Supplementary Information

Quantum dots doped CeO_x-NiB with modulated electron density as highly efficient bifunctional electrocatalyst for water splitting

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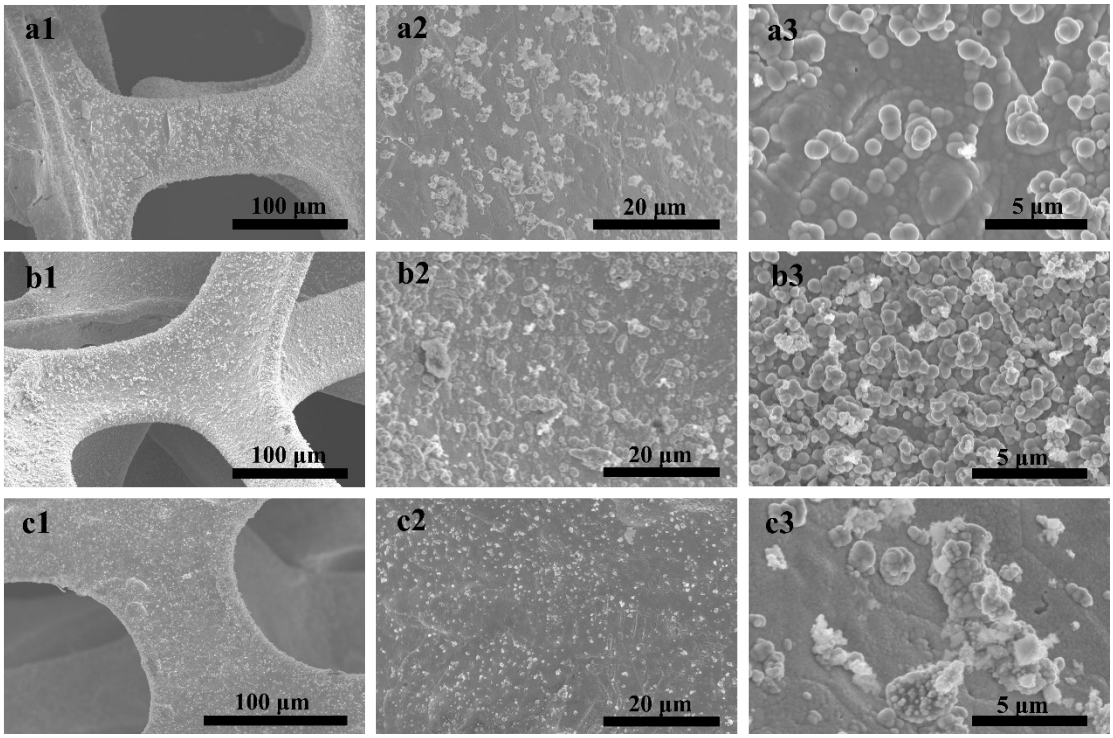

Fig. S1. SEM images of CeO_x-NiB/SiC@NF with different additions of SiC (a) 0.02 g; (b) 0.04 g and (c) 0.06 g.

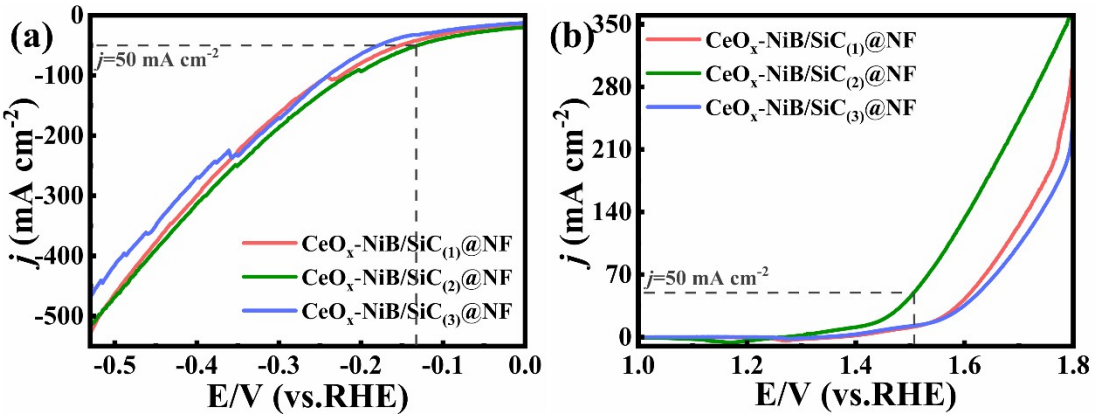

Fig. S2. LSV curves of HER and OER of CeO_x-NiB/SiC@NF with different SiC doping amounts.

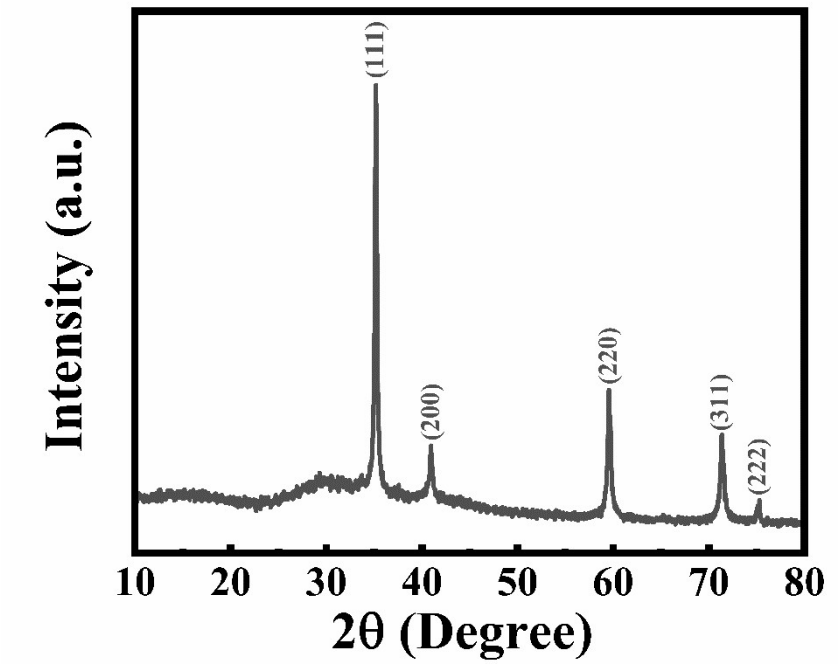

Fig. S3. XRD pattern of SiC powder

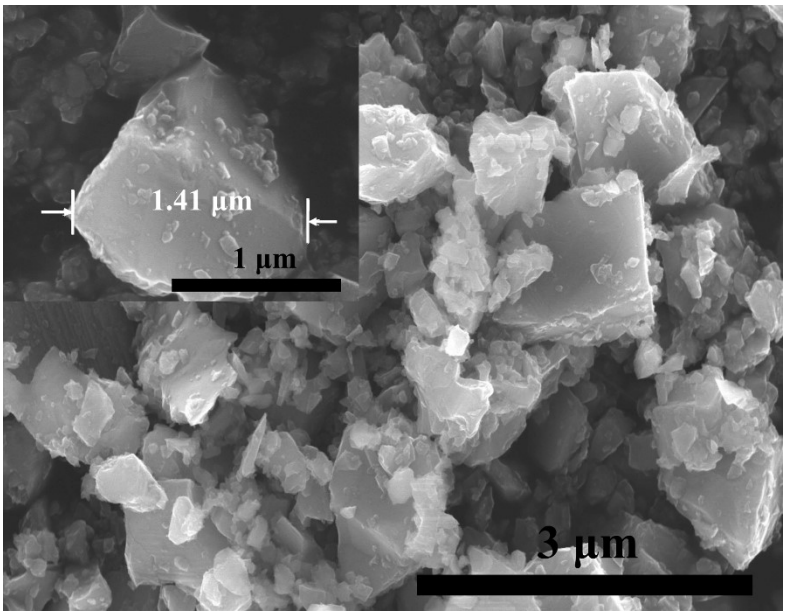

Fig. S4. FESEM image of SiC powder

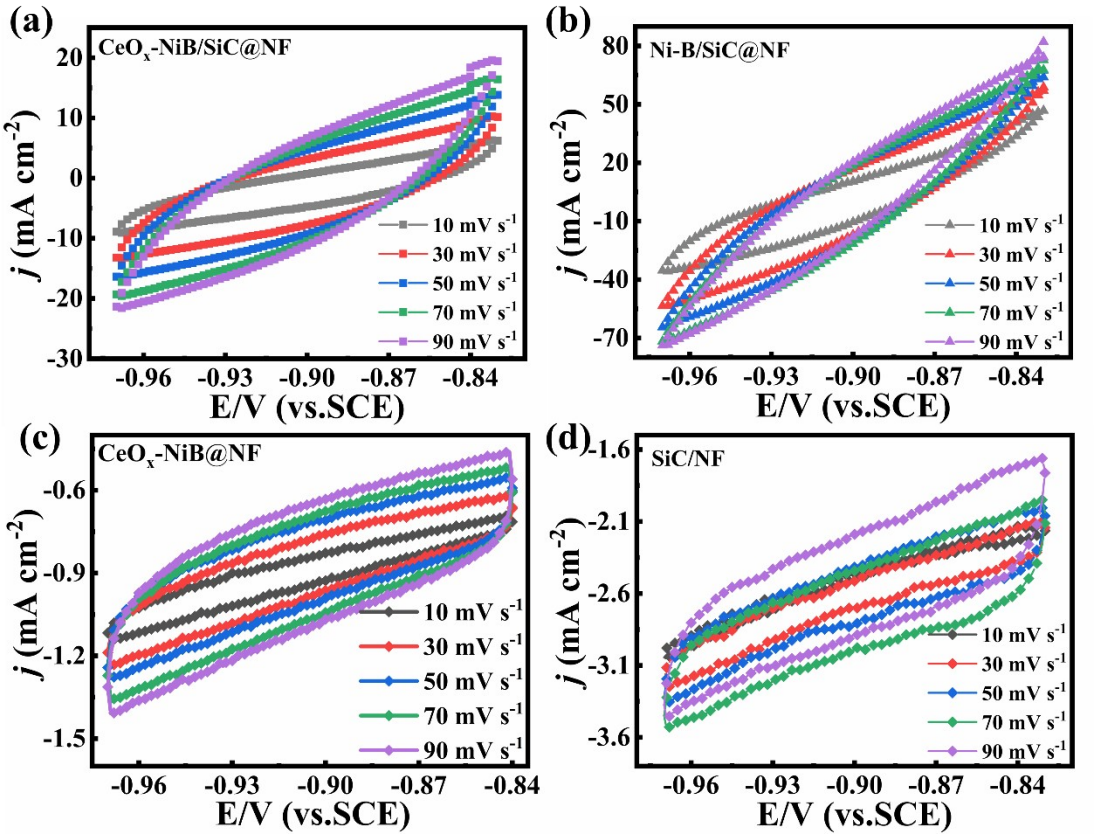

Fig. S5. (a-d) Cyclic voltammograms of CeO_x-NiB/SiC@NF, Ni-B/SiC@NF, CeO_x-NiB@NF and SiC/NF electrodes at different scan rates in 1.0 M KOH for HER.

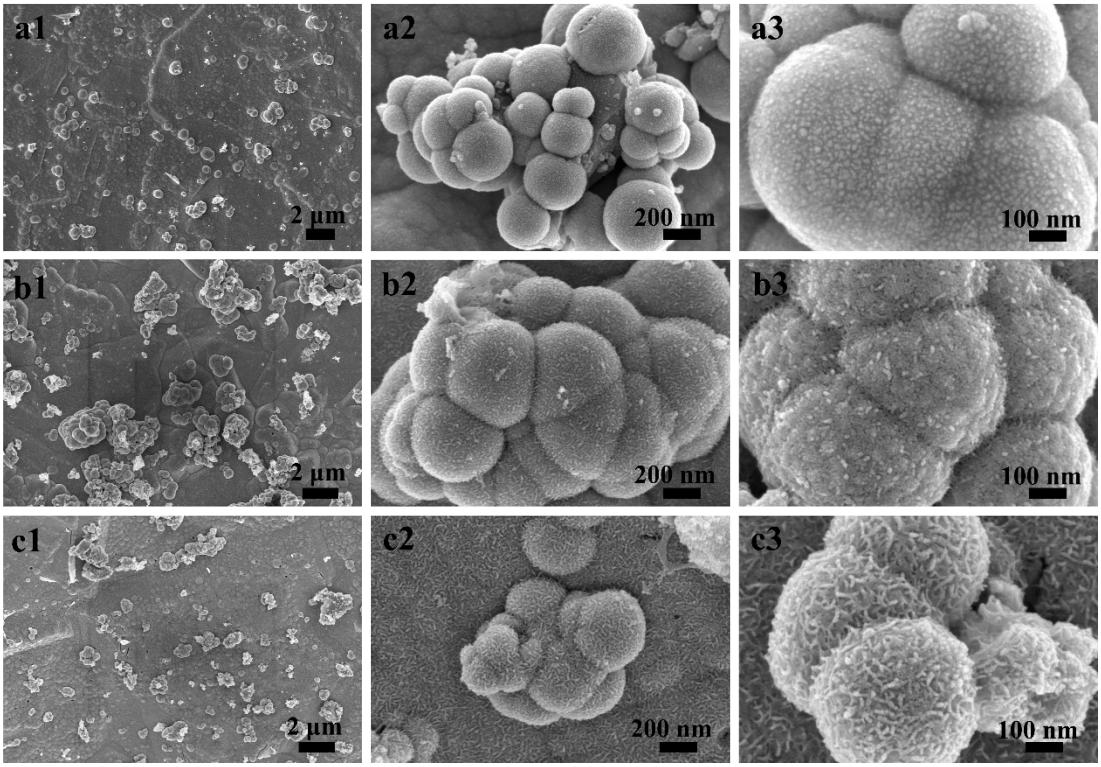

Fig. S6. (a-c) The FESEM images of original, post-HER and post-OER CeO_x-NiB/SiC@NF electrode.

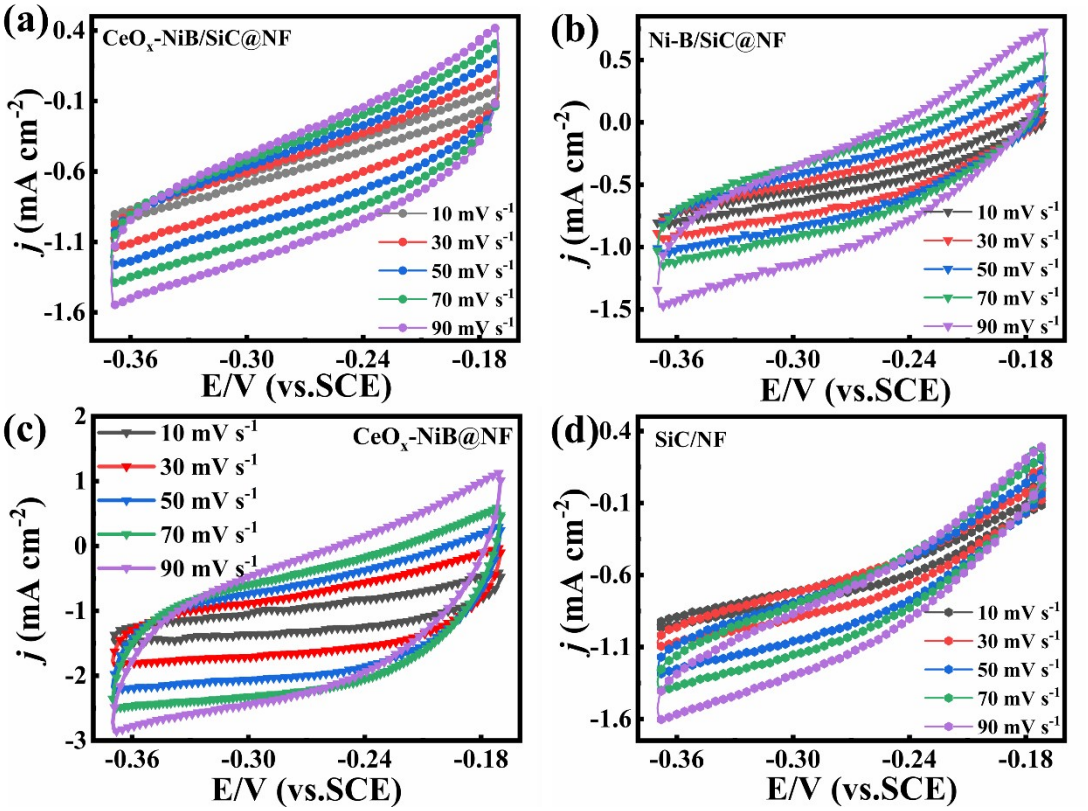

Fig. S7. (a-d) Cyclic voltammograms of CeO_x-NiB/SiC@NF, Ni-B/SiC@NF, CeO_x-NiB@NF and SiC/NF electrodes at different scan rates in 1.0 M KOH for OER.

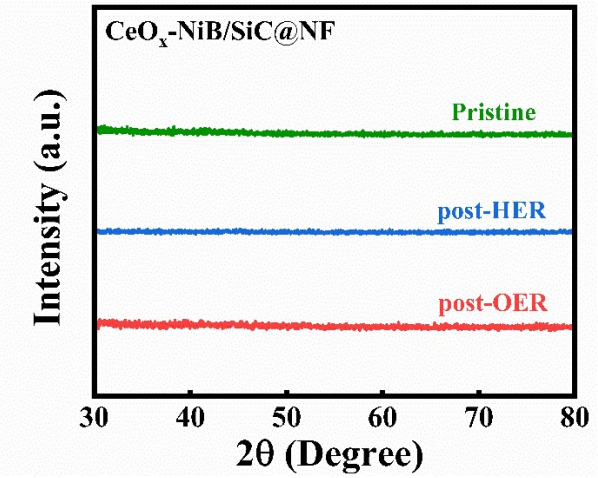

Fig. S8. XRD comparison pattern for pristine CeO_x-NiB/SiC@NF and after HER and OER stability tests for 24 h.

Table S1 ICP-AES test results of CeO_x-NiB/SiC@NF and Ni-B/SiC@NF samples

Element	Ni	Ce	Si	B	Ni: Ce: Si: B
CeO_x-NiB/SiC@NF	14.6	1.19	0.35	7	2.08: 0.17: 0.05: 1
Ni-B/SiC@NF	246.9	0	0.94	23.5	10.5: 0: 0.04: 1

Table S2 Comparison of the HER catalytic performance of CeO_x-NiB/SiC@NF and other electrocatalyst electrodes in 1.0 M KOH.

Catalysts	**Electrolyte**	**j ($mA \cdot cm^{-2}$)**	**Potential (mV)**	**Reference**
CeO_x-NiB/SiC@NF	1M KOH	50	131	This work
NX600C	1M KOH	50	290	1
$Co_{1-x}Fe_x$-LDH	1M KOH	50	273	2
$(Ni_{0.33}Fe_{0.67})_2$	1M KOH	50	214	3
A-CFWO	1M KOH	50	248	4
Mn-NiCoP	1M KOH	50	142	5
S-0.80	1M KOH	50	144	6
CoSAs-MoS_2/TiN NRs	1M KOH	50	232.8	7
Co-NiS@MoS_2	1M KOH	50	139.9	8
NiCoDPA	1M KOH	50	253	9
5% Co-MoS_2/NiS_2/CC	1M KOH	50	162	10
S-0.80	1M KOH	50	205	11
Ni/Mo_2C@NCe-0.15	1M KOH	50	138	12
CoP/rGO/NF-3	1M KOH	50	136	13
B-Ni	1M KOH	50	235	14
$NiMo_3S_4$/CTs	1M KOH	50	252.8	15
Cu-(a-$NiSe_x$/c-$NiSe_2$)/TiO_2 NRs	1M KOH	50	374.5	16
NMCP@NF	1M KOH	50	143	17
NiFe-MS/MOS@NF	1M KOH	50	156	18
NiCoPO@NC/P-NF-e	1M KOH	50	122.7	19
Ni-Mo-S/MoO_x/NF	1M KOH	50	180	20

Table S3 Comparison of the OER catalytic performance of CeO_x-NiB/SiC@NF and other electrocatalyst electrodes in 1.0 M KOH.

Catalysts	Electrolyte	j (mA·cm^{-2})	Potential (mV)	Reference
CeO_x-NiB/SiC@NF	1M KOH	10	234	This work
CeO_x-NiB@NF	1M KOH	10	274	21
CoP/EEBP	1M KOH	10	335	22
CoB@CoBi-800	1M KOH	10	291	23
CoNiB@NF-500	1M KOH	10	313	24
Ni_xB-300	1M KOH	10	380	25
Ni_xB/f-MWCNT	1M KOH	10	286	26
NiCoB	1M KOH	10	300	27
$NiCoBO_x$	1M KOH	10	290	28
Ni_3B/rGO	1M KOH	10	290	29
$NiB_{0.45}$-250/Cu	1M KOH	10	296	30
CoB/NF-200	1M KOH	10	315	31
NGNF	1M KOH	10	340	32
CuO@Cu_3P	1M KOH	10	267	33
FeCoNiB@B-VG	1M KOH	10	387	34
P-$NiSe_2$@N-CNTs/NC	1M KOH	10	306	35
RRMC-500	1M KOH	10	260	36
NiS_2@V_2O_5/VS_2	1M KOH	10	333	37
Mo-CoP_X/NF	1M KOH	10	268	38
$Co_{0.21}Fe_{0.28}$(OH)F	1M KOH	10	193	39
NMCP@NF	1M KOH	10	250	17
3D porous P-MoO_3 FCL MXene/NF	1M KOH	10	179	40

Table S4 Comparison of the overall water splitting performance of CeO_x-NiB/SiC@NF and other electrocatalyst electrodes in 1.0 M KOH.

Catalysts	Electrolyte	j ($mA \cdot cm^{-2}$)	Potential (V)	Reference
CeO_x-NiB/SiC@NF||CeO_x-NiB/SiC@NF	1M KOH	10	1.437	This work
FeIr/NF||FeIr/NF	1M KOH	10	1.48	41
$Ni_{0.93}Ir_{0.07}$/rGO||$Ni_{0.93}Ir_{0.07}$/rGO	1M KOH	10	1.52	42
Co_5Fe_5-C||Co_5Fe_5-C	1M KOH	10	1.46	43
NiFeOH/CoS_x/NF||NiFeOH/CoS_x/NF	1M KOH	10	1.563	44
Ni_2P/Co_2P||Ni_2P/Co_2P	1M KOH	10	1.57	45
Co_3S_4/CeO_2-CF||Co_3S_4/CeO_2-CF	1M KOH	10	1.64	46
CeO_2-NiCoP_x/NCF||CeO_2-NiCoP_x/NCF	1M KOH	10	1.49	47
Ru@Co-B/Ni||Ru@Co-B/Ni	1M KOH	10	1.66	48
Mo_2NiB_2||Mo_2NiB_2	1M KOH	10	1.57	49
Fe_1Mn_1@BN-PCFs||Fe_1Mn_1@BN-PCFs	1M KOH	10	1.622	50
Ni_xFe_{1-x}B-2||Ni_xFe_{1-x}B-2	1M KOH	10	1.57	51
C3||C3	1M KOH	10	1.55	52
Fe_3N@Co_4N@CoFe||Fe_3N@Co_4N@CoFe	1M KOH	10	1.59	53
$Co(OH)_2$||$Co(OH)_2$	1M KOH	10	1.61	54
MoP-Mo_2C/NPC||MoP-Mo_2C/NPC	1M KOH	10	1.55	55
CMC/750SA||CMC/750SA	1M KOH	10	1.589	56
Co_9S_8@NiFe-LDH-200||Co_9S_8@NiFe-LDH-200	1M KOH	10	1.585	57
50MCNP@NF||50MCNP@NF	1M KOH	10	1.45	58
Ni_xS_y@MnO_xH_y/NF||Ni_xS_y@MnO_xH_y/NF	1M KOH	10	1.530	59
P-MoO_3 FCL MXene/NF||P-MoO_3 FCL MXene/NF	1M KOH	10	1.53	40

NiCoPO@NC/P-NF-e|| NiCoPO@NC/P-NF-e	1M KOH	10	1.50	19

References

1 N. Shaikh, I. Mukhopadhyay and A. Ray, *J. Mater. Chem. A*, 2022, **10**, 12733-12746.

2 G. Rajeshkhanna, T. I. Singh, N. H. Kim and J. H. Lee, *ACS Appl Mater Interfaces*, 2018, **10**, 42453-42468.

3 Y. Li, H. Zhang, M. Jiang, Q. Zhang, P. He and X. Sun, *Adv. Funct. Mater.*, 2017, **27**, 1702513.

4 A. Muthurasu, G. P. Ojha, M. Lee and H. Y. Kim, *Electrochim. Acta*, 2020, **334**, 135537.

5 X. Yu, S. Xu, Z. Wang, X. Cheng, Y. Du, G. Chen, X. Sun and Q. Wu, *Nanoscale*, 2021, **13**, 11069-11076.

6 Y. H. Wu, Y. Zhang, Y. X. Wang, Z. He, Z. J. Gu and S. C. You, *Int. J. Hydrogen Energy*, 2021, **46**, 26930-26939.

7 T. L. L. Doan, D. C. Nguyen, S. Prabhakaran, D. H. Kim, D. T. Tran, N. H. Kim and J. H. Lee, *Adv. Funct. Mater.*, 2021, **31**, 2100233.

8 H. Gao, J. Zang, Y. Wang, S. Zhou, P. Tian, S. Song, X. Tian and W. Li, *Electrochim. Acta*, 2021, **377**, 138051.

9 P. Bhanja, B. Mohanty, S. Chongdar, A. Bhaumik, B. K. Jena and S. Basu, *ACS Appl. Energy Mater.*, 2021, **4**, 12827-12835.

10 Y. Zheng, J. Rong, J. Xu, Y. Zhu, T. Zhang, D. Yang and F. Qiu, *Appl. Surf. Sci.*, 2021, **563**, 150385.

11 Z. Zhang, Y. Wu and D. Zhang, *Int. J. Hydrogen Energy*, 2022, **47**, 1425-1434.

12 R. Ge, J. Zhao, J. Huo, J. Qu, J. Yang, Y. Li, M. Zhu, J. M. Cairney, R. Zheng, S. Li, J. Zhang, B. Liu and W. Li, *Mater. Today Nano*, 2022, **20**, 100248.

13 Z. Yang, R. He, H. Wu, Y. Ding and H. Mei, *Int. J. Hydrogen Energy*, 2021, **46**, 9690-9698.

14 T. Zhang, F. Song, Y. Qian, H. Gao, J. Shaw and Y. Rao, *ACS Appl. Energy Mater.*, 2021, **4**, 5434-5442.

15 D. Kong, Y. Wang, S. Huang, Y. V. Lim, M. Wang, T. Xu, J. Zang, X. Li and H. Y. Yang, *J. Colloid Interface Sci.*, 2022, **607**, 1876-1887.

16 K. R. Park, D. T. Tran, T. T. Nguyen, N. H. Kim and J. H. Lee, *Chem. Eng. J.*, 2021, **422**, 130048.

17 M. R. Kandel, U. N. Pan, D. R. Paudel, P. P. Dhakal, N. H. Kim and J. H. Lee, *Composites, Part B*, 2022, **239**, 109992.

18 M. Zhao, W. Li, J. Li, W. Hu and C. M. Li, *Adv Sci (Weinh)*, 2020, **7**, 2001965.

19 H. Gao, Y. Wang, S. Zhou, S. Song, X. Tian, W. Li, Y. Yuan and J. Zang, *Chem. Eng. J.*, 2021, **426**, 130854.

20 Z. Han, X. Liang, S. Wang, L. Zhou and Z. Zhao, *Mater. Lett.*, 2019, **246**, 63-66.

21 H. Wang, H. Liu, T. Feng, L. Wang, W. Yuan, Q. Huang and Y. Guo, *Dalton Trans.*, 2022, **51**, 675-684.

22 T. Liang, Y. Liu, P. Zhang, C. Liu, F. Ma, Q. Yan and Z. Dai, *Chem. Eng. J.*, 2020, **395**, 124976.

23 T. Tan, P. Han, H. Cong, G. Cheng and W. Luo, *ACS Sustainable Chem. Eng.*, 2019, **7**, 5620-5625.

24 N. Xu, G. Cao, Z. Chen, Q. Kang, H. Dai and P. Wang, *J. Mater. Chem. A*, 2017, **5**, 12379-12384.

25 J. Masa, I. Sinev, H. Mistry, E. Ventosa, M. de la Mata, J. Arbiol, M. Muhler, B. Roldan Cuenya and W. Schuhmann, *Adv. Energy Mater.*, 2017, **7**, 1700381.

26 X. Chen, Z. Yu, L. Wei, Z. Zhou, S. Zhai, J. Chen, Y. Wang, Q. Huang, H. E. Karahan, X. Liao and Y. Chen, *J. Mater. Chem. A*, 2019, **7**, 764-774.

27 S. Wang, P. He, Z. Xie, L. Jia, M. He, X. Zhang, F. Dong, H. Liu, Y. Zhang and C. Li,

Electrochim. Acta, 2019, **296**, 644-652.
28 M. Ramadoss, Y. Chen, Y. Hu and D. Yang, *Electrochim. Acta*, 2019, **321**, 134666.
29 M. Arivu, J. Masud, S. Umapathi and M. Nath, *Electrochem. Commun.*, 2018, **86**, 121-125.
30 J. Jiang, M. Wang, W. Yan, X. Liu, J. Liu, J. Yang and L. Sun, *Nano Energy*, 2017, **38**, 175-184.
31 Z. Chen, Q. Kang, G. Cao, N. Xu, H. Dai and P. Wang, *Int. J. Hydrogen Energy*, 2018, **43**, 6076-6087.
32 D. Navadeepthy, A. Rebekah, C. Viswanthan and N. Ponpandian, *Int. J. Hydrogen Energy*, 2021, **46**, 21512-21524.
33 S. Lv, J. Li, B. Zhang, Y. Shi, X. Liu and T. Wang, *Int. J. Hydrogen Energy*, 2022, **47**, 9593-9605.
34 B. Jiang, K. Liang, Z. Yang, K. Guo, F. Shaik and J. Zheng, *Electrochim. Acta*, 2021, **386**, 138459.
35 J. Yu, W.-J. Li, G. Kao, C.-Y. Xu, R. Chen, Q. Liu, J. Liu, H. Zhang and J. Wang, *J. Energy Chem.*, 2021, **60**, 111-120.
36 Y. Fan, X. Zhang, Y. Zhang, X. Xie, J. Ding, J. Cai, B. Li, H. Lv, L. Liu, M. Zhu, X. Zheng, Q. Cai, Y. Liu and S. Lu, *J. Colloid Interface Sci.*, 2021, **604**, 508-516.
37 Z. Yang, X. Xie, Z. Zhang, J. Yang, C. Yu, S. Dong, M. Xiang and H. Qin, *Int. J. Hydrogen Energy*, 2022, **47**, 27338-27346.
38 Y. Yu, J. Li, J. Luo, Z. Kang, C. Jia, Z. Liu, W. Huang, Q. Chen, P. Deng, Y. Shen and X. Tian, *Mater. Today Nano*, 2022, **18**, 100216.
39 Y. Li, X. Zhai, C. Fan, X. Chen, Y. Liu, J. Yang, L. Chen, G. Ge and J. Zhang, *J. Mater. Chem. A*, 2022, **10**, 11774-11783.
40 M. Li, R. Sun, Y. Li, J. Jiang, W. Xu, H. Cong and S. Han, *Chem. Eng. J.*, 2022, **431**, 133941.
41 F. Shen, Y. Wang, G. Qian, W. Chen, W. Jiang, L. Luo and S. Yin, *Appl. Catal., B*, 2020, **278**, 119327.
42 S. Zhang, X. Zhang, X. Shi, F. Zhou, R. Wang and X. Li, *J. Energy Chem.*, 2020, **49**, 166-173.
43 Y. Yan, Y. Han, F. Wang, Y. Hu, Q. Shi, G. Diao and M. Chen, *J. Alloys Compd.*, 2022, **897**, 163126.
44 R. Bose, V. R. Jothi, K. Karuppasamy, A. Alfantazi and S. C. Yi, *J. Mater. Chem. A*, 2020, **8**, 13795-13805.
45 H. Liu, M. Jin, D. Zhan, J. Wang, X. Cai, Y. Qiu and L. Lai, *Appl. Catal., B*, 2020, **272**, 118951.
46 Z. Feng, J. Pu, M. Liu, W. Zhang, X. Zhang, L. Cui and J. Liu, *J. Colloid Interface Sci.*, 2022, **613**, 806-813.
47 S. Wen, J. Huang, T. Li, W. Chen, G. Chen, Q. Zhang, X. Zhang, Q. Qian and K. Ostrikov, *Appl. Catal., B*, 2022, **316**, 121678.
48 L. Chen, B. Lu, J. Zhang, R. Wu and Y. Guo, *J. Colloid Interface Sci.*, 2022, **623**, 897-904.
49 A. Saad, Y. Gao, K. A. Owusu, W. Liu, Y. Wu, A. Ramiere, H. Guo, P. Tsiakaras and X. Cai, *Small*, 2022, **18**, e2104303.
50 Z. Liu, F. Guo, L. Cheng, X. Bo, T. Liu and M. Li, *J. Colloid Interface Sci.*, 2022, **629**, 179-192.
51 W. Hong, S. Sun, Y. Kong, Y. Hu and G. Chen, *J. Mater. Chem. A*, 2020, **8**, 7360-7367.
52 D. Chinnadurai, R. Rajendiran and P. Kandasamy, *J. Colloid Interface Sci.*, 2022, **606**, 101-112.
53 Z. Cui, X. Liang, P. Wang, P. Zhou, Q. Zhang, Z. Wang, Z. Zheng, Y. Liu, Y. Dai and B. Huang, *Electrochim. Acta*, 2021, **395**, 139218.
54 M. Duraivel, S. Nagappan, K. H. Park and K. Prabakar, *Electrochim. Acta*, 2022, **411**, 140071.

55 E. Jiang, J. Li, X. Li, A. Ali, G. Wang, S. Ma, P. Kang Shen and J. Zhu, *Chem. Eng. J.*, 2022, **431**, 133719.

56 W. Yaseen, M. Xie, B. A. Yusuf, Y. Xu, N. Ullah, M. Rafiq, A. Ali and J. Xie, *Appl. Surf. Sci.*, 2022, **579**, 152148.

57 Y. Lu, C. Liu, Y. Xing, Q. Xu, A. M. S. Hossain, D. Jiang, D. Li and J. Zhu, *J. Colloid Interface Sci.*, 2021, **604**, 680-690.

58 Y. Zhang, H. Liu, R. Ge, J. Yang, S. Li, Y. Liu, L. Feng, Y. Li, M. Zhu and W. Li, *Sustainable Mater. Technol.*, 2022, **33**, e00461.

59 P. Wang, Y. Luo, G. Zhang, Z. Chen, H. Ranganathan, S. Sun and Z. Shi, *Nano-Micro Lett.*, 2022, **14**, 120.