Bimetallic sulfide Co$_8$FeS$_8$/N–C dodecahedral nanocages via cation exchange as counter electrode for dye-sensitized solar cells

Dongmei Tang $^a$, Rongfang Zhao $^b$, Ju Xie $^a$, **, Kehan Zhou $^a$, Yue Han $^a$, Xiaoyu Wu $^a$, Huayu Wu $^a$, Guowang Diao $^a$, Ming Chen $^a$, $^*$

$^a$ School of Chemistry and Chemical Engineering, Yangzhou University, Yangzhou, 225002, Jiangsu, China
$^b$ Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai, 264003, China

** Corresponding author.
$^*$ Corresponding author.
E-mail addresses: xieju@yzu.edu.cn (J. Xie), chenming@yzu.edu.cn (M. Chen).

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ABSTRACT

The bimetallic sulfides with unique catalytic ability are highly attractive in energy conversion field. Herein, Co$_8$FeS$_8$/N–C dodecahedral nanocages (DNCs) are synthesized by ZIF-67 as a template through subsequent sulfidation and cation exchange strategy. Co$_8$FeS$_8$/N–C DNCs are fabricated by Co$_8$FeS$_8$ nanoparticles with superior crystallinity, which are coated with the N-doped carbon shell derived from organic ligands in ZIF-67. When Co$_8$FeS$_8$/N–C DNCs are applied as an efficient and low-cost Pt-free counter electrode (CE) for the dye-sensitized solar cells, they achieve a high power conversion efficiency (PCE) of 8.06%. The electrochemical results show that Co$_8$FeS$_8$ DNCs exhibit the best electrocatalytic activity for the reduction of triiodide (the smallest peak-to-peak separation and electron transfer impedance) than those of Pt counter electrode and monometallic sulfide Co$_9$S$_8$/N–C counter electrode.

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1. Introduction

Dye-sensitized solar cells (DSSCs) as a new generation of solar cells have attracted significant attention due to their low manufacturing cost and relatively high power conversion efficiency (PCE) [1–5]. The counter electrode (CE), as one of the essential and crucial components of DSSCs, plays a key role in typical DSSC device. The desired CE materials with good conductivity should exhibit high catalytic activity toward the reduction reaction of I$_3^–$. However, the precious metal catalysts with high cost, scarcity in nature and poor long-term stability limit the large-scale applications of DSSCs [6].

Tremendous efforts to develop nonprecious metal-based catalysts with low cost and high performance aim to realize the industrialization of DSSCs. So far, several kinds of new CE materials have been proposed, such as conductive organic polymers, carbon materials, transition metal carbides [7,8], nitrides [9,10], oxides [11–13], sulfides [14,15], and their composite materials [16,17]. Among various CE materials, cobalt sulfides, as one kind of low-cost metal compound with different chemical structures, including Co$_9$S$_8$, CoS, Co$_4$S$_3$, Co$_4$S$_2$, and Co$_3$S$_4$ [18–21], have been deemed as promising CE materials in DSSCs due to their excellent electrocatalytic activity for the I$^-$/I$_3^–$ redox reaction. However, most DSSCs using cobalt sulfides as CEs show lower PCE values than those employing Pt CEs, which is mainly ascribed to the poor charge transfer kinetics of cobalt sulfide nanoparticles at the CE/electrolyte interface [22].

In this modified ZIF-67 as a template, Co$_8$FeS$_8$/N–C dodecahedral nanocages (DNCs) were fabricated and explored as efficient and low-cost Pt-free counter electrode (CE) for the dye-sensitized solar cells. They exhibit a high power conversion efficiency (PCE) of 8.06%. The electrochemical results show that Co$_8$FeS$_8$ DNCs exhibit the best electrocatalytic activity for the reduction of triiodide (the smallest peak-to-peak separation and electron transfer impedance) than those of Pt counter electrode and monometallic sulfide Co$_9$S$_8$/N–C counter electrode.
obtained via the sulfidation of ZIF-67 and cation exchange. Then, Co8FeS8/N–C DNCs were applied as counter electrode material for DSSCs. Numerous analytical techniques were performed to estimate the electrocatalytic activity of the Co8FeS8/N–C DNCs. Remarkably, Co8FeS8/N–C DNCs have much higher PCE and catalytic activity than Co3S8/N–C and Pt.

2. Experimental section

2.1. Synthesis of Co8FeS8/N–C dodecahedral nanocages (DNCs)

ZIF-67 was prepared by reported method [30]. The as-obtained ZIF-67 and sulfur powder, which were placed at two separated quartz boat with sulfur powder at the upstream side, were annealed at 600 °C for 2 h under argon gas flow to obtain Co8S8/N–C. During the process of cation exchange, 60 mg Co8S8/N–C and 30 mg Iron (III) 2,4-pentanedionate were dissolved in a mixing solvent consisting of 5 ml oleyl amine and 5 ml benzyl ether, and then stirred for 1 h at 300 °C under nitrogen to synthesize the Co8FeS8/N–C DNCs. One Co atom was successfully replaced with one Fe atom by the cation exchange method.

2.2. Preparation of Co8FeS8/N–C counter electrode

Co8FeS8/N–C DNCs were mixed with the carboxyethyl cellulose solution to form an ink slurry. This slurry was respectively spread on the fluorine-doped tin oxide (FTO) glasses via the screen printing, then heated at 500 °C for 30 min to produce the CEs under N2 atmosphere. Moreover, Pt CEs as a control sample were prepared by spin-coating 50 mM H2PtCl6 isopropanol solution on the FTO glass and thermally deposited at 400 °C under nitrogen to synthesize the Co8FeS8/N–C DNCs. We followed a two-step method to obtain Co8FeS8 by cation exchange strategy. Then, the cation exchange and cation exchange process, the recrystallization of Co8FeS8 nanoparticles bring about the formation of surface mesopores and double shells, however, Co8FeS8/N–C still maintains the dodecahedral structure (Fig. 2c–e), named as Co8FeS8/N–C dodecahedral nanocages (DNCs). The high-resolution TEM (HRTEM) images reveal that the Co8S8 nanoparticles are coated with the N-doped carbon shell (Fig. 2f) and the lattice distances of 0.30 and 0.18 nm are well corresponded to the d-spacing of the (311) and (440) lattice planes of Co3S8, respectively (Fig. 2g and h). The diffuse rings in the select-area electron diffraction (SAED) pattern (Fig. 2i) show the Debye–Scherrer ring patterns of (311) and (440), all of which are indexed to Co3S8. The EDX spectrum shows the existence of C, N, Co, Fe, and S (Fig. 2j) and HAADF-STEM image also proves the accumulation of nanoparticles and the formation of mesopores (Fig. 2k). Then, the element mapping images show that the distribution of Co, Fe, and S, C and N elements, which are consistent with the structure of dodecahedral nanocages (Fig. 2l–p). The weight fraction of Co3S8 in Co8FeS8/N–C is about 57.5 wt% by TGA (Fig. S2). The C and N elements in Co8FeS8/N–C are derived from 2-methylimidazole and estimated to be about 39.0 and 3.5 wt% (Table S1), which evidences the appearance of N-doped carbon shell. Furthermore, the ICP (Table S2) reveals that the atom ratio of Co:Fe is about 8:1, which powerfully confirms the formation of Co3S8 by cation exchange strategy.

The N2 adsorption-desorption isotherm indicates a mesoporous feature for Co8FeS8/N–C (Fig. 3a). Specific surface area of Co8FeS8/N–C DNCs obtained from Brunauer–Emmett–Teller (BET) analysis is 275.86 m² g⁻¹ and larger than that of Co3S8/N–C (223.92 m² g⁻¹), which is attributed to the formation of surface mesopores and double shells in Co8FeS8/N–C DNCs. The average pore size of Co8FeS8/N–C DNCs is 2.47 nm, which is bigger than that of Co3S8/N–C (2.01 nm) (Fig. S3). The chemical state of surface composition was further confirmed by X-ray photoelectron spectroscopy (XPS). The survey spectra (Fig. S4) of Co3S8 determines the existence of Co, Fe, S, C and N. In Fig. 3b, the binding energies of 777.8, 780.55, 792.73 and 796.36 eV should be assigned to Co2p3/2, Co2p1/2, Co3s+3/2, and Co3s+1/2, which are derived from two spin–orbit doublets characteristic of Co2+ and Co3+. The peaks at 711.15 and 723.89 eV are assigned to Fe 2p1/2 and Fe 2p3/2, respectively (Fig. 3c), illustrating the Fe element as +3 valence exists in Co3S8. It is evidenced that the Fe occupies the position of Co3+ in the crystal structure, which avoids destroying Co–Co metallic bond due to the theoretical arithmetic (Fig. 1a). The 2p peaks at 161.80 and 163.16 eV are assigned to the characteristic peaks of metal sulfide, respectively (Fig. 3d) [32]. The peak at 168.1 eV indicates high valence state sulfur element on the surface. The high-resolution N 1s is ascribed to three types of nitrogen species: 398.16 eV pyridinic N (N–H), 399.69 eV pyrrolic N (N=C), and 402.38 eV graphitic N,
respectively (Fig. 3e). The C 1s peaks at 283.97, 285.16, and 287.03 eV are ascribed to C=C, C=N, and C=O, respectively (Fig. 3f) [33]. The N-doped carbon from the decomposition of 2-methylimidazole ligand should improve the electrical conductivity and the ion transmission rate so as to enhance the electrocatalytic ability of Co$_8$Fe$_8$S$_8$.

3.2. Electro catalytic activity and photovoltaic performance of Co$_8$Fe$_8$S$_8$/N–C DNCs counter electrode

The main parameters, such as higher short-circuit current density ($J_{sc}$), open-circuit voltage ($V_{oc}$), fill factor (FF) and power conversion efficiency (PCE), all indicate photovoltaic performances for an applicable CE material in DSSCs. We have hence assembled the DSSCs devices with Co$_8$Fe$_8$S$_8$/N–C DNCs, Co$_9$S$_8$/N–C HPHs and Pt as counter electrodes (CEs) to assess their performance under the same circumstances. Photovoltaic performance of these solar cells were evaluated under illuminated 1.5 G sunlight (100 mW cm$^{-2}$ intensity). Fig. 4 shows the photovoltaic characteristics, listing in Table 1. The PCE of Co$_8$Fe$_8$S$_8$/N–C, Co$_9$S$_8$/N–C and Pt based DSSCs are 8.06%, 7.17% and 7.35%, respectively. Apparently, the DSSCs fabricated with Co$_8$Fe$_8$S$_8$/N–C DNCs perform much higher PCE (8.06%) and $J_{sc}$ (18.19 mA cm$^{-2}$), increasing 9.66% and 11.73% compared with that of Pt CE (7.35% and 16.28 mA cm$^{-2}$). The highest value of $V_{oc}$ should be attributed to the excellent electrocatalytic performance of reduction of I$_3^-$.

Moreover, the peak-to-peak separation ($E_{pp}$) as the primary electrochemical parameter evaluates the electrocatalytic activity of electrode materials. As shown in Fig. 5a–b, three electrodes all exhibit two typical pairs of oxidation/reduction peaks (Ox-1/Red-1, Ox-2/Red-2). The first pair of redox peaks Ox-1/Red-1 in the CV plot is assigned to the oxidation and reduction of I$_3^-$, and the Ox-2/Red-2 is attributed to the oxidation and reduction of I$_2$/I$^-$. The left pair of peaks (Ox-1/Red-1) is closely correlated with the
catalytic activity of electrode material during the reduction of I$_3^-$ [34,35]. The values of $E_{pp}$ for the first redox peaks are shown in Table 2. The values of $E_{pp}$ are in the order of Co$_8$Fe$_8$/N–C (177 mV) < Pt (378 mV) < Co$_9$S$_8$/N–C (413 mV). Furthermore, the values of the cathodic peak current density ($|J_{\text{red-1}}|$) show the order of Co$_8$Fe$_8$/N–C (0.81 mA cm$^{-2}$) > Pt (0.69 mA cm$^{-2}$) > Co$_9$S$_8$/N–C (0.62 mA cm$^{-2}$). The largest $|J_{\text{red-1}}|$ and the smallest $E_{pp}$ represent the best electrocatalytic activity. The Co$_8$Fe$_8$/N–C DNCs electrode with the smallest $E_{pp}$ and largest $|J_{\text{red-1}}|$ exhibits the highest catalytic activity in the reduction of I$_3^-$, which indicates that the Co$_8$Fe$_8$/N–C should be an excellent CE material for DSSCs [36,37]. In addition, to examine the stability of Co$_8$Fe$_8$/N–C, it is evaluated by repeating the CV tests for 50 cycles. As shown in Fig. S5, there is no significant shift for the two pairs of redox peaks, which indicates that Co$_8$Fe$_8$/N–C CEs show good stability.

Electrochemical impedance spectroscopy (EIS) represents the intrinsic interfacial charge transfer process at the symmetrical CE/electrolyte/CE cells consisting of two identical CEs. The obtained Nyquist plots of three electrodes with multi-semicircles (usually, exhibiting two semicircles) are presented in Fig. 6a, and these spectra was fitted into an equivalent circuit to extract the main parameters. The series resistance ($R_s$) was revealed by the intercept of Nyquist plots (left side) with the horizontal axis. The high-frequency semicircle represents the charge transfer resistance ($R_{ct}$) between the interface of the electrolyte and the catalyst. The Nernst diffusion impedance ($Z_{N}$) of the redox couple transport in the electrolyte was reflected with the right semicircle in the low-frequency range. Typically, $R_{ct}$ is evaluated the catalytic activity of catalysts, which is regarded as an indicator to reveal the charge transfer process. A small $R_{ct}$ can facilitate the electron transfer between CE and electrolyte for catalytic reduction of I$_3^-$ and consequently result in less interfacial recombination. On the contrary, a large $R_{ct}$ indicating a sluggish electron transfer will lead to a lower $J_{sc}$ of DSSCs [38–40]. It is a surprising finding that the EIS plot of the cell fabricated with Co$_9$S$_8$/N–C DNCs shows three semicircles, meanwhile, the Bode plot of Co$_8$Fe$_8$/N–C (Fig. 6b) also displays three time constants. It deduces the existence of multiple interface reaction processes. The multiple interface model might be electrolyte/catalyst (Co$_8$Fe$_8$/N–C, outer shell)/electrolyte/catalyst (Co$_9$S$_8$/N–C, inner shell)/electrolyte (Fig. 6c), which is attributed to the existence of multiple reaction pathways.
to the double-shell structure of Co$_8$Fe$_8$/N–C. Hence the electron transfer impedance of Co$_8$Fe$_8$/N–C is made up of $R_{ct1}$ and $R_{ct2}$. In contrast, the EIS and Bode plots of Pt and Co$_9$S$_8$/N–C are typical models for the dummy cells displaying two semicircles and two time constants. The parameters are shown in Table 2. The values of $R_{ct(total)}$ and $Z_N$ are in order of Co$_8$Fe$_8$/N–C < Pt < Co$_9$S$_8$/N–C, which means that the Co$_8$Fe$_8$/N–C electrode exhibits the best electrocatalytic activity than those of Pt and Co$_9$S$_8$/N–C electrodes.

The catalytic activity of CE materials for DSSCs is further elucidated by Tafel polarization. Fig. 7 shows Tafel curves of symmetrical cells based on Co$_8$Fe$_8$/N–C, Co$_9$S$_8$/N–C, and Pt CEs, respectively. In addition, the limiting current density ($J_{lim}$) is directly proportional to the diffusion coefficients ($D$) and reciprocal to $Z_N$ which was expressed by eqs (1) and (2), where $e_0$, $D$, $k$, $c$, $A$, $\omega$, and $\delta$ are the elementary charge, diffusion coefficients, Boltzmann constant, concentration of I$_3^-$, electrode area, angular frequency, and thickness of the diffusion layer, respectively.

$$J_{lim} = \frac{2ne_0DN_A}{I}$$

$$Z_N = \frac{kT}{n^2e_0^2cA\sqrt{\omega D}}\tanh\left(\sqrt{\frac{\omega^2}{D}}\delta\right)$$

$$J_0 = \frac{RT}{nF}r_{ct}$$

As shown in Fig. 7, the order of $J_{lim}$ value is Co$_8$Fe$_8$/N–C > Pt > Co$_9$S$_8$/N–C, which means Co$_8$Fe$_8$/N–C with the smallest $Z_N$ has the highest electrocatalytic activity. Therefore, Co$_8$Fe$_8$/N–C has the best catalytic activity and charge transfer.

**Table 2**

| CEs       | $E_{pp}$ (mV) | $R_{ct1}$ (Ω) | $R_{ct2}$ (Ω) | $Z_N$ (Ω) | $\log_{10}$ ($J_0$ (mA)) |
|-----------|---------------|----------------|----------------|-----------|--------------------------|
| Co$_8$Fe$_8$/N–C | 177           | 1.24           | 5.52           | 2.70      | 0.28                     |
| Co$_9$S$_8$/N–C | 413           | 7.90           | ~              | 5.79      | 0.21                     |
| Pt         | 378           | 6.80           | ~              | 5.14      | 0.27                     |

Fig. 5. (a) CV curves and (b) the histogram of $E_{pp}$ for Pt, Co$_9$S$_8$/N–C, and Co$_8$Fe$_8$/N–C DNCs.

Fig. 6. (a) Nyquist, (b) Bode plots for dummy cells fabricated with Co$_8$Fe$_8$/N–C, Co$_9$S$_8$/N–C and Pt (inset is equivalent circuit model for Co$_8$Fe$_8$/N–C); (c) the diagrams of electron transfer progress for Pt, Co$_9$S$_8$/N–C, and Co$_8$Fe$_8$/N–C.
abilities of the three CE materials. The exchange current density ($j_0$), closely relating to electrocatalytic properties of the CE materials, is the intercept of the line at zero potential with the horizontal line potentials. As shown in Fig. 7, it is obvious that the order of $j_0$ is $\text{Co}_8\text{FeS}_8/\text{N–C} > \text{Pt} > \text{Co}_9\text{S}_8/\text{N–C}$. The largest slope for cathodic branch and the highest $j_0$, indicating that $\text{Co}_8\text{FeS}_8/\text{N–C}$ CE has the highest electrocatalytic performance compared to Pt and $\text{Co}_9\text{S}_8/\text{N–C}$. Moreover, $j_0$ can be calculated by eq [3], where $k$ is the gas constant, $T$ is the temperature, $F$ is the Faraday constant, $n$ is the number of electrons involved in the reduction, and $R_e$ is the charge transfer resistance [41]. The calculated $j_0$ of the CE materials has the same order obtained by Tafel polarization curves.

Combining the analysis from morphology and electrochemical characterization, the superior electrocatalytic performance of $\text{Co}_8\text{FeS}_8/\text{N–C}$ DNs as CE material for DSSCs can be attributed to the following aspects: (1) Fe atom replaces the position of Co with improved superior crystallinity, which can increase more catalysis active sites for the redox reaction; (2) $\text{Co}_8\text{FeS}_8/\text{N–C}$ DNs with distinctive double shells and surface mesoporous provide large specific surface area, which enhances the effective contact area between electrolyte and catalyst; (3) the N-doped carbon shell and the Co–Co metallic bond improve the electrical conductivity of the materials [42].

4. Conclusion

In summary, bimetallic sulfides of $\text{Co}_8\text{FeS}_8/\text{N–C}$ DNs are successfully prepared by ZIF-67 as a template through subsequent sulfidation and cation exchange method. $\text{Co}_8\text{FeS}_8/\text{N–C}$ DNs with large specific surface area exhibit excellent electrocatalytic performance for the reduction reaction of the $\text{I}_3/\text{I}^-$ as CE in DSSCs due to their distinctive and superior crystallinity allowing effective adsorption and catalytic reduction of $\text{I}_3^-$. The electrochemical measurements show that $\text{Co}_8\text{FeS}_8/\text{N–C}$ as the CE material displays the smallest $E_{DPP}$, $R_{ct}$ and the highest $j_0$ compared to Pt and $\text{Co}_9\text{S}_8/\text{N–C}$. The DSSCs fabricated by $\text{Co}_8\text{FeS}_8/\text{N–C}$ CE achieve the highest PCE of 8.06% than those of Pt and monometallic sulfide $\text{Co}_9\text{S}_8/\text{N–C}$ counter electrodes. The present work clearly demonstrates the effectiveness of the proposed synthetic method for the fabrication of highly-efficient and cost-effective bimetallic sulfides counter electrode for DSSCs application.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Dongmei Tang: Data curation. Rongfang Zhao: Writing - original draft. Ju Xie: Software, Validation. Kehan Zhou: Visualization. Yue Han: Investigation. Xiaoyu Wu: Writing - review & editing. Huayu Wu: Formal analysis. Guowang Diao: Funding acquisition. Ming Chen: Supervision, Writing - review & editing.

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Appendix A. Supplementary data

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References

[1] M.G. Brian O’Regan, Nature 353 (1991) 737–740.
[2] J. Wu, Z. Lan, J. Lin, M. Huang, Y. Huang, L. Fan, G. Luo, Y. Lin, Y. Xie, Y. Wei, Chem. Soc. Rev. 46 (2017) 5975–6023.
[3] M. Gratzel, Nature 414 (2001) 338–344.
[4] M. Ye, X. Wen, M. Wang, J. Iocozzia, N. Zhang, C. Lin, Z. Lin, Mater. Today 18 (2015) 155–162.
[5] B. Li, L. Wang, B. Kang, P. Wang, Y. Qiu, Sol Energ Mat Sol C 90 (2006) 549–573.
[6] G.H. Olsen, Sten Erik Lindquist, Sol Energ Mat Sol C 60 (2000) 267–273.
[7] M. Wu, X. Lin, Y. Wang, L. Wang, W. Guo, D. Qi, X. Peng, A. Hagfeldt, M. Gratzel, T. Ma, J. Am. Chem. Soc. 134 (2012) 3419–3428.
[8] M. Wu, X. Lin, A. Hagfeldt, T. Ma, Angew. Chem. Int. Ed. 50 (2011) 3520–3524.
[9] M. Wu, Q. Zhang, J. Xiao, C. Ma, X. Lin, C. Miao, Y. He, Y. Gao, A. Hagfeldt, T. Ma, J. Mater. Chem. 21 (2011).
[10] C.R. Li, J. Song, G.L. Pan, X.P. Gao, Energy Environ. Sci. 4 (2011) 1680–1683.
[11] M. Wu, X. Lin, A. Hagfeldt, T. Ma, Chem. Commun. 47 (2011) 4535–4537.
[12] H. Zheng, Y. Tachibana, K. Kalantar-Zadeh, Langmuir 26 (2010) 19148–19152.
[13] T.F. Jiang, M.B. Dorrer, Y. Farrer, Y. Pellegrin, E. Gautron, M. Bouitjita, L. Cario, S. Jobeck, F. Odobal, RSC Adv. 6 (2016) 112765–112770.
[14] H. Sun, D. Qin, S. Huang, X. Guo, D.L. Yu, L. Meng, Energy Environ. Sci. 4 (2011) 2630–2637.
[15] X. Sun, J. Dou, F. Xie, Y. Li, M. Wei, Chem. Commun. 50 (2014) 9869–9871.
[16] L. Jeong, L. Lee, K.L.V. Joseph, H.J. Lee, J.K. Kim, S. Yoon, J. Lee, Nano Energy 9 (2014) 392–400.
[17] J. Xia, C. Yuan, S. Yanagida, ACS Appl. Mater. Interfaces 2 (2010) 2136–2149.
[18] L. Liu, X. Mai, H. Chen, J. Ren, Z. Liu, Y. Li, L. Gao, N. Wang, J. Zhang, H. He, Z. Guo, Nanoscale 10 (2018) 4194–4201.
[19] M. Wang, A.M. Anghel, B. t. Marsan, N.-L.C. Ha, N. Pootrakulchote, S.M. Zakeeruddin, M. Gratzel, J. Am. Chem. Soc. 131 (2009) 15976–15977.
[20] T. Jiang, S. Yang, P. Dai, X. Yu, Z. Bai, M. Wu, G. Li, C. Tu, Electrochim. Acta 261 (2018) 143–150.
[21] G.C. Zhuang, H.L. Liu, X.B. Chen, RSC Adv. 8 (2018) 18792–18799.
[22] X. Qian, W. Wu, J. Zhuang, Y. Niu, J. Huang, L. Hou, J. Power Sources 417 (2019) 21–28.
[23] S. Ghosami, S.R. Hosseini, M. Moalem-Banhanghi, J. Electroanal. Chem. 833 (2019) 242–250.
[24] C. Zhang, L. Deng, P. Zhang, X. Ren, Y. Li, T. He, J. Solid State Electrochem. 21 (2017) 3579–3588.
[25] F. Bella, R. Bongiovanni, R.S. Kumar, A.M. Kulaianathan, A.M. Stephan, J. Mater. Chem. 1 (2013) 9033–9036.
[26] Z. Xie, X. Cui, W. Xu, Y. Wang, Electrochim. Acta 229 (2017) 361–370.
[27] T.Y. Chen, Y.J. Huang, C.T. Li, C.W. Kung, R. Vittal, K.C. Ho, Nano Energy 32 (2017) 19–27.
[28] Z. Liang, C. Qiu, D. Xia, R. Zou, Q. Xu, Angew. Chem. Int. Ed. 57 (2018) 9604–9633.
[29] W. Li, R. Zhao, K. Zhou, C. Shen, X. Zhang, H. Wu, L. Ni, H. Yan, G. Diao, M. Chen, J. Mater. Chem. 7 (2019) 8443–8450.
[30] R. Zhao, D. Tang, L. Huan, Q. Wu, W. Li, X. Zhang, M. Chen, G. Diao, Sol. Energy 178 (2019) 241–248.
[31] J. Mujtaba, H. Sun, G. Huang, Y. Zhao, A. Aradjiyan, G. Sun, S. Xu, J. Zhu, RSC
[33] Q. Wu, R. Zhao, X. Zhang, W. Li, R. Xu, G. Diao, M. Chen, J. Power Sources 359 (2017) 7–16.

[34] Y. Wu, B. Zhou, C. Yang, S. Liao, W.H. Zhang, C. Li, Chem. Commun. 52 (2016) 11488–11491.

[35] J. Qiu, D. He, R. Zhao, B. Sun, H. Ji, N. Zhang, Y. Li, X. Lu, C. Wang, J. Colloid Interface Sci. 522 (2018) 95–103.

[36] H.M. Kim, I.-Y. Jeon, I.T. Choi, S.H. Kang, S.-H. Shin, H.Y. Jeong, M.J. Ju, J.-B. Baek, H.K. Kim, J. Mater. Chem. 4 (2016) 9029–9037.

[37] C.K. Kim, H. Zhou, T. Kowalewski, K. Matyjaszewski, H.K. Kim, ACS Appl. Mater. Interfaces 11 (2018) 2093–2102.

[38] J.Y. Lin, S.Y. Tai, S.W. Chou, J. Phys. Chem. C 118 (2013) 823–830.

[39] A. Yousef, M.S. Akhtar, N.A.M. Barakat, M. Mortak, O.B. Yang, H.Y. Kim, Electrochim. Acta 102 (2013) 142–148.

[40] K. Saranya, A. S, N. Sivasankar, S. Mallick, Mater. Res. Bull. 75 (2015) 83–90.

[41] J.Y. Bai, R.F. Zhao, G. Han, Z.C. Li, C.W. Diao, RSC Adv. 5 (2015) 43326–43333.

[42] J.Y. Liu, Z.H. Wang, X.D. Yan, P.M. Juan, J. Colloid Interface Sci. 505 (2017) 789–795.