Supporting Information

Phosphate Ions and Oxygen Defects Modulated Nickel Cobaltite Nanowires: A Bifunctional Cathode for Flexible Hybrid Supercapacitors and Microbial Fuel Cells

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Calculations:

The specific or areal capacity can be calculated via the equation (1) and (2) as follows:

CV curves:

\[ C_S = \frac{Q_m}{m} = \frac{S}{2vm} \]  

(1)

GCD curves:

\[ C_S = \frac{Q_m}{m} = \frac{I \Delta t}{m} \]  

(2)

Where \( C_s \) (mAh g\(^{-1}\)) is the specific capacity; \( Q \) (C) is the average charge during the charging and discharging process; \( m \) (g) is the mass loading of the active materials; \( S \)
(A V) is the integrated area of the CV curve; \( v \) (V/s) is the scan rate; \( I \) (A) is the constant discharging current; \( \Delta t \) (s) is the discharging time.

Energy density and power density were calculated by using the following equation (3) and (4):

\[
E = \int_0^{\Delta t} IV(t)dt/m
\]  

(3)

\[
P = \frac{E}{1000 \times \Delta t}
\]

(4)

Where \( E \) (Wh kg\(^{-1}\)) is the energy density, \( P \) is the power density (kW kg\(^{-1}\)), \( V \) (V) is the potential window, \( I \) (mA) is the discharging current, \( m \) (g) is the total mass of active materials of the device, and \( \Delta t \) (h) is the discharging time.

**Balance the charge of electrodes in HSCs device:**

As for a SC, the charge balance will follow the relationship \( q^+ = q^- \). The charge stored by each electrode depends on the capacity \( (C_s) \), the potential range for the charge/discharge process \( (\Delta E) \) and the area of the electrode \( (A) \) following the Equation 10:

\[
q = C_s \times \Delta E \times A
\]

(10)

To obtain \( q^+ = q^- \) at 100 mV s\(^{-1}\), the area balancing between PNCO\(_x\) and 3DPG will be calculated as follow:

\[
\frac{A_{PNCOx}}{A_{3DPG}} = \frac{C_{(3DPG)} \times \Delta E_{3DPG}}{C_{PNCOx} \times \Delta E_{PNCOx}} \approx \frac{1}{1.12}
\]

Therefore, the calculated areal ration between the PNCO\(_x\) electrode and 3DPG electrode was about 1:1.12.
Figure S1. SEM images of the as-prepared NCO NWAs.

Figure S2. (a) N₂ adsorption/desorption isotherms and (b) pore-size distribution of the NCO NWs and PNCOₓ NWs.
Figure S3. (a) TEM, (b) HRTEM, and (c) the corresponding SAED pattern of the pristine NCO NWs.

Figure S4. XPS survey spectra of NCO and PNCO$_x$ NWs.
Figure S5. XPS survey of Ni 2p spectra for the pristine NCO and PNCO$_x$ NWs.

Figure S6. FTIR spectra of pristine NCO and PNCO$_x$ NWs.
Figure S7. Mott-Schottky plots of pristine NCO and PNCO$_x$ NWs.

Figure S8. (a) CV curves of the PNCO$_x$ electrode collected at various scan rates. (b) GCD curves of the PNCO$_x$ electrode collected at different current density.
**Figure S9.** (a) CV and (b) GCD curves of the carbon cloth and PNCO$_x$ NWAs electrodes collected at 100 mV s$^{-1}$ and 2 mA cm$^{-1}$, respectively.

**Table S1.** Electrochemical performance obtained from NCO based electrodes.

<table>
<thead>
<tr>
<th>Type of electrode</th>
<th>capacity (mAh g$^{-1}$)</th>
<th>Rate capability</th>
<th>Cyclability</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNCO$_x$ NWAs</td>
<td>686 (2 mA cm$^{-1}$)</td>
<td>58% (2 to 40 mA cm$^{-2}$)</td>
<td>96.5% (20000)</td>
<td>This work</td>
</tr>
<tr>
<td>NCO nanoneedle arrays</td>
<td>393 (1.11 mA cm$^{-2}$)</td>
<td>18.91% (1.11 to 22.24 mA cm$^{-2}$)</td>
<td>89.32% (2000)</td>
<td>1</td>
</tr>
<tr>
<td>Mesoporous NCO nanosheets</td>
<td>366 (1.8 mA cm$^{-2}$)</td>
<td>39% (1.8 to 48.6 mA cm$^{-2}$)</td>
<td>93% (3000)</td>
<td>2</td>
</tr>
<tr>
<td>NCO@NiCo$_2$S$_4$</td>
<td>260 (2 mA cm$^{-1}$)</td>
<td>70.5% (2 to 20 mA cm$^{-2}$)</td>
<td>65% (4000)</td>
<td>4</td>
</tr>
<tr>
<td>NCO/MCMF</td>
<td>257 (2 mA cm$^{-2}$)</td>
<td>72.68% (2 to 40 mA cm$^{-2}$)</td>
<td>85.8% (10000)</td>
<td>5</td>
</tr>
<tr>
<td>CC@NCO</td>
<td>176 (2.5 mA cm$^{-1}$)</td>
<td>45.8% (2.5 to 60 mA cm$^{-2}$)</td>
<td>No data</td>
<td>8</td>
</tr>
<tr>
<td>Material Type</td>
<td>Current Density (mA cm$^{-2}$)</td>
<td>Initial Efficiency (%)</td>
<td>Current Density Range (mA cm$^{-2}$)</td>
<td>Additional Notes</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------------------</td>
<td>------------------------</td>
<td>---------------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>NCO nanosheets</td>
<td>168 (1.6)</td>
<td>72.14%</td>
<td>1.6 to 16</td>
<td>No data</td>
</tr>
<tr>
<td>NCO-rGO</td>
<td>153 (1.25)</td>
<td>62.84%</td>
<td>1.25 to 100</td>
<td>91.6% (3000)</td>
</tr>
<tr>
<td>NCO@NiCo$_2$O$_4$</td>
<td>143 (2)</td>
<td>74.84%</td>
<td>2 to 40</td>
<td>96% (4000)</td>
</tr>
<tr>
<td>NCO–rGO</td>
<td>133 (2)</td>
<td>69%</td>
<td>2 to 20</td>
<td>90% (5000)</td>
</tr>
<tr>
<td>NCO microspheres</td>
<td>131 (2.8)</td>
<td>73%</td>
<td>2.8 to 56</td>
<td>93.6% (1600)</td>
</tr>
<tr>
<td>NCO/carbon textiles</td>
<td>120 (1.2)</td>
<td>79%</td>
<td>1.2 to 24</td>
<td>No negligible (5000)</td>
</tr>
<tr>
<td>NCO–RGO</td>
<td>116 (2)</td>
<td>73.65%</td>
<td>2 to 40</td>
<td>No negligible (4000)</td>
</tr>
<tr>
<td>Ni@NCO</td>
<td>113 (1.54)</td>
<td>67.85%</td>
<td>1.54 to 30.8</td>
<td>93.2% (6000)</td>
</tr>
<tr>
<td>CC/NCO-S@NiO</td>
<td>105 (2)</td>
<td>91.2%</td>
<td>2 to 16</td>
<td>100% (10000)</td>
</tr>
<tr>
<td>NCO nanospheres</td>
<td>94 (4)</td>
<td>80%</td>
<td>4 to 40</td>
<td>No negligible (5000)</td>
</tr>
<tr>
<td>NCO</td>
<td>82 (1)</td>
<td>80.55%</td>
<td>1 to 10</td>
<td>98.4% (1000)</td>
</tr>
<tr>
<td>NCO NWA</td>
<td>79 (0.5)</td>
<td>47.09%</td>
<td>0.5 to 50</td>
<td>No data</td>
</tr>
</tbody>
</table>
Figure S10. Specific capacity of PNCO₄ electrodes as a function of current densities with (a) different amount of NaH₂PO₂·H₂O and (b) different annealing temperature.

Figure S11. (a) SEM image, (b) Raman spectrum, and (c) C1s core-level XPS spectrum of 3DPG sample.
Figure S12. (a) CV curves for 3DPG electrode collected at different scan rates. (b) GCD curves of 3DPG electrode at various current densities. Specific capacity and capacity retention of 3DPG electrode as a function of (c) scan rate and (d) current density.

Figure S13. CV curves collected for 3DPG and PNCO$_x$ NWAs at the scan rate of 100 mV s$^{-1}$. 
Figure S14. GCD curves of PNCO<sub>x</sub> NWAs//3DPG HSCs device collected at 5 mA cm<sup>-1</sup> in the corresponding potential windows.

Figure S15. (a) CV curves for PNCO<sub>x</sub> NWAs//3DPG HSCs device collected at different scan rates. (b) Specific capacity and capacity retention of PNCO<sub>x</sub> NWAs//3DPG HSCs device as a function of scan rate.
Table S2. A comparison on the ORR activities of the recently reported catalysts.

<table>
<thead>
<tr>
<th>catalysts</th>
<th>ORR $E_{\text{onset}}$ (V vs. RHE)</th>
<th>ORR $E_{1/2}$ (V vs. RHE)</th>
<th>Electrolyte</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNCO$_x$ NWAs</td>
<td>0.95</td>
<td>0.83</td>
<td>0.1 M KOH</td>
<td>This work</td>
</tr>
<tr>
<td>NC/Co-NGC DSNCs</td>
<td>0.92</td>
<td>0.82</td>
<td>0.1 M KOH</td>
<td>22</td>
</tr>
<tr>
<td>N, S-carbon nanosheet</td>
<td>0.92</td>
<td>0.77</td>
<td>0.1 M KOH</td>
<td>23</td>
</tr>
<tr>
<td>NCO/rGO</td>
<td>0.91</td>
<td>0.79</td>
<td>0.1 M KOH</td>
<td>18</td>
</tr>
<tr>
<td>CoO/N-graphene</td>
<td>0.90</td>
<td>0.81</td>
<td>0.1 M KOH</td>
<td>25</td>
</tr>
<tr>
<td>NCO NCs</td>
<td>0.86</td>
<td>0.67</td>
<td>0.1 M KOH</td>
<td>19</td>
</tr>
<tr>
<td>Co$_3$O$_4$/N-graphene</td>
<td>0.86</td>
<td>0.83</td>
<td>0.1 M KOH</td>
<td>26</td>
</tr>
<tr>
<td>Mn$_x$O$_y$/N-carbon</td>
<td>0.85</td>
<td>0.81</td>
<td>0.1 M KOH</td>
<td>24</td>
</tr>
<tr>
<td>MnCo$_2$O$_4$/NCNT</td>
<td>0.85</td>
<td>0.63</td>
<td>0.1 M KOH</td>
<td>27</td>
</tr>
<tr>
<td>Urchin like NCO</td>
<td>0.83</td>
<td>0.64</td>
<td>0.1 M KOH</td>
<td>21</td>
</tr>
<tr>
<td>Sphere like NCO</td>
<td>0.81</td>
<td>0.66</td>
<td>1 M NaOH</td>
<td>20</td>
</tr>
<tr>
<td>Ti$_3$C$_2$/g-C$_3$N$_4$</td>
<td>0.72</td>
<td>0.51</td>
<td>0.1 M KOH</td>
<td>28</td>
</tr>
</tbody>
</table>
References


27. S.V. Devaguptapu, S. Hwang, S. Karakalos, S. Zhao, S. Gupta, D. Su, H. Xu, G.