Supporting Information

B, N- and P, N-doped Graphene as Highly Active Catalysts for Oxygen Reduction Reactions in Acidic Media

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Figure S6. LSV results of bare graphene, BGr, PGr, and NGr in oxygen saturated 0.1M HClO₄.
1. Equations

1.1 Calculation of kinetic current

\[
\frac{1}{I} = \frac{1}{I_k} + \frac{1}{I_d}
\]

\( I \): current from disk electrode, \( I_k \): kinetic current, and \( I_d \): diffusion current.

1.2 Calculation of \( \text{H}_2\text{O}_2 \) yield and number of electrons transferred

\[
\text{H}_2\text{O}_2 \text{ (\%)} = 200 \times \frac{I_R/n}{I_R/n + I_D}
\]

\[
N = 4 \times \frac{I_D}{I_R/n + I_D}
\]

\( I_R \): current from ring disk electrode, \( I_D \): current from disk electrode, \( n \): collection efficient, and \( N \): number of electrons transferred.
2. Tables

**Table S1.** Compositions of the prepared graphene-based catalysts obtained from EA and ICP analysis.

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<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>NGr</td>
<td>86.9</td>
<td>6.6</td>
<td>0.3</td>
<td>5.9</td>
<td>-</td>
<td>0.3</td>
<td>6.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>BNGr</td>
<td>82.6</td>
<td>7.8</td>
<td>0.8</td>
<td>6.9</td>
<td>1.5</td>
<td>0.3</td>
<td>8.4</td>
<td>1.9</td>
<td>-</td>
<td>-</td>
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<td>PNGr</td>
<td>85.8</td>
<td>7.0</td>
<td>1.4</td>
<td>5.1</td>
<td>-</td>
<td>0.4</td>
<td>5.9</td>
<td>-</td>
<td>0.3</td>
<td>0.5</td>
</tr>
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[^a] Compositions obtained from EA analysis (at. %)  
[^b] Compositions obtained from ICP analysis (at. %)  
[^c] Doping concentrations (%)

**Table S2.** Proportion of various N-doping types among pyridinic-N (N1), graphitic-N (N2), and pyridinic-oxide (N3) in the prepared catalysts obtained from the XPS results. The values in parenthesis for BNGr indicate the proportions of all N-doping type including BN (N0).

<table>
<thead>
<tr>
<th></th>
<th>N0</th>
<th>N1</th>
<th>N2</th>
<th>N3</th>
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<tbody>
<tr>
<td>NGr</td>
<td>-</td>
<td>53.8</td>
<td>29.8</td>
<td>16.4</td>
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<tr>
<td>BNGr</td>
<td>-</td>
<td>(40.6)</td>
<td>77.9 (46.3)</td>
<td>18.2 (10.8)</td>
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<tr>
<td>PNGr</td>
<td>-</td>
<td>64.4</td>
<td>28.6</td>
<td>7.0</td>
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**Table S3.** Proportion of B-doping and P-doping types in the BNGr and PNGr, respectively.

<table>
<thead>
<tr>
<th>B (%)[^a]</th>
<th>P (%)[^b]</th>
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<tbody>
<tr>
<td>B1 25.0</td>
<td>P1 16.2</td>
</tr>
<tr>
<td>B2 48.9</td>
<td>P2 77.6</td>
</tr>
<tr>
<td>B3 26.1</td>
<td>P3 6.2</td>
</tr>
</tbody>
</table>

3. Figures

Fig. S1 Newly generated graphite materials *via* carbonization of DCDA on metal seeds.[1]

**Fig. S2** EDS mapping images of NGr, BNGr, and PNGr.
**Fig. S3** XPS results for $C_{1s}$, $O_{1s}$, $Co_{2p}$, and $Fe_{2p}$ in the prepared catalysts.
Fig. S4 Mass activities calculated at 0.75 V for the graphene- and graphite-derived catalysts. The mass activities for the graphite-derived catalysts were calculated from our previous works (ref. 21). Moreover, for more valid comparison, the mass activity of the graphene-derived catalysts were obtained at the same conditions with ref. 21 and was indicated by check-pattered bar.
**Fig. S5** LSV results of the NGr (a) before and (b) after acid-leaching steps in oxygen saturated 0.1M HClO₄.

As shown in Table S1, NGr has ~0.3 at.% metal residues, which is corresponded to ~1.3 wt.% However, most of the metal residue was eliminated (< 0.2 wt. %) after the additional secondary acid leaching step.
**Fig. S6** LSV results of bare graphene, BGr, PGr, and NGr in oxygen saturated 0.1M HClO₄.