Supplementary Information

Mushroom-like Au/NiCo$_2$O$_4$ nanohybrid as high-performance binder-free catalytic cathode for lithium–oxygen batteries

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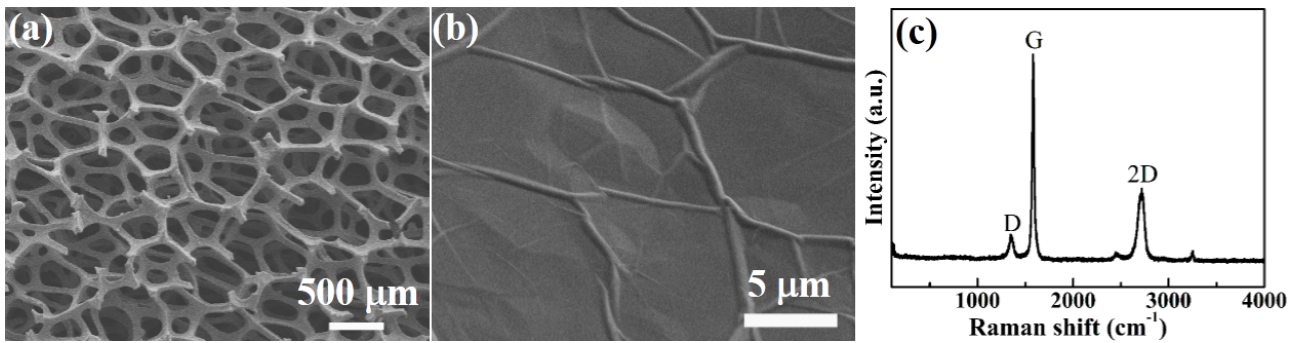
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Fig. S1 (a) SEM image of 3D-G, (b) enlarged view of (a), and (c) Raman spectrum of 3D-G.
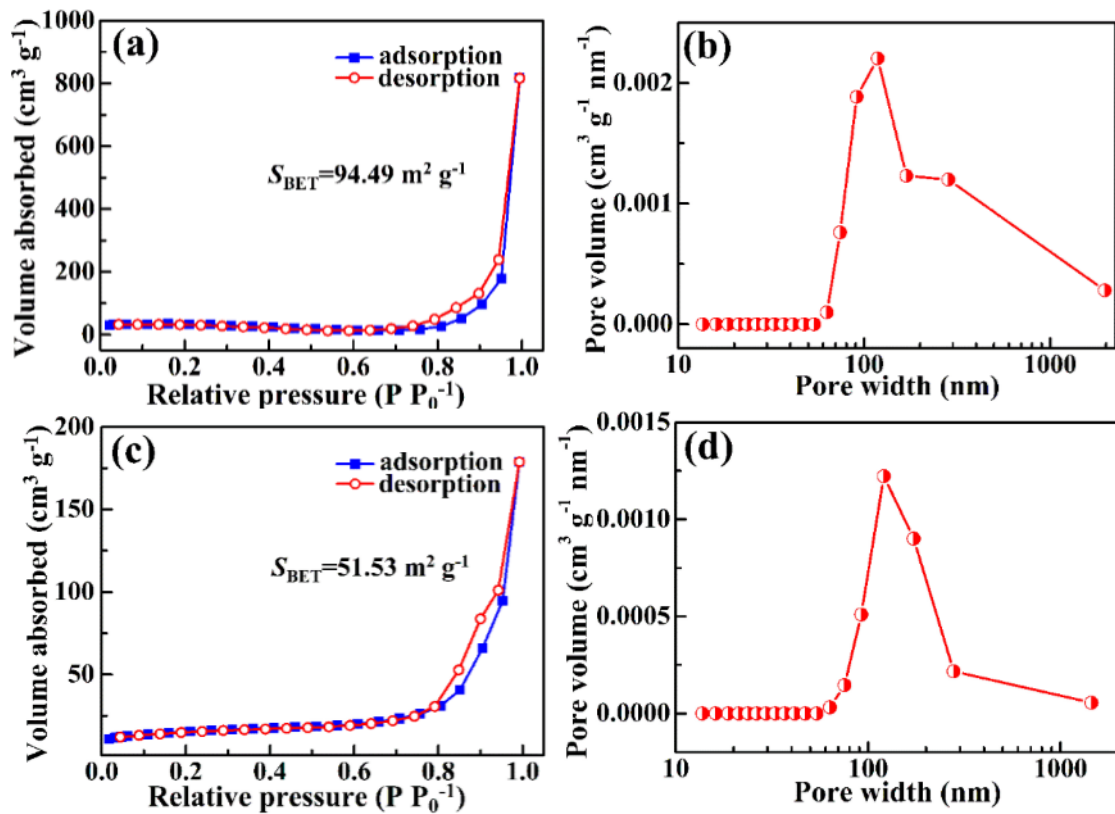

Fig. S2 (a) Nitrogen adsorption and desorption isotherms and (b) pore size distribution of Au/NiCo$_2$O$_4$/3D-G, and (c) nitrogen adsorption and desorption isotherms and (d) pore size distribution of NiCo$_2$O$_4$/3D-G.
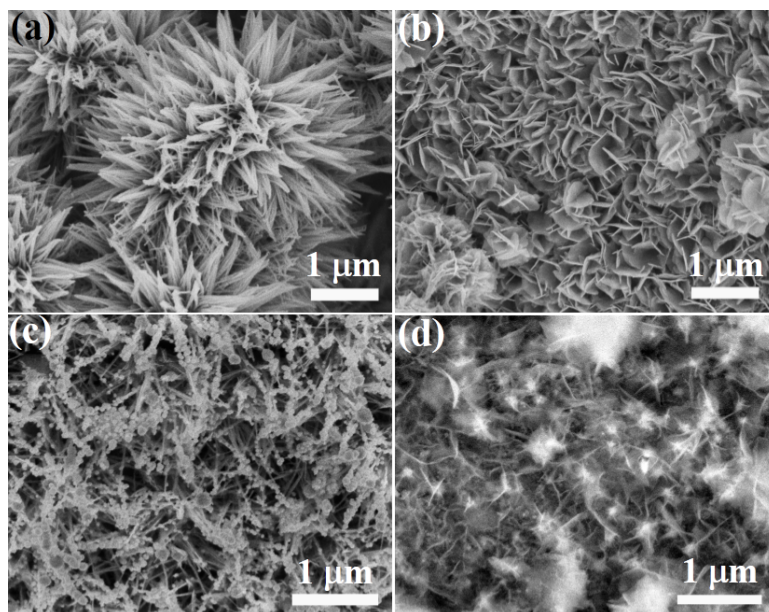
Fig. S3 SEM images of NiCo$_2$O$_4$/3D-G on Ni foam after impregnation in aqueous solution of (a) HCl, (b) H$_2$PtCl$_6$, (c) Na$_2$PdCl$_4$, and (d) Na$_2$PdCl$_4$ with HCl.
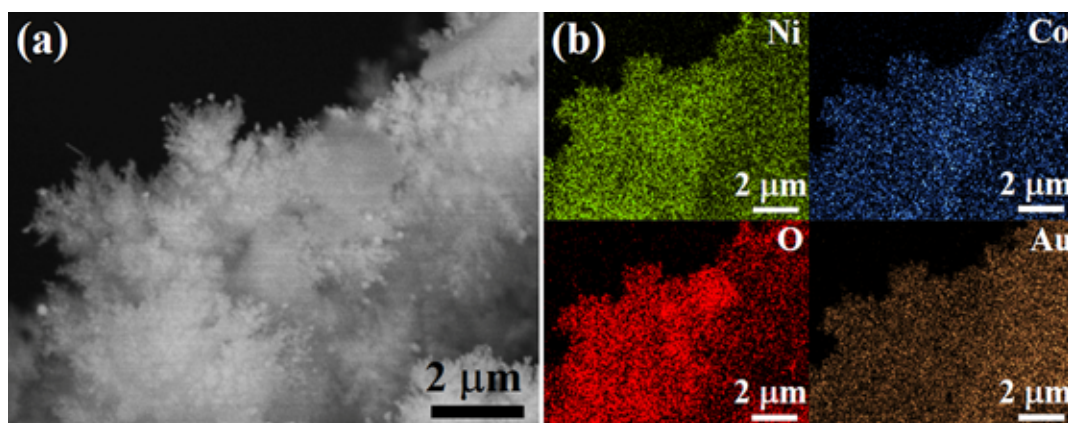

Fig. S4 (a) SEM image of Au/NiCo$_2$O$_4$/3D-G and (b) the corresponding EDS mapping.
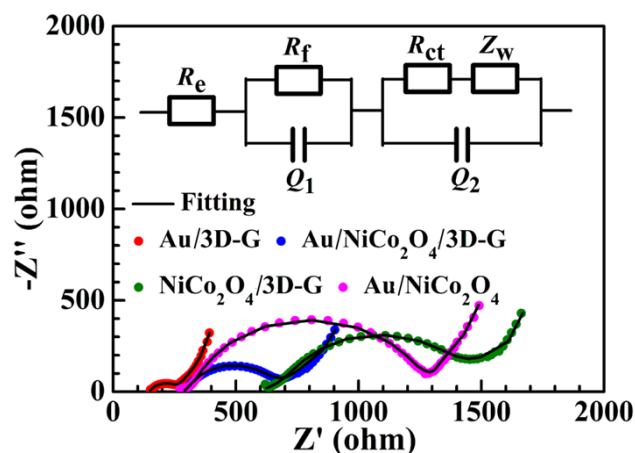
Fig. S5 Nyquist plots of Li–O$_2$ batteries with different catalytic cathodes. The Nyquist plots are fitted using the equivalent circuit in the inset, where R_e denotes the electrolyte and ohm resistance, R_f and Q_1 are the resistance and capacitance of surface film, R_{ct} and Q_2 are the charge transfer resistance and double-layer capacitance, and Z_w represents the Warburg impedance corresponding to the bulk diffusion of Li ions.

Table S1 Fitting results of the Nyquist plots using the equivalent circuit.

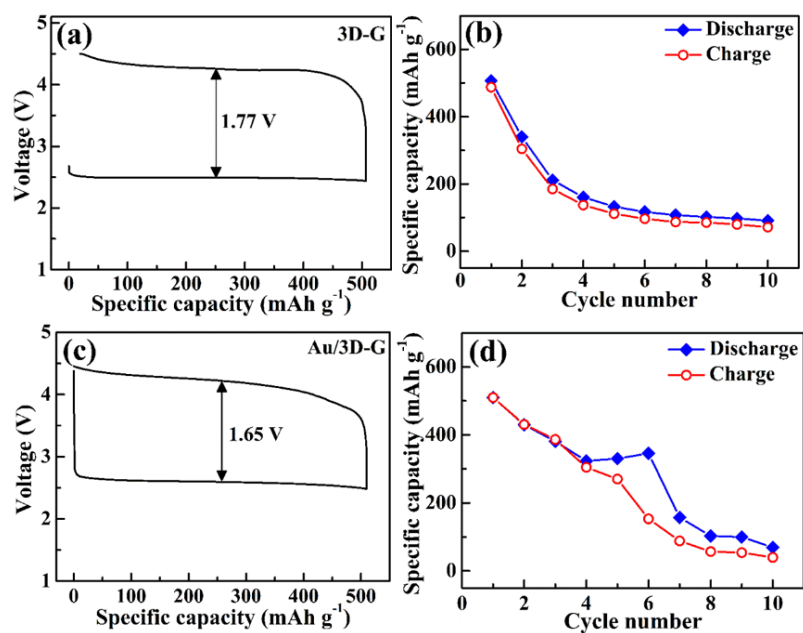| Sample	R_e (Ω)	R_f (Ω)	Q_1		R_{ct} (Ω)	Q_2	
			Y	n		Y	n
Au/3D-G	150.7	118.4	1.5×10^{-5}	0.77	98.9	1.1×10^{-4}	0.96
Au/NiCo$_2$O$_4$/3D-G	283.4	259.4	7.1×10^{-6}	0.90	271.3	7.4×10^{-4}	0.38
NiCo$_2$O$_4$/3D-G	589.4	523.4	1.0×10^{-5}	0.93	688.4	5.5×10^{-4}	0.30
Au/NiCo$_2$O$_4$	286.6	818.7	1.4×10^{-5}	0.91	316.6	1.3×10^{-3}	0.33

Fig. S6 (a) The first discharge-charge curve and (b) cycling performance of Li–O$_2$ battery with 3D-G electrode, and (c) the first discharge-charge curve and (d) cycling performance of Li–O$_2$ battery with Au/3D-G electrode. The current density is 42.5 mA g^{-1} and the specific capacity is limited at 510 mAh g^{-1}.
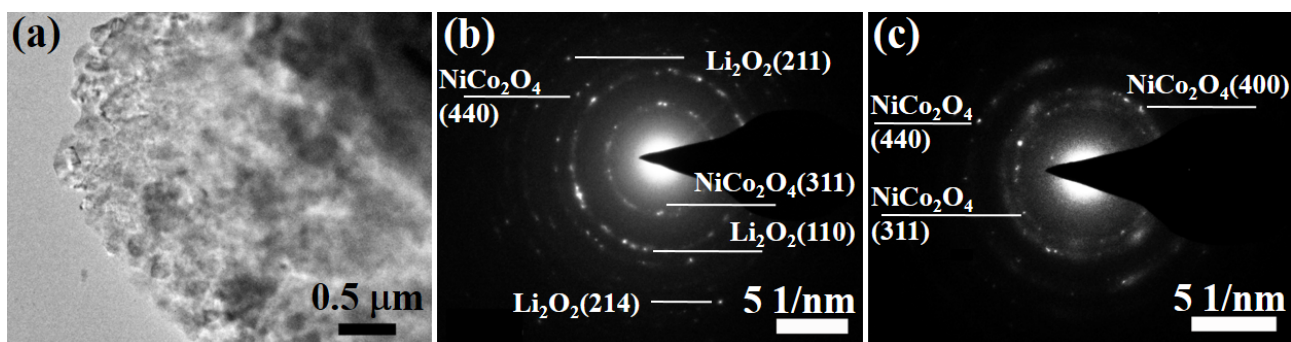

Fig. S7 (a) TEM image and the corresponding SAED patterns of Au/NiCo$_2$O$_4$/3D-G electrodes after (b) discharge and (c) charge to 510 mAh g^{-1} at 42.5 mA g^{-1}.
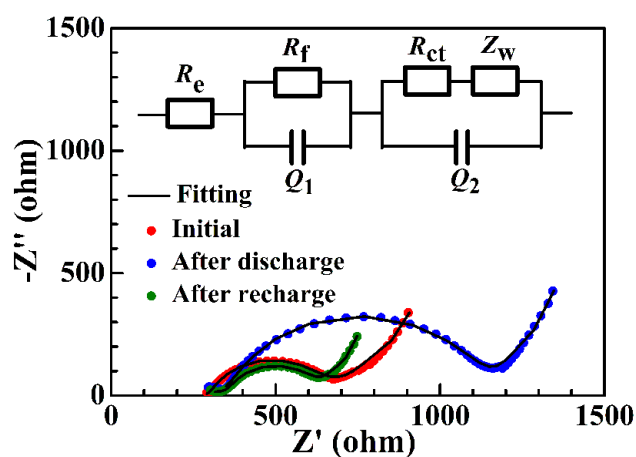
Fig. S8 Nyquist plots of Li–O$_2$ battery with Au/NiCo$_2$O$_4$/3D-G electrode at initial state, discharged to 2.2 V, and recharged to 4.3 V. The meanings of the symbols in the equivalent circuit are same with those in Fig. S5.

Table S2 Fitting results of the Nyquist plots using the equivalent circuit.

Sample	R_e (Ω)	R_f (Ω)	Q_1		R_{ct} (Ω)	Q_2	
			Y	n		Y	n
Initial	283.4	259.4	7.1×10^{-6}	0.90	271.3	7.4×10^{-4}	0.38
After discharge	296.0	631.2	9.8×10^{-6}	0.92	503.2	1.0×10^{-3}	0.28
After recharge	270.0	209.7	4.0×10^{-5}	0.91	206.9	3.0×10^{-4}	0.33
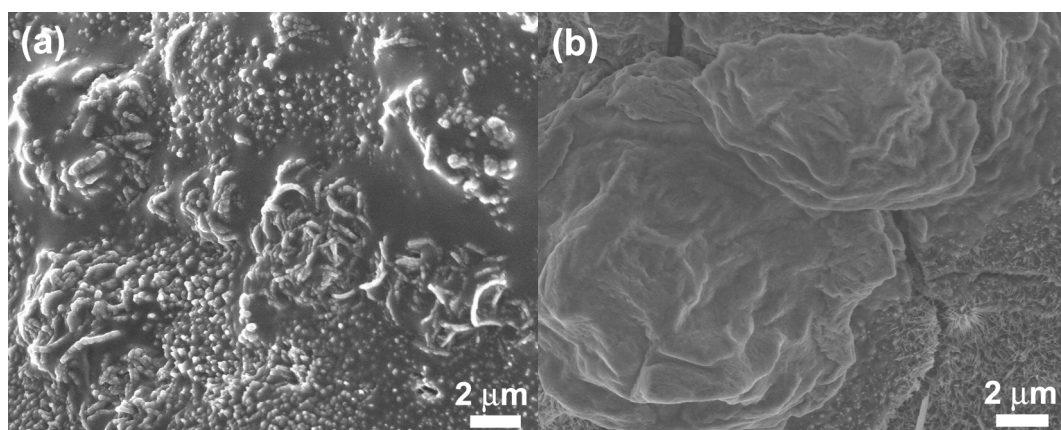
Fig. S9 SEM images of NiCo$_2$O$_4$/3D-G electrode after (a) discharge and (b) recharge to 510 mAh g^{-1} at 42.5 mA g^{-1} on the 10th cycle.
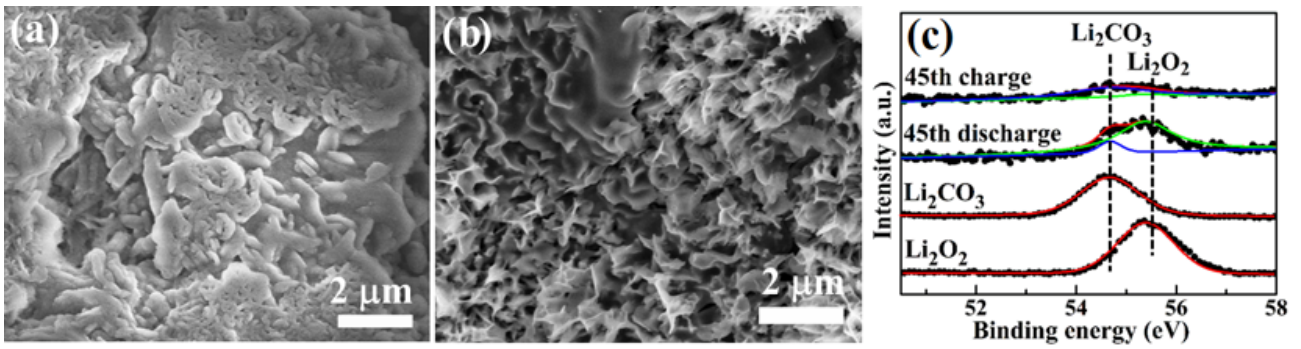
Fig. S10 SEM images and Li1s XPS of Au/NiCo$_2$O$_4$/3D-G electrodes at different states: (a) SEM image after the 45th discharge, (b) SEM image after the 45th charge and (c) Li1s XPS after the 45th cycle. The batteries are charged and discharged to 510 mAh g^{-1} at 42.5 mA g^{-1}.