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Supporting Information

A graphene-like nanoribbon for efficient bifunctional electrocatalysts

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Figures captions in Supporting Information

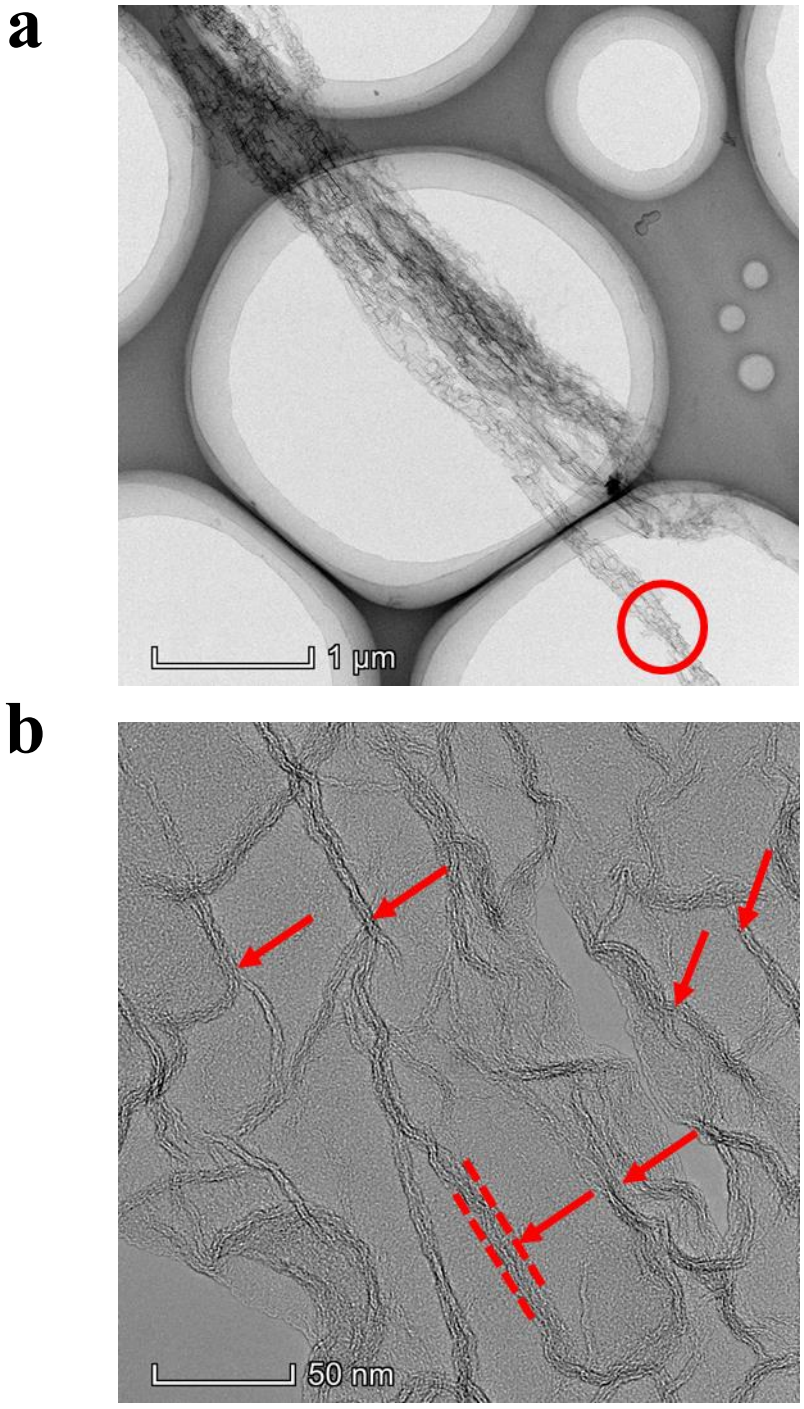


Fig. S1 (a, b) TEM images of C-MP-FeCo.

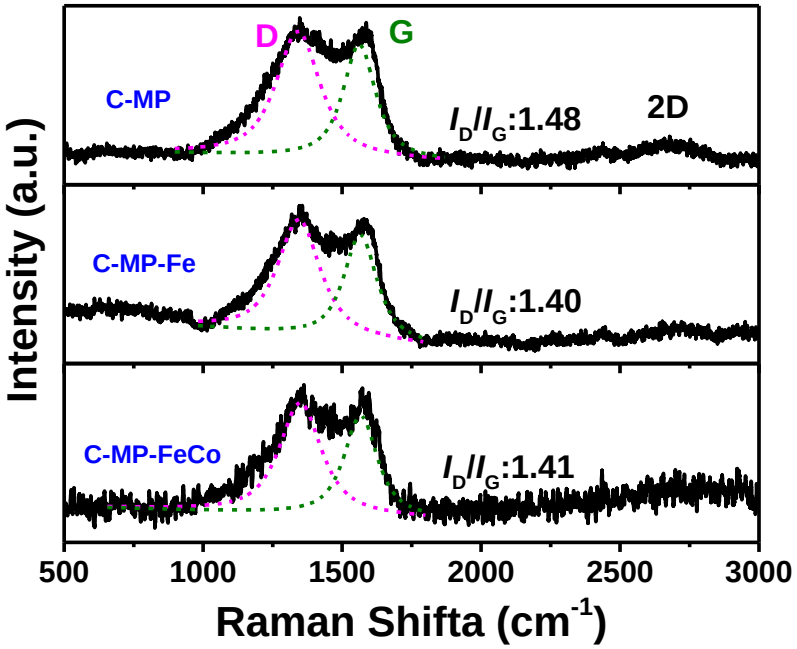


Fig. S2 Raman spectra of C-MP, C-MP-Fe and C-MP-FeCo.

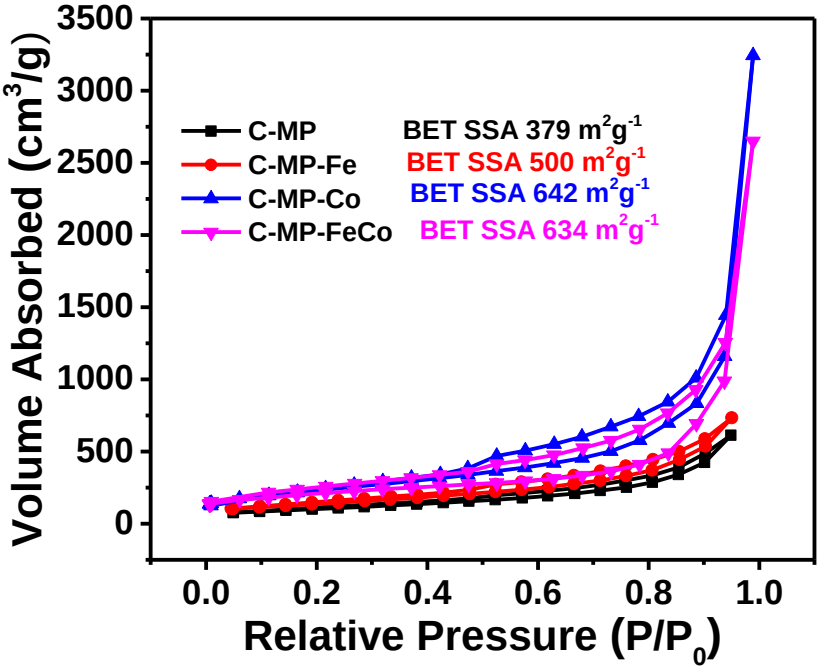


Fig. S3 N_2 adsorption–desorption isotherms of C-MP, C-MP-Fe, C-MP-Co and C-MP.

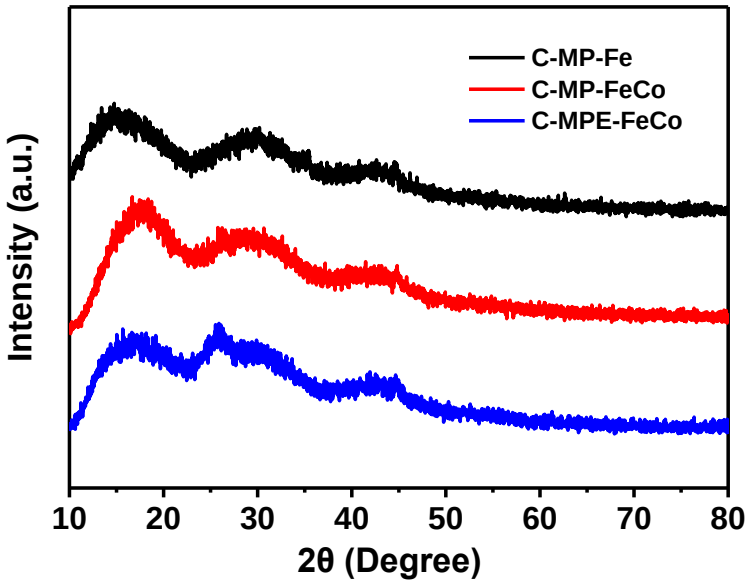


Fig. S4 XRD patterns of C-MP-Fe, C-MP-FeCo, and C-MPE-FeCo.

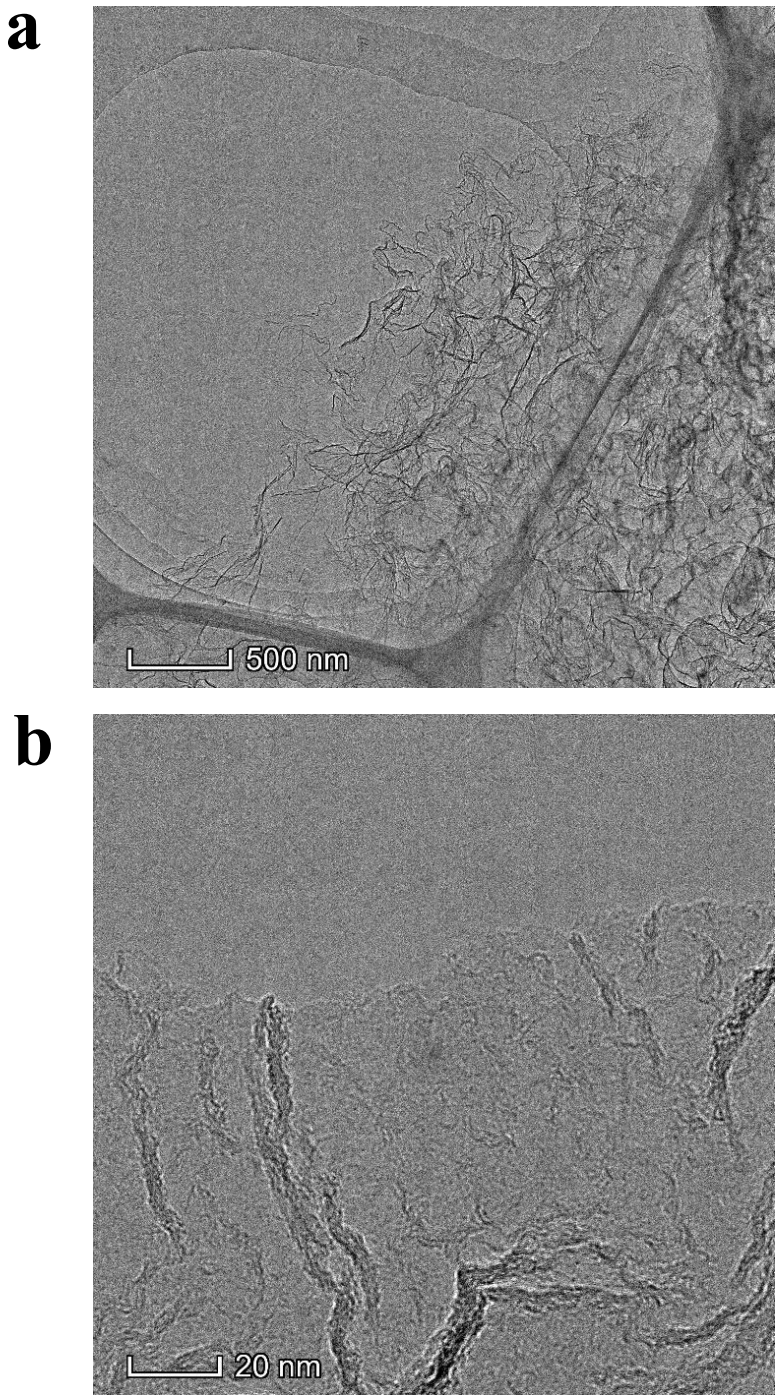


Fig. S5 (a, b) TEM images of C-MP-Co-2.

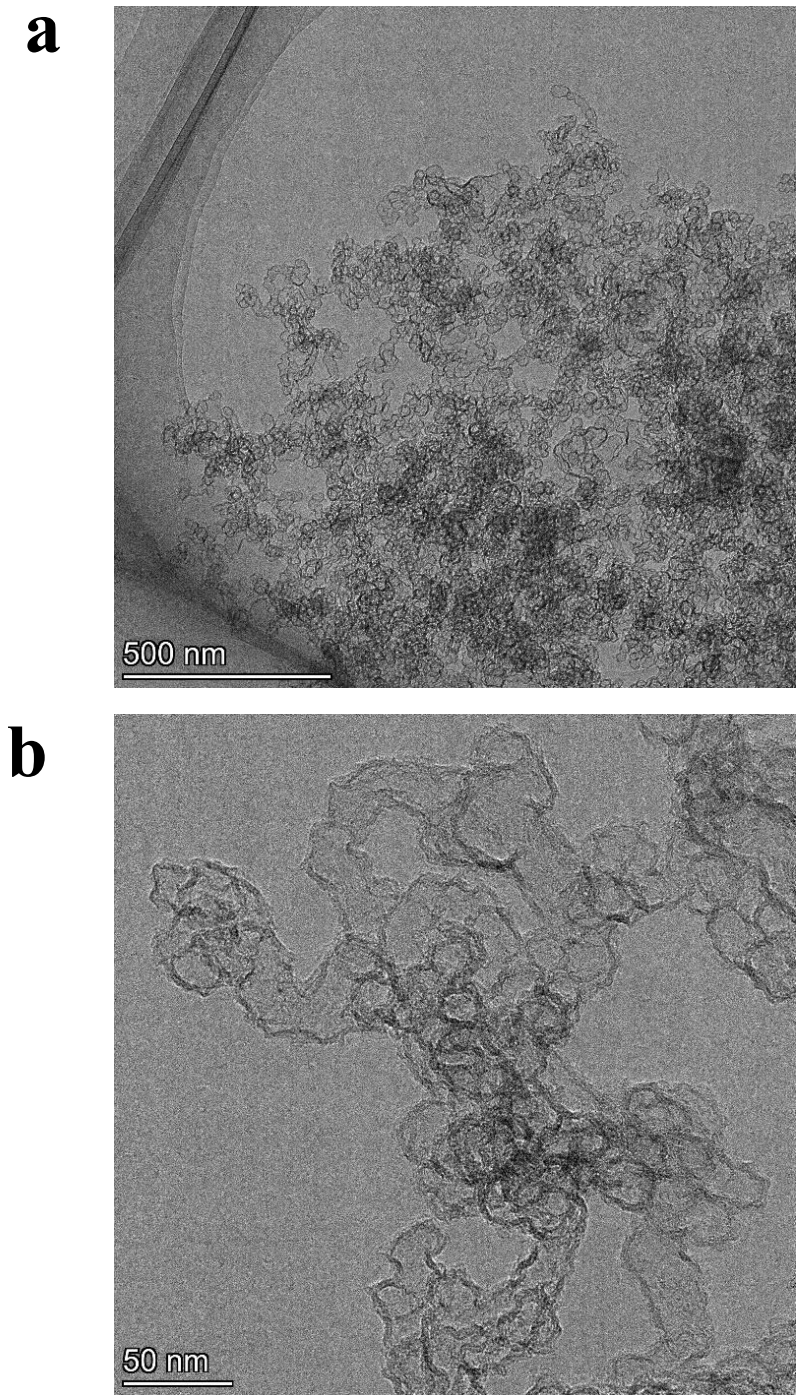


Fig. S6 (a, b) TEM images of C-MP-FeCo-28.

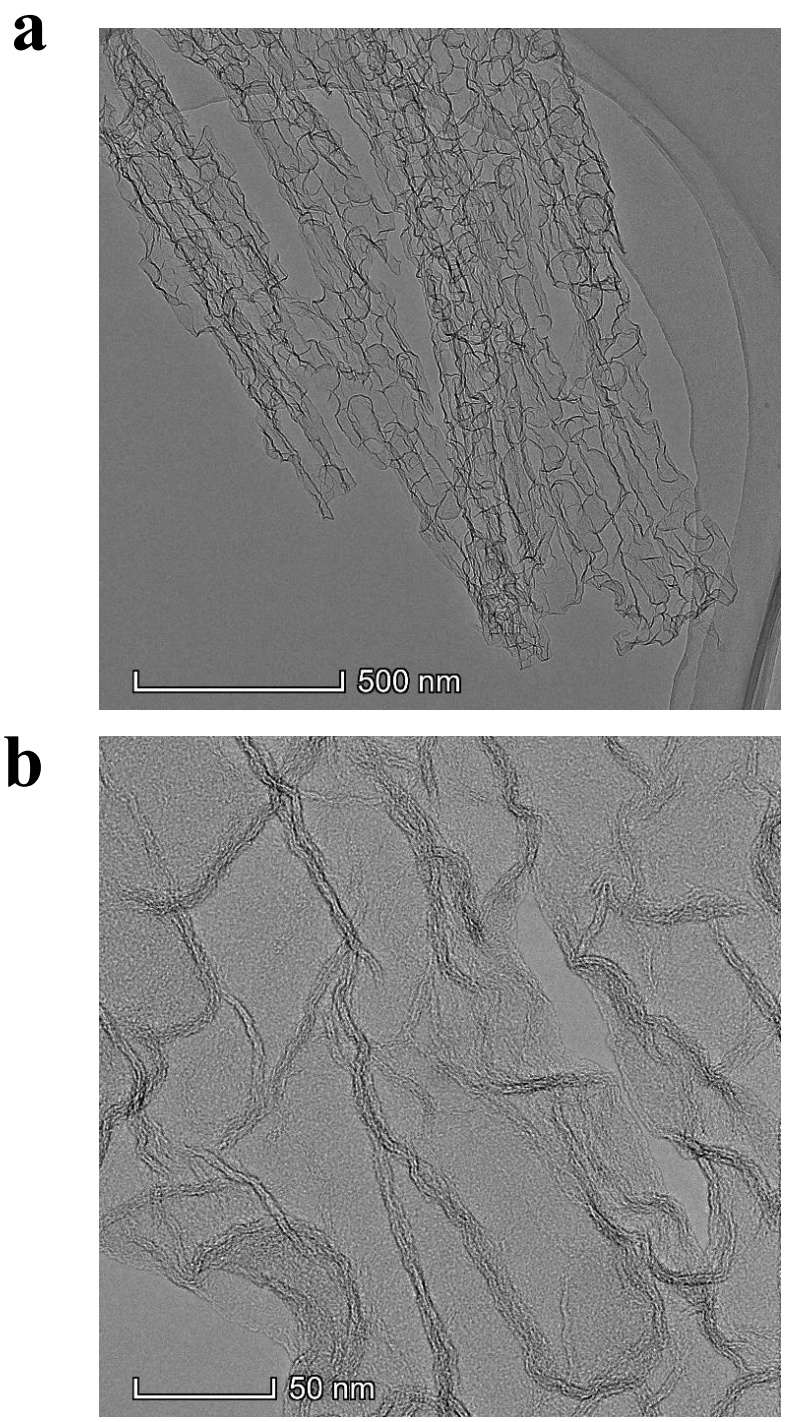


Fig. S7 (a, b) TEM images of C-MP-FeCo-11.

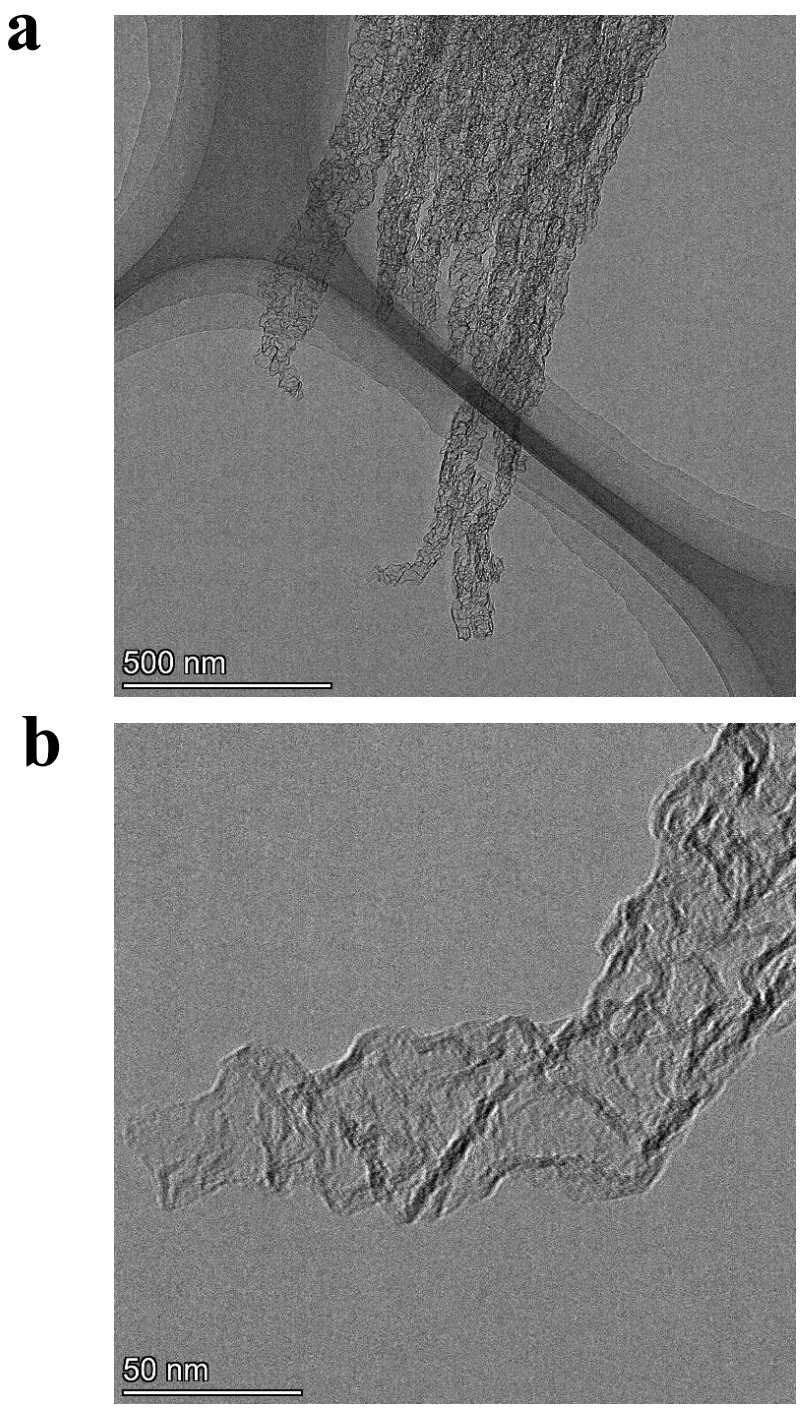


Fig. S8 (a, b) TEM images of C-MP-FeCo-82.

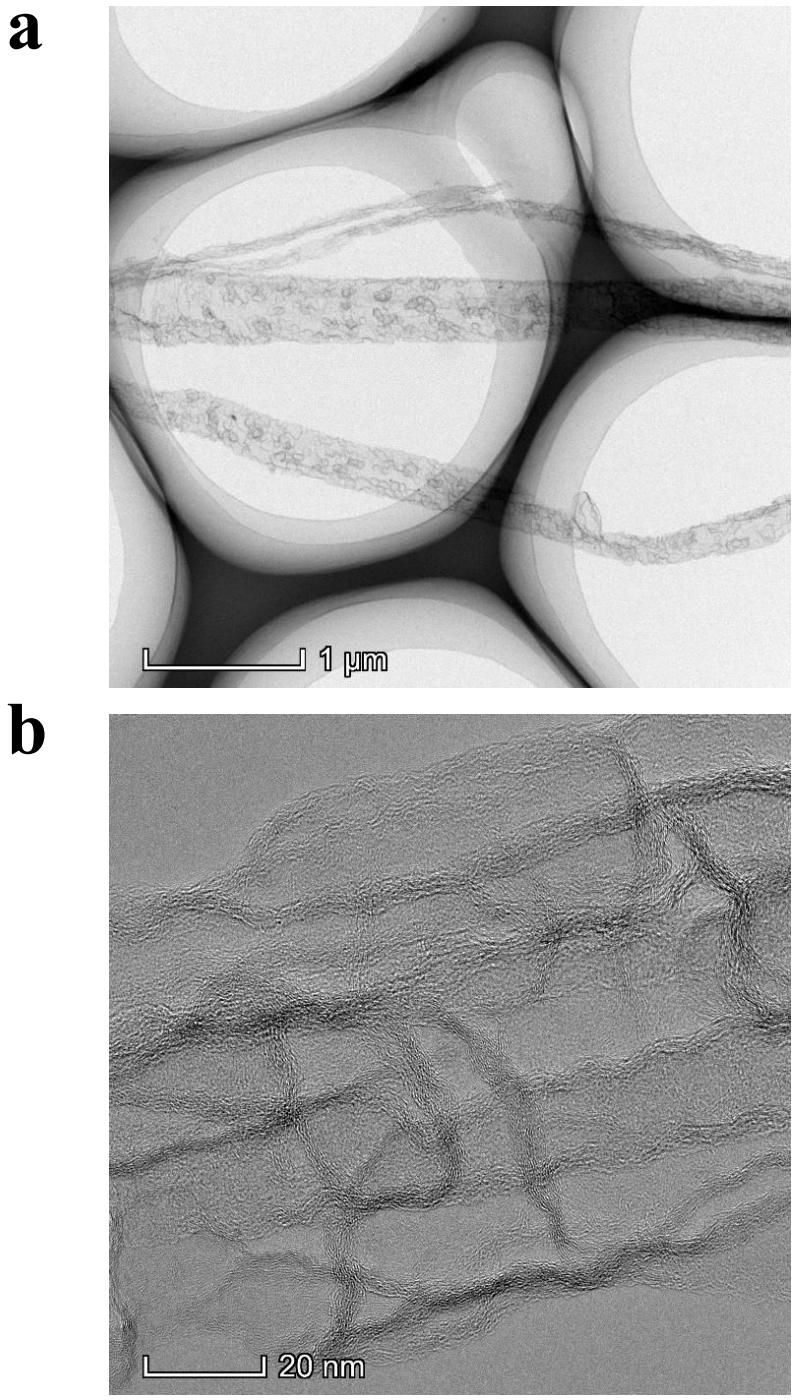


Fig. S9 (a, b) TEM images of C-MP-Fe-2.

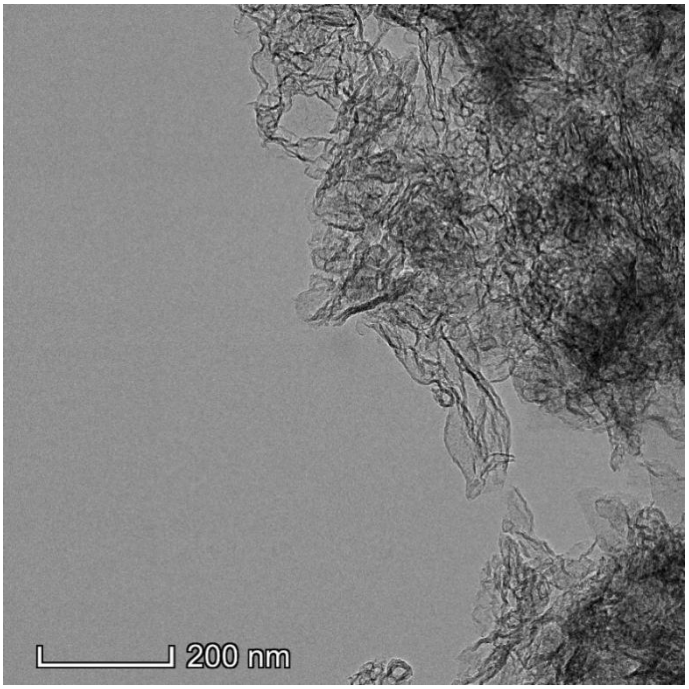
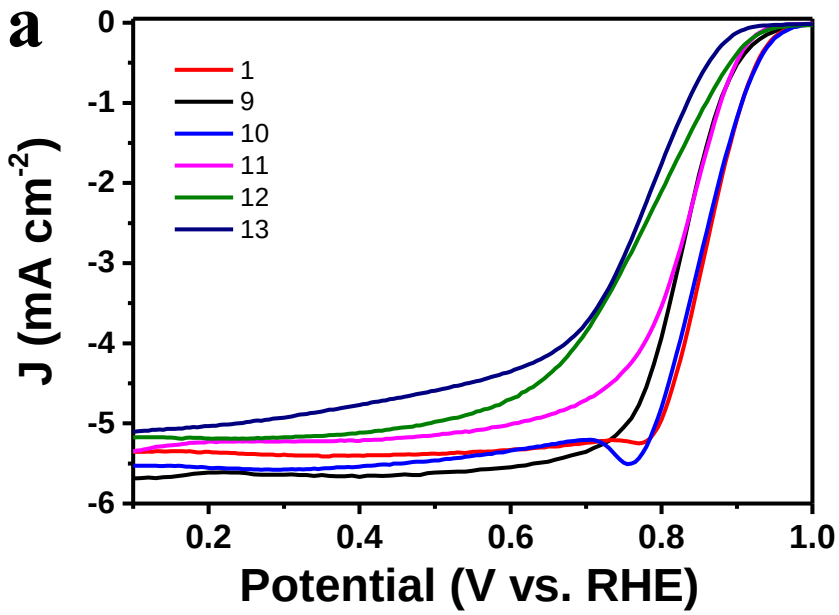


Fig. S10 TEM images of Fe- and Cu- codoped C-MP-FeCu catalysts.



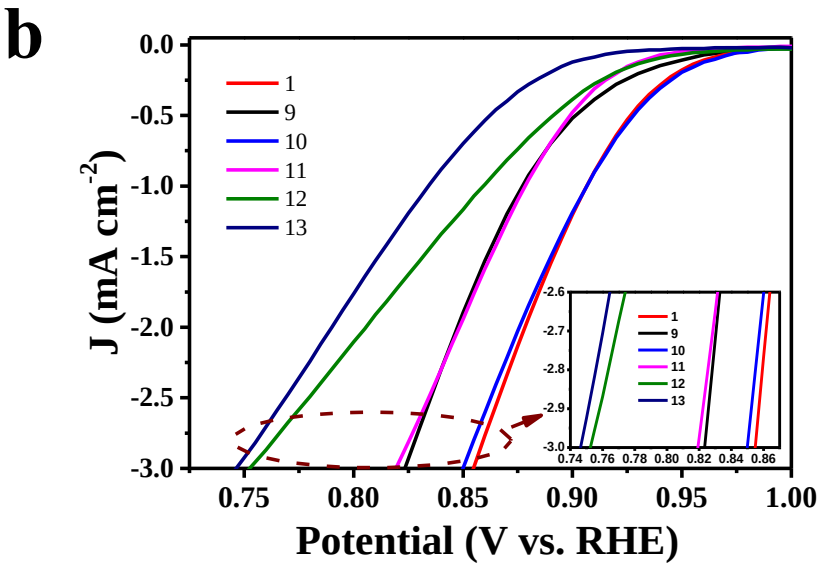


Fig. S11 (a, b) LSV curves of C-MP-Fe prepared at various pyrolysis temperatures: 1, 900 ºC; 10, 950 ºC; 11, 850 ºC; 12, 800 ºC; 13, 700 ºC; and reference catalysts 9, Pt/C.

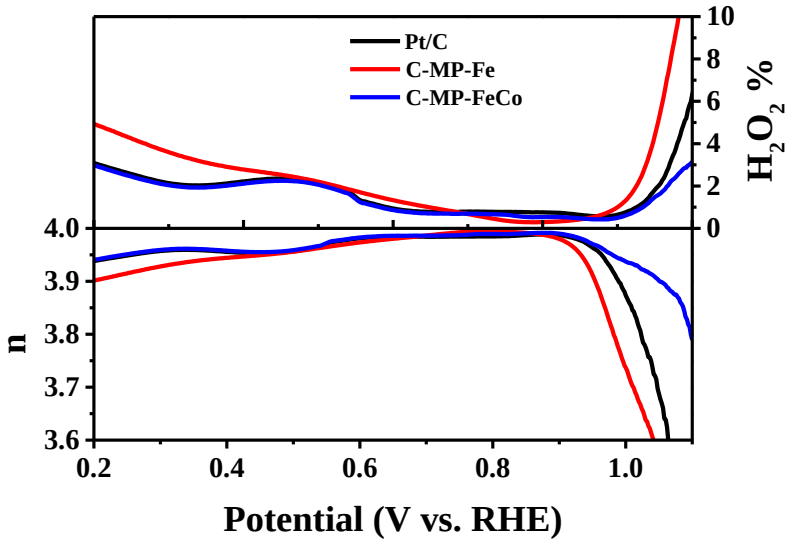


Fig. S12 H_2O_2 yield curves and the transferred electrons n for different catalysts measured at a scan rate of 5 mV s^{-1}.

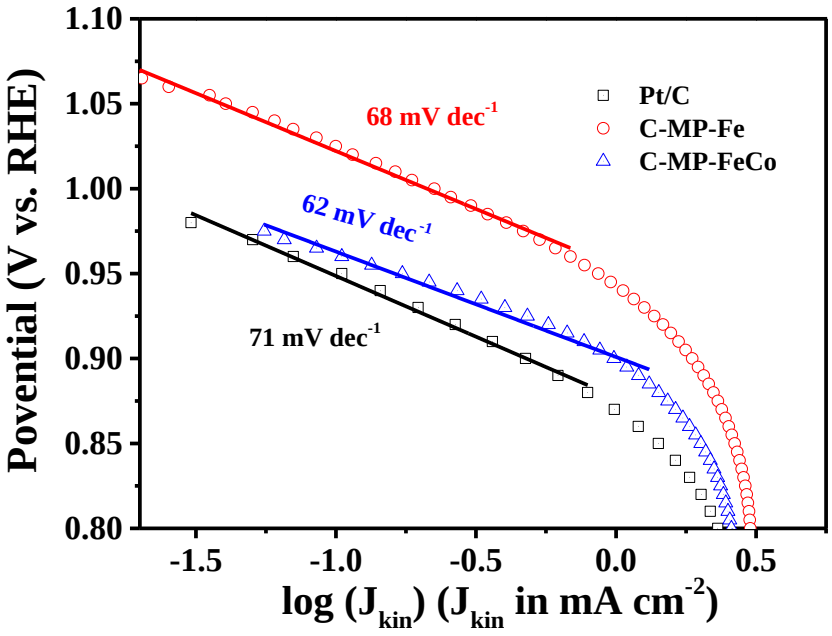


Fig. S13 ORR Tafel plots of different catalysts measured at a scan rate of 5 mV s^{-1}.

Tafel plots are obtained after the measured currents are corrected and calculated from the equation (1)[1] .

$$J_{kin} = J \cdot J_{diff} / (J_{diff} - J) \qquad (1)$$

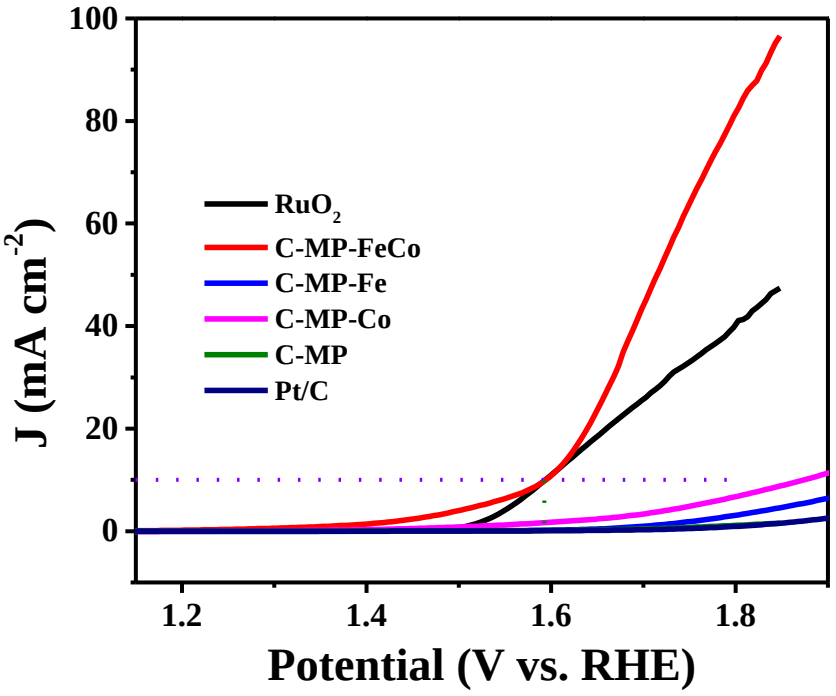


Fig. S14 OER polarization curves of different catalysts measured at a scan rate of 5 mV s^{-1}.

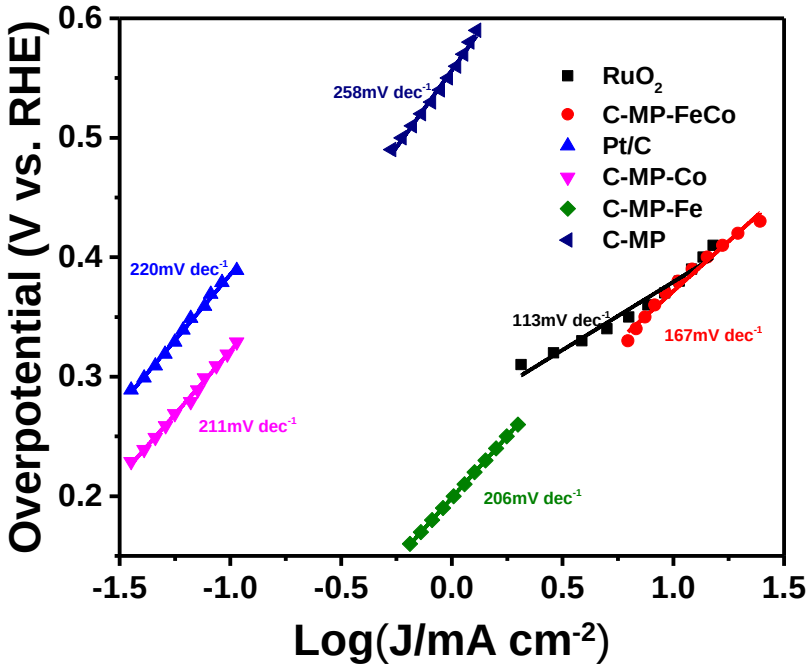


Fig. S15 The OER Tafel plots of different catalysts.

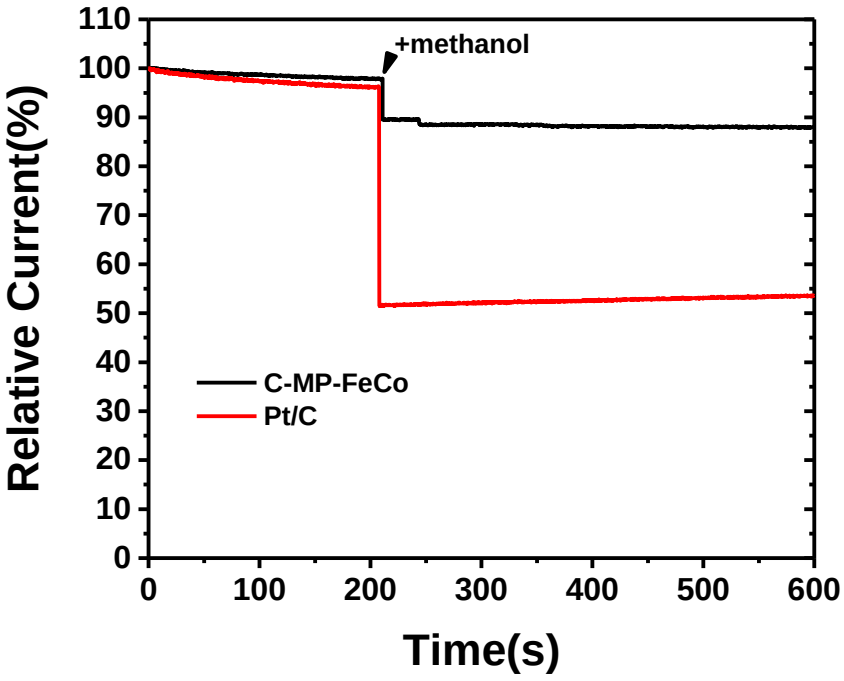
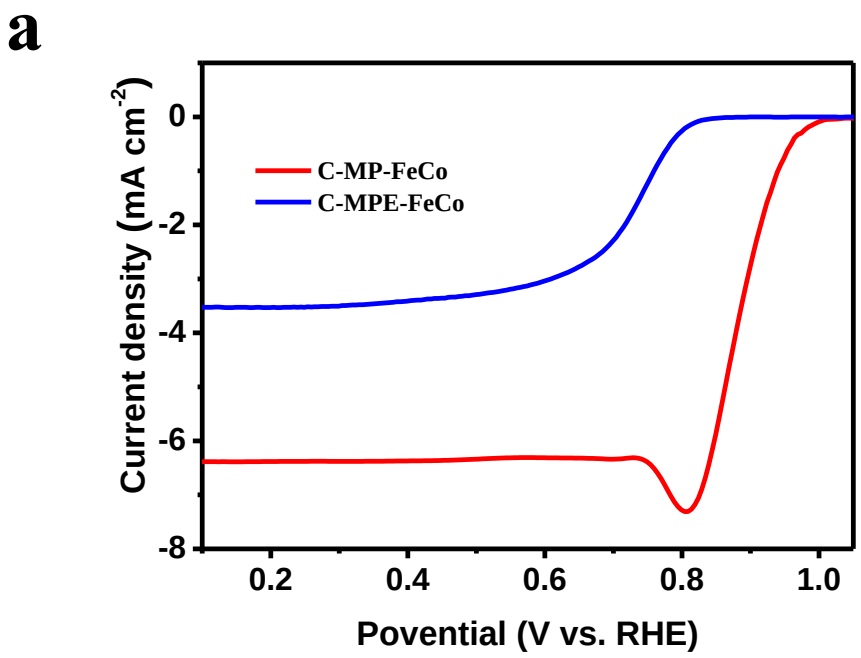


Fig. S16 Chronoamperometric responses of C-MP-FeCo and Pt/C after the addition of methanol.



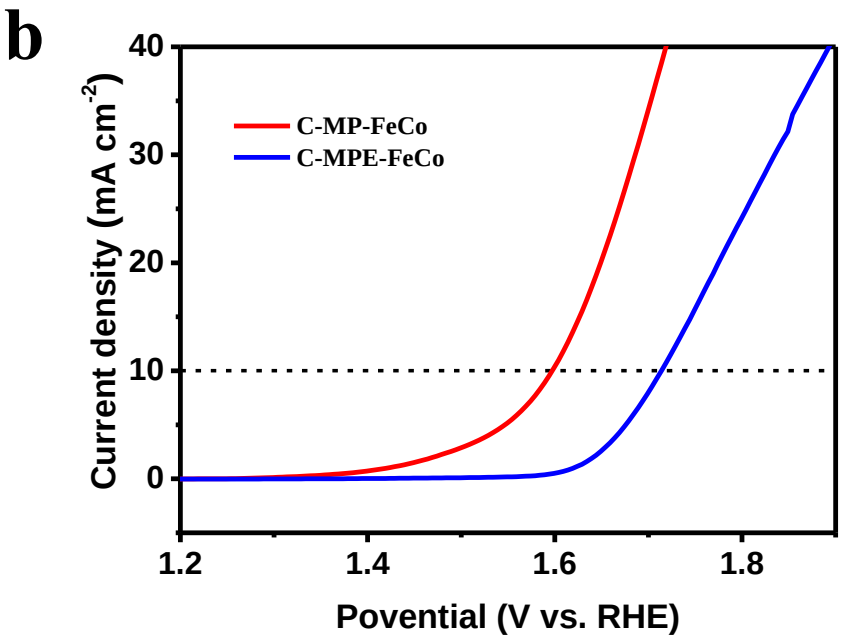
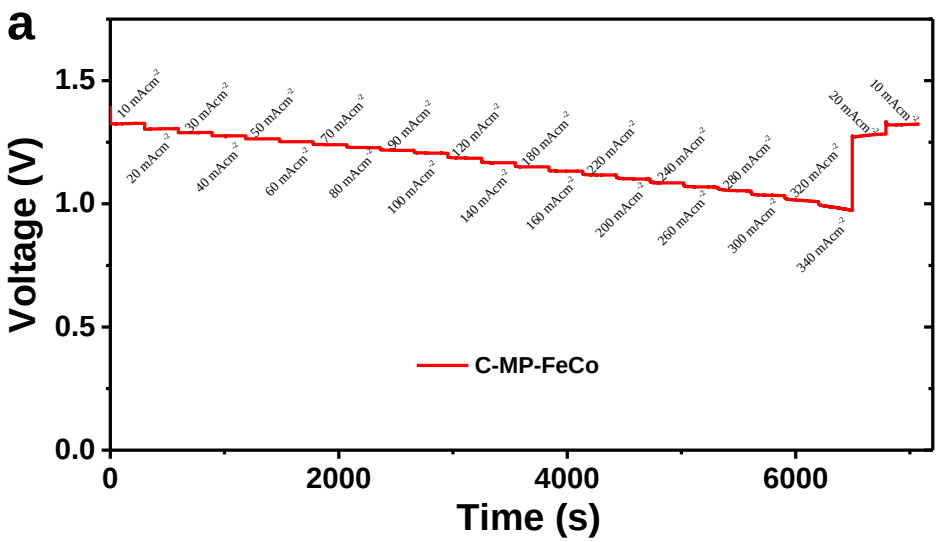


Fig. S17 (a) ORR and (b) OER polarization curves of C-MP-FeCo and C-MPE-FeCo measured at a scan rate of 5 mV s^{-1}.



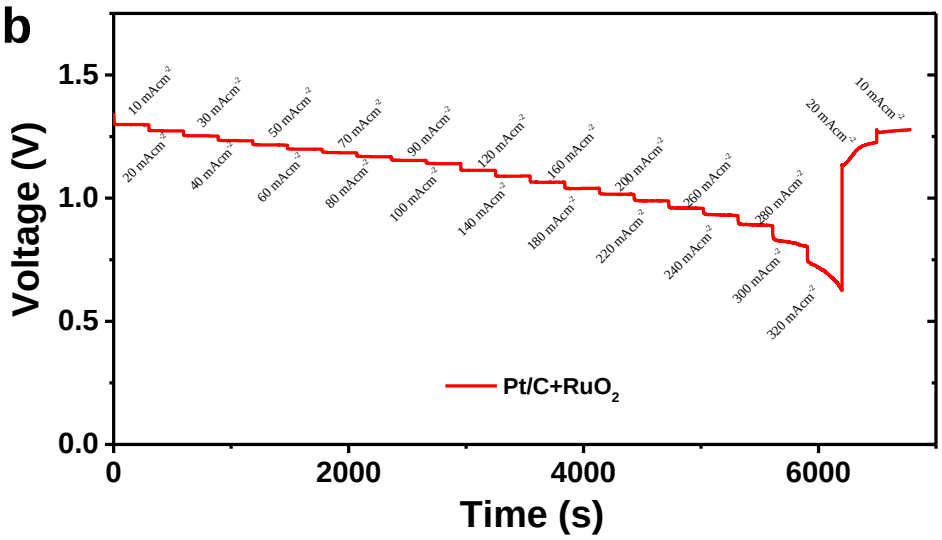


Fig. S18. Galvanostatic discharge curves of the Zn–air battery at different current densities: (a) C-MP-FeCo electrode (mass loading 5.5 mg cm^{-2}); (b) Pt/C+RuO_2 electrode (mass loading 2.0 mg cm^{-2}).

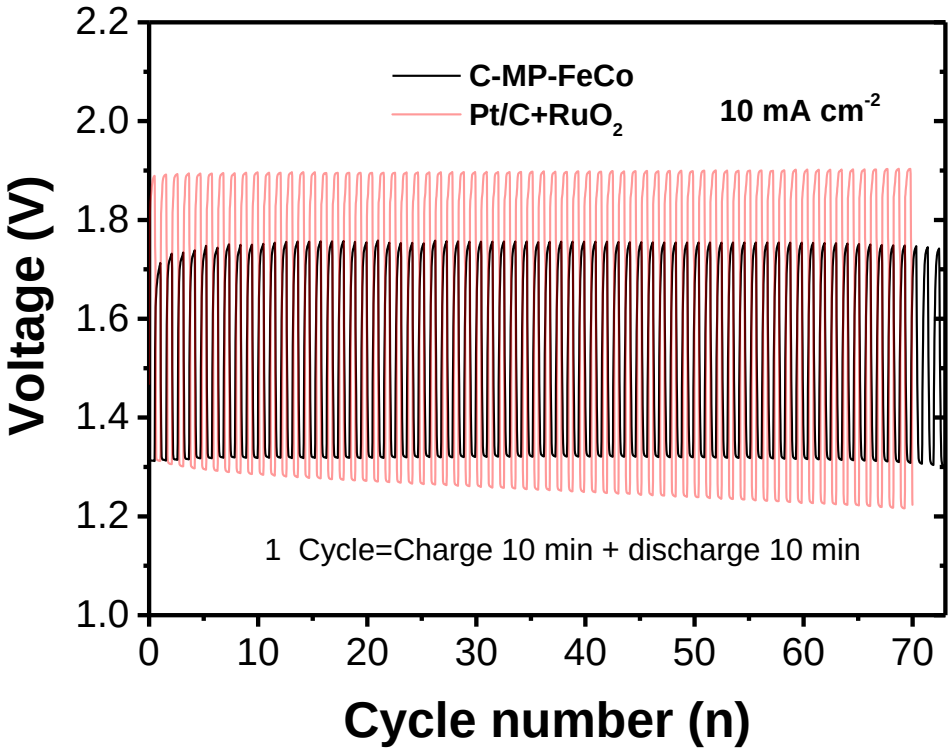


Fig. S19. Discharge and charge cycling of rechargeable Zn–air batteries based on Pt/C+RuO_2 and C-MP-FeCo electrode at the current density of 5 mA cm^{-2}.

Tables in Supporting Information

Table S1 The different preparation conditions of the sample 1 to sample 16.

sample	T (°C)	Melamine (g)	PTFE (g)	PE (g)	0.07 M $FeCl_3$(mL)	0.07 M $Co(CH_3COO)_2·4H_2O$ (mL)
1(C-MP-Fe)	900	5.0	7.5	0	2.0	0
2	900	5.0	7.5	0	1.5	0
3	900	5.0	7.5	0	8.0	0
4	900	5.0	7.5	0	4.0	0
5	900	5.0	7.5	0	3.0	0
6	900	5.0	7.5	0	1.0	0
7	900	5.0	7.5	0	0.5	0
8 (C-MP)	900	5.0	7.5	0	0	0
9 (Pt/C)	/	/	/	0	/	/
10	950	5.0	7.5	0	2.0	0
11	850	5.0	7.5	0	2.0	0
12	800	5.0	7.5	0	2.0	0
13	700	5.0	7.5	0	2.0	0
14(C-MP-FeCo)	900	5.0	7.5	0	1.0	1.0
15(C-MP-Co)	900	5.0	7.5	0	0	2.0
16 (C-MPE-FeCo)	900	5.0	0	7.5	1.0	1.0

Table S2 The different preparation conditions of the different ratio of Fe/Co in C-MP-FeCo sample

sample	T (°C)	Melamine (g)	PTFE (g)	0.07 M $FeCl_3$(mL)	0.07 M $Co(CH_3COO)_2·4H_2O$ (mL)
C-MP-Co-2	900	5.0	7.5	0	2.0
C-MP-FeCo-28	900	5.0	7.5	2.0	8.0
C-MP-FeCo-11	900	5.0	7.5	1.0	1.0
C-MP-FeCo-82	900	5.0	7.5	8.0	2.0
C-MP-Fe-2	900	5.0	7.5	2.0	0

Table S3. 2D-QSPR models for E_{onset}, $E_{1/2}$ and C_{Fe}

Model	*N*	*R*	R^2	*Se*	*F*
E_{onset}=-0.904(±0.012)+0.144 (±0.030)×C_{Fe}	8	0.8930	0.7974	0.0165	23.6219
$E_{1/2}$=-0.755(±0.016)+0.163(±0.038)×C_{Fe}	8	0.8687	0.7546	0.0211	18.4524

Table S4. XPS surface element content (at%) and the ORR Kinetic Data for C-MP-Fe catalysts heat treatment at different temperatures.

		Surface elemet content (at%)					**potential (V)**	
T (°C)	**sample**	**C**	**O**	**F**	**N**	**Fe**	**onset**	**half-wave**
900	1	90.01	1.24	0.63	7.67	0.45	0.98	0.855
950	10	90.43	1.27	0.45	7.48	0.38	0.99	0.85
850	11	67.79	2.52	0.57	28.3	0.82	0.965	0.82
800	12	77.77	2.58	0.63	18.28	0.75	0.97	0.755
700	13	67.49	1.36	0.68	29.97	0.49	0.93	0.745

Table S5. OER/OER performance comparisons of graphene(-like) nanoribbon, Nanosheets, CNT or graphitic carbon polyhedrons

Sample	Morphology	Electrolyte	Potential(V)			Ref
			$E_{1/2}$[a]	E_{10}[b]	E_{10}-$E_{1/2}$	
N-GRW	3D graphene nanoribbon networks	1.0 M KOH	0.84	1.59	0.75	2
DN-UGNR	Graphene Nanoribbons	0.1 M KOH	0.808	1.742	0.934	3
Co_3O_4/N-csCNT-GNR	Carbon Nanotube/Graphene Nanoribbon	0.1 M KOH	0.81	1.89	0.78	4
DN-CP@G	Graphene Nanosheets	0.1 M KOH	0.801	1.788	0.987	5
Co3Fe7/NGNRs	graphene nanoribbon	1.0 M KOH	0.64	1.58	0.94	6
N-HC@G-900	holey carbon layer on a graphene sheet	1.0 M KOH	0.85	1.58	0.73	7
MnO/Co/PGC	Porous graphitic carbon polyhedrons	0.1 M KOH (ORR) 1.0 M KOH (OER)	0.78	1.537	0.757	8
NCN-1000-5	ultrathin carbon nanosheets	0.1 MKOH	0.83	1.64	0.81	9
Co-CoO/N-rGO	3D Nanoporous	0.1 MKOH	0.78	1.62	0.84	10
NOGB-800	Graphene Nanorings	0.1 MKOH (ORR) 1.0 MKOH (OER)	0.84	1.65	0.81	11
SHG	2D graphitic sheet	0.1 MKOH	0.87	1.60	0.73	12
P-3G	N-doped graphene	0.1 MKOH	0.82	1.54	0.72	13
FeCo-DHO/NCNT s	Fe,Co-doped NCNTs	1.0 M KOH	0.86	1.55	0.69	14

FeCo/Co_2P@NPCF	FeCo/Co_2P Hybrid Nanoparticles	0.1 MKOH	0.79	1.56	0.77	15
C-MP-FeCo	graphene-lik nanoribbon	0.1 MKOH	0.895	1.595	0.70	This work

a: Half-wave potential of ORR.

b: Potential at 10 mA cm^{-2} of OER

References

1. M. Jahan, Z. L. Liu and K. P. Loh, *Adv. Funct. Mater.*, 2013, **23**, 5363-5372.
2. H. B. Yang, J. W. Miao, S. F. Hung, J. Z. Chen, H. B. Tao, X. Z. Wang, L. P. Zhang, R. Chen, J. J. Gao, H. M. Chen, L. M. Dai and B. Liu, Sci. Adv., 2016, 2, 11.
3. J. Zhang, Y. Sun, J. Zhu, Z. Gao, S. Li, S. Mu and Y. Huang, Adv. Sci., 2018, 5, 1801375.
4. X. Y. Lu, H. M. Chan, C. L. Sun, C. M. Tseng and C. Zhao, J. Mater. Chem. A, 2015, 3, 13371-13376.
5. C. Hang, J. Zhang, J. Zhu, W. Li, Z. Kou and Y. Huang, Adv. Energy Mater., 2018, 8, 9.
6. J. Joy, S. Rajappa, V. K. Pillai and S. Alwarappan, Nanotechnology, 2018, 29, 8.
7. J. Sun, S. E. Lowe, L. Zhang, Y. Wang, K. Pang, Y. Wang, Y. Zhong, P. Liu, K. Zhao, Z. Tang and H. Zhao, Angew. Chem. Int. Edit., 2018, 57, 16511-16515.
8. X. F. Lu, Y. Chen, S. Wang, S. Gao and X. W. D. Lou, Adv. Mater., 2019, 31, 8.
9. H. Jiang, J. X. Gu, X. S. Zheng, M. Liu, X. Q. Qiu, L. B. Wang, W. Z. Li, Z. F. Chen, X. B. Ji and J. Li, Energ. environ. Sci., 2019, 12, 322-333.
10. X. Liu, W. Liu, M. Ko, M. Park, M. G. Kim, P. Oh, S. Chae, S. Park, A. Casimir, G. Wu and J. Cho, Adv. Funct. Mater., 2015, 25, 5799-5808.
11. Q. Hu, G. M. Li, G. D. Li, X. F. Liu, B. Zhu, X. Y. Chai, Q. L. Zhang, J. Liu and C. He, Adv. Energy Mater., 2019, 9, 9.
12. C. G. Hu and L. M. Dai, Adv. Mater., 2017, 29, 9.
13. Y. F. Bu, H. Jang, O. Gwon, S. H. Kim, S. H. Joo, G. Nam, S. Kim, Y. Qin, Q. Zhong, S. K. Kwak, J. Cho and G. Kim, J. Mater. Chem. A, 2019, 7, 2048-2054.
14. M. J. Wu, Q. L. Wei, G. X. Zhang, J. L. Qiao, M. X. Wu, J. H. Zhang, Q. J. Gong and S. H. Sun, Adv. Energy Mater., 2018, 8, 10.
15. Q. Shi, Q. Liu, Y. Ma, Z. Fang, Z. Liang, G. Shao, B. Tang, W. Yang, L. Qin and X. Fang, Adv. Energy Mater., 2020, 10, 1903854.