Applied Catalysis B: Environmental 293 (2021) 120227

Contents lists available at ScienceDirect

Applied Catalysis B: Environmental

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

# Atomic interactions of two-dimensional $PtS_2$ quantum dots/TiC heterostructures for hydrogen evolution reaction

Sangmin Jeong [a], Hien Duy Mai [a], Tri Khoa Nguyen [a], Jong-Sang Youn [b], Ki-Hun Nam [c], Cheol-Min Park [c,d,**], Ki-Joon Jeon [a,e,*]

[a] *Department of Environmental Engineering, Inha University, Incheon, 22212, Republic of Korea*
[b] *Department of Energy and Environmental Engineering, The Catholic University of Korea, Bucheon, 14662, Republic of Korea*
[c] *School of Materials Science and Engineering, Kumoh National Institute of Technology, 61 Daehak-ro, Gumi, Gyeongbuk, 39177, Republic of Korea*
[d] *Department of Energy Engineering Convergence, Kumoh National Institute of Technology, 61 Daehak-ro, Gumi, Gyeongbuk, 39177, Republic of Korea*
[e] *Program in Environmental and Polymer Engineering, Inha University, Incheon, 22212, Republic of Korea*

ARTICLE INFO

*Keywords:*
Two-dimensional quantum dots $PtS_2$
Titanium carbide
Chemical vapor deposition
In-situ Raman spectroscopy
Hydrogen production
S-H bonding formation

ABSTRACT

Two-dimensional quantum dots (2D QDs) comprising $PtS_2$ with low Pt loading (0.002 wt.%) distributed on a distinctive CVD-grown titanium carbide substrate ($PtS_2$/TiC) was successfully synthesized and employed for a hydrogen evolution reaction (HER). Notably, despite the low loading of the former component, $PtS_2$/TiC showed excellent HER activity with a superior overpotential (55 mV at 10 mA/cm$^{-2}$) to that of commercial Pt/C (50 mV at 10 mA/cm$^{-2}$). The Faraday efficiency of $PtS_2$/TiC was found to be 92.5 %, revealing the superior properties of hydrogen production. The In-situ Raman spectra reveal the important role of S atoms in $PtS_2$ as the active sites for HER, as evidenced by S—H bonding formation at 2532 cm$^{-1}$ during the HER process. This study provides a fundamental understanding essential for the design of more efficient catalysts in the field of electrochemical applications.

## 1. Introduction

Research on 2D quantum dots (QDs) has recently garnered considerable interest due to their unique structure-dependent and electrical properties [1–4]. 2D QDs have a higher surface-to-volume ratio, which can overcome the issues of low metal utilization efficiency in conventional electrocatalysts, wherein only the surfacial atoms participate in the catalytic process while a majority of the bulk atoms state inactive [1,2]. However, adverse aggregation of 2D QDs into larger crystals during the synthesis and operation due to the high surface energy remains problematic, necessitating the dispersion of the catalysts firmly on a conductive and stable matrix to achieve a high hydrogen evolution reaction (HER) performance. Transition metal dichalcogenides (TMDs) with the formula $MX_2$ (where M = group-4 to group-10 transition metals, X=S, Se, Te) are promising catalysts owing to their structure and layer-dependent electrochemical properties [5]. Despite tremendous research effort intensively devoted toward group-6 (e.g., $MoS_2$, $WS_2$) [6–8], only a few reports have revealed the electrocatalytic behaviors of other groups in the TMD family (e.g., group-10 TMDs) [9–12]. Similar to $MoS_2$, $PtS_2$ with band edge energies near the redox potentials of hydrogen evolution ($H^+/H_2$) is considered an efficient HER electrocatalyst among group-10 TMDs [13]. However, research on $PtS_2$ as HER catalysts is very scarce, and the reported HER activity is far below that required to replace commercial Pt/C [11]. Inspired by the high potential of $PtS_2$ for HER, we strive to explore $PtS_2$ QDs deposited on suitable support materials. Titanium carbide (TiC) is a promising electrocatalyst or supporting material for electrochemical applications because of its high electrical conductivity and rigidity as well as exceptional chemical and thermal stability [14,15]. Furthermore, the orbital hybridization between d-orbitals of transition metals and p-orbitals of carbon leads to a strong interaction between TiC and noble metal atoms (e.g., Pt, Pd, Au), thus improving the stability and the electrocatalytic performance [15–17]. Powder-like can be synthesized by direct carbothermal reaction and molten salt-assisted reduction. Nevertheless, most of these materials often undergo harsh reaction conditions (i.e., high temperature and prolonged reaction time) or involve the excessive use of

* Corresponding author at: Department of Environmental Engineering, Inha University, Incheon, 22212, Republic of Korea.
** Corresponding author at: School of Materials Science and Engineering, Kumoh National Institute of Technology, 61 Daehak-ro, Gumi, Gyeongbuk, 39177, Republic of Korea.
*E-mail addresses:* cmpark@kumoh.ac.kr (C.-M. Park), kjjeon@inha.ac.kr (K.-J. Jeon).

https://doi.org/10.1016/j.apcatb.2021.120227
Received 8 December 2020; Received in revised form 1 March 2021; Accepted 11 April 2021
Available online 15 April 2021
0926-3373/