

A cobalt-based hybrid electrocatalyst derived from carbon nanotube inserted metal-organic framework for efficient water-splitting

Fulin Yang,^a Pingping Zhao,^a Xing Hua,^a Wei Luo,^{a*} Gongzhen Cheng,^a Wei Xing,^b and Shengli Chen^{a*}

^aCollege of chemistry and molecular sciences, Wuhan University, Wuhan, 430072, P. R. China

^bChangchun Institute of Applied Chemistry, Chinese Academy of Sciences, Changchun 130022, P. R. China

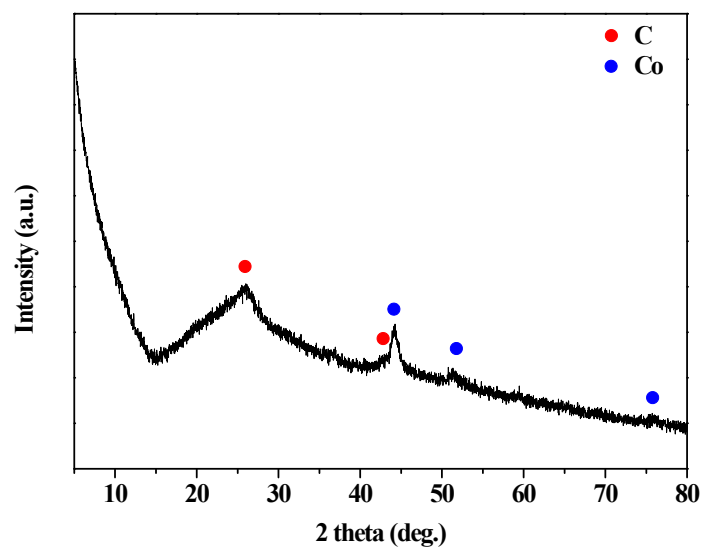


Figure S1 XRD patterns of Co-NC/CNT.

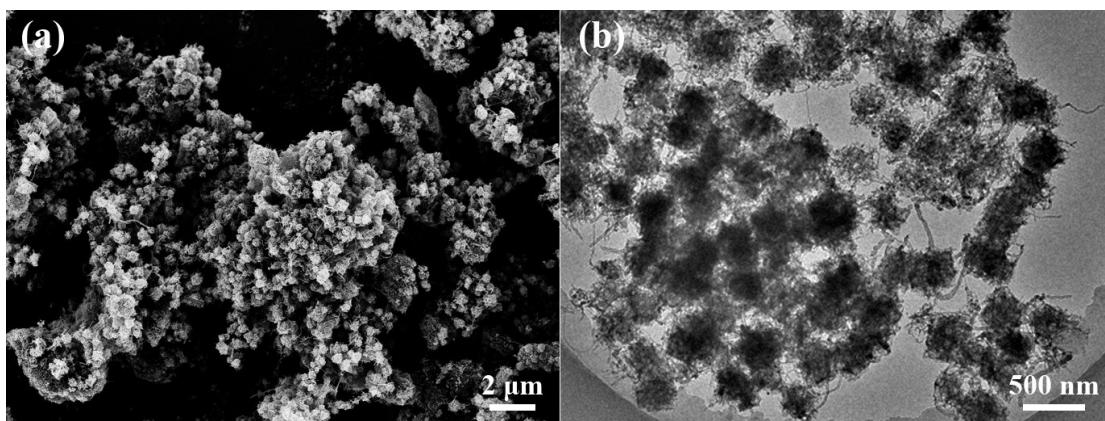


Figure S2 SEM (a) and TEM (b) of Co-NC/CNT.

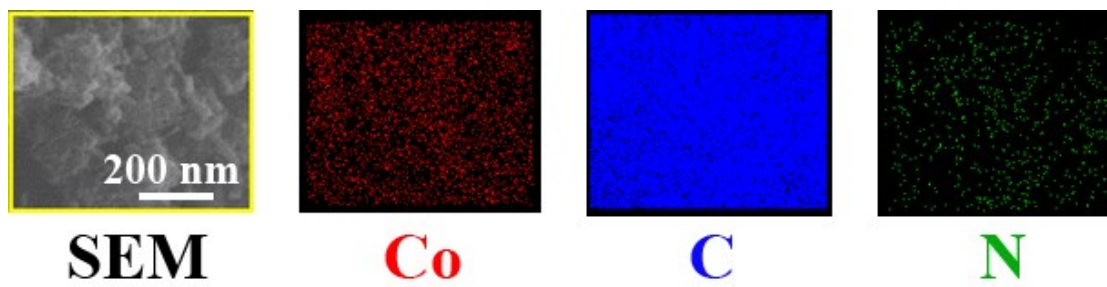


Figure S3 SEM-EDX elemental mapping images of Co-NC/CNT.

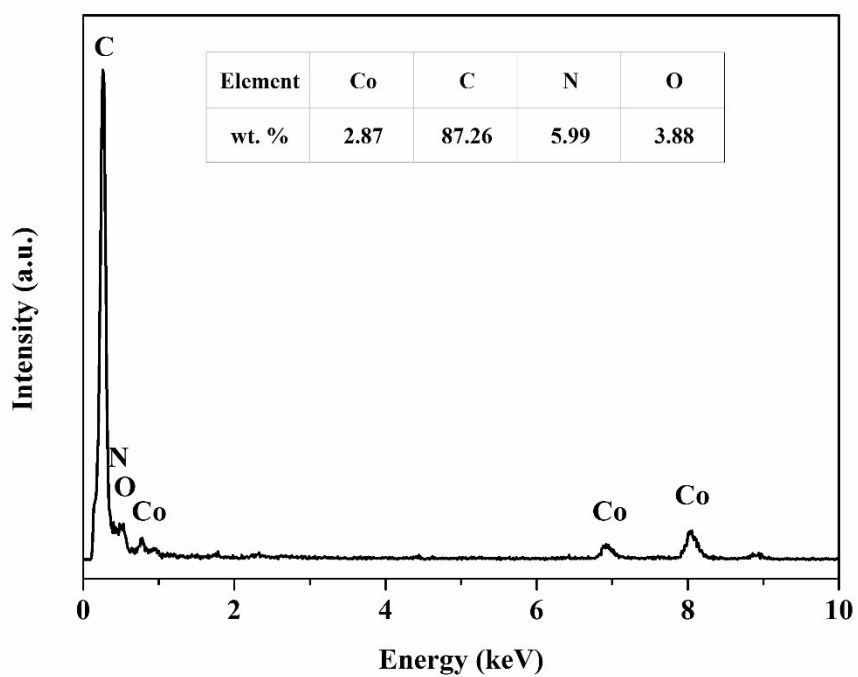


Figure S4 EDX spectrum of Co-NC/CNT.

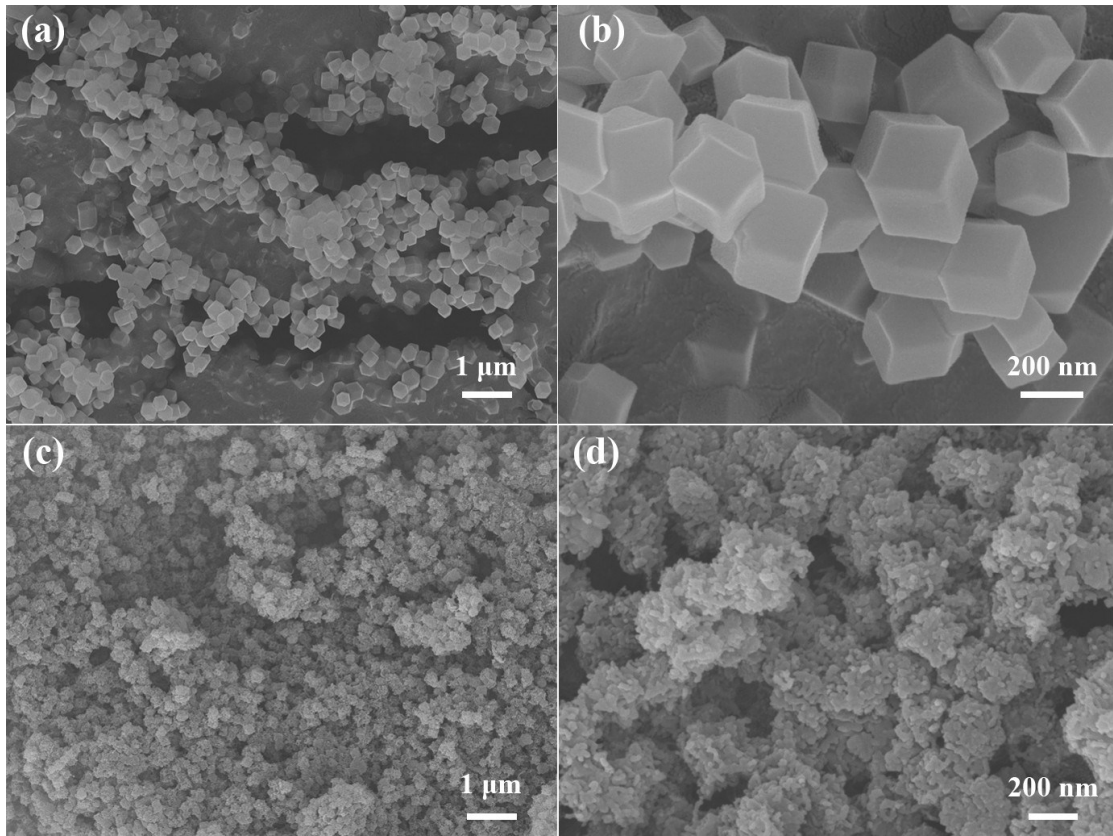


Figure S5 SEM images of ZIF-67 (a, b) and Co-NC (c, d).

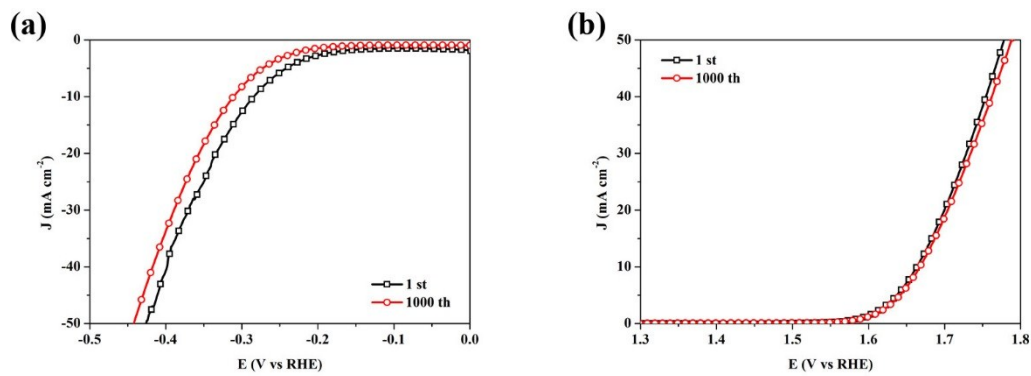


Figure S6 Cycle stability measurement for Co-NC by CV scanning after 1000 cycles for (a) HER and (b) OER.

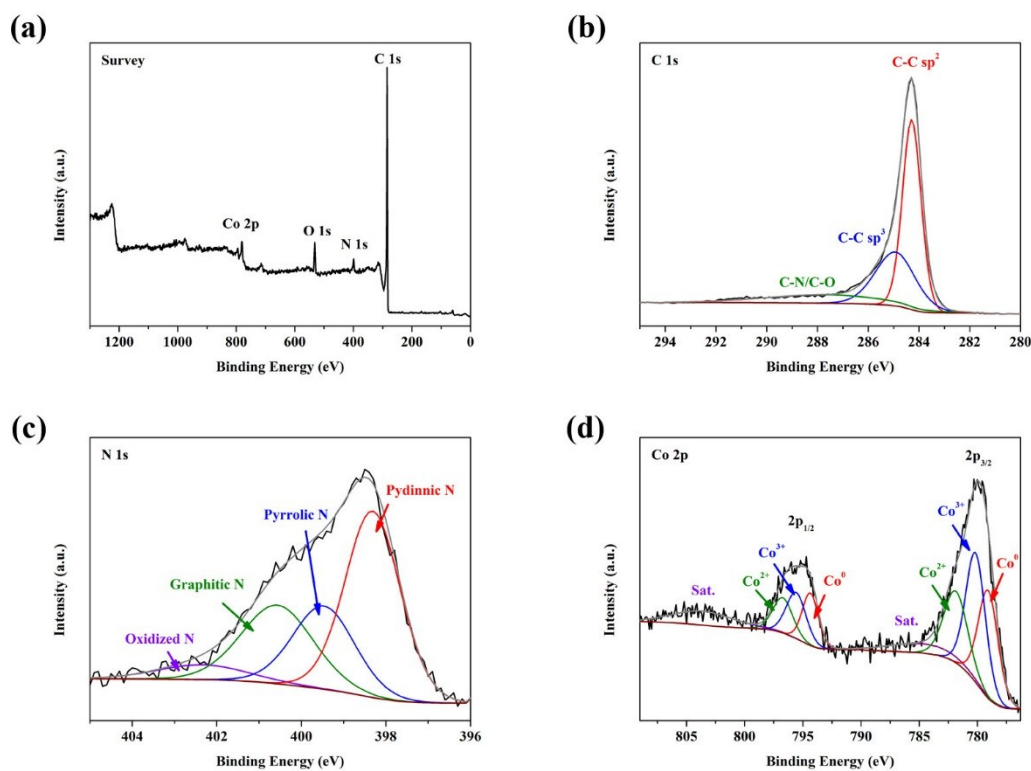


Figure S7 XPS spectra of Co-NC/CNT-700: survey (a), high resolution spectra of C 1s (b), N 1s (c), and Co 2p (d).

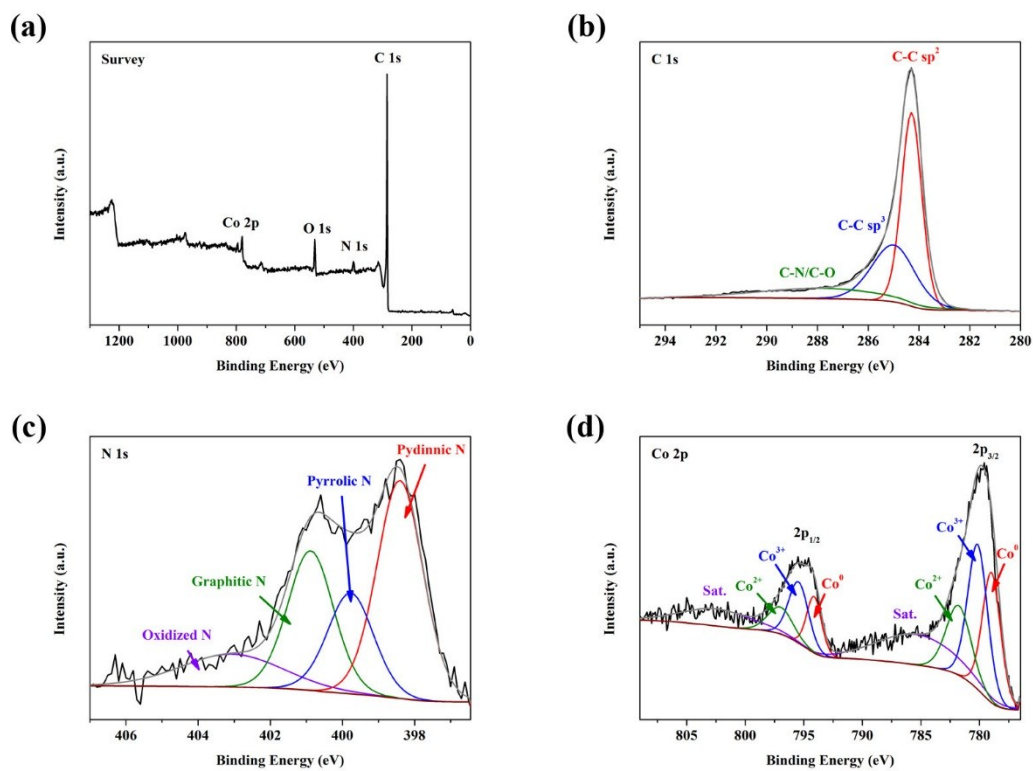


Figure S8 XPS spectra of Co-NC/CNT-900: survey (a), high resolution spectra of C 1s (b), N 1s (c), and Co 2p (d).

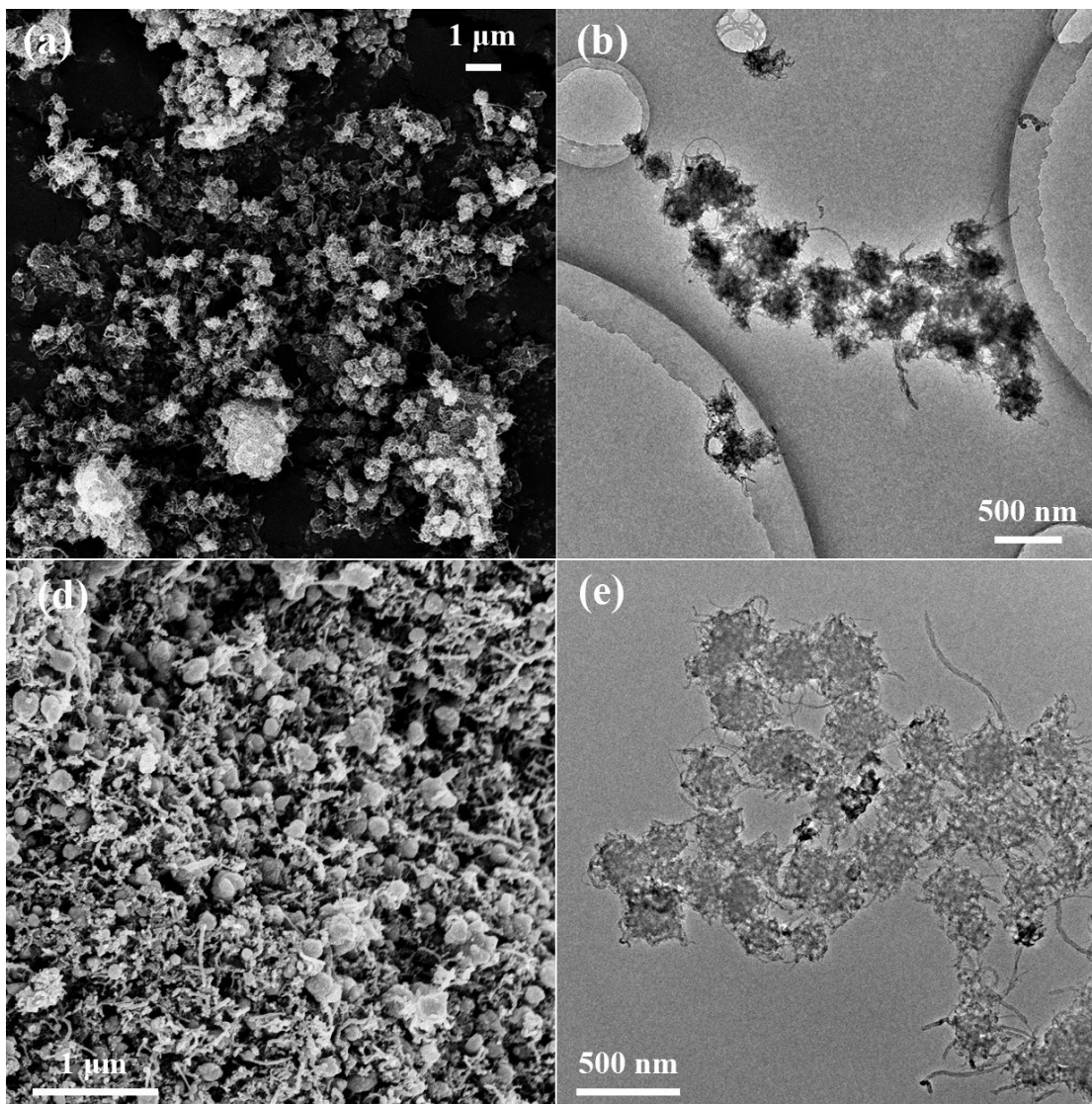


Figure S9 SEM (a, c) and TEM (b, d) images of Co-NC/CNT-700 (a, b) and Co-NC-900 (c, d).

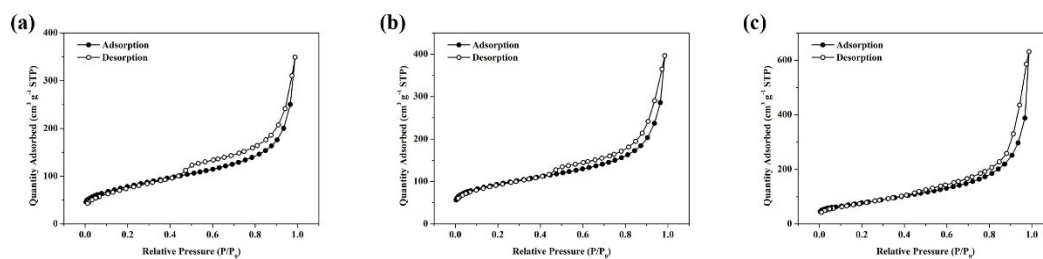


Figure S10 N₂ adsorption-desorption isotherms of Co-NC/CNT-700 (a), Co-NC/CNT-800 (b), and Co-NC/CNT-900 (c), respectively.

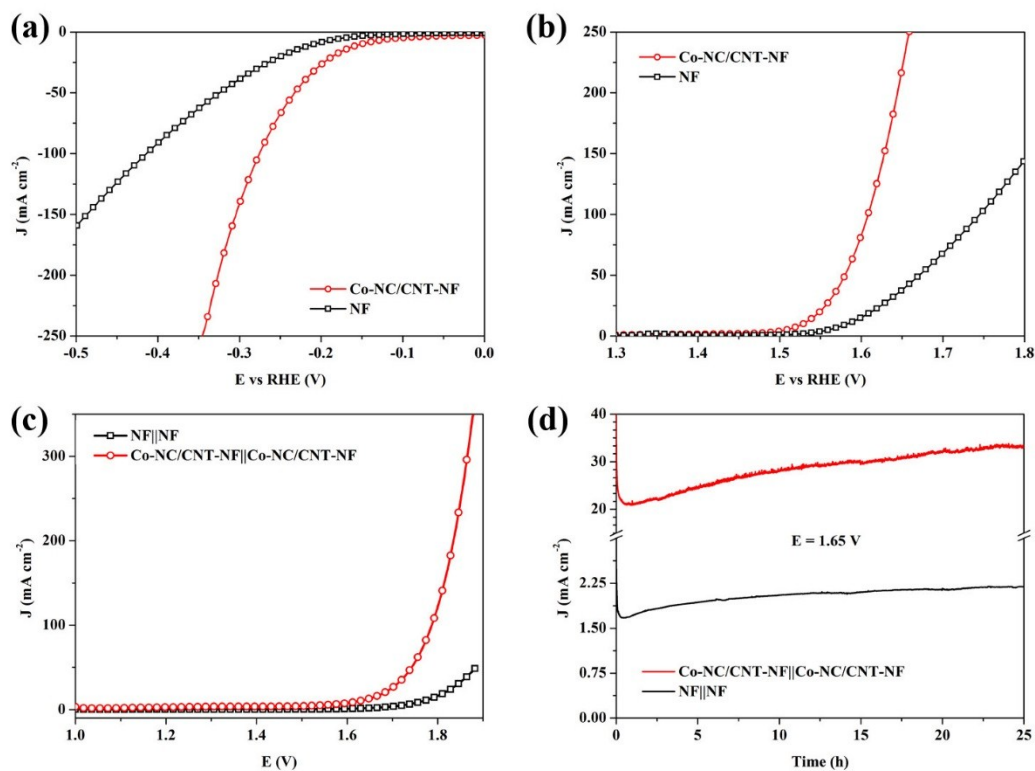


Figure S11 LSV curves of (a) HER and (b) OER with the Co-NC/CNT-NF (nickel foam) (loading: ~ 1.2 mg cm⁻²) or pure nickel foam as the working electrode in three-electrode electrolyzer. (c) LSV curves of water electrolysis in two-electrode electrolyzer with the Co-NC/CNT-NF or pure nickel foam as both anode and cathode in 1.0 M KOH and (d) Chronoamperometry durability test at a constant potential of 1.65 V.

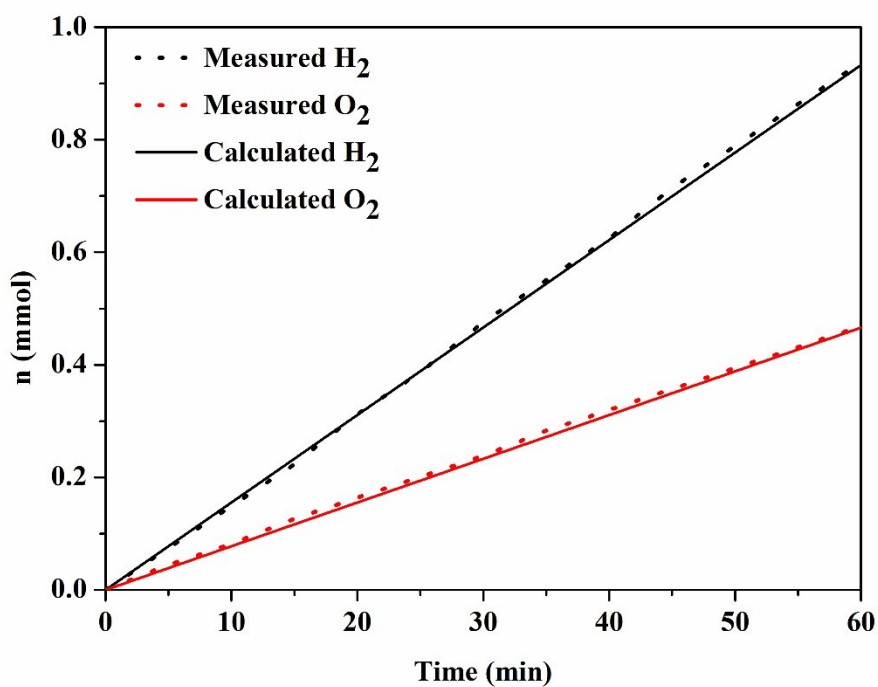


Figure S12 Faraday efficiency of H₂ and O₂ production.

Table S1 Weight percentage of Co, C, N, O of Co-NC/CNT-T obtained by XPS spectrum.

Samples	Co (wt. %)	C (wt. %)	N (wt. %)	O (wt. %)
Co-NC/CNT-700	1.23	87.46	8.69	2.61
Co-NC/CNT-800	1.39	83.84	12.63	2.14
Co-NC/CNT-900	1.53	87.97	7.54	2.96

Table S2 BET surface areas, average pore size, and total pore volumes for Co-NC/CNT with different pyrolysis temperatures (700 °C, 800 °C and 900 °C).

Samples	BET Surface Area (m ² g ⁻¹)	Total pore volume (cm ³ g ⁻¹)	Average pore diameter (nm)
Co-NC/CNT-700	280.798	0.540	3.655
Co-NC/CNT-800	334.384	0.613	3.662
Co-NC/CNT-900	279.442	0.976	3.673

Table S3 Values of I_D/I_G and I_{2D}/I_G of Co-NC/CNT with different pyrolysis temperatures (700 °C, 800 °C and 900 °C).

Samples	I _D /I _G	I _{2D} /I _G
Co-NC/CNT-700	1.156	0.348
Co-NC/CNT-800	0.981	0.537
Co-NC/CNT-900	0.916	0.533

Table S4 Comparison of representative Co-based water-splitting catalysts in alkaline electrolyte.

Catalyst	Water electrolysis test (in 1.0 M KOH)	Substrate	Loading (mg cm ⁻²)	$\eta@10 \text{ mA cm}^{-2}$ (mV)	Reference
CoP mesoporous nanorod arrays	HER	Ni foam	6.2	54	Adv. Funct. Mater. 2015, 25, 7337
	OER			380	
	Overall water splitting			390	
CoP/rGO	HER	GCE	0.28	150	Chem. Sci., 2016, 7, 1690
	OER	Carbon fiber cloth		350	
	Overall water splitting			470	
porous N-rich carbon/Co	HER	GCE	0.35	298	J. Mater. Chem. A, 2016, 4, 3204
	OER	Ni foam		370	
	Overall water splitting			410	
CoOx@CN	HER	GCE	0.42	232	J. Am. Chem. Soc. 2015, 137, 2688
	OER	Ni foam		1	
	Overall water splitting			2	
Co/N-rich CNT	HER	GCE	0.28	370	Angew. Chem. Int. Ed. 2014, 53, 4372
N-doped crumpled graphene/CoO	OER	GCE	0.071	340	Energy Environ. Sci., 2014, 7, 609
Co-P film	HER	Cu foil	2.71	95	Angew. Chem. Int. Ed. 2015, 54, 6251
	OER			345	
	Overall water splitting			> 400	
CoP nanowire arrays	HER	Carbon cloth	0.92	207	J. Am. Chem. Soc. 2014, 136, 7587
Surface oxidized CoP nanorods/C	OER	GCE	0.71	320	ACS Catal. 2015, 5, 6874
	Overall water splitting	Ti felt sheet	5	357	
Carbon paper/carbon tubes/Co-S Sheets	HER	Carbon paper	0.32	190	ACS Nano, 2016, 10, 2342
	OER			306	
	Overall water splitting			413	
Co@carbon nanofibers	HER	GCE	0.44	196	Nano Energy, 2016, 22, 79
Co-C-N	HER	Carbon paper	2	178	J. Am. Chem. Soc. 2015, 137, 15070
Atomic Co on N-doped graphene	HER (1 M NaOH)	GCE	0.285	> 250	Nat. Commun. 2015, 6, 8668
CoCo layered double hydroxides-nanosheets	OER	GCE	0.07	353	Nat. Commun. 2014, 5, 4477
				393	
Co3O4 nanocrystal	HER	Carbon fiber paper	0.35	380	Chem. Commun., 2015, 51, 8066
	OER			320	
	Overall water splitting			680	
Co3O4 nanocages	OER	Ni foam	1	410	J. Am. Chem. Soc. 2015, 137, 5590
Co@N-doped carbon	HER	GCE	\	210	J. Mater. Chem. A, 2014, 2, 20067
	OER			400	
CoP N-doped carbon	HER	GCE	0.283	191	Chem. Mater., 2015, 27, 7636
	OER			354	
	Overall water splitting		1	> 470	
Co-NC/CNT	HER	GCE	0.306	203	This work
	OER			354	
	Overall water splitting	Ni foam	1.2	395	