Electronic Supplementary Information (ESI)

Facile synthesis of NiCo$_2$O$_4$ nanorod arrays on Cu conductive substrate as superior anode materials for high-rate Li-ion batteries

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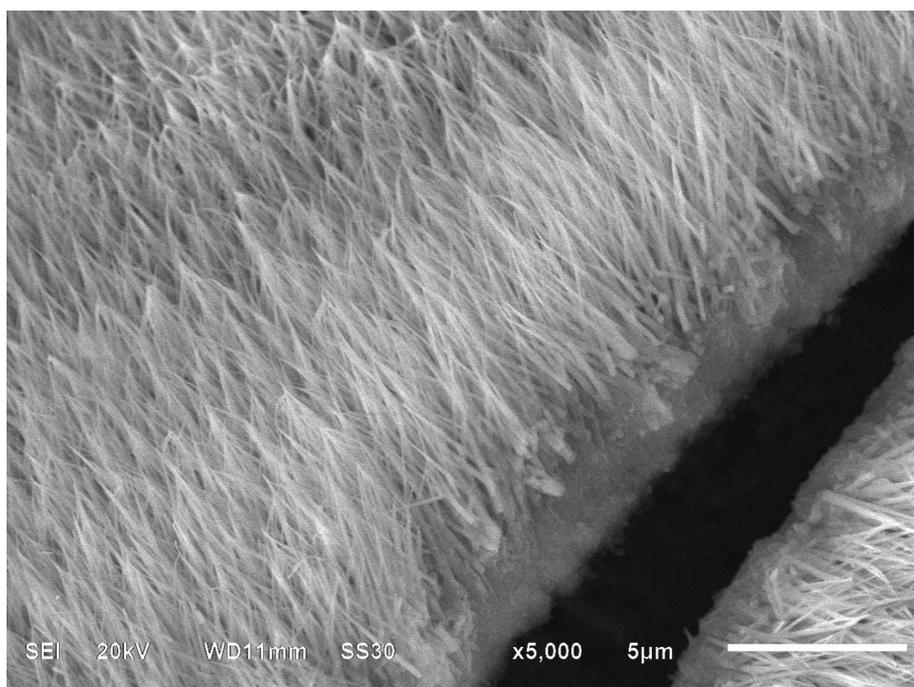
Fig. S1 Low-magnification SEM image displaying the cross-section of $NiCo_2O_4$ nanorod arrays on Cu substrate.
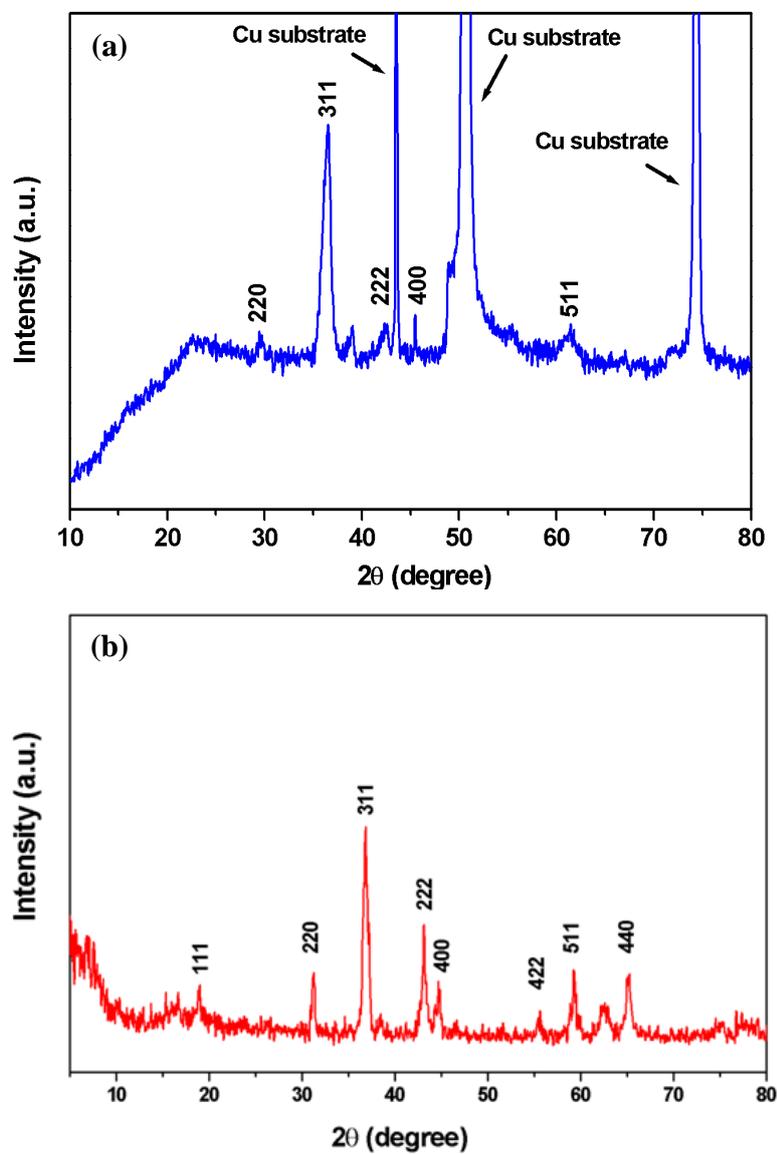
Fig. S2 XRD patterns of NiCo$_2$O$_4$ nanorod arrays on Cu substrate (a) and pure

NiCo$_2$O$_4$ nanorods powders scaled off from Cu substrate (b). All the XRD patterns in

Fig. S2a and b can be indexed to cubic phase of ternary NiCo$_2$O$_4$ products (JCPDS no.

73-1702).
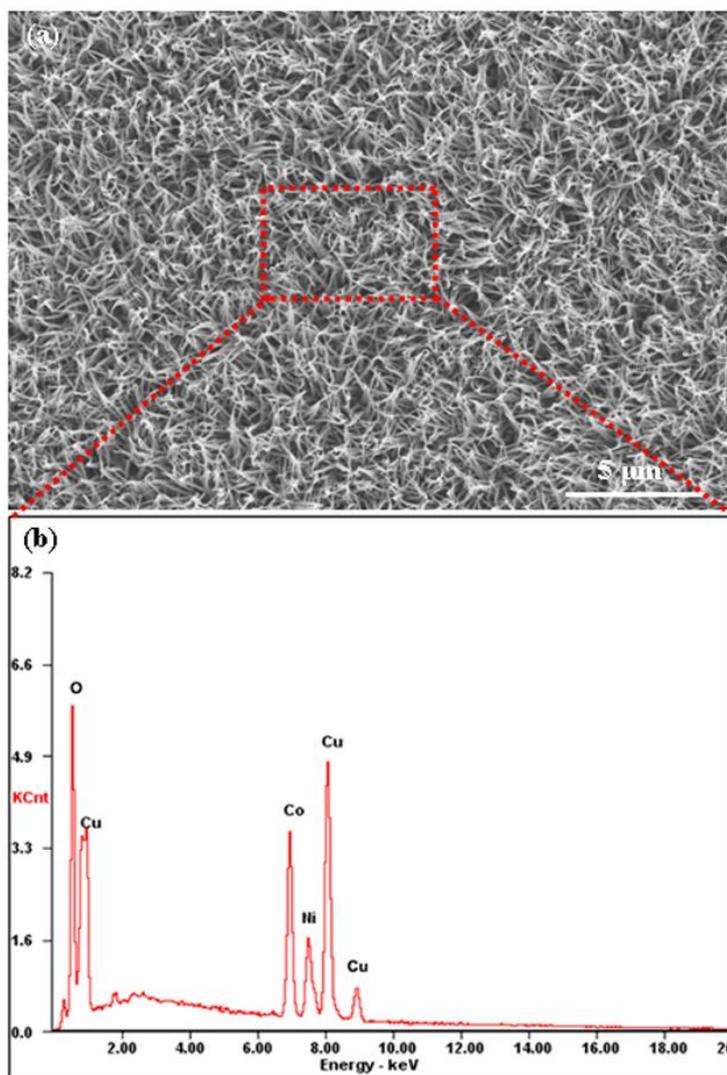
Fig. S3 SEM image (a) and EDS pattern (b) of NiCo$_2$O$_4$ nanorod arrays on Cu

substrate, the peaks of copper originated from Cu substrate.

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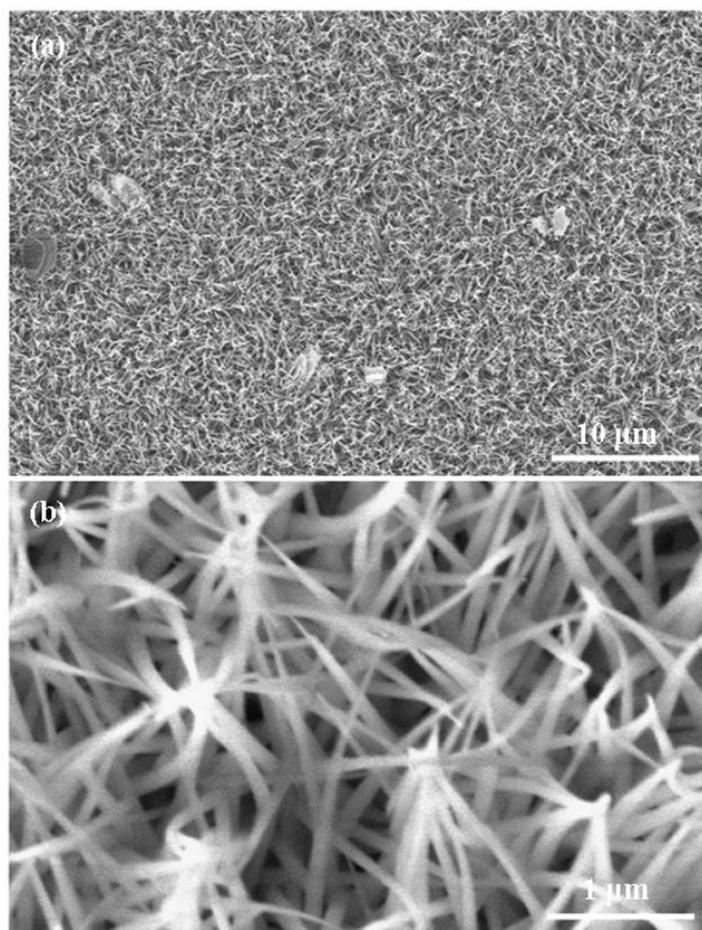
Fig. S4 Different-magnification SEM images of Co_3O_4 nanorod arrays on Cu substrate: (a) low-magnification SEM image; (b) high-mafnification SEM image. The morphology of binary Co_3O_4 nanorod arrays is similar to the ternary $NiCo_2O_4$ electrode, however, they have relatively smaller diameters.

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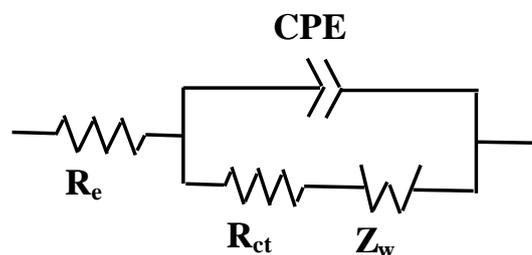
Fig. S5 Equivalent electrical circuit used to fit the EIS data. R_e is the electrolyte resistance, R_{ct} is the charge-transfer resistance, Z_w is the Warburg impedance related to the diffusion of Li ions into the bulk electrodes, and CPE is the constant phase-angle element, involving double layer capacitance.

Table S1 Kinetic parameters of binary Co_3O_4 and ternary $NiCo_2O_4$ nanorod array electrodes

Sample	R_e (Ω)	R_{ct} (Ω)
Co_3O_4 nanorod arrays	10.4	122.4
$NiCo_2O_4$ nanorod arrays	6.8	63.5
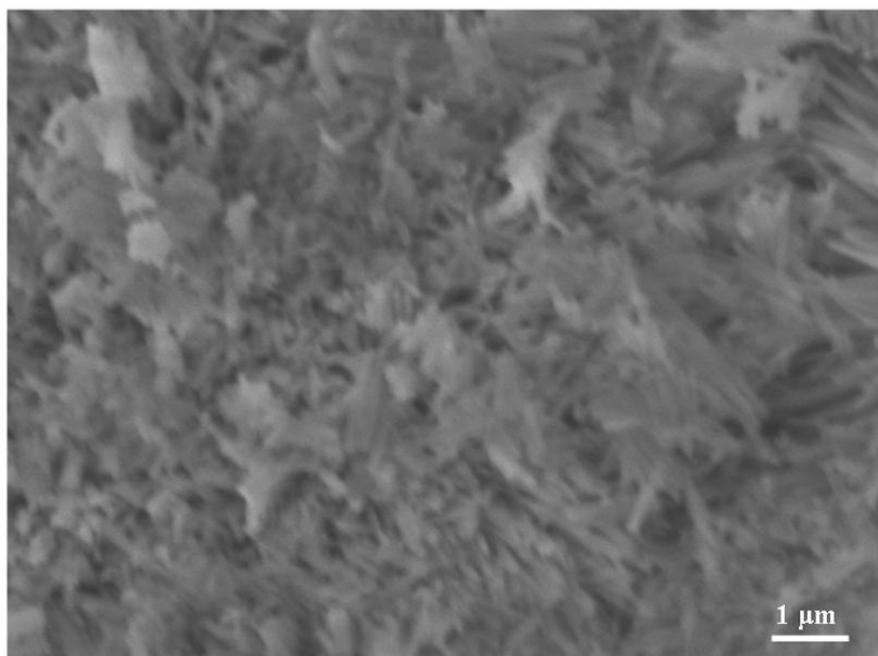
Fig. S6 SEM images of $NiCo_2O_4$ nanorod arrays electrode after 30 cycles at 0.5C. As shown in the SEM image, although the tip of some nanorods was broken, the 1D nanorod configuration of $NiCo_2O_4$ anode materials was still preserved, and the $NiCo_2O_4$ active material layer was still stuck on the surface of the Cu substrate.

The morphology of the final $NiCo_2O_4$ products can be reasonable controlled via changing the parameters of the current reaction. For example, when only urea was used as the OH^{-1} and CO_3^{2-} supplier, and the modification agent instead of the mixture of urea and hexamethylenetetramine, the finally obtained nanorod arrays on Cu substrate were not uniform and pure. And some assembled nanoplates were randomly covered on the top of these nanorods (Fig. S7a,b). The concentration of reactants has an important effect on the morphology and uniformity of the precursor during the hydro-deposition process. When the concentration of reaction solution containing of $Co(NO_3)_2$, $Ni(NO_3)_2$ and modification agents (urea and hexamethylenetetramine) increased into two times, only hierarchical microspheres composed of numerous small nanorods radially grown from the center were achieved. Fig. S7c,d exhibit the morphology of these hierarchical microspheres particle precursors. From these SEM images, it can be seen that these precursors still have the geometry of 1D nanorods, however, all these 1D nanorods self-assembled into 3D microspheres.
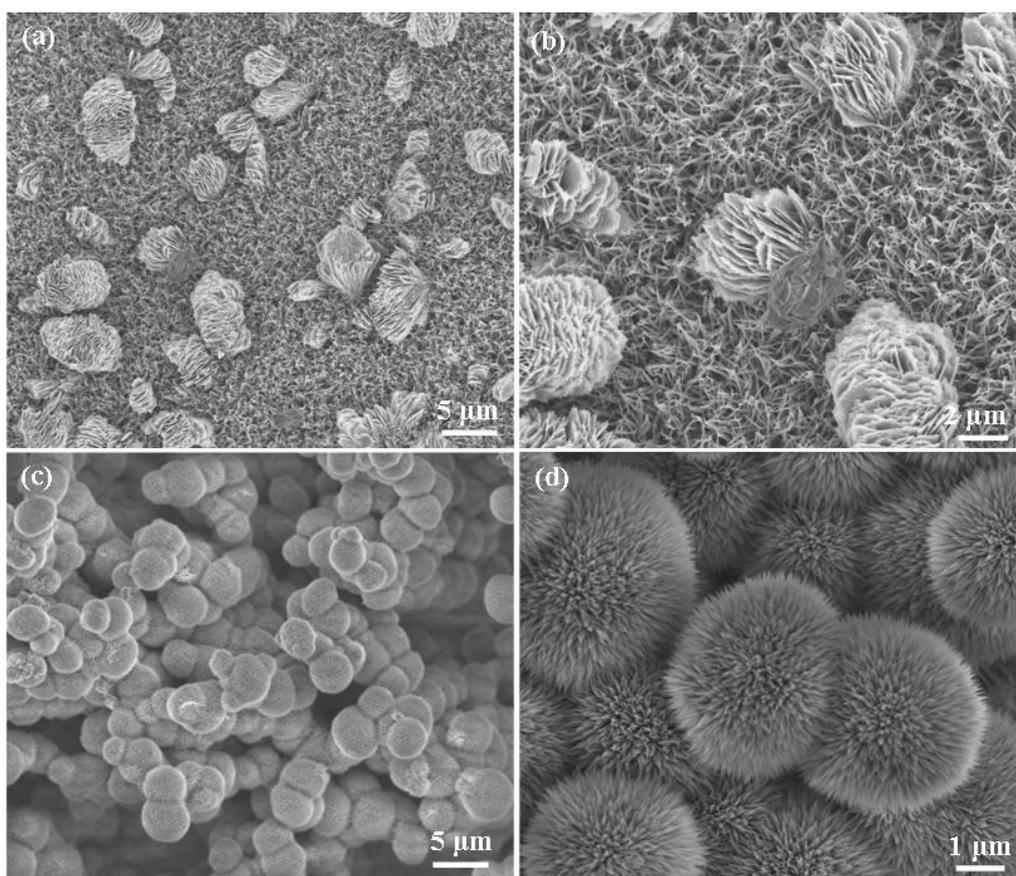
Fig. S7 (a,b) SEM images of precursor nanorod arrays covered with some densely assembled nanoplates obtained with only urea modification agent instead of the mixture of urea and hexamethylenetetramine; (c,d) SEM image of precursor hierarchical microspheres (composed of numerous small nanorods radially grown from the center) obtained with two times concentration of reaction solution containing of $Co(NO_3)_2$, $Ni(NO_3)_2$ and modification agents (urea and hexamethylenetetramine).