# **Electronic Supplementary Information (ESI)**

# Enhanced Oxygen Reduction from the Insertion of Cobalt into Nitrogen-

## doped Porous Carbons

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#### S.1 The conversion of potentials against a reversible hydrogen electrode (RHE)

We used Ag/AgCl as a reference electrode in all of electrochemical analyses. It was required to be converted against reversible hydrogen electrode (RHE) to compare our results with previous studies. The conversion method was reported by several research groups <sup>1, 2</sup>. The measured potentials with respect to Ag/AgCl can be converted to the following equation (**S-1**):

$$E_{RHE} = E_{Ag/AgCl} + 0.059 \, pH + E^o_{Ag/AgCl}$$
 (S-1)

Where pH is 13.6 in 1.0 M NaOH electrolyte, and  $E^o_{Ag/AgCl}$  is 0.1976 V at 25 °C.

### S.2 The rotating ring-disk electrode measurement

For the RRDE measurements, catalyst inks and electrodes were prepared by the same method as RDE's. The disk electrode was scanned cathodically at a rate of 10 mV s<sup>-1</sup> and the ring potential was constant at 1.5 V (vs. RHE). The %  $HO_2^-$  and the electron transfer number (n) were determined by the followed equations <sup>3</sup> (S-2, 3):

% 
$$HO_2^- = 200 \times \frac{I_r/N}{I_d + I_r/N}$$
 (S-2)

$$\mathbf{n} = \mathbf{4} \times \frac{I_d}{I_d + I_r / N}$$
 (S-3)

where  $I_d$  is disk current,  $I_r$  is ring current and N is current collection efficiency of the Pt ring. N was determined to be 0.424 from the manufacture's data.



Figure S1. SEM images of PANK2 in a) x30,000 and b) x200,000.



Figure S2. SEM images of a) PANK1 (x15,000) and b) PANK3 (x15,000).



Figure S3. a) SEM image of PANKCo1 (x2,000), b) BSE image of PANKCo1 (x2,000), c) SEM image of PANKCo2 (x2,000), d) BSE image of PANKCo2 (x2,000), e) SEM image of PANKCo3 (x2,000), f) BSE image of PANKCo3 (x2,000).



Figure S4. Nitrogen sorption isotherms of PANKCo series.



Figure S5. XPS survey scans of a) PANK1 b) PANK2 and c) PANK3.



Figure S6. XPS survey scans of a) PANKCo1 b) PANKCo2 and c) PANKCo3, d) The solution to obtain precise composition data, high resolution scans of e) O 1s and f) Co 2p for PANKCo series.



Figure S7. XPS N 1s high resolution scans and deconvolutions of a) PANKCo1 and b) PANKCo3.



Figure S8. CV graphs of a) Pt/C (which contains 20wt% Pt of the overall) and PANKCo2 b) PANK1 and PANKCo1 c) PANK3 and PANKCo3. (Solid line: O<sub>2</sub> saturation, dotted line: Ar saturation)



Figure S9. Polarization curves of a) PANK1 and PANKCo1 b) PANK3 and PANKCo3. The dotsline and number indicate -0.3V (0.7V vs. RHE) and current density at that potential.



Figure S10. CV graphs of PANK2, PANKCG2 and PANKCo2.



Figure S11 a) Electron transfer number (n) and b) the amount of produced peroxide  $(HO_2)$  calculated from RRDE data.

Sample	Carbon (atom %)	Nitrogen (atom %)	Oxygen (atom %)	Cobalt (atom %)
PANK2	95.02	2.77	2.20	0
PANKCo2	94.69	1.27	2.21	1.81

Table S1. EDX results in the SEM images (Figure 3b & Figure S3) of PANK2 and PANKCo2.

Table S2. Summary of BET surface areas of PANKCo series.

Sample	PANKCo1	ΡΑΝΚCo2	PANKCo3
BET surface area (m² g⁻¹)	2070.2	2743.8	2960.7

Table S3. EDX	K results in	the TEM	[ images	(Figure	2c, e	e).
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Sample	Carbon (atom %)	Nitrogen (atom %)	Oxygen (atom %)	Cobalt (atom %)
PANKCo1	86.78	5.83	6.02	1.37
PANKCo2	85.65	3.55	8.12	2.69
PANKCo3	86.58	3.84	8.07	1.51

Sample	C 1s (atom %)	O 1s (atom %)	N 1s (atom %)	N/C
PANK1	86.39	7.1	6.51	0.075
PANK2	89.55	7.56	2.89	0.032
PANK3	90.65	5.92	3.44	0.038

Table S4. XPS survey results of PANK series.

Sample	Carbon (atom %)	Nitrogen (atom %)	Oxygen (atom %)	N/C
PANK1	91.23	2.81	5.97	0.03
PANK2	93.43	0.92	5.66	0.01
PANK3	96.19	0.56	3.26	0.006

Table S5. EDX results of PANK series using SEM.

Table S6. Average composition data based on atom % and their standard deviations (the values in parentheses) based on the XPS survey scans.

Sample	Carbon	Nitrogen	Oxygen	Cobalt	N/C
PANKCo1	91.94% (0.63)	2.91% (0.40)	4.78% (0.34)	0.37% (0.16)	0.032
PANKCo2	93.44% (0.39)	1.77% (0.45)	4.33% (0.06)	0.47% (0.04)	0.019
PANKCo3	92.38% (0.52)	1.82% (0.27)	4.99% (0.21)	0.82% (0.13)	0.020

Table S7. Current densities produced by ORR for PANKCo series and Pt/C based on the CV results

E <sub>WE</sub>	PANKCo1	PANKCo2	PANKCo3	Pt/C
Peak potential	1.07 mA/cm <sup>2</sup>	0.89 mA/cm <sup>2</sup>	1.03 mA/cm <sup>2</sup>	0.59 mA/cm <sup>2</sup>
-0.3 V	0.46 mA/cm <sup>2</sup>	0.43 mA/cm <sup>2</sup>	0.91 mA/cm <sup>2</sup>	0.38 mA/cm <sup>2</sup>
-0.45 V	0.47 mA/cm <sup>2</sup>	0.41 mA/cm <sup>2</sup>	0.93 mA/cm <sup>2</sup>	0.39 mA/cm <sup>2</sup>

## References

- 1. L. Wang, C. Y. Lee and P. Schmuki, *J Mater Chem A*, 2013, **1**, 212-215.
- 2. S. Mao, Z. H. Wen, T. Z. Huang, Y. Hou and J. H. Chen, *Energ Environ Sci*, 2014, **7**, 609-616.
- 3. U. A. Paulus, T. J. Schmidt, H. A. Gasteiger and R. J. Behm, *J Electroanal Chem*, 2001, **495**, 134-145.