# Supplementary information

## $Co_3O_4$ nanosheet on zeolite-templated carbon as an efficient oxygen electrocatalyst for zinc-air battery

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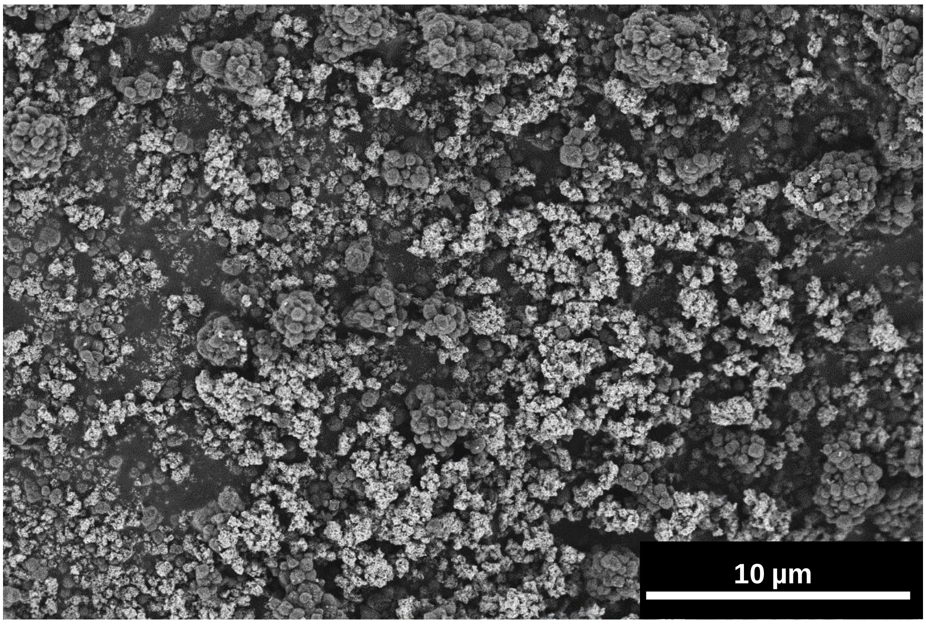


**Fig. S1** Scanning electron microscope (SEM) image of $Co_3O_4$ nanosheet grown on zeolite-templated carbon ($Co_3O_4$ NS/ZTC) at low magnification.

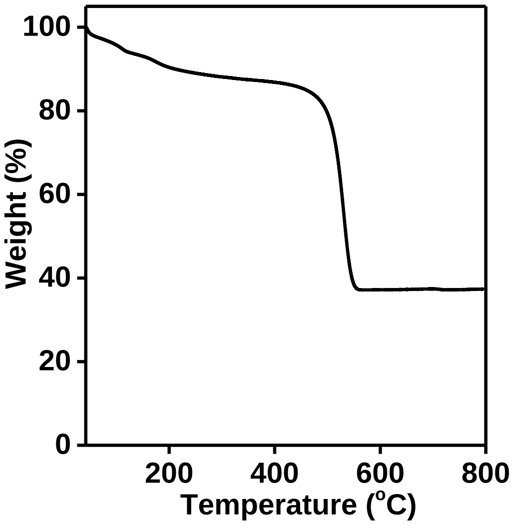


**Fig. S2** Thermogravimetric analysis profile of $Co_3O_4$ NS/ZTC.

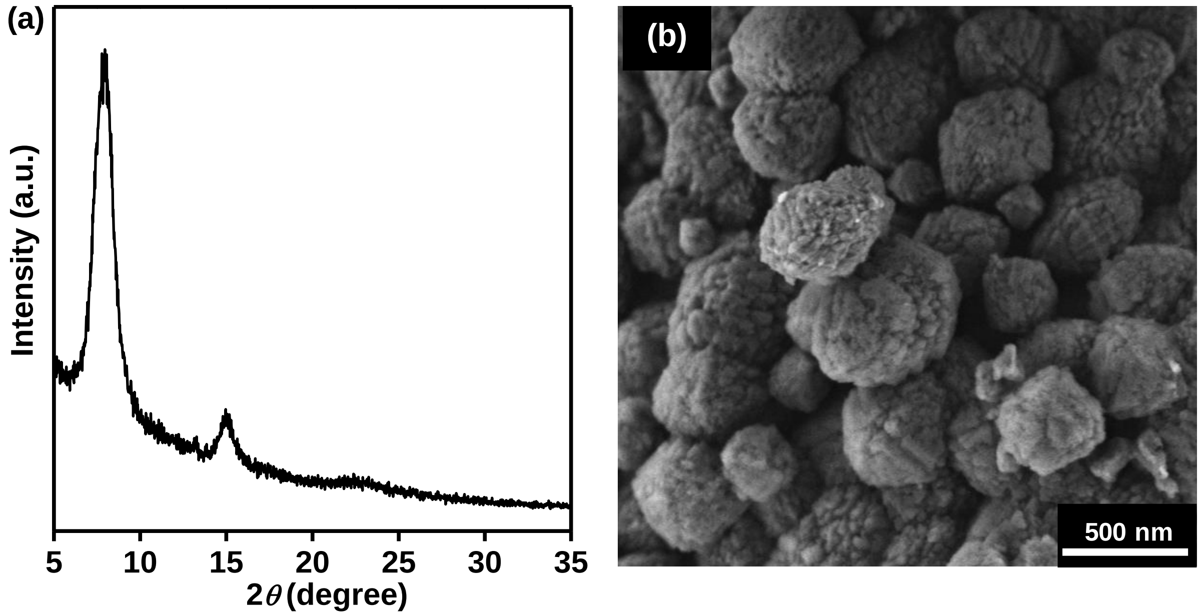


**Fig. S3** Powder X-ray diffraction (XRD) pattern and SEM image of $Co_3O_4$ NS/ZTC after HCl treatment. During HCl treatment, $Co_3O_4$ removed from $Co_3O_4$ NS/ZTC and the XRD peak intensity and morphology of ZTC recovered indicating the retention of ZTC framework in $Co_3O_4$ NS/ZTC.

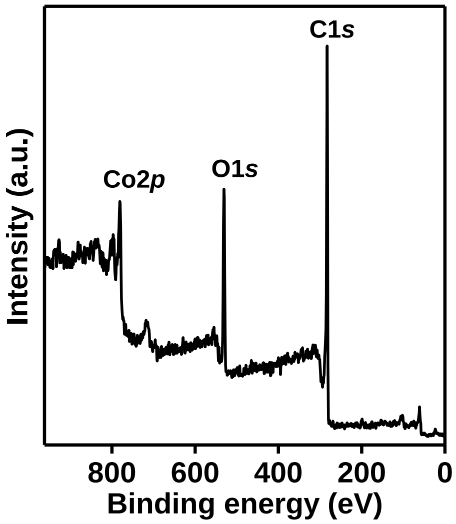


**Fig. S4** The X-ray photoelectron spectroscopy (XPS) elemental survey of $Co_3O_4$ NS/ZTC.

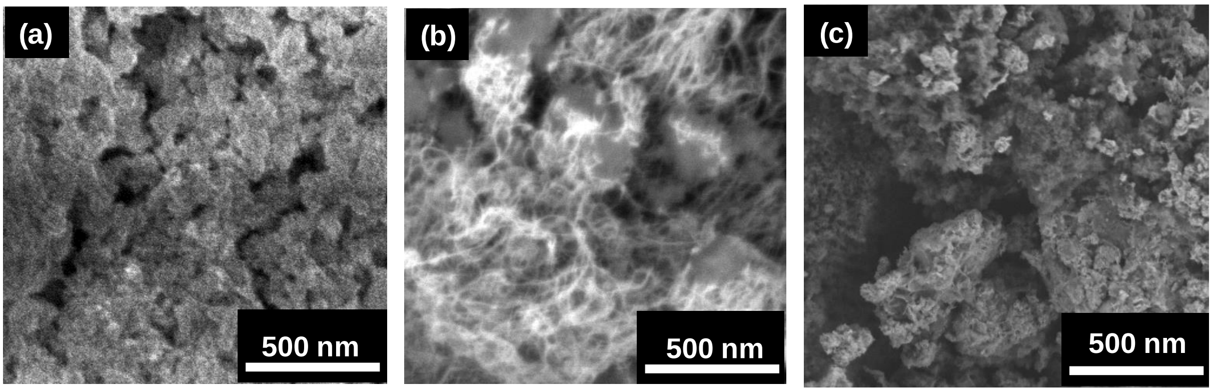


**Fig. S5** SEM images of (a) $Co_3O_4$, (b) $Co_3O_4$/carbon nanotube (CNT), and (c) $Co_3O_4$/activated carbon (AC) nanostructure.

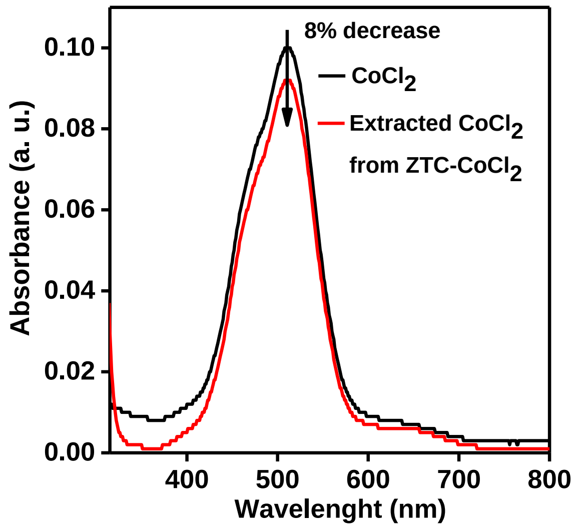


**Fig. S6** UV-vis absorption spectra of $CoCl_2$ solution used and extracted after mixing and stirring with ZTC. The extracted $CoCl_2$ solution shows a decrease in the absorbance by 8% because of the absorption of $Co^{2+}$ on ZTC surface.

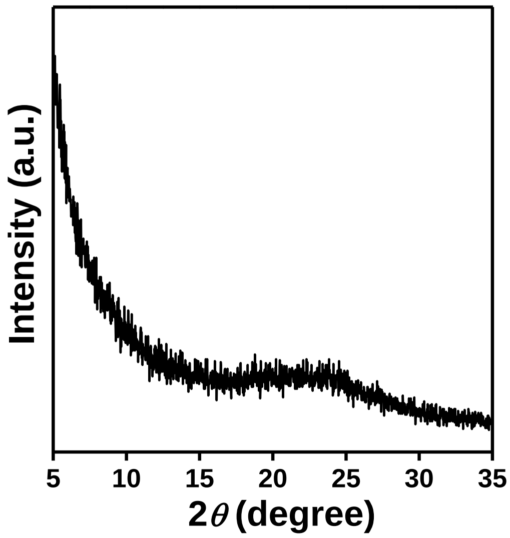


**Fig. S7** XRD pattern of AC that did not possess ordered microporous structure.

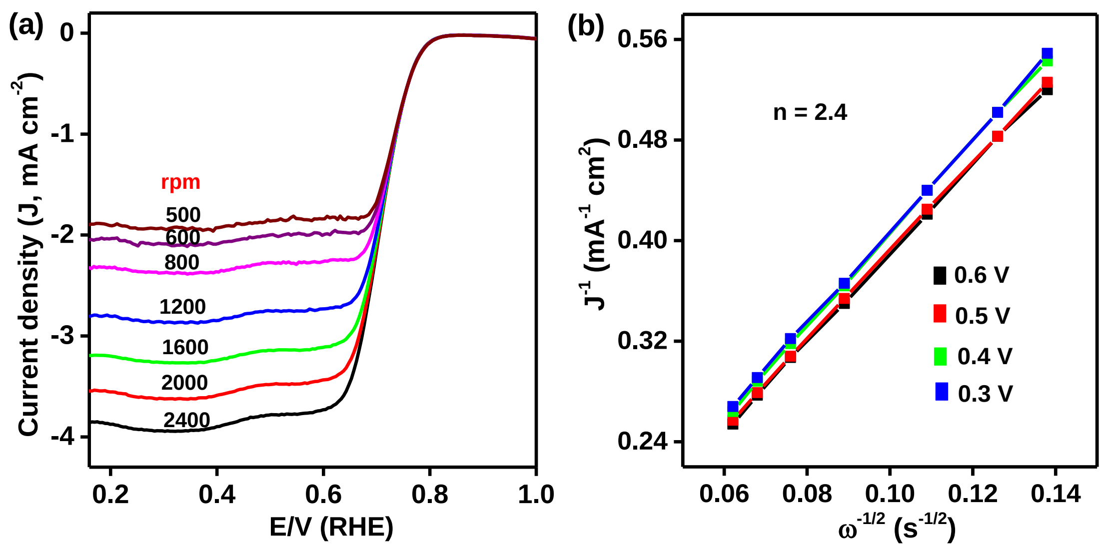


**Fig. S8** (a) Oxygen reduction reaction (ORR) polarization curves of ZTC at different rotation speeds and (b) the corresponding Koutecký-Levich plots at different potential reveals the average number of electron transfer is 2.4.

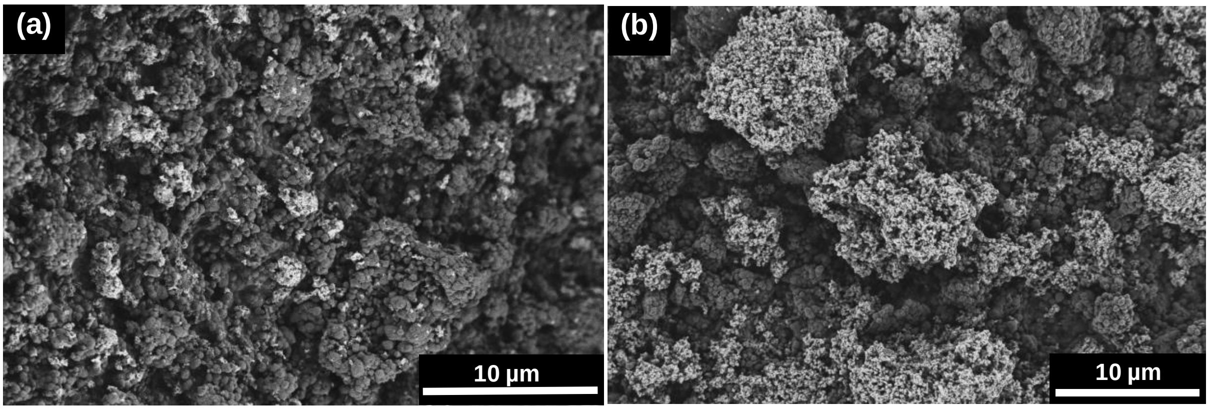


**Fig. S9** SEM images of $Co_3O_4$ NS/ZTC with (a) 20% and (b) 50% of $Co_3O_4$ content.

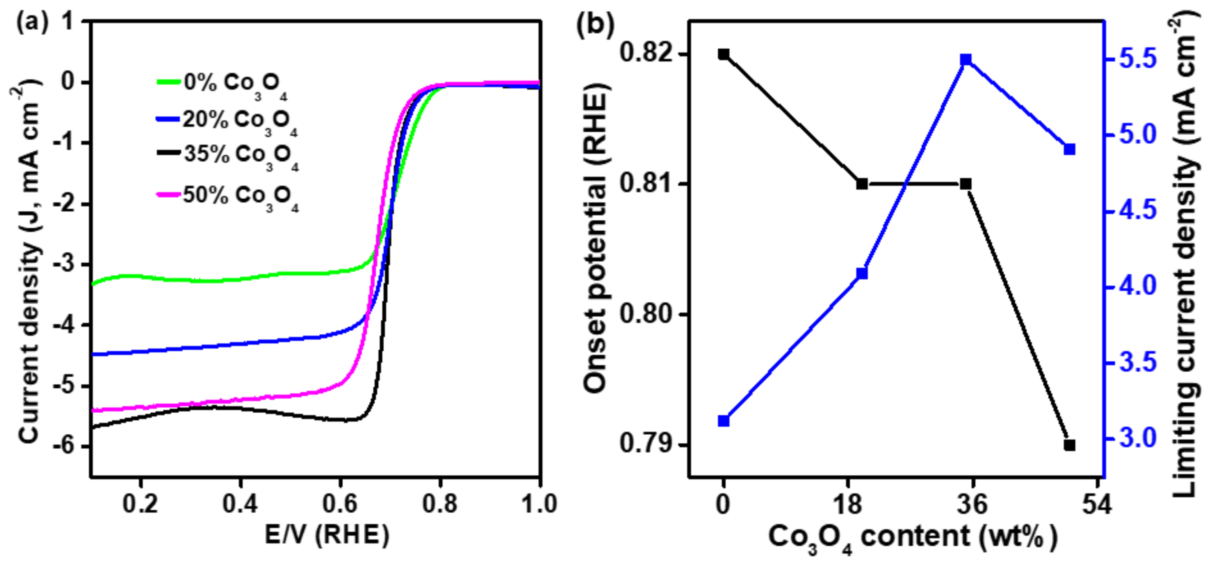


**Fig. S10** (a) ORR polarization curves and (b) variation of onset potential and diffusion limiting current density at 0.6 V of $Co_3O_4$ NS/ZTC with different $Co_3O_4$ contents.

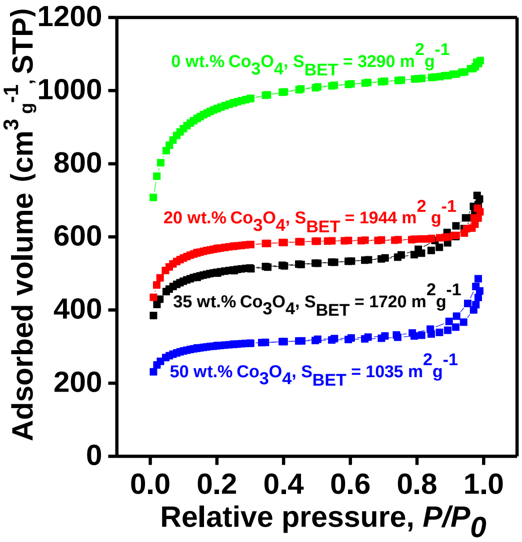


**Fig. S11** $N_2$ adsorption-desorption isotherm of $Co_3O_4$ NS/ZTC with different $Co_3O_4$ contents.

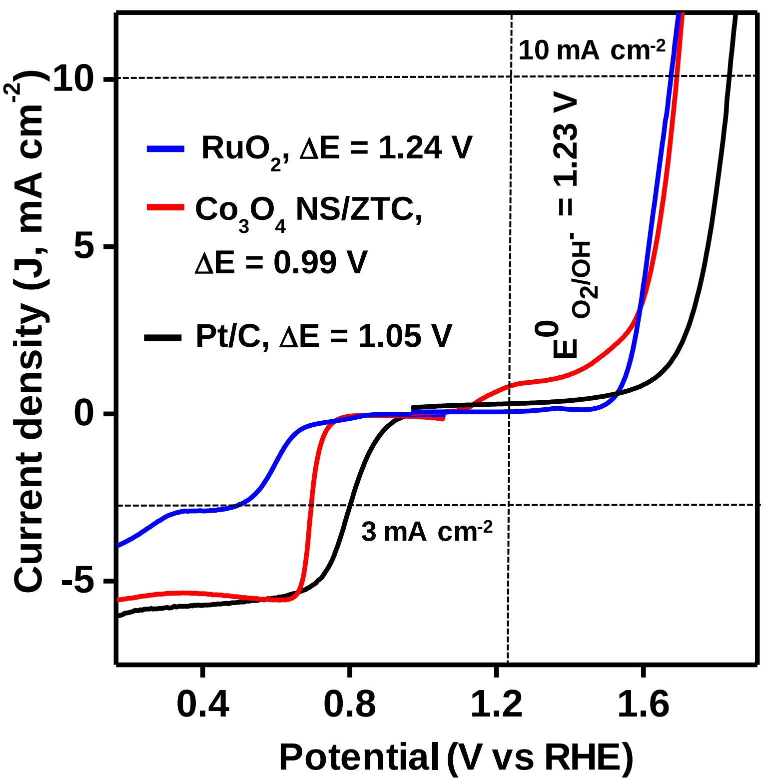


**Fig. S12** Bifunctional oxygen electrocatalytic activity of $Co_3O_4$ NS/ZTC, $RuO_2$, and Pt/C in a 0.1 M KOH solution.

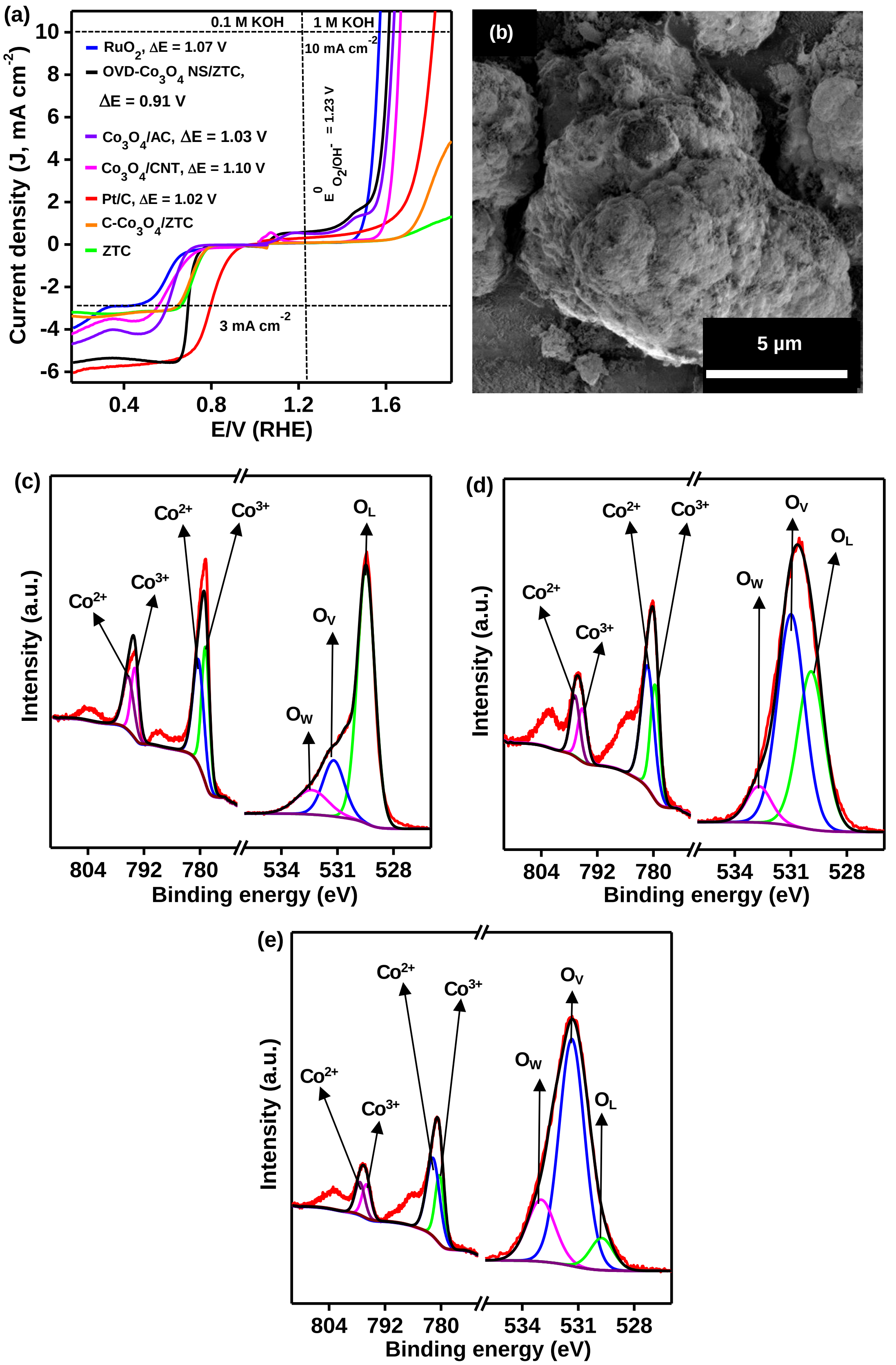


**Fig. S13** (a) Oxygen electrocatalytic activity of different material, (b) SEM image of commercial $Co_3O_4$, and XPS of (c) commercial $Co_3O_4$, (d) $Co_3O_4$/CNT, and (e) $Co_3O_4$/AC. $O_L$, $O_V$, and $O_W$ represent lattice, vacancy, and water oxygen, respectively.

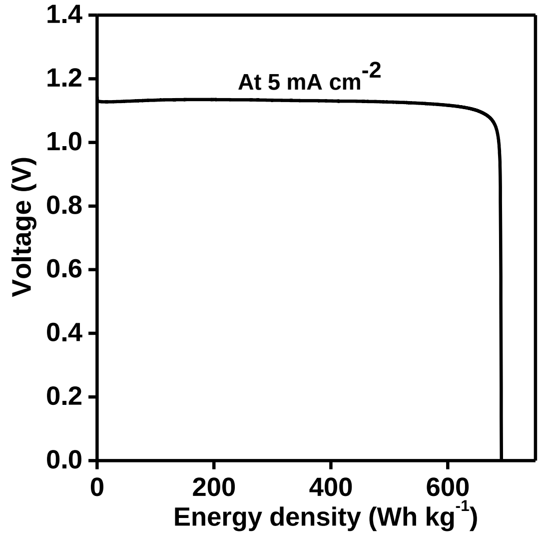


**Fig. S14** Energy density of a Zinc-air battery assembled with $Co_3O_4$ NS/ZTC at a current density of 5 mA $cm^{-2}$.

**Table S1.** Comparison of bifunctional oxygen electrocatalytic activity of $Co_3O_4$ NS/ZTC with the recently reported $Co_3O_4$ NS based electrocatalysts.

| Catalyst | ORR | OER | ΔE [d] | References |
|---|---|---|---|---|
| $Co_3O_4$ NS [a]/carbon cloth | $E_{1/2}$ [b] = ~ 0.8 V vs RHE in 0.1 M KOH | $E_{j\ =\ 10\ mA\ cm^{-2}}$ [c] = 1.71 V vs RHE in 0.1 M KOH | ~ 0.91V | *ACS Appl. Mater. Interfaces* **2017**, *9*, 22694 |
| $Co_3O_4$ NS/nitrogen-doped reduced graphene oxide | $E_{1/2}$ = 0.79 V vs RHE in 0.1 M KOH | $E_{j\ =\ 10\ mA\ cm^{-2}}$ = 1.72 V vs RHE in 0.1 M KOH | 0.93 V | *Adv. Mater.* **2018**, *30*, 1703657 |
| $Co_3O_4$ NS/carbon black | $E_{1/2}$ = ~ - 0.35 V vs, SCE in 0.1 M KOH | $E_{j\ =\ 10\ mA\ cm^{-2}}$ = ~ 0.73 V vs SCE in 0.1 M KOH | ~ 1.08 V | *Small* **2018**, 1702987 |
| $Co_3O_4$ NS/carbon powder (Super P) | $E_{j=\ 1\ mA\ cm^{-2}}$ = - 0.213 V vs Hg/HgO in 0.1 M KOH | $E_{j\ =\ 10\ mA\ cm^{-2}}$ = 0.843 V vs Hg/HgO in 0.1 M KOH | 1.056 V | *Nanoscale*, **2018**, *10*, 10221 |
| $Co_3O_4$ NS/ZTC | $E_{j=\ 3\ mA\ cm^{-2}}$ = 0.7 V vs RHE in 0.1 M KOH | $E_{j\ =\ 10\ mA\ cm^{-2}}$ = 1.69 V vs RHE in 0.1 M KOH<br><br>$E_{j\ =\ 10\ mA\ cm^{-2}}$ = 1.61 V vs RHE in 1 M KOH | 0.99 V<br><br>0.91 V | In this report |

[a] NS represents nanosheet. [b] $E_{1/2}$ is half-wave potential for ORR. [c] Oxygen evolution reaction (OER) activity at $E_{j\ =\ 10\ mA\ cm^{-2}}$. [d] ΔE is the potential gap between $E_{J\ =\ 10\ mA\ cm^{-2}}$ for OER and $E_{1/2}$/$E_{J\ =1\ mA\ cm^{-2}}$/$E_{J\ =3\ mA\ cm^{-2}}$ for ORR.