Electronic Supplementary Information

Advanced oxygen reduction reaction catalyst based on nitrogen and

sulfur co-doped graphene in alkaline medium

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Supplementary data



Figure S1. AFM image of N-S-G 1000.



Figure S2. XRD patterns of GO and N-S-G-1000.



Figure S3. XPS broad scan spectrum and the high-resolution N1s spectrum of N-G 1000.



Figure S4. High-resolution C1s XPS spectra of GO and N-S-G 1000.



Figure S5. CV curves of (a) bare GC electrode, (c) N-S-G 850 and (e) N-S-G 1000 electrode in 5 mM Fe(CN)₆^{3-/4-/1} M KCl at various scan rates from 20 to 300 mV s⁻¹; plots of $i_p vs. v^{1/2}$ for (b) bare GC electrode, (d) N-S-G 850 and (f) N-S-G 1000.

The electrochemically effective surface area of the electrode was estimated by cyclic voltammetry using 5 mM $\text{Fe}(\text{CN})_6^{3-/4-}$ in 1 M KCl. The electroactive surface area can be estimated according to the Randles-Sevcik equation:

$$i_{\rm p} = 2.99 \times 10^5 nACD^{1/2} v^{1/2} \tag{1}$$

Where i_p is the peak current, D and C are the diffusion coefficient and bulk

concentration of the redox probe (5 mM K₃[Fe(CN)₆]), respectively. *n* is the number of electrons transferred (*n*=1), *v* is the scan rate. Figure S3b, d and f demonstrate the linear relationship between the peak current (i_p) and the square root of scan rate ($v^{1/2}$), implying that the process is diffusion controlled. The electrochemically effective surface area of the bare GC electrode, N-S-G 850 and N-S-G 1000 modified electrodes calculated is 0.051, 0.096 and 0.301 cm², respectively.

| Materials | $\Delta E_{\text{onest}}^{a,c}$ (mV) | $\frac{\Delta E_{1/2}}{(\mathrm{mV})}^{\mathrm{a,c}}$ | $\Delta J_{\rm L}^{\rm b,c}$ (mA cm ⁻²) | Electrolyte solution | Reference electrode | Rreference |
|-----------------------|--------------------------------------|---|--|----------------------|------------------------------------|--------------|
| N-S-G 1000 | -30 | -70 | 1.88 | 0.1 M NaOH | Hg/Hg ₂ Cl ₂ | In this work |
| N-S-G | -30 | -200 | 0.3 | 0.1 M KOH | Ag/AgCl | 1 |
| Fe/ANT/C | -100 | -110 | 0.1 | 0.1 M KOH | Ag/AgCl | 2 |
| N-S-HC ₈₅₀ | -70 | -70 | 2.1 | 0.1 M KOH | Ag/AgCl | 3 |
| PAC/5S | -50 | -100 | -0.6 | 0.1 M KOH | Ag/AgCl | 4 |
| N-S-CF-1000 | -10 | -50 | 1.6 | 0.1 M KOH | Ag/AgCl | 5 |
| NSG700 | -150 | -180 | -0.5 | 0.1 M KOH | Hg/Hg ₂ Cl ₂ | 6 |
| N/S-GFs | -200 | -200 | -0.3 | 0.1 M KOH | Ag/AgCl | 7 |

 Table S1 Comparison electrocatalytic performance of recently reported nitrogen and sulfur co-doping materials as catalysts for ORR in alkaline media.

a represents the difference of onset potentials or half-wave potentials between various catalysts and Pt/C.

b represents the difference of diffusion-limited current densities of various catalysts between various catalysts and Pt/C at rotation speed of 1600 rpm.

c The onset (E_{onset}) and half-wave ($E_{1/2}$) potential are reported from the corresponding literatures and the corresponding figures in the present studies.

References

- J. Liang, Y. Jiao, M. Jaroniec and S. Z. Qiao, Angew. Chem. Int. Ed., 2012, 51, 11496-11500.
- Y. Q. Chang, F. Hong, C. X. He, Q. L. Zhang and J. H. Liu, *Adv. Mater.*, 2013, 25, 4794.
- Z. T. Cui, S. Y. Wang, Y. H. Zhang, M. H. Cao, J. Power Sources, 2014, 259, 138-144.
- C. H. You, S. J. Liao , H. L. Li, S. Y. Hou, H. L. Peng, X. Y. Zeng, F. F. Liu, R. P. Zheng, Z. Y. Fu and Y. W. Li, *Carbon*, 2014, **69**, 294-301.
- Z. Liu, H.G Nie, Z. Yang, J. Zhang, Z. P. Jin, Y. Q. Lu, Z. B. Xiao and S. M. Huang, *Nanoscale*, 2013, 5, 3283-3288.
- X. Wang, J. Wang, D. L. Wang, S. Dou, Z. L. Ma, J. H. Wu, L. Tao, A. L. Shen,
 C. B. Ouyang, Q. H. Liu and S. Y. Wang, *Chem. Commun.*, 2014, **50**, 4839-4842.

 Y. Z. Su, Y. Zhang, X. D. Zhuang, S. Li, D. Q. Wu, F. Zhang and X. L. Feng, Carbon, 2013, 62, 296-301.