Electronic Supplementary Material (ESI) for Nanoscale Advances.

Supporting Information

Short-range amorphous carbon nanosheets for oxygen reduction electrocatalysis

Qingyu Li, Dingding Kong, Xinyi Zhao, Yezheng Cai*, Zhaoling Ma*, Youguo Huang, Hongqiang Wang

Guangxi Key Laboratory of Low Carbon Energy Materials, School of Chemistry and Pharmaceutical Sciences, Guangxi Normal University, Guilin, China.

*Corresponding authors: 18810629627@163.com (Y. Cai); zhaolingma@163.com (Z. Ma)

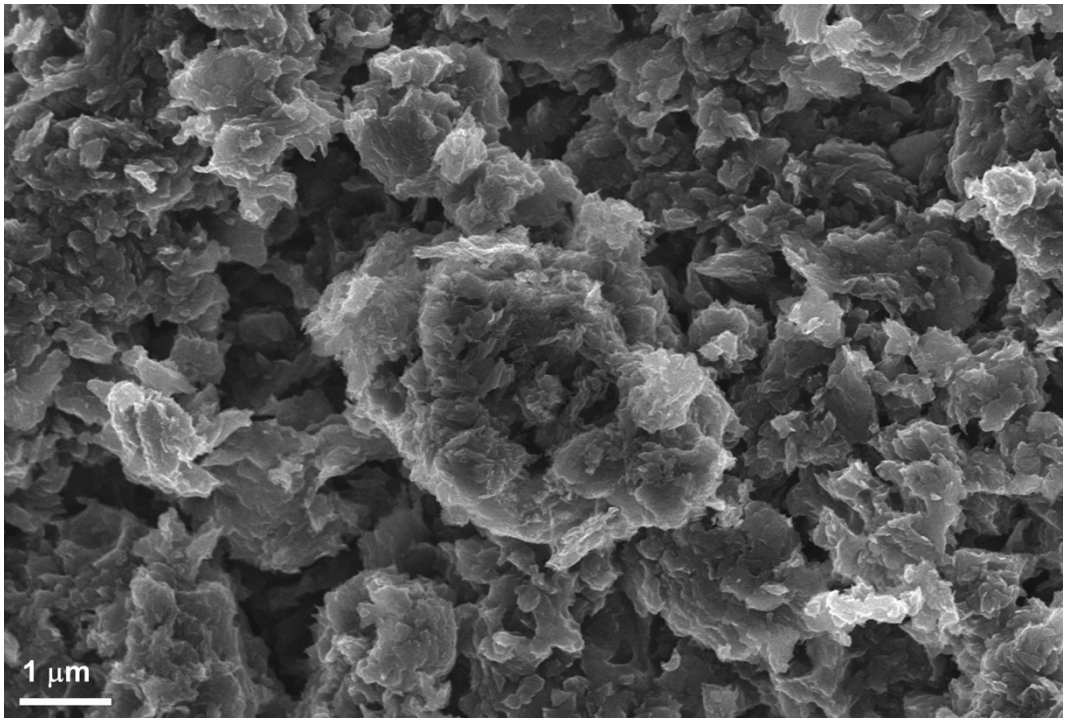

Fig. S1 SEM image of NCS.

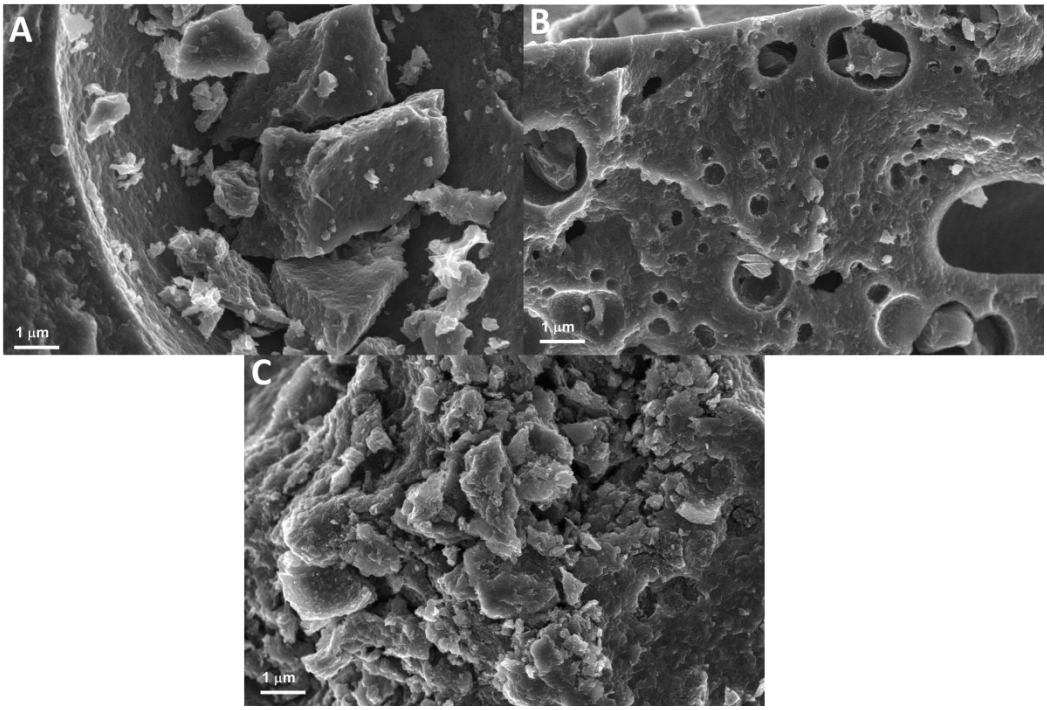

Fig. S2 SEM images of (A) BNC, (B) PBNC-600, and (C) PBNC-1000.

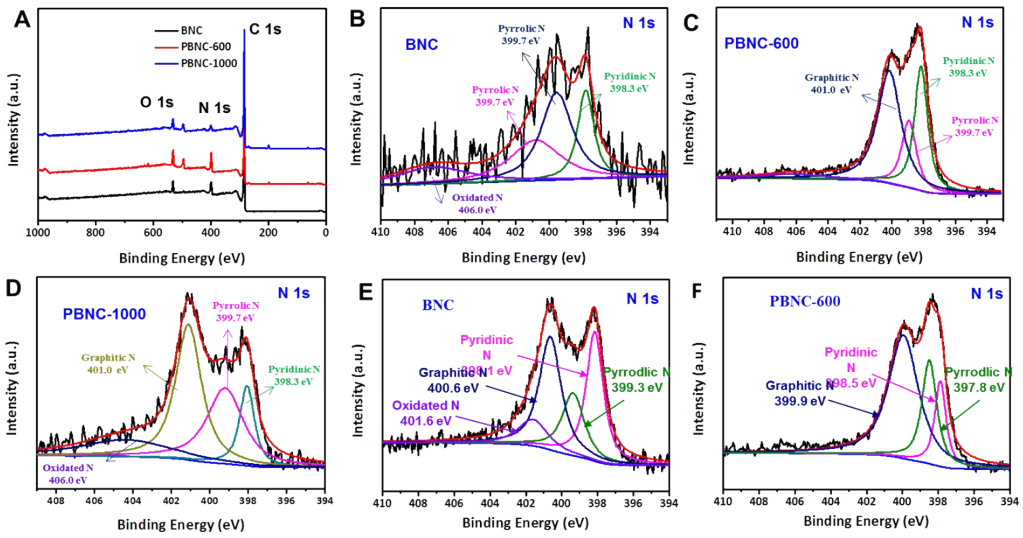

Fig. S3 (A) XPS survey scans and (B-F) high resolution N 1s XPS spectrum of BNC (B), PBNC-600 (C), PBNC-1000 (D), BNC (E), and PBNC (F).

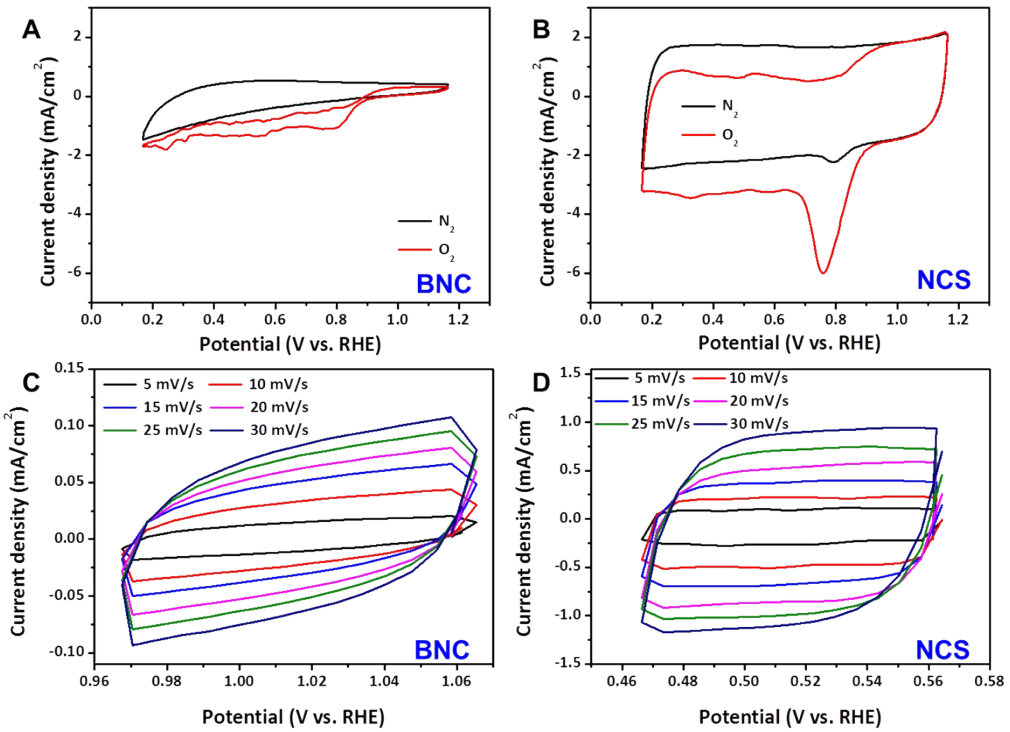

Fig. S4 (A-B) CV curves of BNC (A) and NCS (B) recorded in N_2 or O_2-saturated 0.1 M KOH solution; (C-D) CV curves of BNC (C) and NCS (D) recorded in N_2-saturated 0.1 M KOH solution at different scan rates.

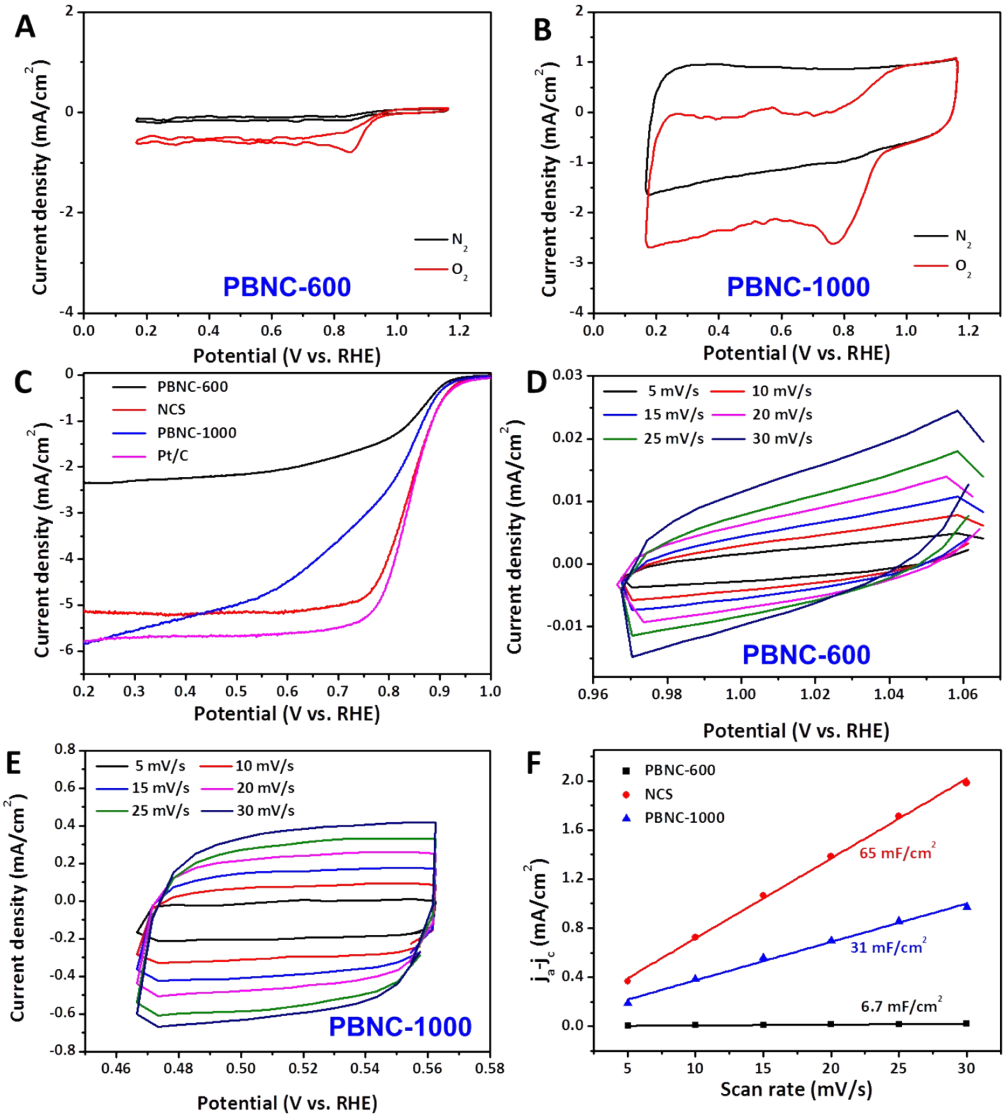

Fig. S5 (A-B) CV curves of PBNC-600 (A) and PBNC-1000 (B) recorded in N_2 or O_2-saturated 0.1 M KOH solution; (C) LSV curves of PBNC-600, NCS, PBNC-1000 recorded in O_2-saturated 0.1 M KOH solution at a scan rate of 10 mV/s and a rotating speed of 1600 rpm; (D-F) CV curves of PBNC-600 (D) and PBNC-1000 (E) recorded in N_2-saturated 0.1 M KOH solution at different scan rates and the corresponding linear relationship (F) between capacitive (j_a-j_c) and CV scan rates.

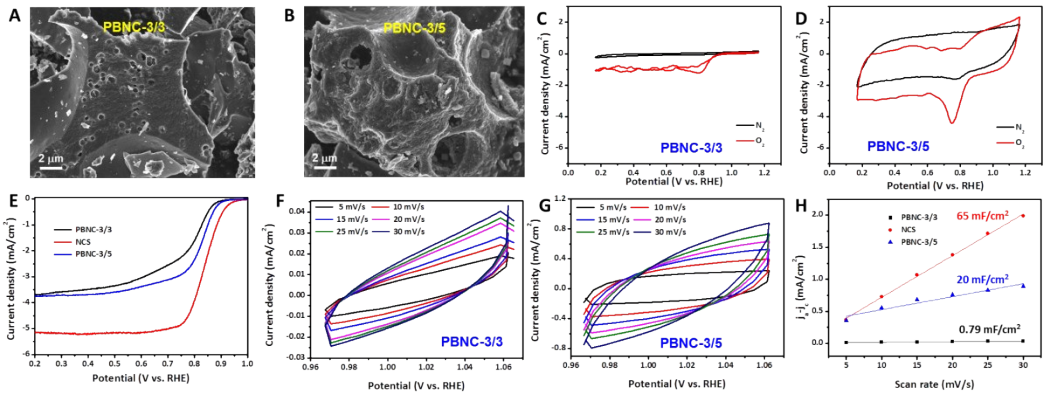

Fig. S6 (A, B) SEM images of PBNC-3/3 and PBNC-3/5; (C, D) CV curves of PBNC-3/3 and PBNC-3/5 recorded in N_2 or O_2-saturated 0.1 M KOH solution; (E) LSV curves of PBNC-3/3, NCS, and PBNC-3/5 recorded in O_2-saturated 0.1 M KOH solution at a scan rate of 10 mV/s and a rotating speed of 1600 rpm; (F-H) CV curves of PBNC-3/3 and PBNC-3/5 recorded in N_2-saturated 0.1 M KOH solution at different scan rates and the corresponding linear relationship (H) between capacitive (j_a-j_c) and CV scan rates.

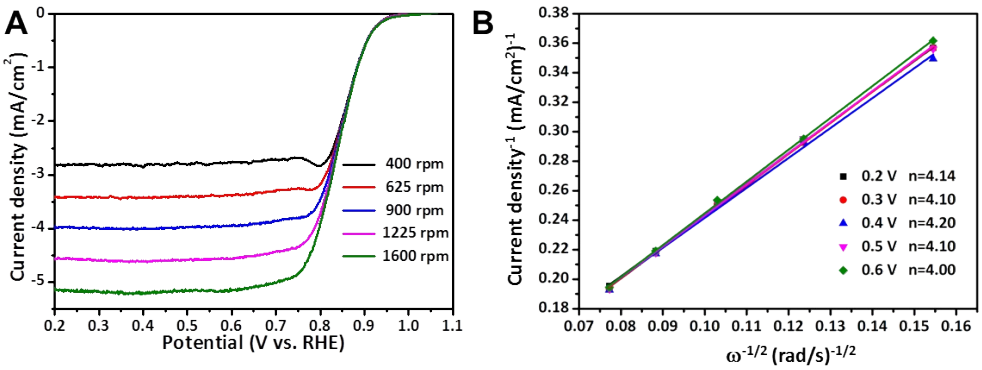

Fig. S7 (A) LSV curves of NCS recorded in O_2-saturated 0.1 M KOH solution at different rotating speeds and (B) the corresponding K-L plots.

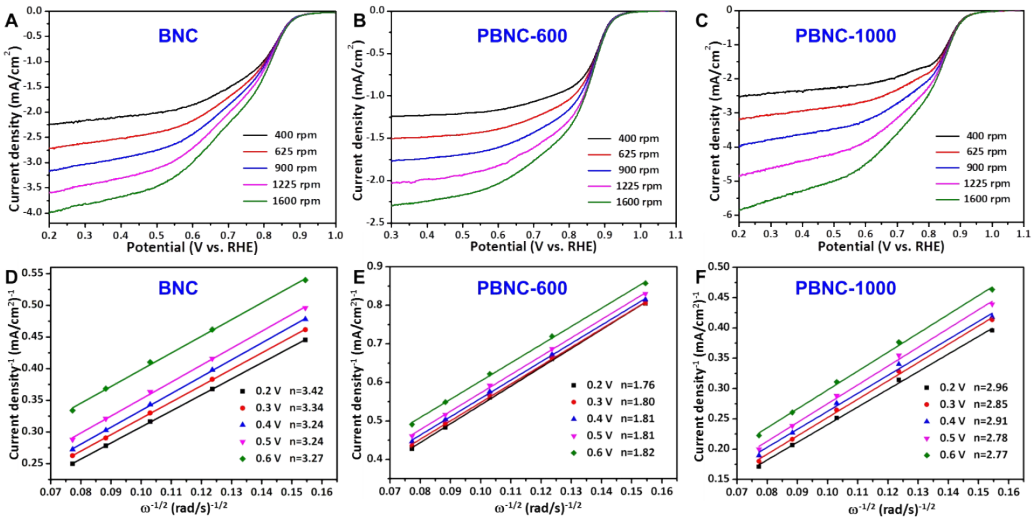

Fig. S8 LSV curves at different rotating speeds and the corresponding K-L plots of (A,D) BNC, (B,E) PBNC-600, and (C,F) PBNC-1000.

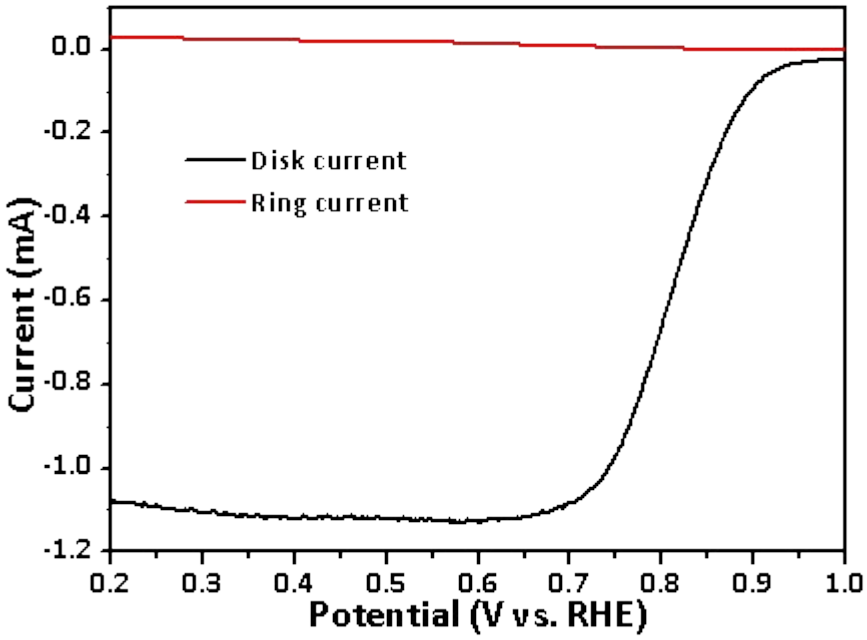

Fig. S9 RRDE curve of NCS recorded in O_2-saturated 0.1 M KOH solution at a scan rate of 10 mV/s and a rotating speed of 1600 rpm.

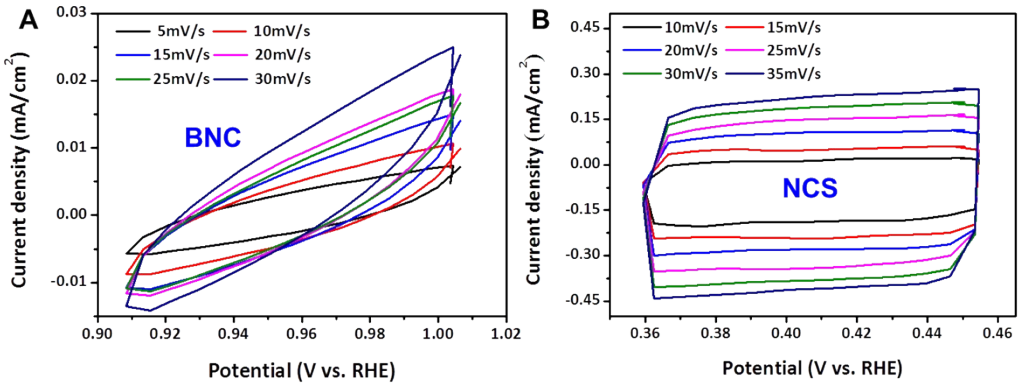

Fig. S10 CV curves of (A) BNC and (B) NCS recorded in N_2-saturated 0.1 M $HClO_4$ solution at different scan rates.

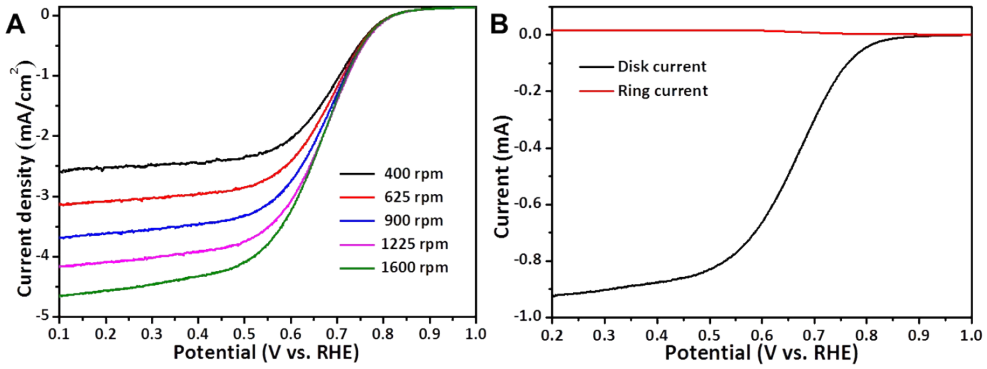

Fig. S11 (A) LSV curves recorded at different rotating speeds and (B) RRDE curve with a ring disk potential of 1.48 V of NCS in O_2-saturated 0.1 M $HClO_4$ solution at a scan rate of 10mV/s.

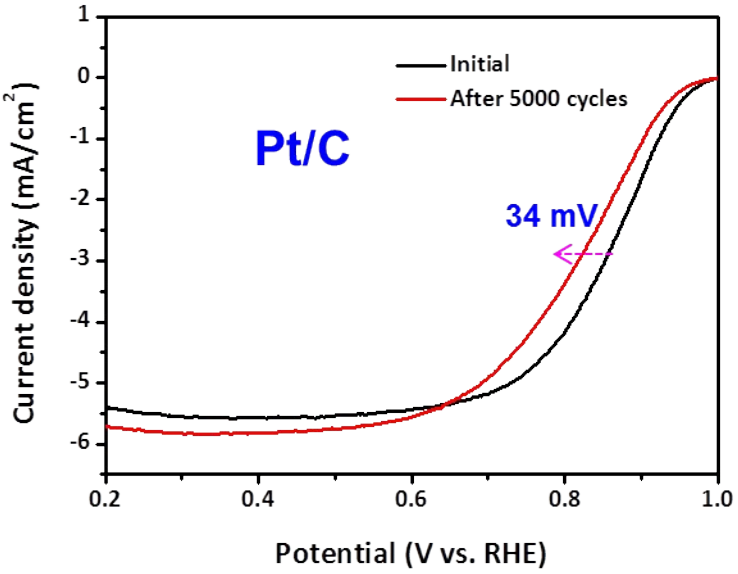

Fig. S12 LSV curves of commercial Pt/C before and after stability test of 5000 cycles.

Table S1 Surface composition of BNC, PBNC-600, NCS, and PBNC-1000.

Samples	Atomic ratio (%)		
	C	N	O
BNC	89.25	10.93	6.12
PBNC-600	74.67	15.52	9.81
NCS	90.5	4.93	4.57
PBNC-1000	90.11	4.48	5.41

Table S2 $E_{1/2}$ value comparison of NCS and the reported metal-free carbon electrocatalysts in alkaline medium.

Electrocatalyst	Electrolyte	$E_{1/2}$ (V)	Reference
NCS	**0.1 M KOH**	**0.832**	**This work**
GNF-H/N (1:20)	0.1 M KOH	0.83	[1]
N-GPp	0.1 M KOH	0.83	[2]
N,P-HCS	0.1 M KOH	0.81	[3]
BN-CA-900	0.1 M KOH	0.77	[4]
NCN-1000-5	0.1 M KOH	0.82	[5]
N–CNSP	0.1 M KOH	0.85	[6]
SWCNTs	0.1 M KOH	0.80	[7]
JUC-528	0.1 M KOH	0.70	[8]
PS-900	0.1 M KOH	0.85	[9]
N,S-CD/rGO	0.1 M KOH	0.69	[10]
GC-900	0.1 M KOH	0.808	[11]
C 4 NNSs/G,	0.1 M KOH	~0.75	[12]
N,S-HPC	0.1 M KOH	0.814	[13]
CF-hydrolyzed PIM-1	0.1 M KOH	0.847	[14]
XWB-CMP-1000	0.1 M KOH	0.774	[15]
C-CMPs-1NP	0.1 M KOH	0.82	[16]
N, F-MCFs	0.1 M KOH	0.81	[17]
NPC	0.1 M KOH	0.864	[18]
GNR@CNT	0.1 M KOH	0.819	[19]
C_3N_7	0.1 M KOH	~0.65	[20]

Table S3 $E_{1/2}$ value comparison of NCS and the reported metal-free carbon electrocatalysts in acidic medium.

Electrocatalysts	Electrolyte	$E_{1/2}$ (V)	Reference
NCS	**0.1 M $HClO_4$**	**0.64**	**This work**
N, P-GC-1000	0.1 M $HClO_4$	0.64	[21]
NCN-1000-5	0.5 M H_2SO_4	~0.58	[5]
PS-900	0.5 M H_2SO_4	0.70	[9]
XWB-CMP-1000	0.5 M H_2SO_4	~0.62	[15]
N, F-MCFs	0.5 M H_2SO_4	0.257	[17]
NPC	0.5 M H_2SO_4	0.74	[18]
GNR@CNT	0.5 M H_2SO_4	0.633	[19]
ZnCoNC-IL20	0.1 M $HClO_4$	~0.65	[22]
MoN	0.1 M $HClO_4$	~0.38	[23]
T_3	0.1 M $HClO_4$	~0.41	[24]

References

1. S. Akula and A. K. Sahu, *ACS Appl. Mater. Interfaces*, 2020, **12**, 11438-11449.
2. N. Komba, Q. Wei, G. Zhang, F. Rosei and S. Sun, *Appl. Catal. B-Environ.*, 2019, **243**, 373-380.
3. C. Zhang, L. Hou, C. Cheng, Z. Zhuang, F. Zheng and W. Chen, *ChemElectroChem*, 2018, **5**, 1891-1898.
4. J. Yu, C. Wang, W. Yuan, Y. Shen and A. Xie, *Chem. Eur.J.*, 2019, **25**, 2877-2883.
5. H. Jiang, J. Gu, X. Zheng, M. Liu, X. Qiu, L. Wang, W. Li, Z. Chen, X. Ji and J. Li, *Energy Environ. Sci.,*, 2019, **12**, 322-333.
6. L. Zong, W. Wu, S. Liu, H. Yin, Y. Chen, C. Liu, K. Fan, X. Zhao, X. Chen, F. Wang, Y. Yang, L. Wang and S. Feng, *Energy Storage Mater.*, 2020, **27**, 514-521.
7. R. Gao, Q. Dai, F. Du, D. Yan and L. Dai, *J. Am. Chem. Soc.*, 2019, **141**, 11658-11666.
8. D. Li, C. Li, L. Zhang, H. Li, L. Zhu, D. Yang, Q. Fang, S. Qiu and X. Yao, *J. Am. Chem. Soc.*, 2020, **142**, 8104-8108.
9. L. Yu, C. Yang, W. Zhang, W. Liu, H. Wang, J. Qi and L. Xu, *J. Colloid Interface Sci.*, 2020, **575**, 406-415.
10. P. Zhang, J. S. Wei, X. B. Chen and H. M. Xiong, *J. Colloid Interface Sci.*, 2019, **537**, 716-724.
11. C. Maouche, Y. Zhou, B. Li, C. Cheng, Y. Wu, J. Li, S. Gao and J. Yang, *J. Electroanal. Chem.*, 2019, **853**, 113536-113543.
12. Y. Li, C. Mo, J. Li and D. Yu, *J. Energy Chem.*, 2020, **49**, 243-247.
13. J. Zhang, J. He, H. Zheng, R. Li and X. Gou, *J. Mater. Sci.*, 2020, **55**, 7464-7476.
14. B. Patil, B. Satilmis and T. Uyar, *J. Power Sources*, 2020, **451**, 227799-227808.
15. S.-B. Ren, X.-L. Chen, P.-X. Li, D.-Y. Hu, H.-L. Liu, W. Chen, W.-B. Xie, Y. Chen, X.-L. Yang, D.-M. Han, G.-H. Ning and X.-H. Xia, *J. Power Sources*, 2020, **461**, 228145-228150.
16. R. Jiao, W. Zhang, H. Sun, Z. Zhu, Z. Yang, W. Liang and A. Li, *Mater. Today Energy*, 2020, **16**, 100382.
17. T. Gong, R. Qi, X. Liu, H. Li and Y. Zhang, *Nano-Micro Lett.*, 2019, **11**, 9-19.
18. H. Han, Y. Noh, Y. Kim, W. S. Jung, S. Park and W. B. Kim, *Nanoscale*, 2019, **11**, 2423-2433.
19. L. Xue, Y. Li, X. Liu, Q. Liu, J. Shang, H. Duan, L. Dai and J. Shui, *Nat. Commun.*, 2018, **9**, 3819-3826.
20. I. Y. Kim, S. Kim, S. Premkumar, J. H. Yang, S. Umapathy and A. Vinu, *Small*, 2019, DOI: 10.1002/smll.201903572, 1903572-1903578.
21. Z. Zhou, A. Chen, X. Fan, A. Kong and Y. Shan, *Appl. Surf. Sci.*, 2019, **464**, 380-387.
22. M. Wang, H. Zhang, G. Thirunavukkarasu, I. Salam, J. R. Varcoe, P. Mardle, X. Li, S. Mu and S. Du, *ACS Energy Lett.*, 2019, **4**, 2104-2110.
23. M. E. Kreider, M. B. Stevens, Y. Liu, A. M. Patel, M. J. Statt, B. M. Gibbons, A. Gallo, M. Ben-Naim, A. Mehta, R. C. Davis, A. V. Ievlev, J. K. Nørskov, R. Sinclair, L. A. King and T. F. Jaramillo, *Chem. Mater.*, 2020, **32**, 2946-2960.
24. G. Zhang, D. Sebastián, X. Zhang, Q. Wei, C. Lo Vecchio, J. Zhang, V. Baglio, W. Wang, S. Sun, A. S. Aricò and A. C. Tavares, *Adv. Energy Mater.*, 2020, **10**, 2000075-2000085.