Supporting Information for

Assembling metal oxide nanocrystals into dense, hollow, porous nanoparticles for lithium-ion and lithium-oxygen battery application

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MATERIALS CHARACTERIZATION

The crystallographic information was investigated by XRD patterns, which were measured on a Bruker D8 GADDS diffractometer using Co Kα radiation (1.79 Å). The particle dispersion and morphology were characterized by field emission scanning electron microscopy (FESEM), which was taken on a XL30 ESEM microscope at a beam energy of 20 kV. The core-shell and hollow structures were characterized by transmission electron microscopy (TEM) using a JEOL-2100F microscope operated at 200 kV. The surface area and porosity of dense hollow porous nanoparticles were determined using a Quantachrome Autosorb-iQ-MP automated gas adsorption system using nitrogen as the adsorbate at liquid nitrogen temperature (77 K). The samples were outgassed under vacuum for 24 h at 100^{o}C. The specific surface area was calculated using the Brunauer-Emmett-Teller (BET) method and the pore diameters were obtained from the desorption branch of the isotherm using the Barrett-Joyner-Halenda (BJH) method. The actual mass percent of CoO on C@CoO was analyzed by the thermalgravimetric analysis (TGA, 10 ^{o}C min^{-1}, air).

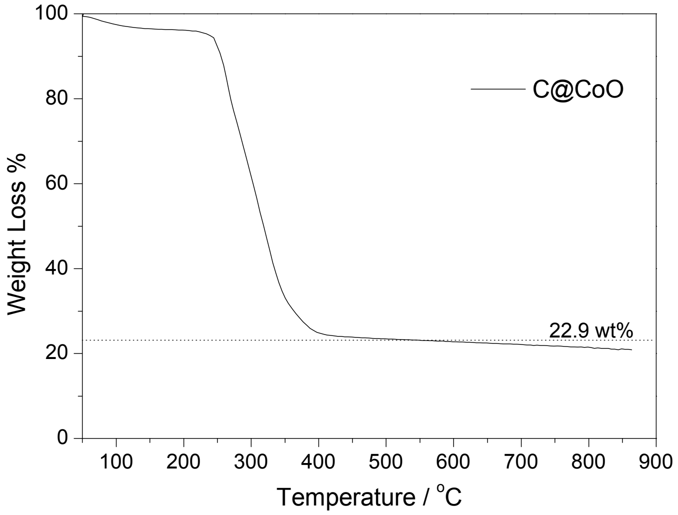

Figure S1. Thermalgravimetric analysis (TGA) of C@CoO with a heating rate of 10 °C min^{-1} in air. The actual mass percent of CoO (22.9 wt%) is higher than theoretic one (18.4%) which was calculated as below:

The mole of Co (n_{Co}): $n_{Co} = 0.15$ mmol (Experimental parameter);

The molar mass of CoO (M_{CoO}): $M_{CoO} = 74.93$ g mol^{-1};

The mass of CoO (m_{CoO}): $m_{CoO} = n_{Co} \times M_{CoO} = 0.15 \text{ mmol} \times 74.93 \text{ g mol}^{-1} = 11.24 \text{ mg}$;

The mass percent of CoO ($m_{CoO}\%$):

$m_{CoO}\% = m_{CoO} / (m_{carbon\ colloids} + m_{CoO}) \times 100\% = 11.24 / (50 + 11.24) \times 100\% = 18.4\%$.

It is reasonable because the carbon colloids (50 mg) are a well-known carbonaceous material which contains a lot of H and O atoms.[Ref.S1-S3] In the N_2 atmosphere calcination to form C@CoO from C@Co-salt, the carbon colloids will lose a certain amount of C, H and O ($C + O \rightarrow CO_2/CO$, $H + O \rightarrow H_2O$), thereby giving rise to a higher actual value than theoretic one.

S1. X. M. Sun and Y.D. Li, *Angew. Chem. Int. Ed.*, 2004. **43**, 597-601

S2. M. Sevilla and A. B. Fuertes, *Carbon*, 2009, **47**, 2281-2289.

S3. J. Ming, R. X. Liu, G. F. Liang, H. Y. Cheng, Y. C. Yu and F. Y. Zhao, *J. Mater. Chem.*, 2011, **21**, 10929-10934.

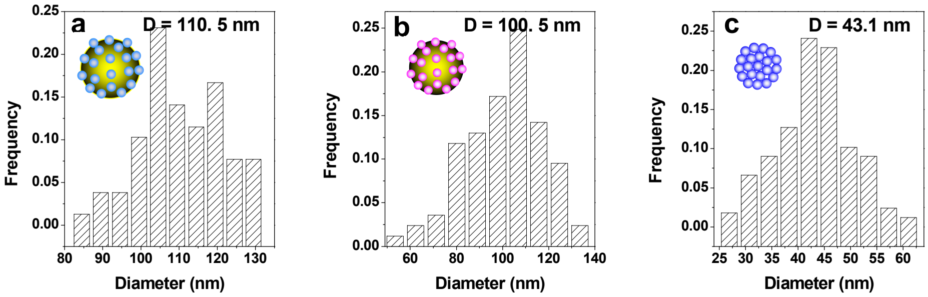

Figure S2. Variation of (a) C@Co-salt, (b) C@CoO$_x$ and (c) DHP Co$_3$O$_4$ nanoparticle diameters.

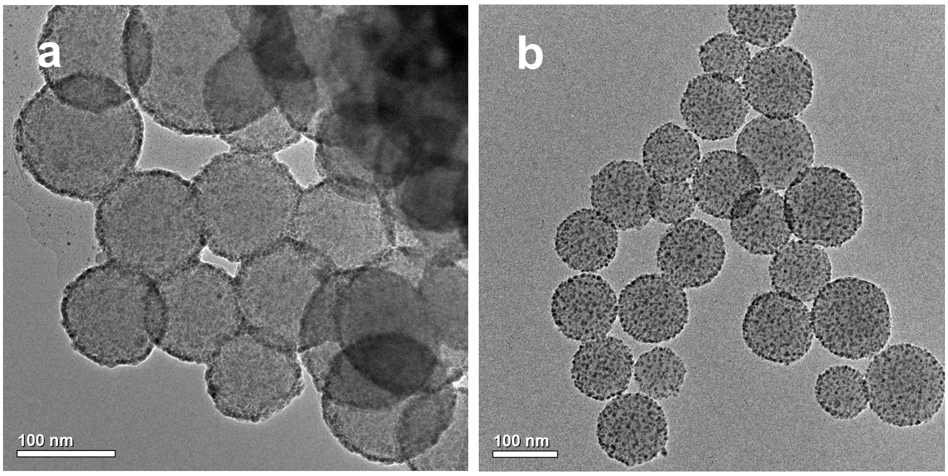

Figure S3. TEM images of core-shell structured (a) C@FeO$_x$ and (b) C@NiO$_x$ particles.