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Role of two-dimensional nanointerfaces in enhancing the photocatalytic performance of 2D-2D MoS_2/CdS photocatalysts for H_2 production

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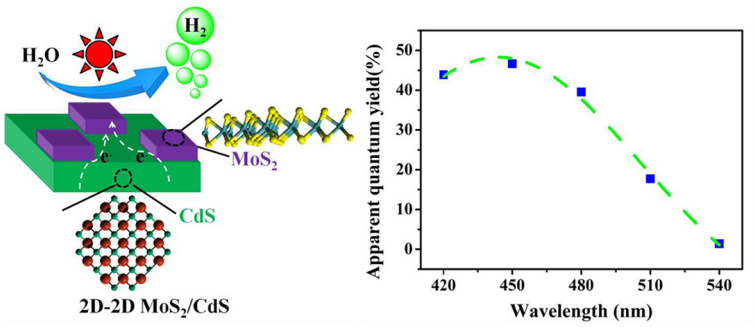
HIGHLIGHTS

- A smart architecture of 2D-2D MoS_2/CdS photocatalyst was developed for solar H_2 generation.
- Two-dimensional nanointerfaces can act as efficient charge transfer channels for photocatalytic hydrogen evolution reaction.
- Enhancing photocatalytic activity of 2D-2D MoS_2/CdS photocatalysts by interface engineering.
- Synthesis of noble-metal-free and highly-efficient MoS_2/CdS photocatalysts.

GRAPHICAL ABSTRACT



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ABSTRACT

Promoting the charge separation to improve photocatalytic performance of semiconductor photocatalysts is very important in the field of artificial photosynthesis. Here, we report the synthesis of 2D CdS micro/nano leaves combined with 2D MoS_2 nanosheets cocatalyst for efficient photocatalytic H_2 production by visible light via a rapid and cost-effective hydrothermal method. This smart architecture of 2D-2D MoS_2/CdS photocatalyst possesses remarkably large 2D nanointerfaces, which provides abundant channels for photoinduced charge transfer between CdS and MoS_2. As demonstrated by the photoluminescence and transient photocurrent studies, the large 2D nanointerfaces can efficiently accelerate charge carrier transfer and separation, resulting in the superior photocatalytic performance and favorable stability of MoS_2/CdS hybrid photocatalysts for visible-light-driven hydrogen evolution from water. As a consequence, the maximum H_2 evolution rate of 26.32 $mmol \cdot h^{-1} \cdot g^{-1}$ under visible light irradiation and an apparent quantum yield of 46.65% at 450 nm for hydrogen production are achieved on 6% MoS_2/CdS, exceeding that of optimized Pt-loaded CdS photocatalyst. The findings indicate that 2D-2D photocatalysts possess great potential for efficient solar hydrogen generation.

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1. Introduction

Solar-to-hydrogen energy conversion via photocatalytic water splitting provides a carbon-free renewable resource for the sustainable economic development [1–3]. Since the original study of Fujishima and Honda regarding the use of TiO_2 electrodes for photolysis of water, numerous semiconductors have been extensively developed as active photocatalysts for solar H_2 generation [4]. During the past decades, much attention has been paid to develop visible-light even near-infrared responsive semiconductor photocatalysts with the aim of harvesting more solar energy [5–10]. For example, various narrow-bandgap semiconductors including graphitic carbon nitride (g-C_3N_4 [11]), CdS [12], $ZnIn_2S_4$ [13], $CuInS_2$ [14], $Cu_2ZnSn_2S_4$ [15] and Zn-Cd-S solid solutions and so on [16,17], have been widely investigated as photocatalysts for photocatalytic H_2 production. Among them, CdS has been demonstrated to be one of the most renowned photocatalysts for visible-light-driven H_2 production owing to its narrow bandgap, suitable conduction and valence band edges and excellent reactivity [18–20]. Unfortunately, the bare CdS exhibited low photocatalytic performance for H_2 production owing to the poor charge separation efficiency. To address this challenge, researchers found that loading zero-dimensional (0D) noble metals nanoparticles (such as Ru, Rh, Pd, Pt and Au etc.) on semiconductor photocatalysts as a hydrogen evolution reaction cocatalyst is a good strategy to enhance charge separation [21–25]. However, in the practical application, there are at least two obvious drawbacks arising from using noble metal loaded semiconductor photocatalysts: one is the high cost of noble metals, and the other is the point contact between noble metal cocatalyst and semiconductor photocatalyst provides limited interfaces for charge transfer. Therefore, there is great significance for the development of noble-metal-free cocatalyst modified semiconductor photocatalysts with relatively large contact interfaces.

Recently, two-dimensional (2D) materials with unique photophysical and electrochemical properties have attracted considerable interest from scientists in the field of solar energy conversion [26–30]. As compared to 0D and one-dimensional (1D) materials, 2D materials have larger specific surface area, good conductivity and abundant exposed edge sites, making them to be promising candidates for photocatalytic H_2 production [31,32]. More importantly, the combination of 2D semiconductor and 2D cocatalyst can form large 2D interfaces for photoinduced charge transfer, which could play a key factor in determining the photocatalytic performance of photocatalysts. As a result, superior photocatalytic performance of the 2D-2D composite photocatalyst can be expected. Although some recent advance has been made in the development of some assembly of 2D composite photocatalysts based on TiO_2 nanosheets [33], Cu-$ZnIn_2S_4$ [34], and layered graphitic carbon nitride (g-C_3N_4) [35], the quantum efficiency of those photocatalytic systems is still low. Recently, Li et al., reported the enhanced visible-light photocatalytic H_2 generation by constructing 2D layered hybrid CdS nanosheets/MoS_2 heterojunctions[36], but the H_2 generation activity of CdS/MoS_2 is much smaller than many other reports [18,19], which could be assigned to the relatively poor crystallinity of CdS. The construction of highly efficient 2D-2D CdS/MoS_2 photocatalysts is still a great challenge. Herein, we demonstrate the use of 2D MoS_2 nanosheets as an efficient cocatalyst on 2D CdS micro/nano leaves photocatalyst for visible light driven photocatalytic H_2 production from water. The MoS_2 nanosheets was used as the cocatalyst due to its matched 2D structure as well as abundant exposed edge sites for H_2 generation reaction [37,38]. Owing to the positive effect of large 2D nanointerfaces in improving the separation efficiency of photogenerated charge carriers, the 2D-2D MoS_2/CdS photocatalysts show superior photocatalytic activity for H_2 production in presence of Na_2S/Na_2SO_3 pair as a sacrificial regent. The MoS_2/CdS photocatalyst with 6 wt% MoS_2 reaches a high H_2 evolution rate of 26.32 mmol·h^{-1}·g^{-1} under visible light irradiation ($\lambda > 420$ nm), and the apparent quantum yield reaches 46.65% at 450 nm.

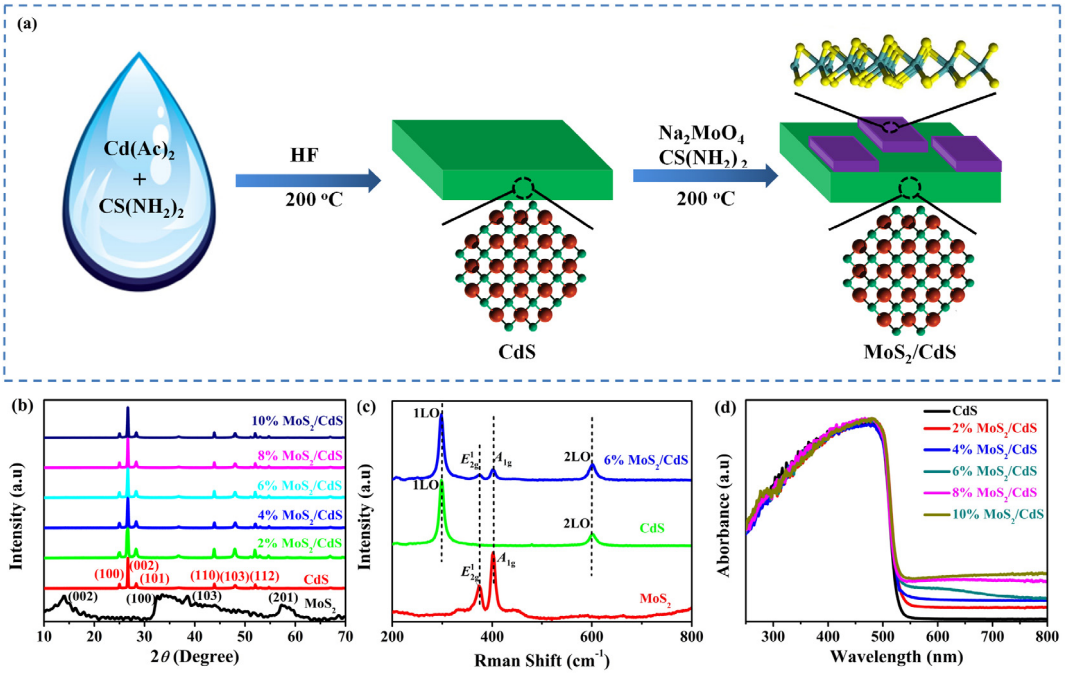

Fig. 1. (a) Schematic illustration of hydrothermal route to prepare 2D-2D MoS_2/CdS photocatalysts. (b) XRD patterns of CdS, MoS_2 and MoS_2/CdS composites containing different amounts of MoS_2. (c) Raman spectra of CdS, MoS_2 and 6 wt% MoS_2/CdS composite. (d) UV–vis diffuse reflectance spectra of CdS and MoS_2/CdS composites containing different amounts of MoS_2.