# N, P-Doped Carbon with Encapsulated Co Nanoparticles as E□cient Electrocatalyst for Oxygen Reduction Reaction

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Keywords: Co Nanoparticles; Oxygen reduction reaction; N, P-Doped Carbon; Metal-Organic Framework

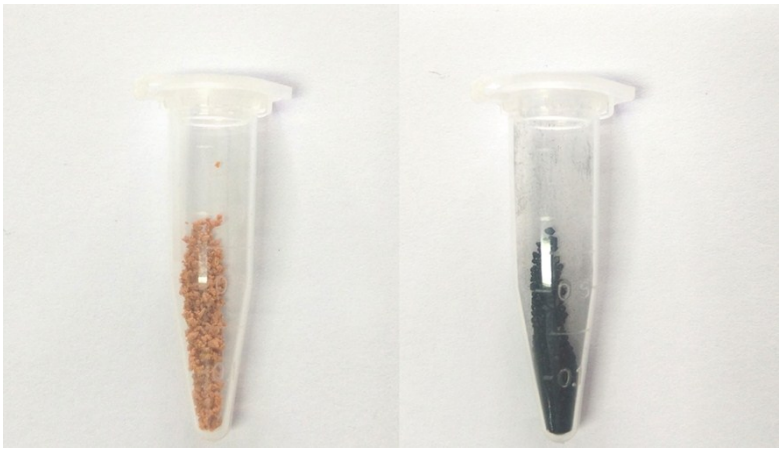

**Figure S1** Digital photos of the Co-MOF (left) and corresponding Co@NC-P(3-1) catalyst (right).

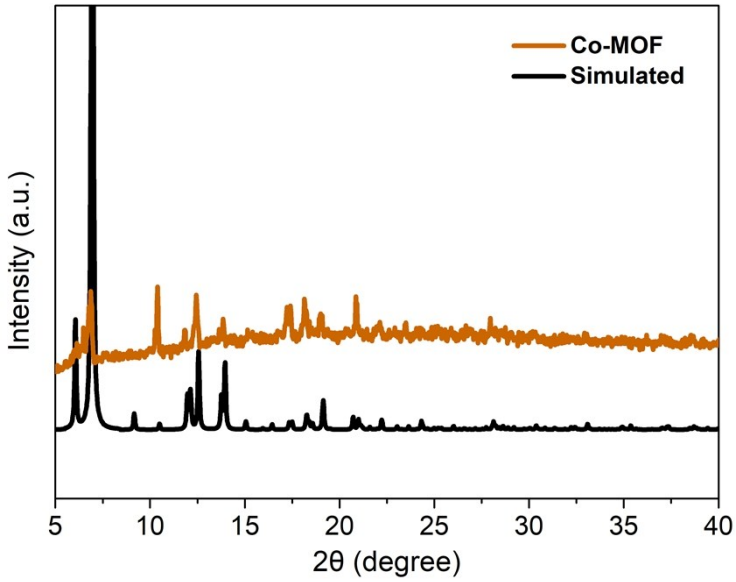


**Figure S2** PXRD patterns of the simulated and as-synthesized Co-MOF.

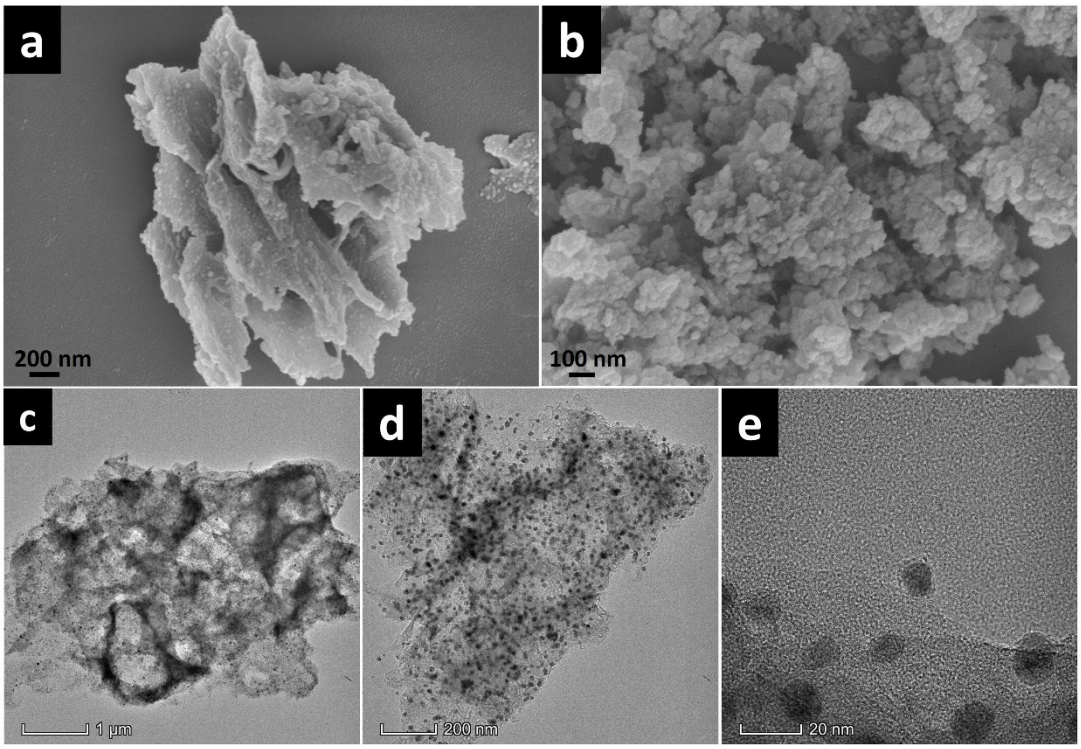


**Figure S3** SEM images (a, b) and TEM images (c-e) of Co@NC-P(3-1).

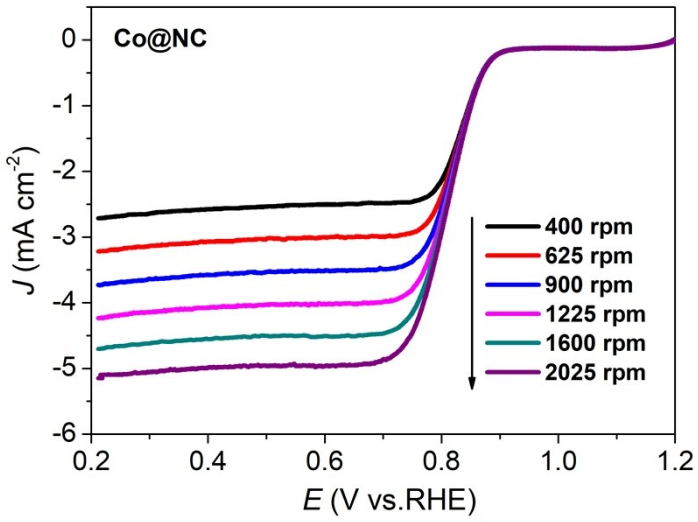


**Figure S4** LSV curves of Co@NC at different rotation rates.

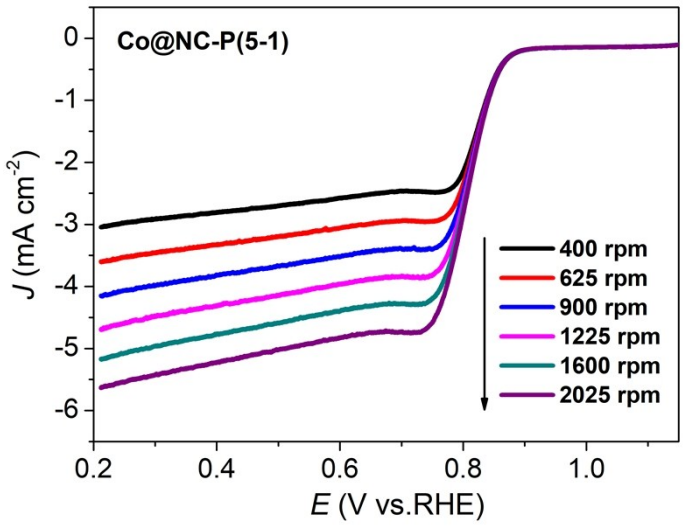


**Figure S5** LSV curves of Co@NC-P(5-1) at different rotation rates.

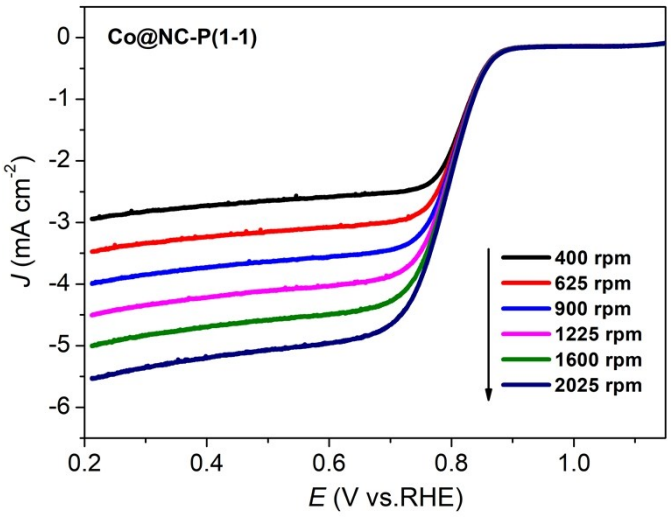


**Figure S6** LSV curves of Co@NC-P(1-1) at different rotation rates.

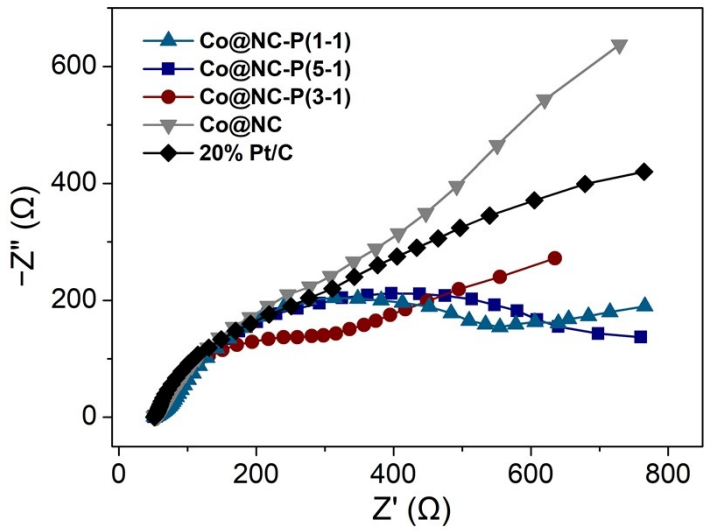


**Figure S7** Nyquist plots of Co@NC, Co@NC-P(5-1), Co@NC-P(3-1), Co@NC-P(1-1) and 20 % Pt/C, respectively.

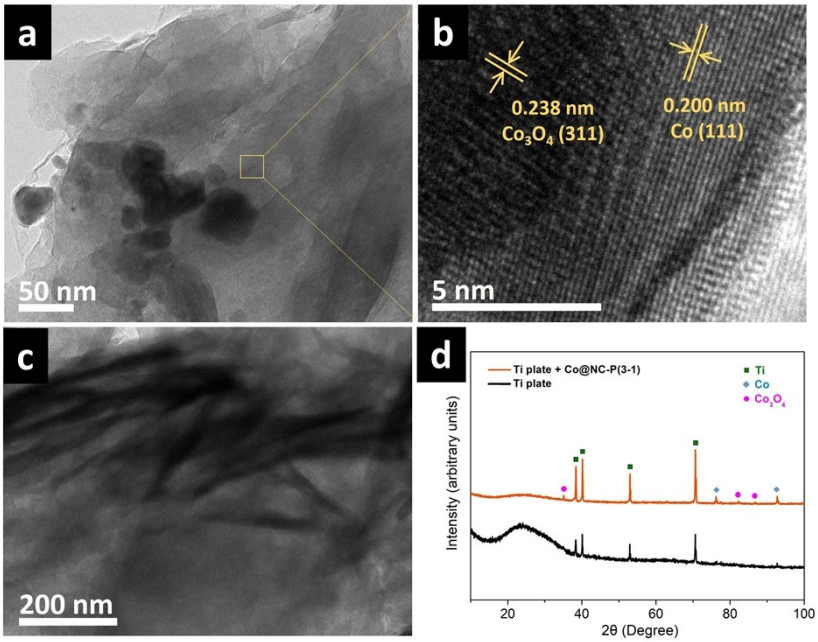


**Figure S8** (a-c) TEM images and (d) XRD patterns of Co@NC-P(3-1) after 10 h chronoamperometry test.

**Table S1** XPS results of surface element contents in all the as-synthesized samples.

| Element Content (Atomic %) | Co@NC | Co@NC-P(5-1) | Co@NC-P(3-1) | Co@NC-P(1-1) |
|---|---|---|---|---|
| C | 82.89 | 84.68 | 82.69 | 83.41 |
| N | 5.16 | 3.71 | 5.88 | 4.91 |
| Co | 1.04 | 0.76 | 0.84 | 0.94 |
| O | 10.91 | 10.46 | 10.06 | 10.26 |
| P | -- | 0.39 | 0.52 | 0.48 |

**Table S2** ICP-OES results of the Co content of as-synthesized samples.

| Element Content (Mass %) | Co@NC | Co@NC-P(5-1) | Co@NC-P(3-1) | Co@NC-P(1-1) |
|---|---|---|---|---|
| Co | 32.08 | 9.18 | 16.36 | 33.12 |

**Table S3** Comparison of the ORR performance of this work with reported Co-based materials.

| Catalysts | Half-wave Potential (V) | Current density (mA $cm^{-2}$) | Onset Potential (V) | Tafel slope (mV $dec^{-1}$) | Electron transfer number | Reference |
|---|---|---|---|---|---|---|
| **Co@$Co_3O_4$@C** | 0.81 | 4.65 | 0.93 | -- | -- | Energy Environ. Sci., 2015 [1] |
| **Co-NC@CoP-NC** | 0.78 | -- | 0.89 | -- | -- | J. Mater. Chem. A, 2016 [2] |
| **Co-N/CNFs** | 0.82 | 4.5 | 0.92 | -- | 4 | ACS Catal., 2017 [3] |
| **CoNC (MOF-Derived)** | 0.81 | 4.3 | 0.9 | -- | 3.5 | J. Mater. Chem. A, 2017 [4] |
| **Co/CoP–HNC (MOF-Derived)** | 0.82 | 4.9 | 0.95 | 59.4 | 4.0 | Mater. Horiz., 2018 [5] |
| **Co-Nx@CNF700** | 0.814 | 5.6 | 0.941 | 74 | 3.9 | J. Power Sources, 2018 [6] |
| **C3-900-N/S (MOF-Derived)** | 0.78 | 5.3 | 0.80 | -- | 3.9 | Dalton Trans., 2018 [7] |
| **Co-N-PC** | 0.833 | 5.7 | 0.95 | 70.5 | 3.8 | Carbon, 2018 [8] |
| **CoNC-CNF-1000 (MOF-Derived)** | 0.8 | 5.9 | -- | -- | 3.96 | Small, 2018 [9] |
| **Co@Co3O4/N-C** | 0.81 | 5.5 | 0.89 | 61 | 3.83 | Chem. Commun., 2018 [10] |
| **FeCo/N-DNC** | 0.81 | 6.1 | 0.89 | -- | 3.92 | Nanoscale, 2018 [11] |
| **Co-N-C** | 0.75 | 4.2 | 0.88 | -- | 3.8 | Carbon, 2018 [12] |
| **Co@NC-P(3-1)** | 0.80 | 5.93 | 0.88 | 66 | 4.0 | This work |

Reference


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