Supporting Information for *Acta Phys. -Chim. Sin.* doi: 10.3866/PKU.WHXB202011050

超薄氮掺杂碳纳米片负载单原子镍用于高效电催化还原二氧化碳

黄小雄[1,2]，马英杰[1,*]，智林杰[1,2,*]

[1] 国家纳米科学中心，纳米科学卓越创新中心，纳米系统与多级次制造重点实验室，北京 100190

[2] 中国科学院大学，北京 100049

Ultrathin Nitrogenated Carbon Nanosheets with Single-atom Nickel as an Efficient Catalyst for Electrochemical CO_2 Reduction

Xiaoxiong Huang[1,2], Yingjie Ma[1,*], Linjie Zhi[1,2,*]

[1] CAS Key Laboratory of Nanosystem and Hierarchical Fabrication, CAS Center for Excellence in Nanoscience, National Center for Nanoscience and Technology, Beijing 100190, China.

[2] University of Chinese Academy of Sciences, Beijing 100049, China.

[*]Corresponding authors. Emails: mayj@nanoctr.cn (Y.M.); zhilj@nanoctr.cn (L.Z.).

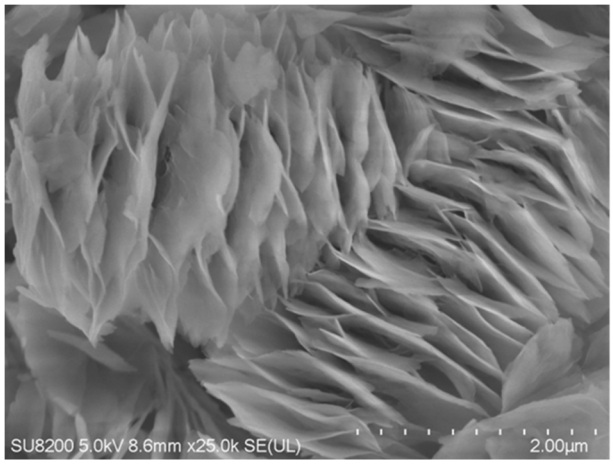

Fig. S1 SEM image of Ni-MOF precursor.

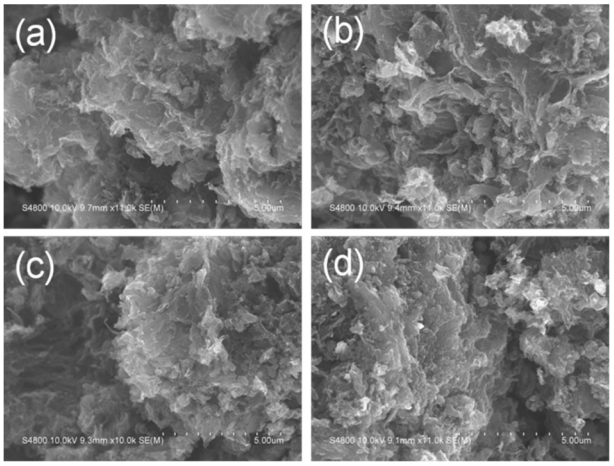

Fig. S2 SEM images of (a) Ni-N-C-700, (b) Ni-N-C-800, (c) Ni-N-C-900, (d) Ni-N-C-1000.

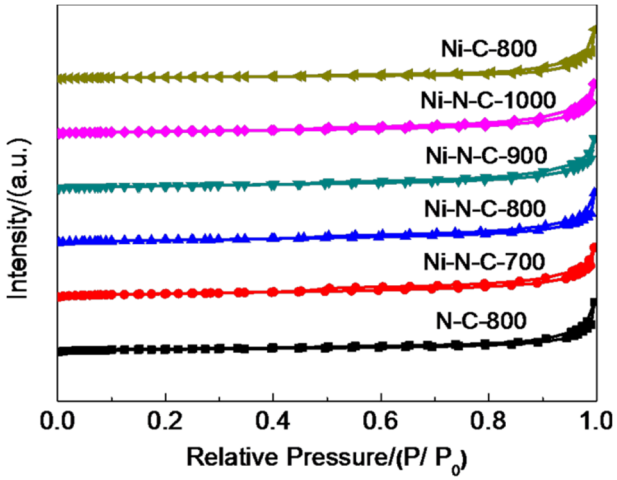

Fig. S3 N_2 adsorption-desorption isotherms of Ni-N-C annealed at different temperatures.

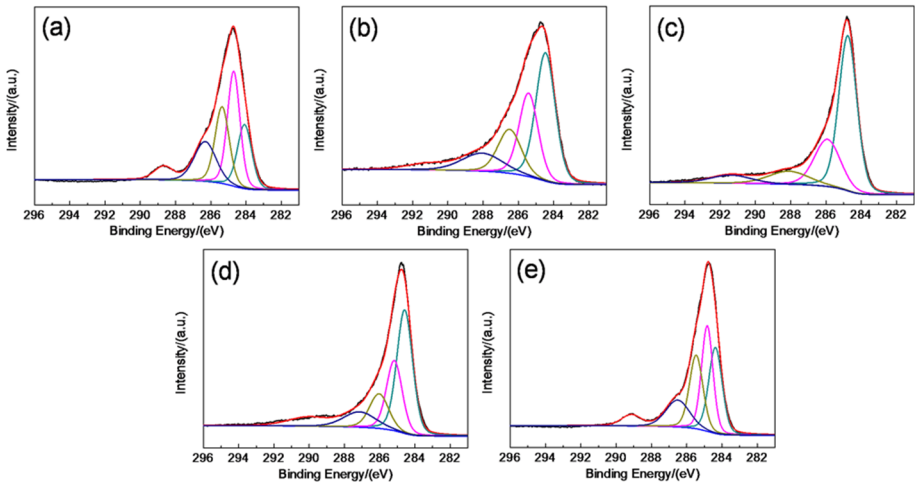

Fig. S4 XPS spectra of C 1*s* for (a) N-C-800, (b) Ni-N-C-700, (c) Ni-N-C-900, (d) Ni-N-C-1000, (e) Ni-C-800.

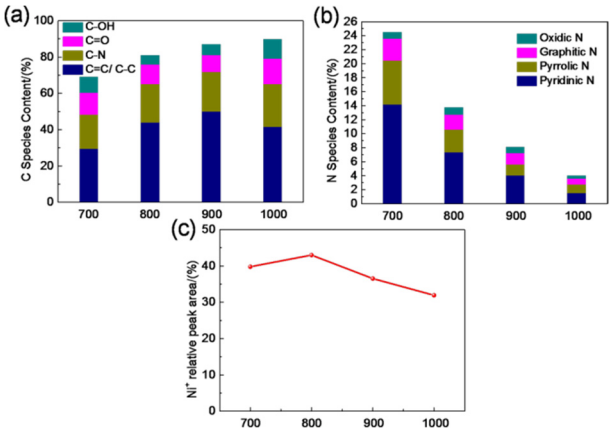

Fig. S5 Elemental content of Ni-N-C annealed at different temperatures, obtained from XPS measurements.

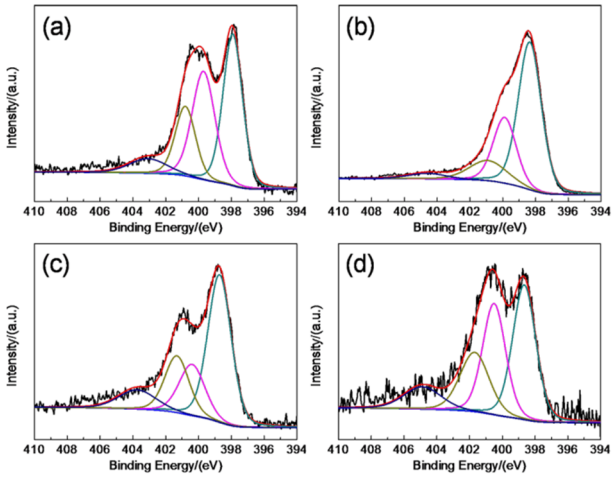

Fig. S6 XPS spectra of N 1*s* for (a) N-C-800, (b) Ni-N-C-700, (c) Ni-N-C-900, (d) Ni-N-C-1000.

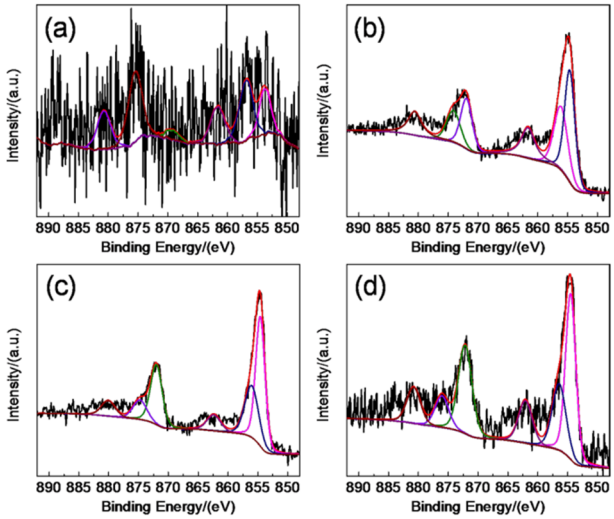

Fig. S7 XPS spectra of Ni 2*p* for (a) Ni-C-800, (b) Ni-N-C-700, (c) Ni-N-C-900, (d) Ni-N-C-1000.

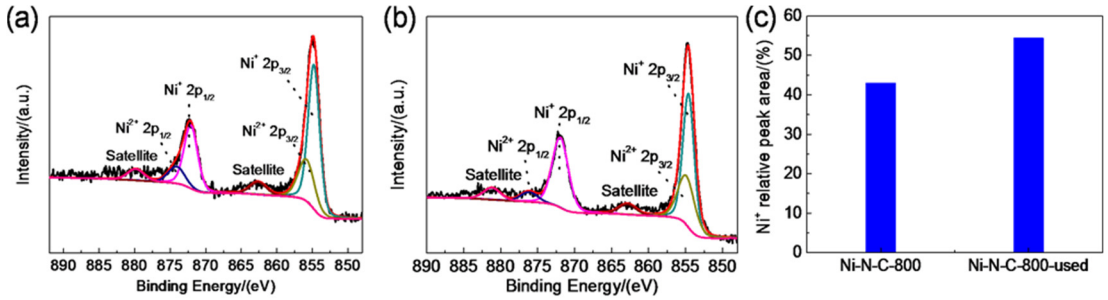

Fig. S8 XPS spectra of Ni 2*p* for Ni-N-C-800 (a), Ni-N-C-800-used (b) and elemental content obtained from XPS measurements (c).

Table S1 The nitrogen adsorption/desorption measurement results of samples annealed at different temperatures.

Sample	N-C-800	Ni-N-C-700	Ni-N-C-800	Ni-N-C-900	Ni-N-C-1000	Ni-C-800
BET surface area ($m^2 \cdot g^{-1}$)	108	224	201	175	118	607
Pore volume ($cm^3 \cdot g^{-1}$)	0.11	0.29	0.29	0.25	0.22	0.63

Table S2 Ni contents in various catalysts determined by ICP-AES and XPS.

Content	Ni-N-C-700	Ni-N-C-800	Ni-N-C-900	Ni-N-C-1000
ICP-AES (% (*w*))	9.32	7.77	7.32	0.44
XPS (% (*a*))	1.67	1.25	1.00	0.43

Table S3 CO_2RR catalytic performances of various Ni-based catalysts in similar operating conditions for CO production.

Catalyst	Electrolyte	Onset potential (V *vs*. RHE)	Operating potential (V *vs*. RHE)	Current density ($mA \cdot cm^{-2}$)	Specific current density ($mA \cdot mg^{-1}$)	Faradaic efficiency for CO (%)	Reference
SE-NiSAs@PNC	0.5 $mol \cdot L^{-1}$ $KHCO_3$	−0.6	−1	18.3	N/A	87.8	1
Ni SAs/N-C	0.5 $mol \cdot L^{-1}$ $KHCO_3$	N/A	−1	10.48	N/A	70.30	2
Ni-NC_ATPA@C	0.5 $mol \cdot L^{-1}$ $KHCO_3$	−0.5	−0.7	~7	N/A	94	3
Ni-N-C	0.1 $mol \cdot L^{-1}$ $KHCO_3$	N/A	−0.64	8.2	N/A	96	4
Ni/NCTs	0.5 $mol \cdot L^{-1}$	−0.32	−1	34.3	N/A	98	5

	$KHCO_3$						
A-Ni-NG	0.5 mol·L^{-1}	−0.3	−0.7	22	N/A	97%@−0.61 V	6
	$KHCO_3$						
C-Zn_1Ni_4ZIF-8	1 mol·L^{-1}	−0.53	−0.63	4.7	N/A	94.5	7
	$KHCO_3$						
Ni-N-C	0.5 mol·L^{-1}	−0.4	−0.77	12.6	N/A	97.9	This work
	$KHCO_3$		−0.87	18.8	N/A	95.6	
			−0.97	25.9	N/A	92.0	
			−1.07	32.7	N/A	90.3	

References

(1) Yang, J.; Qiu, Z. Y.; Zhao, C. M.; Wei, W. C.; Chen.; Li, Z. J.; Qu, Y. T.; Dong, J. C. W. X.; Luo, J.; Li, Z. Y.; Wu, Y. *Angew. Chem. Int. Ed.* **2018,** *57*, 14095. doi: 10.1002/anie.201808049

(2) Zhao, C.; Dai, X.; Yao, T.; Chen, W.; Wang, X.; Wang, J.; Yang, J.; Wei, S.; Wu, Y.; Li, Y.; *et al*. *J. Am. Chem. Soc.* **2017,** *139*, 8078. doi: 10.1021/jacs.7b02736

(3) Jia, M. W.; Choi,C. H.; Wu, T.-S.; Ma, C.; Kang, P.; Tao, H. C.; Fan, Q.; Hong, S.; Liu,S. Z.; Soo, Y.-L.; *et al*. *Chem. Sci.* **2018,** *9*, 8775. doi: 10.1039/C8SC03732A

(4) Pan, F. P.; Deng, W.; Justiniano, C.; Li, Y. *Appl. Catal. B: Environ.* **2018,** *226*, 463. doi: 10.1016/j.apcatb.2018.01.001

(5) Hou, Y.; Liangc, Y. L.; Shi, P. C.; Huangaa, A. B.; Ccoaa, R. *Appl. Catal. B: Environ.* **2020,** *271*, 118929. doi: 10.1016/j.apcatb.2020.118929

(6) Yang, H. B.; Hung, S.-F.; Liu, S.; Yuan, K. D.; Miao, S.; Zhang, L. P.; Huang, X.; Wang, H.-Y.; Cai, W. Z.; Chen, R.; *et al*. *Nat. Energy* **2018,** *3*, 140. doi: 10.1038/s41560-017-0078-8

(7) Yan, C.; Li, H.; Ye, Y.; Wu, H.; Cai, F.; Si, R.; Xiao, J.; Miao, S.; Xie, S.; Yang, F. *Energy Environ. Sci.* **2018,** *11*, 1204. doi: 10.1039/C8EE00133B