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Synthesis of cadmium sulfide quantum dot-decorated barium stannate nanowires for photoelectrochemical water splitting†

Zemin Zhang,‡a Xiaodong Li,‡a Caitian Gao,‡a Feng Teng,a Youqing Wang,a Lulu Chen,a Weihua Han,*a Zhenxing Zhang* and Erqing Xie*a

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We report the fabrication of cadmium sulfide (CdS) quantum dot-decorated barium stannate (BaSnO₃) nanowires and their application as photoanode for photoelectrochemical water splitting. First, polycrystalline BaSnO₃ nanowires, which have a perovskite structure, were prepared by electrospinning their polyvinylpyrrolidone polymer precursors and calcining the resultant polymer fibres. Then, CdS quantum dots were decorated onto the BaSnO₃ nanowires with a wet-chemical method. Our results show that the hybrid photoanode made of the CdS quantum dot-decorated BaSnO₃ nanowires exhibits a high photocurrent density up to 4.8 mA cm⁻² at 0 V (vs. saturated calomel electrode), which corresponds to a hydrogen generation rate of 71.8 μmol (h cm⁻²)⁻¹ with a Faradaic efficiency of around 80%. Its favourable performance was attributed to the effective charge separation at the type II staggered gap heterojunction formed at the BaSnO₃/CdS interface, and the low charge recombination in BaSnO₃ nanowires during transport. Our findings indicate that the water splitting performance of photoelectrochemical cells can be highly improved by rationally building a type II band alignment heterojunction with sensitizing quantum dots and wide band gap semiconductor nanowires which have a low charge recombination rate during transport.

1. Introduction

Solar-driven water-splitting with photoelectrochemical (PEC) cells is a promising approach to convert solar energy into storable hydrogen (H₂) fuel in an environment friendly manner.1−4 Generally, PEC water-splitting occurs in three steps: the generation of electron-hole pairs excited by the photons, the migration of photo-excited carriers to the active sites on electrode surface and the redox of water to generate hydrogen and oxygen.5,6 Obviously, the amount of photo-excited carriers which can reach the active sites on the surface and participate in the redox reaction will vitally determine the ultimate energy conversion efficiency. Significant efforts have been devoted to finding new photoanode materials which can effectively generate and transfer the photo-excited carriers to the active sites since its first discovery by Honda and Fujishima in 1972.11

Among all these attempts, building a type-II staggered gap heterojunction structure8 in which one material’s conduction band and valence band are more negative than the other ones, is deemed as a potential solution to increase the generation rate of photo-excited carriers.8,10 In such a structure, photo-excited electrons will flow to the lower conduction band, while the holes will go into the other materials which have a higher valence band and lower overall hole energy.13−23 It works like a PN solar cell and predictably leads to a high electron-hole separation rate.4 Moreover, the type II band heterojunction made of two materials, which has two band gaps and allows capturing two lights, is believed to have a higher energy utilizing efficiency compare with single light absorber.14−24

Another issue that limits the energy conversion efficiency of PECs from practical application is the carrier’s recombination that undergoes all the water splitting process. Effective water splitting requires a successful carrier transfer from the photocarrier generation location to the active sites where the redox reaction occurs on the photoelectrode. From this point, photoanode materials which have a high carrier mobility and long life time are preferred for water splitting.14,25

As alternative PEC photoanode materials, ternary oxide semiconductors are better candidates than binary oxides, due to their tuneable properties by altering their chemical composition.26 Among the reported ternary oxide photoanode materials, BaSnO₃ has gathered much more attentions for the potential application as working electrode material of PEC device. BaSnO₃ is an n-type semiconductor with a band gap of 3.1 eV. The conduction band edge potential of BaSnO₃ is 0.69 V negative than normal hydrogen electrode, which is very suitable for electron transfer from BaSnO₃ to electrolyte.27 In this work, BaSnO₃ nanowires (NWs) and CdS quantum dots (QDs) were selected to build a type-II heterojunction which facilitates an effective charge separation. Benefited by the high charge separation rate, lower charge recombination rate in BaSnO₃ and effective visible light absorption of CdS QDs, the CdS QD-decorated BaSnO₃ NWs photoanode exhibits a high photocurrent density up to 4.8 mA cm⁻² at 0 V (vs. saturated
calomel electrode), which corresponds to a hydrogen generation rate of 71.8 μmol (h cm\(^{-2}\))\(^{1}\) with a Faradaic efficiency of around 80%. The BaSnO\(_3\) NWs were fabricated with a facile electrospinning method associated with a calcination process. CdS QDs were decorated onto the NWs with a wet-chemical method.

2. Experimental

The scheme in Fig. 1 illustrates the experimental procedures for the preparation of CdS QD-decorated BaSnO\(_3\) NWs. Firstly, polymer fibres consisted of PVP, BaCl\(_2\) and SnCl\(_2\) were prepared with a facile electrospinning method. BaSnO\(_3\) NWs were formed after a calcination process to remove the organic polymer. Then, CdS QDs were decorated onto the NWs with a wet-chemical method.

2.1. Synthesis of the BaSnO\(_3\) NWs

The miscible solvent used in this work is a mixture of conventional solvents containing ethanol, N, N-dimethyl formamide (DMF), acetic acid and deionized water with a mass ratio of 3:4:2:3. Firstly, ethanol, N, N-dimethyl formamide (DMF) and acetic acid were mixed together with the afore-mentioned mass ratio. Then 0.158 g tin dichloride dehydrate (SnCl\(_2\)•2H\(_2\)O, Tianjin Chemical Corp, China) was dissolved in 4.5 g mixture obtained previously and stirred for 30 min at room temperature on a magnetic stirring stage. Secondly, 1.5 g deionized water and 0.171 g barium chloride dehydrate (BaCl\(_2\)•2H\(_2\)O, Chengdu Kelong chemical Corp, China) were added into the solution and then stirred for another 30 min. Thirdly, various amount of polyvinylpyrrolidone (PVP, Sigma Aldrich, Mw = 1, 300, 000) was added into the resultant solution and vigorously stirred for 4 h at ambient temperature. Three typical weight ratios, 9%, 11% and 13% between PVP and the solution were selected in our experiment.

In the electro-spinning process, the high voltage and needle-to-collector distance were 20 kV and 20 cm, respectively. The flow rate of the polymer solution used here was fixed at 0.6 mL h\(^{-1}\) in all the experiments. The electrospun fibres were collected on an aluminium foil.

The as-spun products were transferred to an aluminium boat and calcinated at 900 °C for 2 h in the air to remove the polymer with a temperature increasing rate of 2 °C min\(^{-1}\).

2.2. BaSnO\(_3\) NWs coated onto transparent substrates

The obtained BaSnO\(_3\) NWs (0.02 g) were ultrasonically dispersed in a mixture of 0.34 g deionized water, 0.067 g ethanol and 0.817 g acetic acid. Then, 0.015 g polyethylene glycol (PEG, Mw = 20 000) was added into the above solution and vigorously stirred for 1 h at ambient temperature. The paste was drop-coated onto F-doped tin oxide glasses (FTO, 2.2 mm in thickness, >90% transmittance, 14 Ω per square, Nippon, China). The films were then annealed at 500 °C for 2 h with a temperature increasing rate of 2 °C min\(^{-1}\).

2.3. CdS QDs decoration

The CdS QDs were decorated onto the BaSnO\(_3\) NWs with a successive ionic layer adsorption and reaction (SILAR) method.\(^{22}\)

Briefly, the samples (BaSnO\(_3\) NW coated FTO) were successively immersed into Cd(NO\(_3\))\(_2\) aqueous solution (0.05 M) for 4 min, DI water for 30 sec, Na\(_2\)S aqueous solution (0.05 M) for 4 min and DI water for 30 sec again. The entire four-step procedure is one SILAR cycle. The desired amount of CdS QDs was obtained by controlling the running cycles. Finally, the films were annealed at 400 °C for 30 min in the air.

2.4. Characterization

The morphology of the CdS-decorated BaSnO\(_3\) NWs were investigated by a field emission scanning electron microscope (FE-SEM, Hitachi S-4800), and high-resolution transmission electron microscope (HRTEM, FEI Tecnai F30). Elemental analysis was performed on an X-ray photoelectron spectroscopy (XPS), which is carried out on a Kratos AXIS Ultra DLD XPS instrument equipped with an Al K\(_\alpha\) source. An energy-dispersive X-ray (EDX) spectroscopy equipped to the TEM (in-situ) is also performed to confirm their chemical compositions. X-ray diffraction (XRD, Philips, X-per, Cu Ka) is employed to characterize the crystal structure of the samples. Optical absorption spectra of the photoanodes between 350 nm and 900 nm were also recorded using a spectrophotometer (TU-1901).

The PEC performances of the photoanode were evaluated in a three-electrode configuration. The BaSnO\(_3\) NWs-CdS QDs serve as the working electrode, saturated calomel electrode (SCE) is the reference electrode and platinum foil works as the counter electrode. The electrolyte was a mixed aqueous solution of 0.25 M Na\(_2\)S and 0.35 M Na\(_2\)SO\(_4\) with a pH of 12.8. The illumination was provided by a 500 W Xe lamp equipped with an AM 1.5 G...
filter. The incident photo intensity was calibrated to 100 mW cm\(^{-2}\) by a standard silicon solar cell.

Fig. 2 The morphology evolution of the samples (11 wt.% PVP) as a function of calcination temperature. (a) 850 °C, (b) 900 °C, (c) 950 °C and (d) 1000 °C.

3. Results and discussion

Fig. 2 shows the morphology evolution of the BaSnO\(_3\) NWs (PVP 11 wt.%) as a function of the calcination temperature. It is evident that the NWs calcined at 850 °C are consisted of numerous primary nanoparticles with an average diameter of 38.5 nm. When increasing the temperature, the average size of the primary nanoparticles increases. The sizes are 43.8 nm, 64.3 nm and 430 nm when calcined at typical temperature of 900 °C, 950 °C and 1000 °C, respectively. While the BaSnO\(_3\) NWs tend to be broken at the high temperature.

The content of PVP also plays an important role on the formation of BaSnO\(_3\) NWs. Fig. S1 shows the FESEM images of the BaSnO\(_3\) NWs with PVP content of 9%, 11% and 13% in weight. All of the three samples were thermally treated at the same conditions. It is clear that the NWs stacked with nanoparticles become looser when the content of PVP increases. The nanoparticles in the NWs prepared from 11% PVP stacked more tightly, implying good inter-crystalline connections, which can facilitate fast electron transport and suppress charge recombination.

The crystallization degree of the pristine NWs (PVP content of 11 wt.%) influenced by calcination temperature are shown in Fig. 3 with XRD patterns. For the sample annealed at 850 °C, four diffraction peaks at 26.61°, 33.89°, 37.95° and 51.78° can be well indexed to the rutile structure of SnO\(_2\) (JCPDS No. 41-1445), and the peaks at 30.69°, 43.96°, 54.56°, 63.91° and 72.56° indicate the emergence of cubic perovskite BaSnO\(_3\) (JCPDS No. 15-0780). When the temperature rose to 900 °C, the characteristic peaks of SnO\(_2\) almost disappeared, which indicated that the phase of cubic perovskite BaSnO\(_3\) become dominant in this case. When continue to increase the temperature, the characteristic peaks of BaSnO\(_3\) become much sharper, while a weak peak of SnO\(_2\) (200) facet still exists in the products. This weak peak of SnO\(_2\) (200) facet was believed to come from the FTO substrates, rather than the products.

In this work, the BaSnO\(_3\) NWs prepared from the optimized precursor (11% PVP) and calcination temperature of 900 °C were selected for all the following investigation.

Further insight into the structural information was obtained by a TEM characterization on a single BaSnO\(_3\) NW. As shown in Fig. 4a, the stacking of the nanoparticles is very tight and no obvious pores can be observed. The compact structure will promise a larger carrier mobility and lower charge recombination. Fig. 4b is an HRTEM image at a higher magnification, which shows well resolved lattice fringes even at the outer surface, indicating a high crystallinity of the NWs. The resolved spacing between two parallel adjacent fringes is about 0.21 nm, corresponding to the (200) plane of the cubic perovskite phase of BaSnO\(_3\) (JCPDS No. 15-0780).

To increase the light absorption in visible region, the BaSnO\(_3\) NWs were decorated with CdS QDs by a SILAR method. As shown in Fig. S2, after being decorated with CdS QDs for ten cycles, the surface of the NWs were coated with a layer of CdS nanoparticles uniformly, which is crucial to obtaining good PEC properties. SEM cross-sectional images of the CdS QD-decorated BaSnO\(_3\) NWs on the fluorine-doped tin oxide (FTO) layer are...
shown in Fig. S3. The NW structure of BaSnO$_3$ still can be clearly seen after CdS decoration. In addition, the film has a good adhesion with the FTO substrate, and there are no cracking or peeling-off, even the thickness of the films reaches up to 30 µm.

The structural information of the CdS QD-decorated BaSnO$_3$ NWs was characterized by TEM. As shown in Fig. 4c, CdS QDs have an average size of 5 nm and uniformly distributed on the BaSnO$_3$ NW. Such a uniformly distribution of CdS QDs is attributed to the advantage SILAR method. In the second step of SILAR procedure, excess ions adsorbed on the substrate by Van-der Waals force will be removed by the rinse water, and the chemical reaction can only happen between the strongly specific adsorbed cations (Cd$^{2+}$) and the less strongly adsorbed anions (S$^{2-}$) adjacent to the nanowire surface. The uniform distribution of the QDs is attributed to the uniformly absorption of the ions in such a high temperature treated clean surface of the BaSnO$_3$ NWs. The loaded amount of CdS is about 0.2 mg after 10-cycle decoration when the amount of BaSnO$_3$ is 2 mg. The lattice spacing, 0.29 and 0.24 nm, in the HRTEM image (Fig. 4d) correspond to the (200) and (111) planes of CdS (JCPDS No. 80-0019), respectively. In order to further confirm the formation of CdS QDs on the fiber, the Cd and S elemental mapping has been performed. As shown in Fig.S4, the Cd (blue) and S (yellow) elements are homogeneously distributed on the surface of nanowire. This result implies that the CdS QDs are uniformly distributed on the BaSnO$_3$ nanowires’ surface.

X-ray photoelectron spectra (XPS) were performed on the BaSnO$_3$ NWs-CdS QDs film to investigate its chemical compositions and electronic structures. Fig. 5a exhibits the survey spectrum, which including the peaks from Ba, Sn, O, Cd and S. Fig. 5b, c and d shows the O 1s, Cd 3d and S 2p core level XPS scanned at higher resolution over smaller energy windows, respectively. The O 1s XPS spectrum shows a peak with a binding energy of 573.1 eV. The Cd 3d core level XPS spectrum has two sharp peaks at 405.5 eV (Cd 3d 5/2) and 412.2 eV (Cd 3d 3/2) with a typical splitting energy of 6.7 eV, consisted with the previously reported values for CdS. The S 2p core level spectrum given in Fig. 5d indicates that the S 2p has a doublet structure corresponds to S 2p 3/2 and 2p 1/2 orbitals of divalent sulfide ions (S$^{2-}$) at 162.2 and 163.0 eV. Only a weak peak from oxidized form of sulfur (such as sulfate) was observed at 168.8 eV, indicating that the CdS QDs were heat stable at 400 °C in short-time.

The light absorption of BaSnO$_3$ NWs and BaSnO$_3$ NWs-CdS QDs were determined by UV-vis absorption spectra (Fig. 6a). It can be seen that the BaSnO$_3$ NWs only absorbs UV light with correlation to its optical band gap (3.1 eV). After decorated with CdS QDs, the absorption range of the photoanode has been extended to visible region with a maximum wavelength about 600 nm, indicating an effective usage of visible light. It’s worth noting, that the band gap of pure CdS is 2.34 eV, and the
Fig. 5 (a) XPS fully scanned spectra of BaSnO$_3$ NWs-CdS QDs. High resolution XPS spectrum of O 1s (b), Cd 3d (c) and S 2p (d).

Fig. 6 (a) UV-vis absorption spectra and (b) the plots of band gap energy of pure BaSnO$_3$ NWs and BaSnO$_3$ NWs-CdS QDs.

The absorption edge of pure CdS is around 530 nm in theory. However, in Fig.6a, the hybrid BaSnO$_3$-CdS shows an absorption edge of 600 nm. Such a red shift of absorption edge may be attributed to the sulfide vacancies. It can be seen that there is a weak peak of S$^{6+}$ in S 2p core level in the XPS spectrum (Fig. 6d). In general, point defects, such as sulfide vacancies and oxygen vacancies, are likely to narrow the band gap in many cases. The relationship of the absorption coefficient and the incident photon energy of the semiconductor can be estimated by modified Kubelka–Munk function, as shown in Fig. 6b. It can be seen that CdS QD-decorated BaSnO$_3$ NWs have a slightly lower band gap (2.3 eV) than individual BaSnO$_3$ NWs (3.3 eV), which are very close to the reported value of CdS and BaSnO$_3$. These values demonstrated that the obtained BaSnO$_3$ NWs-CdS QDs samples exhibit a strong absorption in both UV and visible light.

As known, electrochemical impedance spectroscopy (EIS) can provide the interfacial information of photoanodes. Fig. S5 shows the semicircular features of the photoanode/electrolyte interface.
interface Nyquist plots. The diameter of the semicircle equals to the electrical resistance $R$ of photoanode/electrolyte interface, which controls the electron transfer kinetics of the redox probe. As shown in Fig S5, the arc diameter for the BaSnO$_3$/CdS heterostructures is much smaller than that of pristine BaSnO$_3$ nanowires, which indicates that the resistance $R$ of BaSnO$_3$/CdS heterostructures is lower than that of BaSnO$_3$ nanowires. This shows that such a heterojunction structure has effectively enhanced the electron mobility and suppressed the recombination of photoexcited electron-hole pairs in the BaSnO$_3$/CdS heterostructure photoanode. The reduced charge transfer resistance is believed to be a key factor for the improvement of PEC’s performance.

It is worth mentioning that the photocurrent going through an external circuit is widely used as a reliable surrogate for gas measurement in PEC hydrogen generation. The hydrogen generation rate can be calculated from the photocurrent according to the following equation:

$$n \text{H}_2 (\text{H}_2 \text{mol}/\text{h cm}^2) = \frac{1800 \times j \text{ (mA/cm}^2\text{)} \times \eta_e}{e(c) \times N_A}$$

Here, $j$ is the photocurrent density, $\eta_e$ is the faradic efficiencies, $e(c)$ is the electronic charge, and $N_A$ is the Avogadro constant. More details about this equation can be found in supplementary materials.

In order to evaluate the PEC performance of BaSnO$_3$ NWs-CdS QDs photoanode, linear sweep voltammograms were measured in a three-electrode configuration with a solution containing 0.25 M Na$_2$S and 0.35 M Na$_2$SO$_3$ as electrolyte. The working area of the photoanode is about 0.4 cm$^2$. Fig. 7a displays a set of linear-sweep voltammograms of the BaSnO$_3$ NWs-CdS QDs photoanode with different decorating cycles. The dark current is almost zero through all the sweeping voltage. The BaSnO$_3$ NWs photoanode yields a photocurrent density of 0.5 mA cm$^{-2}$ at 0 V versus SCE and photocurrent onset potential of 0.5 V vs. SCE under AM 1.5G (100 mW cm$^{-2}$) illumination. From Fig. 7b we can see, the photocurrent density drastically increased with the decoration cycle of CdS. When the decoration cycle is 10, it reached its maximum value of ~4.8 mA cm$^{-2}$ (0 V vs. SCE) which corresponds to a hydrogen generation rate of 90 $\mu$mol (h cm$^{-2}$)$^{-1}$ in theory by assuming $\eta_{PEC}$. However, $\eta_e$ is always less than 1 in practical due to the existence of sacrificial agents. The maximum photocurrent is about nine times larger than that of the pure BaSnO$_3$ NWs. While further increasing the running cycles, the photocurrent density decreased sharply. It decreased to 2.5 mA cm$^{-2}$ after 15 cycles. This phenomenon is in accordance with the reports of other groups, which can be explained by the morphology change of the samples shown in Fig. S6. When the decorating cycle is less than 10, the amount of CdS QDs loaded on the surface of BaSnO$_3$ NWs increases with the decorating times, which facilitates photo absorption and generation of more electron-hole pairs. It is known that the ultrafast interfacial electron transfer and high-efficiency charge separation occurs only in the directly coupled QDs/semiconductor system. Therefore, direct contact between CdS QDs and BaSnO$_3$ NWs is essential to obtain high PEC performance. However, as shown in Fig. S6c, further increase in the amount of CdS QDs results in the aggregation of the CdS NWs-CdS QDs photoanode with different decorating cycles. The dark current is almost zero through all the sweeping voltage. The BaSnO$_3$ NWs photoanode yields a photocurrent density of 0.5 mA cm$^{-2}$ at 0 V versus SCE and photocurrent onset potential of 0.5 V vs. SCE under AM 1.5G (100 mW cm$^{-2}$) illumination.
Fig. 7 (a) Linear-sweep voltammograms curves of BaSnO$_3$ NWs-Cds QDs with different decoration cycles. (b) Short-circuit photocurrent as a function of decoration cycles. Short-circuit photocurrent (c) and open circuit voltage (d) response of BaSnO$_3$ NWs-Cds QDs photoanode with on and off cycles.

QDs than that of BaSnO$_3$ NWs. Moreover, the recycle performance of the CdS QD-decorated BaSnO$_3$ photoanode was characterized in the three-electrode configuration. As shown in Fig. S7, the remained photocurrent was about 73% of the initial after 100 cycles.

Fig. 7c and d show the photoresponse of BaSnO$_3$ NWs-Cds QDs over time at 0 V vs. SCE for photocurrent ($J$-t) and at open circuit condition for voltage response ($V$-t) under pulsed light illumination. It can be seen that the photocurrent jumps sharply to $\sim$4.0 mA cm$^{-2}$ when the light is switched on, which indicates rapidly transferring of the photo-generated electrons from CdS QDs to BaSnO$_3$ NWs. In addition, the photocurrent decay rapidly to dark current once the light is switched off, indicating fast transport of photo-generated electrons in BaSnO$_3$ NWs. The $V$-t curves of BaSnO$_3$ NWs and BaSnO$_3$ NWs-Cds QDs were shown in Fig. 7d. The photovoltage for both of BaSnO$_3$ NWs and BaSnO$_3$ NWs-Cds QDs rises rapidly when the light was switched on and reached the saturation state within 10 s, which agrees with the rapid jump of the $J$-t curve. It is interesting that the photovoltage decay time ($\tau_d$, defined as time to recovery to 1/e (37%) of the maximum photovoltage) of BaSnO$_3$ NWs-Cds QDs is more than 84 s, much larger than that of BaSnO$_3$ NWs (10 s), implying longer electron lifetime in BaSnO$_3$ NWs-Cds QDs than that in pure BaSnO$_3$ NWs. Such an increasing in electron lifetime is attributed to the contribution of BaSnO$_3$ NWs-Cds QDs heterojunction with type II band alignment. As show in Fig. 8, the conduction and valance band of CdS are both negative than that of BaSnO$_3$. The photoexcited electrons are transferred upon light irradiation from the CdS conduction band to the conduction band of BaSnO$_3$. The photoexcited holes accumulate on the valance band of CdS, thus reducing the recombination probability and increasing the lifetime of electrons. Photoluminescence (PL) spectra analysis was also applied to reveal the functions of such a heterojunction formed at the BaSnO$_3$/CdS interface. As shown in Fig. S8, the PL intensity of BaSnO$_3$ NWs was significantly decreased after being decorated with CdS QDs. This decrease can be attributed to the increased PL quenching, because of the enhanced electron transfer from CdS to BaSnO$_3$ by such a
IPCE is a valuable tool to provide insight into the PEC photoresponse properties. The IPCE measurements were carried out on typical photoanodes at 0 V (vs. RHE). As shown in Fig. S9, compared to BaSnO$_3$ NWs, CdS QD-decorated BaSnO$_3$ NWs showed a significantly enhanced photocactivity in the range of 350-550 nm. The results clearly confirm that the decoration of CdS QDs has effectively improved the visible-light absorption of BaSnO$_3$ NWs. Moreover, the heterojunction between CdS and BaSnO$_3$ will facilitate the charge separation and suppress the charge recombination, which greatly enhanced the IPCE.

The practical hydrogen generation rate has been quantified by gas chromatography. Fig. S10 shows the evolution of H$_2$ as a function of time under visible light irradiation and the bias is 0 V (vs. SCE). The hydrogen generation rate is about 71.8 μmol (h cm$^{-2}$)$^{-1}$ for the CdS QD-decorated BaSnO$_3$ photoanode, corresponding to a Faradaic efficiency around 80%.

4. Conclusions

In summary, highly crystalline BaSnO$_3$ NWs have been prepared by electrospinning from a precursor solution with a suitable mixed solvent. The optimized PVP content and annealing temperature are 11% and 900°C, respectively. After decorated with CdS QDs, the BaSnO$_3$ NWs yield remarkable photocurrent density of ~4.8 mA cm$^{-2}$ at 0 V vs. SCE and a hydrogen generation rate of 71.8 μmol (h cm$^{-2}$)$^{-1}$, corresponding to a Faradaic efficiency of close to 80%, which are nine times higher than that of BaSnO$_3$ NWs. Such a favorable PEC performance of the CdS QD-decorated BaSnO$_3$ NWs results from the high electron-hole generation rate at the CdS/BaSnO$_3$ interface and the low degree of charge recombination in the BaSnO$_3$ NWs during transport. The results indicate that CdS QD-decorated BaSnO$_3$ NWs is a promising candidate for high-efficient PEC water splitting, and the water splitting performance of PEC cells can be highly improved by rationally building interface band structures.

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Notes and references

A staggered gap heterojunction has been built with BaSnO$_3$ nanowires and CdS quantum dots for high efficient water splitting photoanode.