Science
Bulletin

When hierarchical structure meets the solar cell

Nailiang Yang

Citation: Science Bulletin **62**, 234 (2017); doi: 10.1016/j.scib.2017.01.023

View online: http://engine.scichina.com/doi/10.1016/j.scib.2017.01.023

View Table of Contents: http://engine.scichina.com/publisher/scp/journal/SB/62/4

Published by the Science China Press

Articles you may be interested in

Hierarchical self-assembly: when sugar meets amino acid
SCIENCE CHINA Chemistry **59**, 1621 (2016);

Artemisinin, GABA signaling and cell reprogramming: when an old drug meets modern medicine
Science Bulletin **62**, 386 (2017);

When water meets iron at Earth's core-mantle boundary
National Science Review **4**, 870 (2017);

When multi-functional landscape meets Critical Zone science: advancing multi-disciplinary research for sustainable human well-being
National Science Review **6**, 349 (2019);

When the East meets the West: the future of traditional Chinese medicine in the 21st century
National Science Review **2**, 377 (2015);

Science Bulletin 62 (2017) 234–235

Contents lists available at ScienceDirect

Science Bulletin

journal homepage: www.elsevier.com/locate/scib

Research Highlight

When hierarchical structure meets the solar cell

Nailiang Yang

Center for Programmable Materials, School of Materials Science and Engineering, Nanyang Technological University, Singapore 639798, Singapore

Hierarchical structures with different length scales, which appear in many animals and plants, play important roles in their structural and functional integrity [1,2]. These structures endow their host animals and plants with intriguing properties including super-hydrophobicity, reversible adhesion as well as mechanical or optical properties. Efforts also have been devoted to introducing bio-inspired hierarchical structures for solar cells to enhance their energy utilization efficiency. Among the various structures, inverse opal structure with controllable light utilization is considered as one of the most important structural designs for photo-anode materials [3]. However, it is still an open question whether a hierarchically ordered inverse opal structure can be obtained to further increase the charge injection and regeneration efficiency [4,5], which hinders the further understanding on the structure-efficiency relationship.

Recently, Yang et al. [6] reported their research progress in dye sensitized solar cells (DSSCs) with hierarchical structures. By precisely controlling the fabrication process, they prepared a film that had an inverse opal structure with meso-pores (IOM), which enhanced the efficiency of solar cell by improving both light utilization and charge transport.

In a typical DSSC device, the incident photon to current efficiency (IPCE) follows:

$$\mathrm{IPCE} = \mathrm{LHE} \cdot \varphi_{\mathrm{inj}} \cdot \varphi_{\mathrm{reg}} \cdot \eta_{\mathrm{CC}}, \qquad (1)$$

where LHE is the light harvesting efficiency, φ_{inj} and φ_{reg} are the efficiency of electron injection and regeneration, respectively, and η_{CC} is the efficiency of charge collection [7].

To enhance light utilization, they discovered that light reflection region can be continuously tuned from ultraviolet to visible light by adjusting the macro-pore size of IOM structure. More specifically, IOM with macro-pore size of 195 nm showed the highest light scattering ability in the visible light region, and IOM with macro-pore size of 285 nm exhibited the best reflection in the UV region. Systematic analysis revealed that these IOM structures played different but important roles in enhancing efficiencies in DSSCs and improving catalytic performance in hydrogen evolution reaction (HER). For DSSCs, electrons can only be excited by light in a certain region. For instance, N719 dye has abundant light absorption in the range of 400–600 nm. Hence, a perfect IOM film should effectively reflect light within this wavelength region to increase the light harvesting efficiency of the dye. The authors discovered that the IOM structure with a macro-pore size of 195 nm perfectly met the requirement, which brought the highest reported efficiency in DSSCs in their system. In the case of HER, where dye is not involved in the system, electrons are induced by the semiconductor (e.g., TiO_2) itself. Hence, the light reflection region of IOM should be excluded from the light absorption region of TiO_2. As a counterexample, IOM structure with macro-pore size of 285 nm presented the best reflection within the wavelength region of 300–400 nm, which led to the worst HER performance (Fig. 1).

Furthermore, as light utilization has been improved by IOM structure, the efficiency of DSSCs can be further enhanced by improving the electron injection and regeneration efficiency (φ_{inj} and φ_{reg}). Hence, ordered meso-porous channels were introduced. These channels were confined within the walls of macro-pores, which further increased the accessible surface area of the film and thus enhanced dye adsorption. Also, the ordered *meso*-porous structure improved the charge transport efficiency between photo-anode and electrolyte, and hence enhanced dye regeneration, which is analogous to the blood capillary in animal body. At this stage, by adopting this dually ordered structure, i.e., meso-ordered and macro-ordered, the efficiency of solar cell has been improved due to the enhanced light utilization, charge injection and regeneration capability.

The authors also noticed this IOM structure would increase the resistance of charge transport. And then, this problem was solved by the integration with r-GO. The good conductivity of r-GO can effectively increase the charge collection efficiency (η_{CC}) and decrease the transport resistance [8]. Thus, the efficiency of DSSCs was further improved.

In summary, a topologically ordered hierarchical structure was successfully introduced into solar cell. With precise control of the structure, on the one hand, light harvesting was increased by macro-structures; on the other hand, charge transport and dye adsorption was improved by *meso*-structures. However, more questions remain unsolved: how to reduce the contact resistance between different layers? How to improve the mechanical strength of the film? Also, how to find a balance between reflection and absorption is another interesting open question and emerges as a new research topic for the further application of solar energy. By understanding and designing more complicated and delicate hierarchical structures, various synergistic effects can be introduced

---

E-mail address: nlyang@ntu.edu.sg

http://dx.doi.org/10.1016/j.scib.2017.01.023

2095-9273/© 2017 Science China Press. Published by Elsevier B.V. and Science China Press. All rights reserved.

Downloaded to IP: 223.0.13.174 On: 2020-02-27 01:13:54 http://engine.scichina.com/doi/10.1016/j.scib.2017.01.023

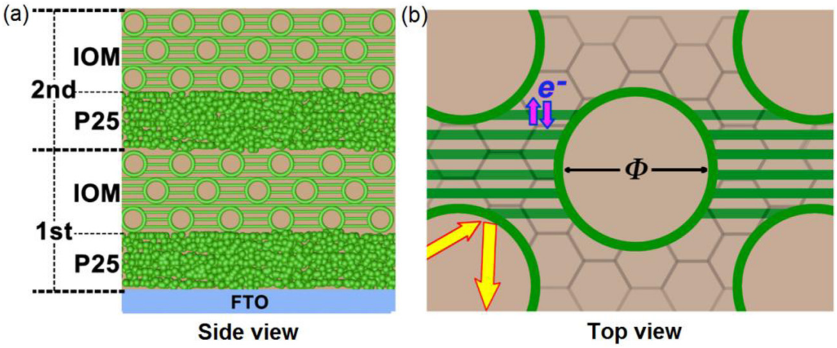

Fig. 1. (Color online) Top view (a) and side view (b) of the dually ordered porous photoanode. Macro-porous-ordered structure can improve light utilization (diameter Φ, dependent), while *meso*-porous-ordered structure can enhance charge diffusion and dye loading. The dually ordered structure increase the efficiency synergistically. The embedded reduced graphene oxide (r-GO, network structure in (b) can further collect and transport the photo-excited electrons. These benefits all improved the efficiency of DSSCs.

into this system, which would inspire new ideas for other energy and environment research as well.

References

[1] Wegst UG, Bai H, Saiz E, et al. Bioinspired structural materials. Nat Mater 2015;14:23–36.

[2] Liu K, Jiang L. Bio-inspired design of multiscale structures for function integration. Nano Today 2011;6:155–75.

[3] Cheng C, Karuturi SK, Liu L, et al. Quantum-dot-sensitized TiO_2 inverse opals for photoelectrochemical hydrogen generation. Small 2012;8:37–42.

[4] Du J, Lai X, Yang N, et al. Hierarchically ordered macro–mesoporous TiO_2-graphene composite films: improved mass transfer, reduced charge recombination, and their enhanced photocatalytic activities. ACS Nano 2011;5:590–6.

[5] Karuturi SK, Luo J, Cheng C, et al. A novel photoanode with three-dimensionally, hierarchically ordered nanobushes for highly efficient photoelectrochemical cells. Adv Mater 2012;24:4157–62.

[6] Yang Y, Jin Q, Mao D, et al. Dually ordered porous TiO_2-rGO composites with controllable light absorption properties for efficient solar energy conversion. Adv Mater 2016. http://dx.doi.org/10.1002/adma.201604795.

[7] Yang N. The preparation of nano composites and their applications in solar energy conversion. Berlin: Springer; 2017.

[8] Yang N, Zhai J, Wang D, et al. Two-dimensional graphene bridges enhanced photoinduced charge transport in dye-sensitized solar cells. ACS Nano 2010;4:887–94.

Downloaded to IP: 223.0.13.174 On: 2020-02-27 01:13:54 http://engine.scichina.com/doi/10.1016/j.scib.2017.01.023