Wenfeng SHANGGUAN, Akihiko KUDO, Zhi JIANG, Yuichi YAMAGUCHI

Photocatalysis: from solar light to hydrogen energy

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The exploitation and utilization of fossil energy has caused serious problems such as environmental pollution and climate change. It is imperative to develop renewable and clean energy sources. Hydrogen energy is recognized as one of the most superior energy carriers in the world because of its characteristics of high energy density, convenient storage and transportation, and pollution-free energy conversion products. Many energy sources could be converted to hydrogen energy, of which, solar energy is abundant and clean. Therefore, nowadays, the efficient conversion of solar energy to hydrogen energy has become one of the hot topics in the renewable energy area. Photocatalysis based on the principles of Honda-Fujishima effect provides an opportunity to address the above challenge. The recent years have witnessed the rapid growth of photocatalytic hydrogen production from photocatalysis and photoelectrocatalysis via solar light.

In this thematic issue, nineteen feature articles either from invited or selected contributions were assembled to collectively illustrate typical progresses in this area, of which, eight invited review papers contribute knowledge on visible light responsive photocatalyst design by substitution with metal cations, polymer photocatalysts, hydrogel photocatalysts, layered alkali titanates and photoelectrochemical water splitting system together with photo anode design while twelve research papers contribute experimental and theoretical results about new photocatalyst, photoelectrode as well as the study on solar photocatalytic reactor optimization.

For a practical application of solar hydrogen production using a photocatalyst, it is strongly required to develop visible light responsive photocatalysts which split water efficiently under solar light irradiation. **A. Kudo** and coworkers reviewed the progress of Rh-doped, Ir-doped, valence band-controlled photocatalysts developed by metal ion doping, exchange (Ag(I) and Cu(I)) for alkali ions in various metal oxides using molten salts treatment and the solid solution strategy to synthesis photocatalysts responding to visible light. $\text{SrTiO}_3\text{:Rh}$, $\text{IrO}_x/\text{SrTiO}_3\text{:Rh,Sb}$, $\text{CuLi}_{1/3}\text{Ti}_{1/3}\text{O}_2$, $\text{Cu(I)-K}_2\text{SrTa}_2\text{O}_7$, $\text{Cu}_3\text{Nb}_{0.9}\text{V}_{0.1}\text{S}_4$ were illustrated as success example in this area. They also suggested that although the number of reported photocatalysts responding to long wavelength of light is increasing, photocatalysts with a high quantum yield is still limited. Future work needs to be conducted to clarify the strategy for the design of photocatalyst with a high quantum efficiency.

Photocatalytic particles need to be in contact with their respective media to exhibit an efficient photocatalytic performance. However, it is difficult to later separate nanometer-sized photocatalytic materials from the reaction media, which may lead to secondary pollution and a poor recycling performance. **C. Terashima** and coworkers reviewed the current state of art hydrogel photocatalysts for efficient hydrogen energy conversion and environmental treatment. They suggested that hydrogel photocatalysts with a three-dimensional (3D) network structures are promising support materials for photocatalysts based on features such as high specific surface areas and adsorption capacities and a good environmental compatibility. They also indicated that it is likely that an in-depth investigation of

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Wenfeng SHANGGUAN (✉), Zhi JIANG (✉)

Research Center for Combustion and Environment Technology, Shanghai Jiao Tong University, Shanghai 200240, China
E-mails: shangguan@sjtu.edu.cn (Wenfeng SHANGGUAN); zhijiang@sjtu.edu.cn (Zhi JIANG)

Akihiko KUDO (✉), Yuichi YAMAGUCHI (✉)

Department of Applied Chemistry, Faculty of Science, Tokyo University of Science, Tokyo 162-8601, Japan
E-mails: a-kudo@rs.tus.ac.jp (Akihiko KUDO); y-yama@rs.tus.ac.jp (Yuichi YAMAGUCHI)

the intrinsic properties of the hydrogel components, and regulation of the gel network structure and swelling properties and adsorption properties will offer an effective strategy for achieving efficient and sustainable recycling of photocatalytic gels to overcome the drawbacks of existing hydrogel photocatalysts.

J. Zhang and coworkers reported another solution to address the above-mentioned challenge. They fabricated a direct Z-scheme CdS/WO₃ composite photocatalyst supported on carbon cloth through a two-step process. With the support of carbon cloth, photocatalysts tend to grow uniformly. The experimental results showed that the H₂ yield of adding one piece of CdS/WO₃ composite material was 5.5 times as compared to that of pure CdS-loaded carbon cloth material. The cycle experiment indicated that the H₂ generation performance of CdS/WO₃ decreased only slightly after 3 cycles. This work provides another new idea for the development of recyclable photocatalysts and has a positive significance for the practical applications.

Photoelectrochemical (PEC) water splitting is regarded as another promising way for solar hydrogen production. The PEC process is based on the all-in-one photoelectrode where light harvesting and water electrolysis occur in the same component. Meanwhile, the photovoltaic-electrocatalysis (PV-EC) process is based on separated modules of the PV part and the EC part for solar-to-electricity conversion and water splitting, respectively. **L. Wang** and coworkers compared PEC and PV-EC in terms of efficiency, cost, and stability. It is suggested that PEC should target on high solar-to-hydrogen efficiency based on cheap semiconductors in order to maintain its role in the technological race of sustainable hydrogen production.

The flow characteristics and radiation distribution in the direct solar photo-catalysis reactor is another important factor influencing the engineering performance. **L. Zhao** and coworkers established an optimized six-flux model based on the mixture flow model and applied it to the tubular solar photocatalytic reactor. They found that parameters, such as catalyst concentration and circulation speed, influence radiation distribution at the reactor outlet. It is found that, at the outlet of the reactor, the optimized six-flux model has better performances with a higher catalyst concentration and a lower speed. This work offers theoretical guidance and technical support for the engineering application of direct solar photocatalytic water hydrogen production.

We very much appreciate this opportunity to edit this special issue. We hope this collection can provide valuable information for readers on the topic of photocatalytic production hydrogen from water splitting. Great thanks goes to all the authors for their contributions and peer-reviewers for their efforts made in reviewing the papers. Special thanks also goes to the Editorial Office of *Frontiers in Energy* for their tireless efforts and great support in making this special issue.

Editor's bio sketches:

Dr. Wenfeng SHANGGUAN is a professor of Department of Power and Energy Engineering at Shanghai Jiao Tong University, China. He received his Ph.D. degree in applied physical chemistry from Nagasaki University, Japan in 1996. He worked as a post-doctor researcher at Kyushu National Industrial Research Institute of Japan from 1996 to 2000. In 2000, he was promoted to Professor at Shanghai Jiao Tong University. His research interests include environment catalysis, photocatalysis, solar hydrogen production, nanomaterials for energy conversion and air quality. He has published over 280 journal papers and 3 books on energy materials and environmental catalysis. He was elected as the Most Cited Chinese Researchers by Elsevier in 2014–2020. E-mail: shangguan@sjtu.edu.cn.

Dr. Akihiko KUDO is a professor of Faculty of Science at Tokyo University of Science, Japan. He received his bachelor's degree from Tokyo University of Science in 1983 and his doctorate from Tokyo Institute of Technology in 1988. After a postdoctoral fellow at the University of Texas in Austin, he worked as a research associate at the Tokyo Institute of Technology until 1995. He then joined the Tokyo University of Science as a Lecturer before he became an associate professor in 1998 and a full professor in 2003. He has published over 290 international journal papers on photocatalysis. His current research interest focuses on photocatalyst and photoelectrode materials for water splitting and CO₂ fixation of artificial photosynthesis. E-mail: a-kudo@rs.tus.ac.jp.

Dr. Zhi JIANG is an associate professor of Department of Power and Energy Engineering at Shanghai Jiao Tong University, China. He received his Bachelor and Ph.D. degrees in physical chemistry from the University of Science and Technology of China in 2000 and 2005 respectively. He worked as a post-doctor researcher at New Jersey Institute of Technology and Purdue University from 2006 to 2009. He worked at Shanghai Jiao Tong University since 2009. His research interests include photocatalysis, spectroscopy, and renewable energy. He has published over 50 SCI journal papers in journals such as *ACS Catalysis*, *Journal of Catalysis*, *Applied Catalysis B: Environmental*, *Journal of Material Chemistry A*, *ChemCatChem*, *Catalysis Science and Technology*, etc. E-mail: zhijiang@sjtu.edu.cn.

Dr. Yuichi YAMAGUCHI is an assistant professor of Faculty of Science at Tokyo University of Science, Japan. He received his bachelor's and Ph.D. degrees from Tokyo University of Science in 2012 and 2017 respectively. He worked as a postdoctoral researcher at the Tokyo University of Science in 2017 and the University of Liverpool in 2018. Then, he joined Tokyo University of Science as an assistant professor in 2019. He has published over 15 international journal papers on photocatalysis. Now, he focuses on development of novel photocatalysts for water splitting and CO₂ fixation of artificial photosynthesis. E-mail: y-yama@rs.tus.ac.jp.