Photocatalytic Hydrogen Production: Recent Advances and Opportunities in Heterojunction Photocatalysts

Yigit Osman Akyıldız[a, b]*, Emre Aslan[a], İmren Hatay Patır[c]

[a] Selcuk University, Department of Biochemistry, 42030, Konya, Türkiye

[b] YEO Technology R&D Center, 34870, İstanbul, Türkiye

[c] Selcuk University, Department of Biotechnology, 42030, Konya, Türkiye, e-mail: imrenhatay@gmail.com

The increasing global energy demand, depletion of fossil fuel resources, and growing environmental concerns have accelerated the search for sustainable and carbon-neutral energy technologies. Among the various alternatives, hydrogen has emerged as one of the most promising energy carriers due to its high gravimetric energy density and environmentally benign combustion products. In this context, photocatalytic hydrogen evolution reaction (HER) has attracted significant attention as a sustainable strategy for converting abundant solar energy directly into chemical energy in the form of hydrogen. The efficiency of photocatalytic HER is primarily governed by the properties of semiconductor photocatalysts. However, the practical application of conventional photocatalysts remains limited by several intrinsic challenges, including insufficient visible-light absorption, rapid recombination of photogenerated electron-hole pairs, and sluggish surface redox reaction kinetics. These limitations significantly reduce the overall solar-to-hydrogen conversion efficiency and have motivated the development of advanced photocatalytic systems. Among the various strategies proposed to overcome these challenges, heterojunction engineering has emerged as one of the most effective approaches. By integrating two or more semiconductors with complementary electronic structures, heterojunction photocatalysts can promote efficient charge separation and transfer, broaden the light absorption range, and enhance the utilization of photogenerated charge carriers. Depending on their band alignment and interfacial charge-transfer pathways, different heterojunction architectures offer unique advantages for improving photocatalytic performance. This study presents a comprehensive overview of heterojunction photocatalysts for photocatalytic hydrogen evolution, emphasizing their fundamental charge-transfer mechanisms, classification, and recent advances in heterojunction design. The advantages and limitations of different heterojunction architectures are critically discussed, together with the key factors governing photocatalytic efficiency.

Keywords: Photocatalysis, Heterojunction, Hydrogen evolution.

Acknowledgment: This project is financially supported by TUBITAK-1001 programme (Grant number: 123Z412).