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Supporting Information for

# Yolk-shell $NiS_x$@C nanosheets as K-ion battery anode with high rate capability and ultralong cycle life

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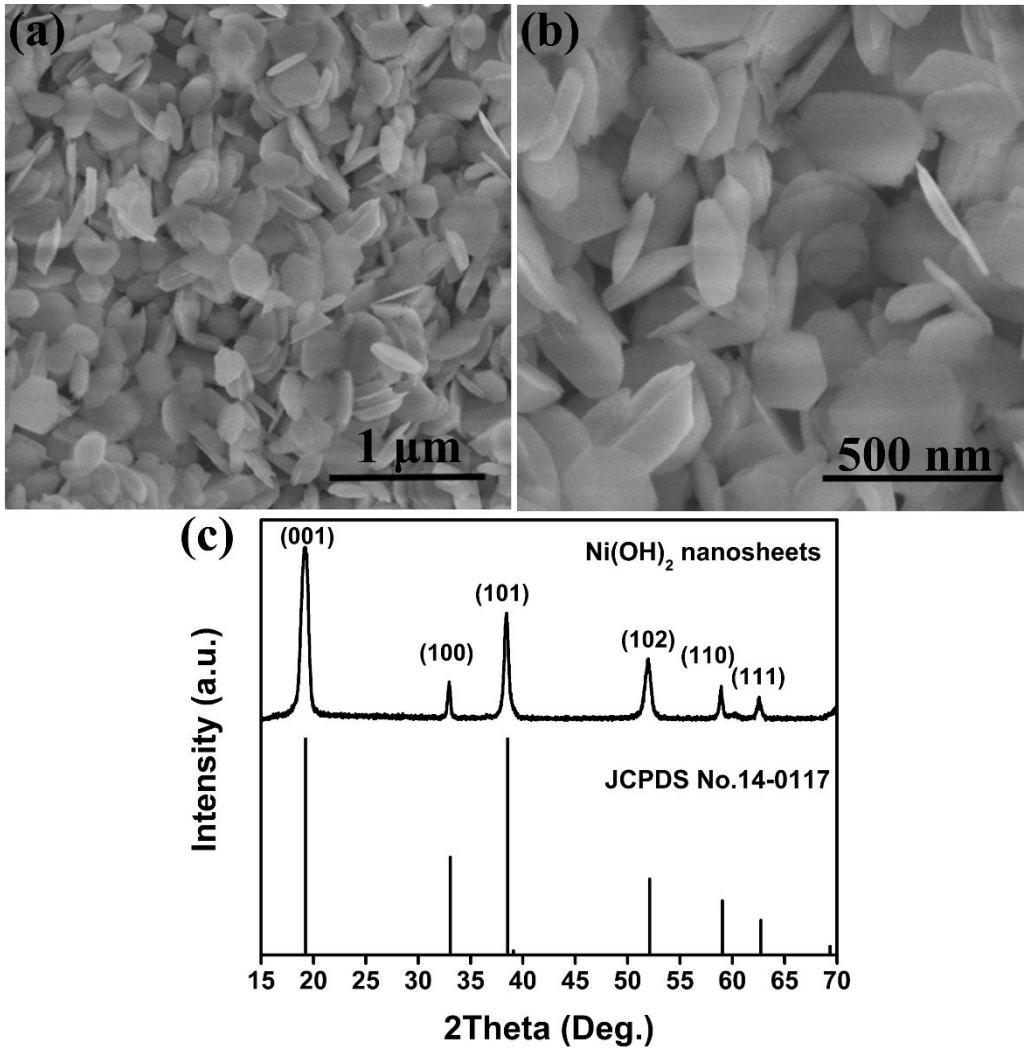


**Fig. S1** (a-b) SEM images, and (c) XRD pattern of $Ni(OH)_2$ nanosheets.

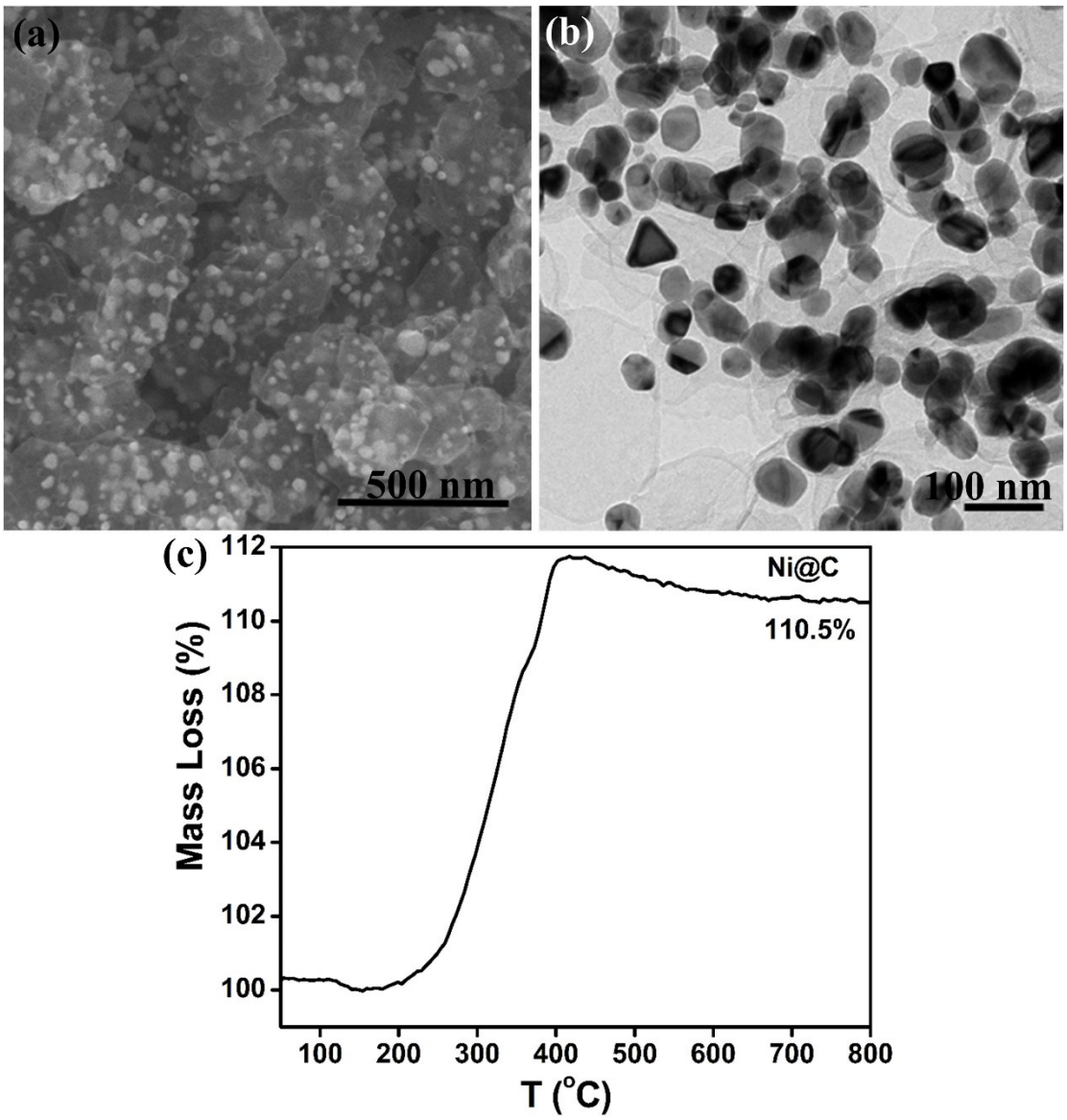


**Fig. S2** (a) SEM and (b) TEM images, and (c) TGA curve of Ni@C composite.

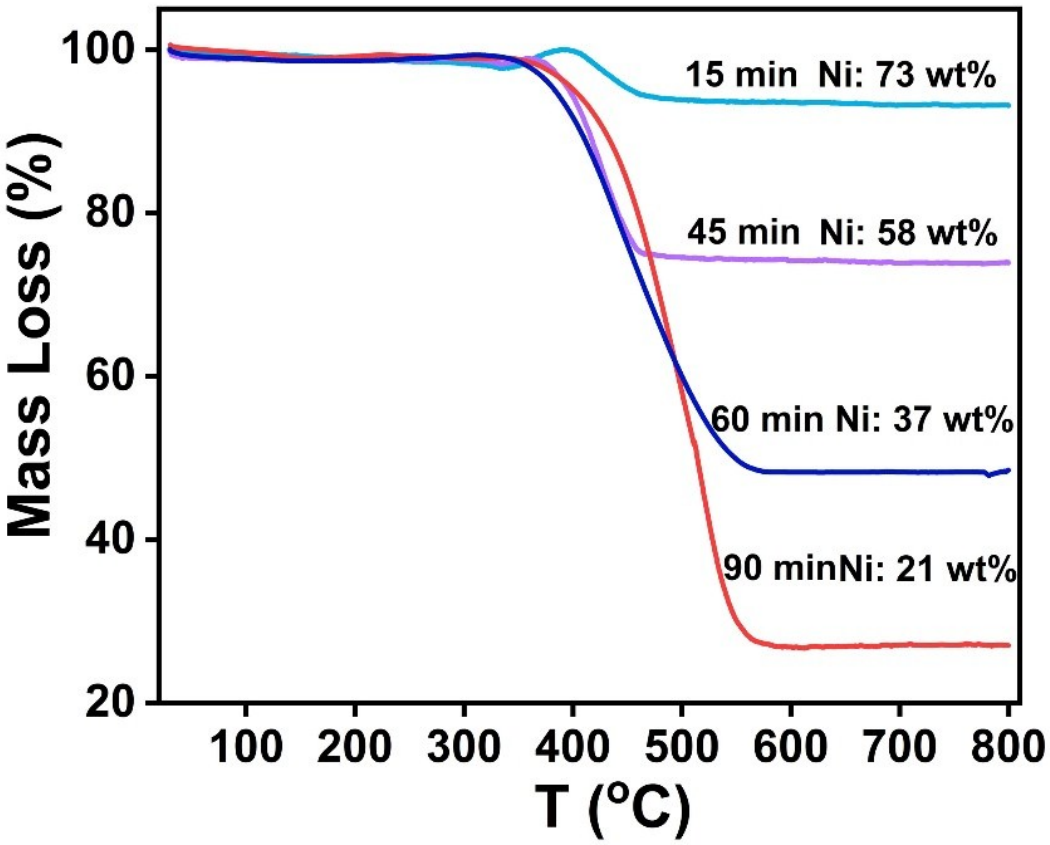


**Fig. S3** TGA curves of Y-S Ni@C under different etch time.

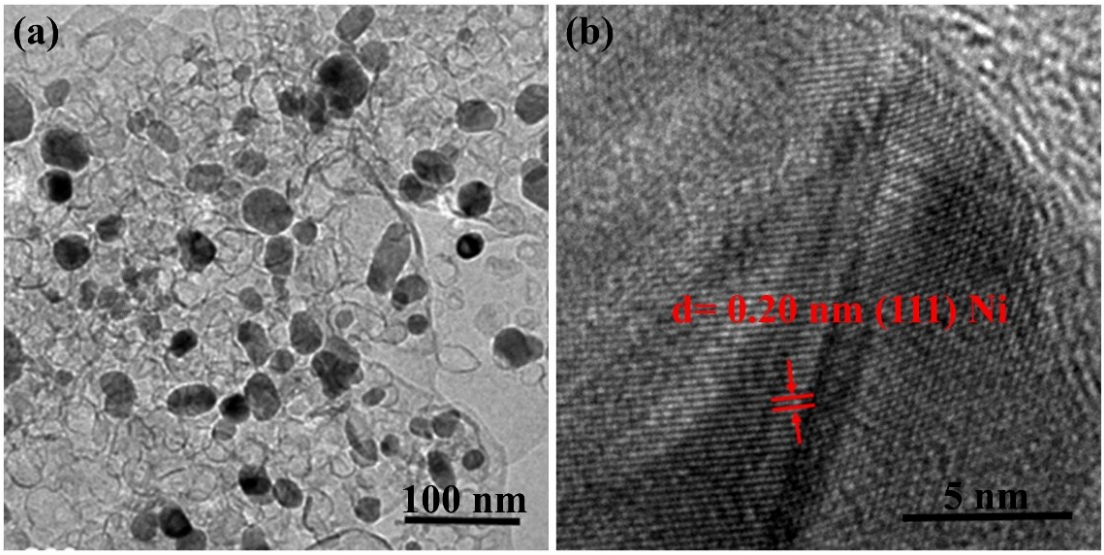


**Fig. S4** (a) TEM and (b) HRTEM images of Y-S Ni@C composite.

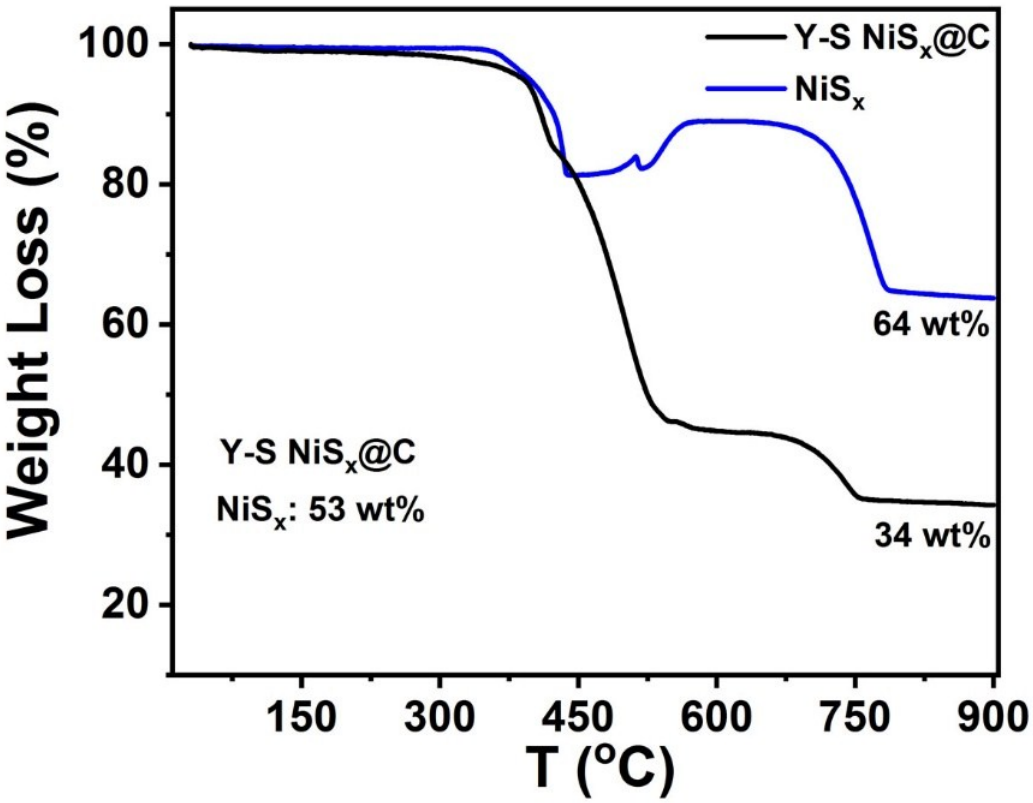


**Fig. S5** TGA curves of $NiS_x$ and Y-S $NiS_x$@C composite.

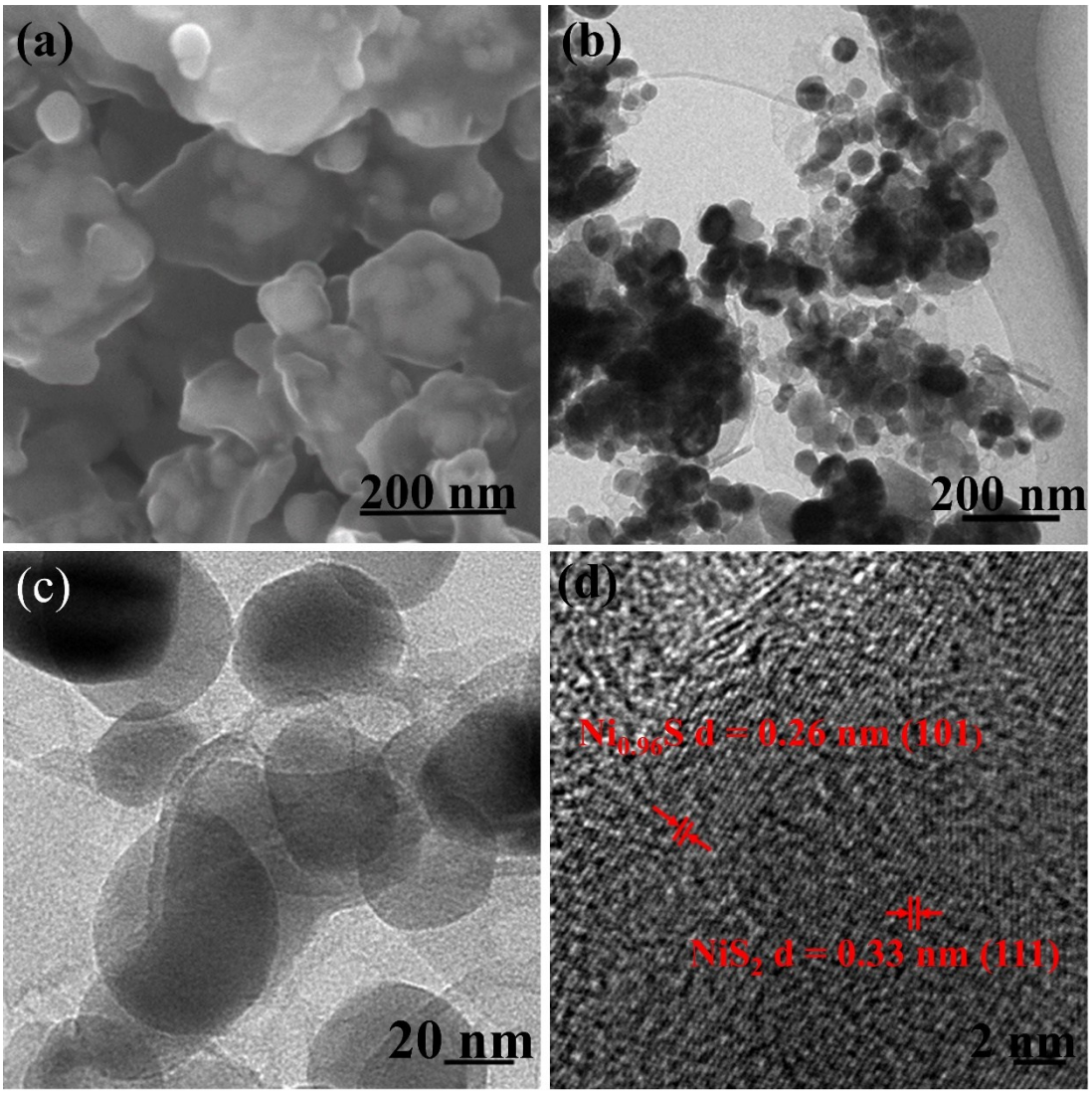


**Fig. S6** (a) SEM, (b-c) TEM, and (d) HRTEM images of $NiS_x$@C composite.

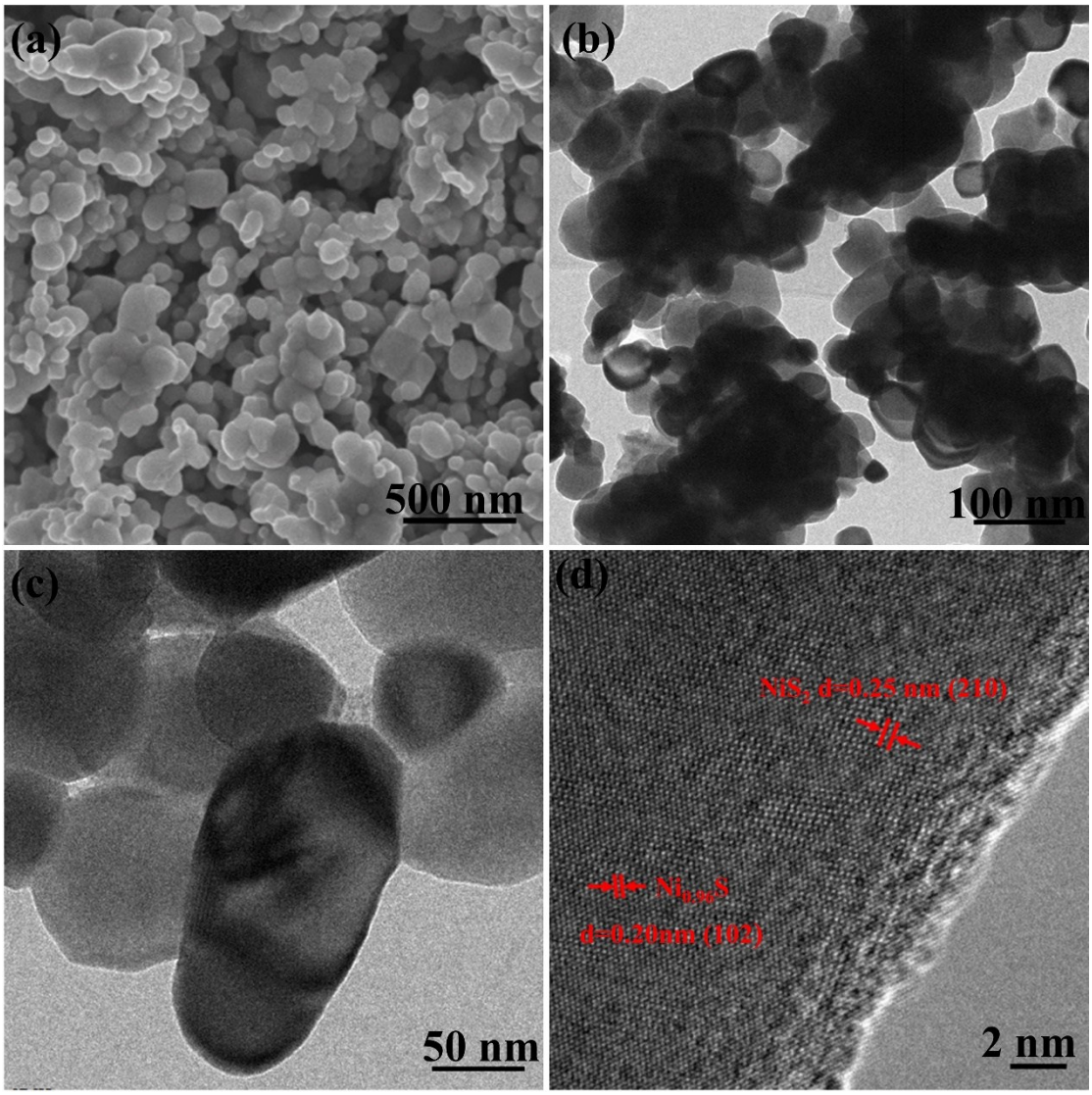


**Fig. S7** (a) SEM, (b-c) TEM, and (d) HRTEM images of $NiS_x$.

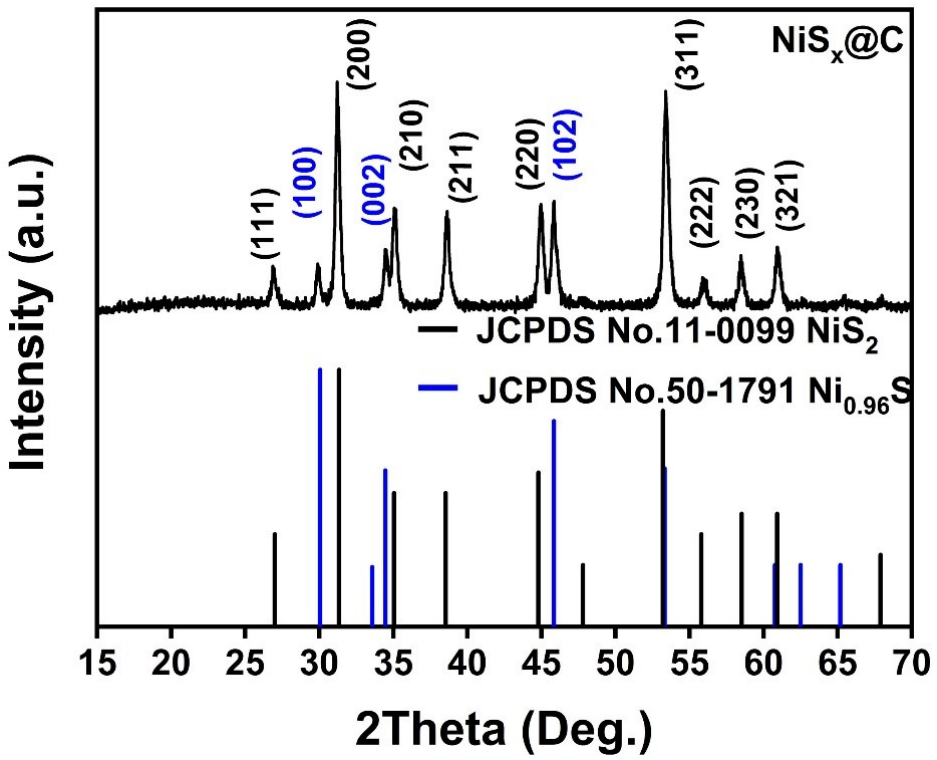


**Fig. S8** XRD pattern of $NiS_x$@C composite.

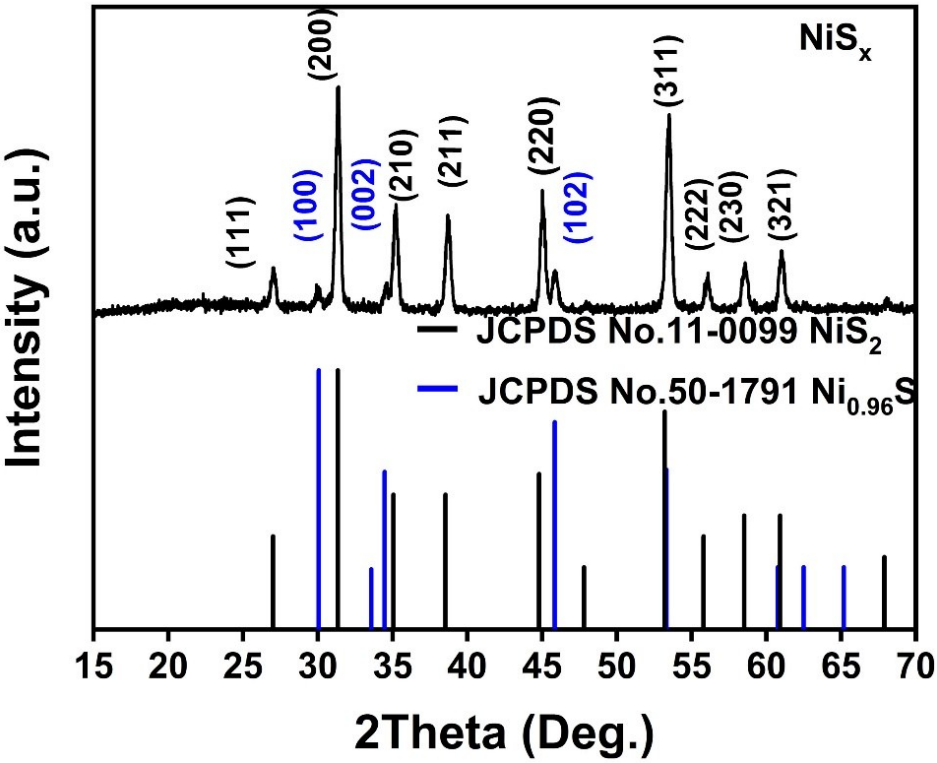


**Fig. S9** XRD pattern of $NiS_x$.

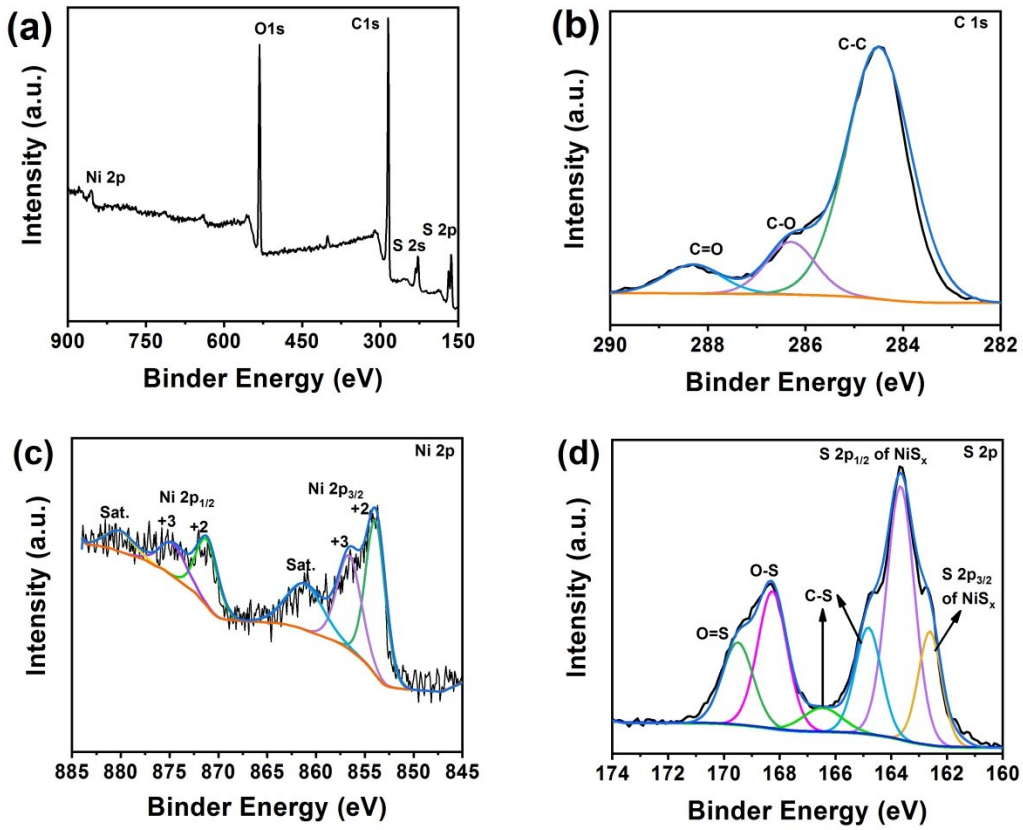


**Fig. S10** XPS spectra of Y-S $NiS_x$@C composite: (a) survey spectrum, (b) C1s, (c) Ni 2p and (d) S 2p.

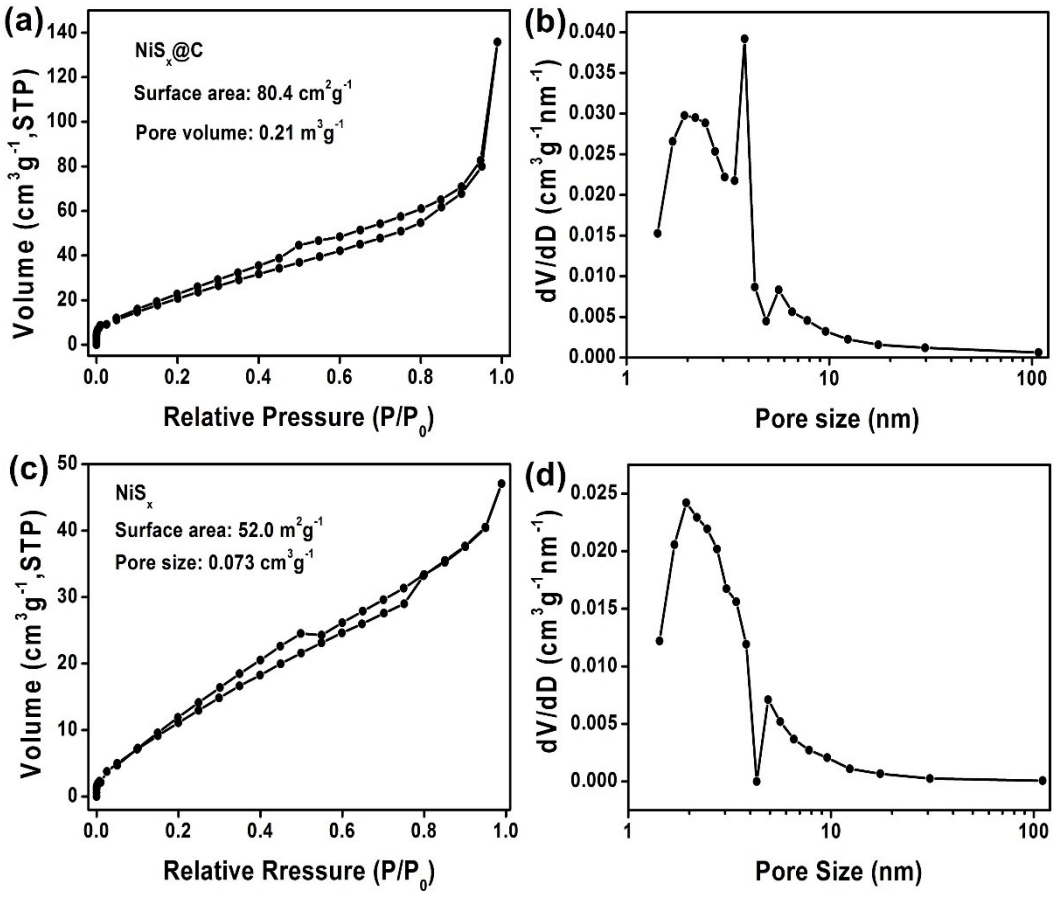


**Fig. S11** (a, c) $N_2$ adsorption-desorption isotherms, (b, d) pore size distributions of (a-b) $NiS_x$@C and (c-d) $NiS_x$.

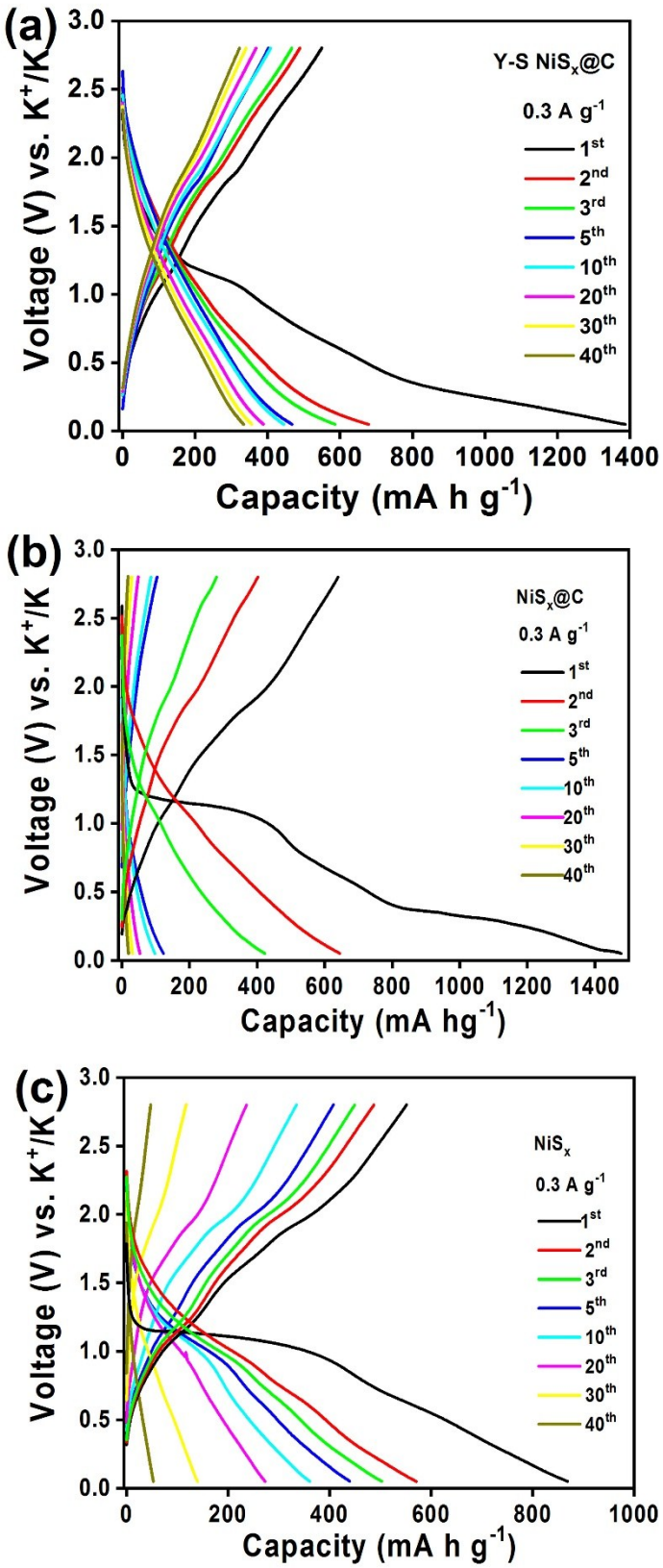


**Fig. S12** Discharge/charge profiles at selected cycles at 0.3 A $g^{-1}$ of (a) Y-S $NiS_x$@C composite, (b) $NiS_x$@C composite, and (c) $NiS_x$ for PIBs.

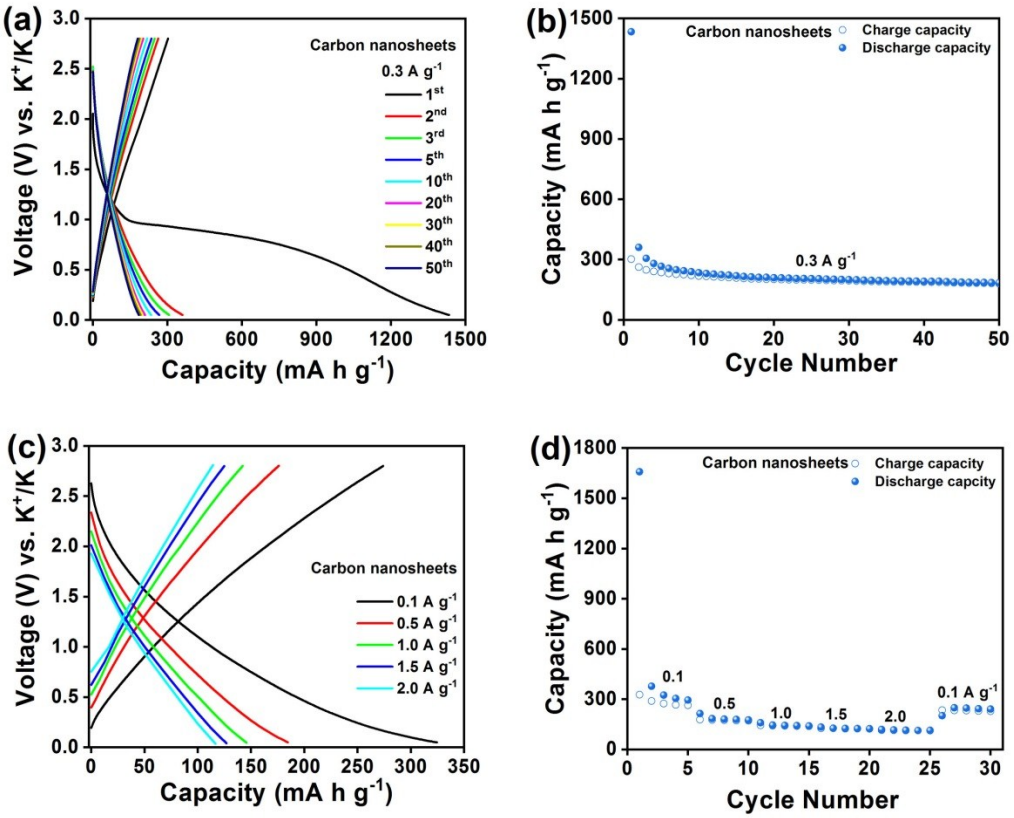


**Fig. S13** (a) Discharge/charge profiles at selected cycles, and (b) cycle performance of carbon nanaosheets at 0.3 A $g^{-1}$. (c) Discharge/charge profiles at various densities, and (d) rate performance from 0.1 to 2.0 A $g^{-1}$ of carbon nanosheets for PIBs

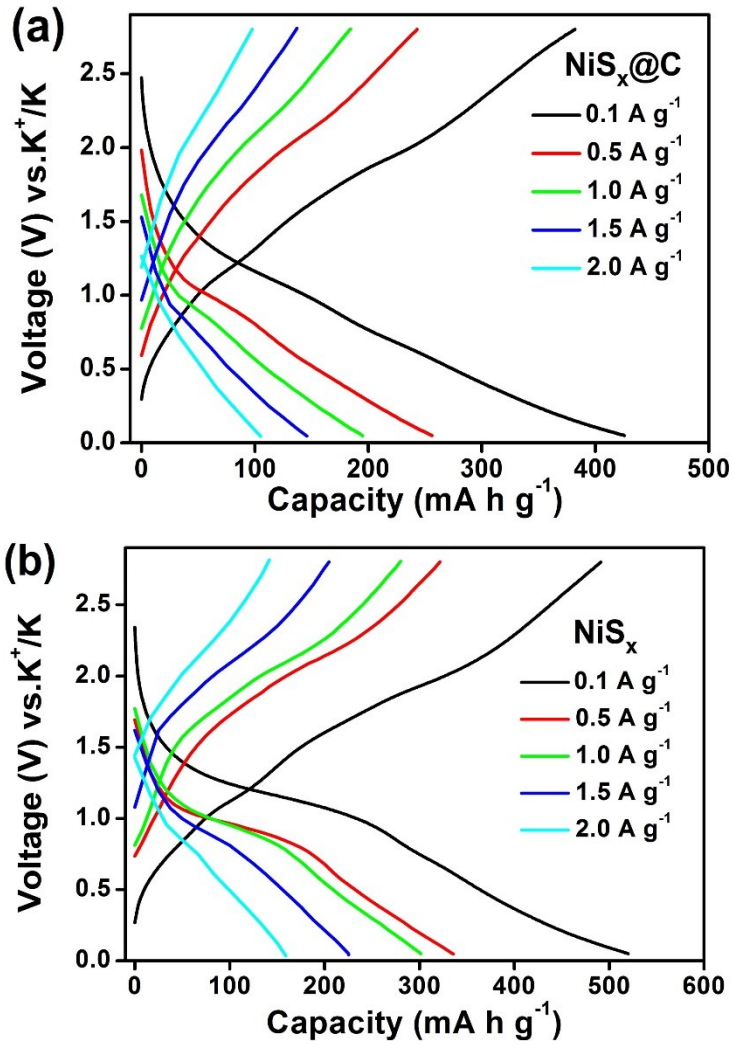


**Fig. S14** Discharge/charge profiles at various current densities from 0.1 to 2.0 A $g^{-1}$ of (a) $NiS_x$@C composite, and (b) $NiS_x$ for PIBs.

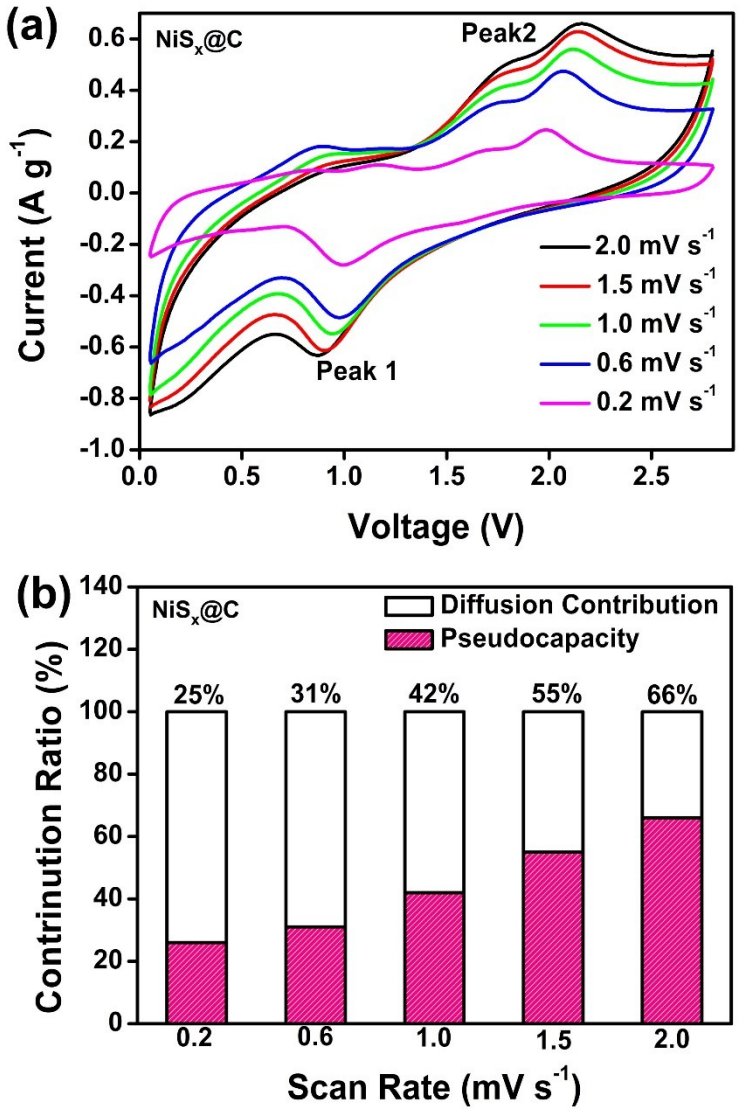


**Fig. S15** (a) CV cruves at various scan rates of initial state, and (b) contribution ratio of diffusion and pseudocapacity-controlled capacities of $NiS_x$@C anode from 0.2 to 2.0 mV $s^{-1}$.

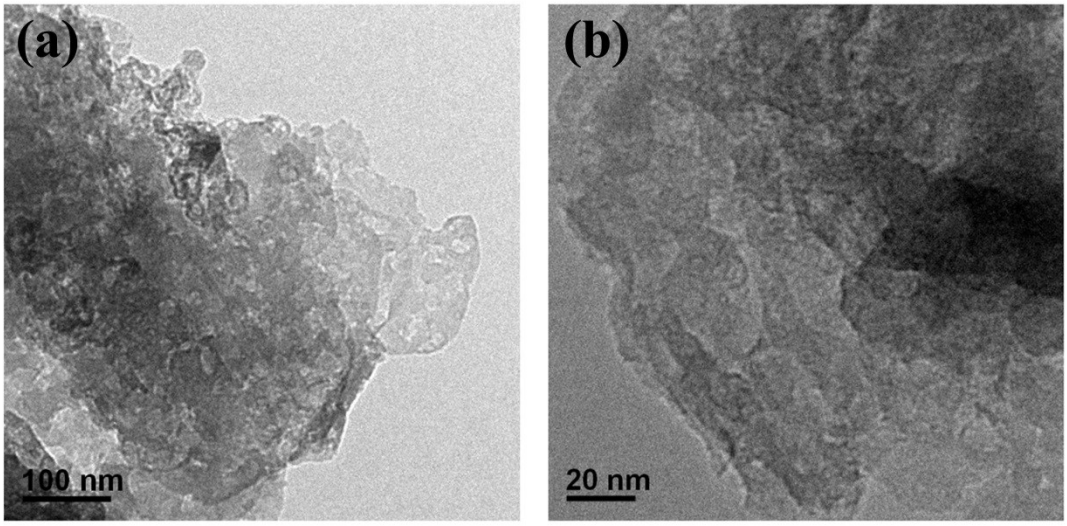


**Fig. S16** (a-b) TEM images of Y-S $NiS_x$@C electrode after cycles.

**Table. S1** Comparison of cycle and rate capabilities between Y-S $NiS_x$@C composite and as-reported anode materials for PIBs.

| Materials | Current density (A $g^{-1}$) | Cycle Number | Capacity (mAh $g^{-1}$) | Rate Capability (mAh $g^{-1}$/A $g^{-1}$) | Ref. |
|---|---|---|---|---|---|
| **CoS@rGO** | 0.5 | 100 | 310 | 232/2.3 | 1 |
| **$SnS_2$-rGO** | 0.025 | 30 | 250 | - | 2 |
| **$SnS_2$@rGO** | 1.0 | 300 | 205 | 247/1.0 | 3 |
| **$MoS_2$@rGO** | 0.1 | 100 | 380 | 178/0.5 | 4 |
| **$MoS_2$/N-doped-C** | 0.05 | 30 | 330 | 131/2.0 | 5 |
| **$MoS_2$/C** | 0.05 | 35 | 391 | 164/2.0 | 6 |
| **$MoS_2$@$SnO_2$@C** | 0.05 | 25 | 312 | 86/0.8 | 7 |
| **$FeS_2$@rGO** | 0.05 | 50 | 264 | 151/0.5 | 8 |
| **$Fe_3S_4$@C** | 0.1 | 100 | 226 | 139/1.0 | 9 |
| **$ReS_2$/N-CNFs** | 0.05 | 100 | 235 | - | 10 |
| **$MoSe_2$@N-C** | 0.1 | 100 | 258 | 218/0.5 | 11 |
| **$MoS_2$/C** | 0.1 | 50 | 239 | 123/0.8 | 12 |
| **$Sb_2S_3$-SNG** | 0.05 | 100 | 330 | - | 13 |
| **$MoSe_2$/C** | 1.0 | 1000 | 226 | 224/2.0 | 14 |
| **$CoSe_2$@NCT** | 0.2 | 100 | 253 | 196/2.0 | 15 |
| **$VSe_2$ nanosheets** | 2.0 | 500 | 335 | 269/1.0 | 16 |
| **$ReSe_2$@G@CNTs** | 0.2 | 200 | 230 | 157/2.0 | 17 |
| **FeP@CNBs** | 0.1 | 300 | 205 | 37/2.0 | 18 |
| **$SnP_{0.96}$@GO** | 0.2 | 100 | 106 | 57/1.0 | 19 |
| **$Sn_4P_3$@C** | 0.5 | 800 | 181 | 183/2.0 | 20 |
| **$V_2O_3$@PNCNFs** | 0.05 | 500 | 240 | 134/1.0 | 21 |
| **$SnO_2$-rGO** | 0.1 | 60 | 286 | 208/1.0 | 22 |
| **$MoO_2$/rGO** | 0.05 | 200 | 219 | 176/0.5 | 23 |
| **Sn@C** | 0.05 | 100 | 276 | 150/0.5 | 24 |
| **Sb/PC** | 0.5 | 200 | 90 | 70/2.0 | 25 |
| **Sb/rGO** | 0.5 | 200 | 210 | 222/1.0 | 26 |
| **3D SbNPs@C** | 1.0 | 50 | 225 | 288/1.0 | 27 |
| **Sb@C-3DP.** | 0.5 | 260 | 342 | 286/1.0 | 28 |

| | | | | | |
|---|---|---|---|---|---|
| **Sb@NPMC** | 0.05 | 50 | 226 | 161/1.0 | 29 |
| | **0.1** | **300** | **300** | | |
| **Y-S $NiS_x$@C** | **0.3** | **5000** | **173** | **232/2.0** | **This work** |
| | **0.5** | **8000** | **128** | | |

**Reference**


1. H. Gao, T. Zhou, Y. Zheng, Q. Zhang, Y. Liu, J. Chen, H. Liu and Z. Guo, *Adv. Funct. Mater.,* 2017, **27**, 1702634.
2. V. Lakshmi, Y. Chen, A. A. Mikhaylov, A. G. Medvedev, I. Sultana, M. M. Rahman, O. Lev, P. V. Prikhodchenko and A. M. Glushenkov, *Chem. Commun*., 2017, **53**, 8272-8275.
3. L. Fang, J. Xu, S. Sun, B. Lin, Q. Guo, D. Luo and H. Xia, *Small*, 2019, **15**, 1804806.
4. K. Xie, K. Yuan, X. Li, W. Lu, C. Shen, C. Liang, R. Vajtai, P. Ajayan and B. Wei, *Small*, 2017, **13**, 1701471.
5. B. Jia, Q. Yu, Y. Zhao, M. Qin, W. Wang, Z. Liu, C.-Y. Lao, Y. Liu, H. Wu, Z. Zhang and X. Qu, *Adv. Funct. Mater*., 2018, **30**, 1803409.
6. B. Jia, Y. Zhao, M. Qin, W. Wang, Z. Liu, C.-Y. Lao, Q. Yu, Y. Liu, H. Wu, Z. Zhang and X. Qu, *J. Mater. Chem. A*, 2018, **6**, 11147-11153.
7. Z. Chen, D. Yin and M. Zhang, *Small*, 2018, **14**, 1703818.
8. J. Xie, Y. Zhu, N. Zhuang, H. Lei, W. Zhu, Y. Fu, M. S. Javed, J. Li and W. Mai, *Nanoscale*, 2018, **10**, 17092-17098.
9. Q. Yu, J. Hu, Y. Gao, J. Gao, G. Suo, P. Zuo, W. Wang and G. Yin, *J. Alloys*

*Compounds*, 2018, **766**, 1086-1091.

10. M. Mao, C. Cui, M. Wu, M. Zhang, T. Gao, X. Fan, J. Chen, T. Wang, J. Ma and C. Wang, *Nano Energy*, 2018, **45**, 346-352.
11. J. Ge, L. Fan, J. Wang, Q. Zhang, Z. Liu, E. Zhang, Q. Liu, X. Yu and B. Lu, *Adv. Energy Mater*., 2018, **30**, 1801477.
12. D. Yin, Z. Chen and M. Zhang, *J. Phy. Chem. Solids*, 2019, **126**, 72-77.
13. Y. Lu and J. Chen, *Sci. China Chem.*, 2017, **60**, 1533-1539.
14. W. Wang, B. Jiang, C. Qian, F. Lv, J. Feng, J. Zhou, K. Wang, C. Yang, Y. Yang and S. Guo, *Adv. Mater.,* 2018, **30**, 1801812.
15. Q. Yu, B. Jiang, J. Hu, C.-Y. Lao, Y. Gao, P. Li, Z. Liu, G. Suo, D. He, W. A. Wang and G. Yin, *Adv. Sci.*, 2018, **5**, 1800782.
16. C. Yang, J. Feng, F. Lv, J. Zhou, C. Lin, K. Wang, Y. Zhang, Y. Yang, W. Wang, J. Li and S. Guo, *Adv. Mater.*, 2018, **30**, 1800036.
17. Y. Liao, C. Chen, D. Yin, Y. Cai, R. He and M. Zhang, *Nano-Micro Lett*., 2019, **11**, 2150-5551.
18. F. Yang, H. Gao, J. Hao, S. Zhang, P. Li, Y. Liu, J. Chen and Z. Guo, *Adv. Funct. Mater*., 2019, **29**, 1808291.
19. X. Zhao, W. Wang, Z. Hou, G. Wei, Y. Yu, J. Zhang and Z. Quan, *Chem. Eng. J*., 2019, **370**, 677-683.
20. D. Li, Y. Zhang, Q. Sun, S. Zhang, Z. Wang, Z. Liang, P. Si and L. Ci, *Energy Storage Mater., 2019.* 10.1016/j.ensm.2019.04.037.
21. T. Jin, H. Li, Y. Li, L. Jiao and J. Chen, *Nano Energy*, 2018, **50**, 462-467.

22. Z. Huang, Z. Chen, S. Ding, C. Chen and M. Zhang, *Nanotechnology*, 2018, **29**, 375702.

23. C. Liu, S. Luo, H. Huang, Y. Zhai and Z. Wang, *ChemSusChem*, 2019, **12**, 873-880.

24. K. Huang, Z. Xing, L. Wang, X. Wu, W. Zhao, X. Qi, H. Wang and Z. Ju, *J. Mater. Chem. A*, 2018, **6**, 434-442.

25. H. Wang, X. Wu, X. Qi, W. Zhao and Z. Ju, *Mater. Res. Bull.*, 2018, **103**, 32-37.

26. Z. Yi, N. Lin, W. Zhang, W. Wang, Y. Zhu and Y. Qian, *Nanoscale*, 2018, **10**, 13236-13241.

27. C. Han, K. Han, X. Wang, C. Wang, Q. Li, J. Meng, X. Xu, Q. He, W. Luo, L. Wu and L. Mai, *Nanoscale*, 2018, **10**, 6820-6826.

28. J. Zheng, Y. Yang, X. Fan, G. Ji, X. Ji, H. Wang, S. Hou, M. R. Zachariah and C. Wang, *Energy Environ. Sci*., 2019, **12**, 615-623.

29. L. Wang, J. Jia, Y. Wu and K. Niu, *J. Appl. Electrochem*., 2018, **10**, 1115–1120.