# Supporting information

# Synthesis of spinel $(Mg_{0.2}Co_{0.2}Ni_{0.2}Cu_{0.2}Zn_{0.2})Fe_2O_4$ in seconds for lithium-ion battery anode

Ruiqi Ren,<sup>a</sup> Dixian Wu,<sup>a</sup> Jingyuan Zhang,<sup>a</sup> Xiangyu You,<sup>a</sup> Zikang Xu,<sup>a</sup> Jinyao Yang,<sup>a</sup> Hang Ren,<sup>a</sup> Guoyin Zhu,<sup>a</sup> Yizhou Zhang,<sup>a</sup> and Shengyang Dong<sup>\*a, b</sup>

<sup>a</sup> School of Environmental Science and Engineering, School of Chemistry and Materials Science, Nanjing University of Information Science and Technology, Nanjing 210044, P. R. China
\*E-mail: dongsyst@nuist.edu.cn

<sup>b</sup> Institute of Applied Physics and Materials Engineering, University of Macau, Taipa, Macao SAR 999078, P. R. China

## **Experimental section**

# Synthesis of $(Mg_{0.2}Co_{0.2}Ni_{0.2}Cu_{0.2}Zn_{0.2})Fe_2O_4$ HEO

Metal oxide powder mixtures, including Fe<sub>2</sub>O<sub>3</sub> (16.000 g, 98.8 %, Shanghai Aladdin Biochemical Technology Co., Ltd.), CoO (0.749 g, 99 %, Shanghai Macklin Biochemical Technology Co., Ltd.), NiO (0.747 g, 99.3 %, Shanghai Macklin Biochemical Technology Co., Ltd.), MgO (0.403 g, 99 %, Shanghai Macklin Biochemical Technology Co., Ltd.), ZnO (0.814 g, 99 %, Sinopharm Chemical Reagent Co., Ltd.), and CuO (0.795 g, 99 %, Sinopharm Chemical Reagent Co., Ltd.) with a molar ratio of  $M^{2+}:M^{3+} = 1:2$  was subjected to mechanical mixing using a planetary ball mill for 2 hours at a rotational speed of 250 r min<sup>-1</sup>. Subsequently, the mixture of 0.5 g is then pressed into a sheet with a thickness of approximately 1 mm. Next, the pressed precursor is transferred onto a graphite paper. Then another piece of graphite paper with the same size is placed on the top. By controlling the temperature and time in a Joule heating device (JH-3, Hefei In-Situ Technology. Co. Ltd.), the target HEO can be obtained. In this process, current and energizing time are the main considerations to control the temperature. For example, the optimized parameters of 1250 °C, 5 s are 200 A, 5 s (temperature raising step) and 190 A, 5 s (temperature holding step).

### <u>Characterization</u>

X-ray diffraction (XRD) was performed on a Rigaku Ultra 250 detector with Cu K $\alpha$  radiation. The diffraction peaks were recorded with an interval of 0.02° and a sweep rate of 3° min<sup>-1</sup>. The morphologies and microstructures were collected by scanning electron microscopy (SEM, ZEISS, Gemini300S) and transmission electron microscopy (TEM, JEOL). X-ray photoelectron spectroscopy (XPS, PerkinElmer PHI 550 spectrometer) was performed on an Al K $\alpha$  source.

#### **Electrochemical measurements**

Electrochemical performance testing was conducted using CR2032 coin cells. The active materials (70 wt%) were uniformly mixed with acetylene black (20 wt%) and polyvinylidene fluoride (PVDF) (10 wt%). This mixture was then dissolved in N-

methyl pyrrolidone (NMP) to form a slurry. The slurry was subsequently cast onto a copper foil and dried under vacuum at 110 °C for 10 hours. The mass loading of working electrode is about 2 mg cm<sup>-2</sup>. The half-cells were assembled within an argon-filled glove box, with the moisture and oxygen content maintained at less than 1 ppm. The electrolyte is a mixture of 1 M LiPF<sub>6</sub> in a volumetric ratio of 1:1:1 of ethylene carbonate (EC), ethyl methyl carbonate (EMC), and dimethyl carbonate (DEC). For the counter electrode and reference electrode, thin Li sheets were employed. Additionally, a microporous polyolefin separator (Celgard 2400, 20 mm) was used to be the separator.

The galvanostatic charge-discharge (GCD) and the galvanostatic intermittent titration technique (GITT) processes were performed using a LANBTS battery testing system. Cyclic voltammogram (CV) and electrochemical impedance spectroscopy (EIS) tests were conducted on an electrochemical workstation (CorrTest CS-350).

The Li<sup>+</sup> diffusion coefficient reflects the kinetic behaviors of the HEO was calculated by the following equation:

$$D = \frac{4}{\pi\tau} \left(\frac{m\nu}{MS}\right)^2 \left(\frac{\Delta E_S}{\Delta E_t}\right)^2 \tag{1}$$

where D (cm<sup>2</sup> s<sup>-1</sup>) is the diffusion coefficient.  $\tau$  (s) corresponds to the constant current pulse time; m (g), M (g mol<sup>-1</sup>), v (cm<sup>3</sup> mol<sup>-1</sup>) and S (cm<sup>2</sup>) mean to the active mass, molar mass, molar volume, and contacting area of electrode with the electrolyte of the active material, respectively;  $\Delta E_s$  (V) is the change of steady-state voltage during the current pulse, and  $\Delta E_t$  (V) represents the potential difference at a constant current subtracting IR drop.



Fig. S1. XRD pattern of raw materials.



Fig. S2. XRD patterns of (MgCoNiCuZn)Fe<sub>2</sub>O<sub>4</sub> under different synthetic processes. (a) Different temperatures at the same sintering times of 5 s. (b) Different sintering time at the same temperature of 1250 °C. The impurity peaks are labeled with black

inverse triangles and rhombi.



Fig. S3. SEM image of (MgCoNiCuZn)Fe<sub>2</sub>O<sub>4</sub> HEO.



Fig. S4. High-resolution XPS spectra of O 1s.



Fig. S5 (a~h) The pseudocapacitance contribution of (MgCoNiCuZn)Fe $_2O_4$  at

different scan rates.



Fig. S6. Current step diagram of (MgCoNiCuZn)Fe<sub>2</sub>O<sub>4</sub> electrode.



Fig. S7. Ex-situ XRD test. (a) GCD curves of (MgCoNiCuZn)Fe<sub>2</sub>O<sub>4</sub> electrode at 50 mA  $g^{-1}$ . (b) XRD patterns under different charge and discharge states.



Fig. S8. The SEI film (inside the red dotted line) in HRTEM after first charge-

discharge cycle.