Introducing special issue on photocatalysis and photoelectrochemistry

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Victor Batista,[1] Can Li,[2] Wilson Smith,[3] and Dunwei Wang[4,a)]

AFFILIATIONS

[1] Department of Chemistry, Yale University, New Haven, Connecticut 06520, USA
[2] Dalian Institute of Chemical Physics, Dalian, Liaoning, China
[3] Delft Technological University, University of Colorado, NREL, Golden, Colorado 80401, USA
[4] Department of Chemistry, Boston College, Chestnut Hill, Massachusetts 02467, USA

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[a)] **Author to whom correspondence should be addressed:** dunwei.wang@bc.edu

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It has been over 100 years since Giacomo Ciamician[1] laid out his vision on a future where chemical reactions are powered by "light and light alone." With the alarmingly fast pace at which the globe is warming, this vision has become ever more relevant. If successfully executed, light-driven chemical reactions could hold the key to a sustainable future. Indeed, this recognition has driven continuous research efforts during the past 100 years. Exciting progress has been made. For instance, we now have a fairly good understanding on how natural photosystems function. The cost of solar electricity has been reduced to a regime where it is competitive with electricity generated by other means. However, chemical reactions that can be entirely driven by light remain few; those that make economic sense are even more scarce. The community is still eagerly waiting for breakthroughs to realize the dream presented by Ciamician more than 100 years ago. It is with this understanding that we assembled this special virtual issue. The collection of recent publications in this journal highlights the key issues faced by the field; they also present new ideas aimed at addressing these challenges.

From the outset, the definition of photocatalysis can be broad or narrow. If we only view photons as an enabler of a reaction that otherwise can take place spontaneously due to favorable thermodynamics, photocatalysis should refer to processes such as dye degradation or pollutant removal. In this category, we draw your attention to articles by Li *et al.*,[2] Long *et al.*,[3] and Zhang *et al.*[4] in this virtual issue. Similarly, amine oxidation as reported by Li and Lang[5] also fits this definition. Nevertheless, if we view photons as part of the reactants, whose inclusion would make an otherwise non-spontaneous reaction spontaneous, the scope of reactions that can be described by photocatalysis would be far broader. Perhaps the most prominent example of these classes of reactions would be water splitting. This is indeed represented by the majority of papers in this collection, as well. However, CO_2 reduction is another model reaction that has received significant attention, as reported by Zhong *et al.*[6] and Kim *et al.*[7]

For the purpose of harvesting energy delivered by photons to power chemical reactions, one of the important tasks is to maximize the efficiency by the light-absorbing materials. This understanding is reflected by a large portion of the collections in this virtual issue focusing on material engineering, e.g., articles by Kumari *et al.*[8] and Jing *et al.*[9] For instance, Cho *et al.*[10] report how the bandgap of the photocatalytic materials depends on temperature. Hayashi *et al.*[11] report photon and surface area management through materials engineering. Increasingly, researchers realize that a single material will unlikely deliver the desired efficiency. Instead, attention has been turned to engineer combinations of materials, where bandgap matching becomes critical (see, e.g., articles by Bae *et al.*,[12] Yoda *et al.*,[13] Méndez-Medrano *et al.*,[14] and Das *et al.*[15]). Indeed, heterostructure is a popular idea that has been explored by multiple other papers in this virtual issue, e.g., articles by Lin *et al.*,[16] Zhu *et al.*,[17] and Wang *et al.*[18] To this end, another idea is to utilize portions of the solar spectrum that are difficult to directly utilize by ideas such as plasmonic effect (see the article by Li *et al.*[19]) or upconversion (see the article by Jiang *et al.*[20]).

Another important concept in realizing light-driven chemical reactions is co-catalysts. To better understand the role played by co-catalysts, Ketwong *et al.*[21] report on the possible complex functionalities. How and where co-catalysts interface with the photoactive material is also important, as shown by Adler *et al.*,[22]

Sinha *et al.*,[23] Wang *et al.*,[24] Chen *et al.*,[25] Yang *et al.*,[26] and Li *et al.*[27] More broadly, from a design perspective, the light-harvesting and catalytic components are not limited to solid-state materials. Indeed, molecular photosensitizers have been broadly studied for solar cell applications. Their utility for photocatalysis and photoelectrochemistry is reported by Wang *et al.*,[28] Wehlin *et al.*,[29] Zhang *et al.*,[30] Kardumyan *et al.*,[31] and Cai *et al.*,[32] separately in this virtual issue. By extension, studies on solar cells within the context of photocatalysis and/or photoelectrochemistry are also included in this issue, e.g., articles by Yu *et al.*[33] and Lian *et al.*[34]

Admittedly, the goal of enabling light-driven chemical reactions is exceedingly challenging. Achieving this feat will require developments in all fronts, including new tools for characterizations. In this front, Katayama[35] reports a new imaging tool with nanosecond temporal resolutions. Doughty *et al.*[36] further applied the surface photovoltage technique to study III–V photoelectrode materials. Transient absorption spectroscopy is reviewed by Miao and Tang[37] within the context of photocatalysis and photoelectrochemistry. A few reports on exciting new theoretical advancements are also included in this virtual issue (see articles by Yamamoto and Takatsuka,[38] Di Liberto *et al.*,[39] Li *et al.*,[40] and Huang *et al.*[41]).

Owing to the paramount importance of light-driven chemical reactions to a sustainable future, research on the topic of photocatalysis and photoelectrochemistry will remain fertile. New ideas are still critically needed, and implementations at a scale that is relevant for meaningful societal impacts have yet to be demonstrated. We expect to see an increasing number of publications on this topic in the years to come, which will help to build a knowledge base that will gradually transform how to harvest and utilize energy, as well as carry out chemical reactions. We hope this virtual issue will serve as a catalyst to fuel these continued endeavors.

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