area of the ZnO nanoparticle electrode by a factor of 3 relative to that of the corresponding ZnO nanorod electrode, they noted similar photocurrent generation efficiencies. Rattanavoravipa *et al* coated ZnO nanorod arrays with TiO_2 to fabricate a P3HT-PCBM devices resulting in a PCE of 0.7% because of the low crystallinity and small surface area of TiO_2 nanotubes.[2] Further improvement of the hybrid electron-transporting layers would be required for enhancing charge separation and preventing charge recombination. For instance, the cell performance of DSSC can be improved by treating the TiO_2 nanotube arrays with $TiCl_4$.[3] After $TiCl_4$–treatment the TiO_2 nanotubes were covered with a small amount of TiO_2 crystals. Both the J_{sc} and the PCE were ca. 2 times larger than those without the TiO_2 treatment. In order to clarify the difference between the behaviors in DSCs based on 1D nanostructure arrays electrode and those based on conventional nanoparticle electrode, the electron transport properties in the nanorod /nanotube electrodes were evaluated through the measurements of IMPS and IMVS, which showed the superiority of 1D materials in both methods.[4]

Coakly *et al* reported that the hole mobility of P3HT can be enhanced 20 times by the vertical alignment through infiltrating it into straight nanopores of anodic alumina.[5] We are also successful to develop the polymer brash of PEDOT:PSS as the efficient hole transporting layer of less than 10nm thick in P3HT polymer solar cell.

Although further tailoring is still required, such 1D nanostructured organic/inorganic semiconducting materials, which are vertically phase-separated with respect to a transparent conducting electrode by rational design and strategy, will allow us to achieve excellent optical absorption and efficient carrier transport and collection, resulting in remarkable improvement of the device performance.

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