SnO_2 nanotubes with N-carbon coating for advanced Li-ion battery anodes

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Supplementary materials

1 Characterization

Scanning electron microscopy (SEM; S8100) with energy-dispersive X-ray spectroscopy (EDS) and high-resolution transmission electron microscopy (HRTEM; HT-7700) were performed to determine the morphologies and microstructures. The structure information and element valences were analyzed by X-ray diffraction (XRD; Bruker D8 Advance) using Cu Kα radiation at a wavelength of 1.5418 Å and X-ray photoelectron spectroscopy (XPS; ESCALAB 250). The Raman spectra were conducted on a Renishaw in-Via spectrometer equipped with a 532 nm laser. Thermogravimetric analysis (TGA; SDT 2960) was used to analyze the SnO_2 and the carbon contents. The analysis was conducted from room temperature to 600 °C at a heating rate of 10 °C·min^{-1} in air. The N_2 adsorption/desorption isotherms and pore size distribution were measured using the Brunauer–Emmett–Teller (BET) method (Micromeritics ASAP 2460).

2 Electrochemical measurements

CR2032 coin cells were used for the battery performance tests. Li-ion batteries (LIBs) were assembled in an argon-filled glove box ([O_2] < 0.5 ppm, [H_2O] < 0.5 ppm). The working electrodes were prepared by mixing SnO_2@N-C nanotubes or SnO_2 nanotubes, acetylene black (conductive agent), and sodium carboxymethyl cellulose (CMC, binder) with a mass ratio of 8:1:1 with deionized water to produce the slurry. The copper foil was coated evenly with the slurry and dried in a vacuum oven at 60 °C for 24 h. The electrodes were pressed into a disc (d = 12 mm). The mass loading of the active mass among SnO_2/N-C NT and SnO_2 NT anodes were approximately 1.89 and 1.85 mg·cm^{-2}, respectively. The counter electrode was a lithium sheet with a polypropylene film (Celgard 240) as the separator. 1 mol·L^{-1} $LiPF_6$ dissolved in carbonate/diethyl carbonate, ethylene carbonate/dimethyl with 1:1:1 (volume ratio) was used as the electrolyte. All cells were tested using a galvanostatic discharge/charge cycle test on a battery test instrument (Shenzhen Neware

Technology Co., Ltd., CT-4008) at different current densities from 0.01 to 3.0 V (*vs.* Li/Li^+) at room temperature. Cyclic voltammetry (CV) was performed on an electrochemical workstation (CHI-660D) at different scan rates between 0.01 to 3.0 V (*vs.* Li/Li^+). The impedance measurements were carried out by applying an AC amplitude of 5 mV_{rms} on an equilibrium potential of 2.4 V (*vs.* Li/Li^+) over the frequency range of 10 mHz to 100 kHz.

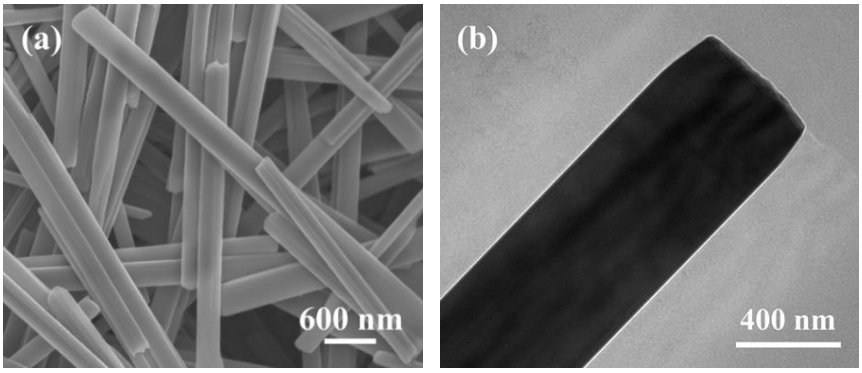

Fig. S1 (a) SEM and **(b)** TEM images of MoO_3 nanorods.

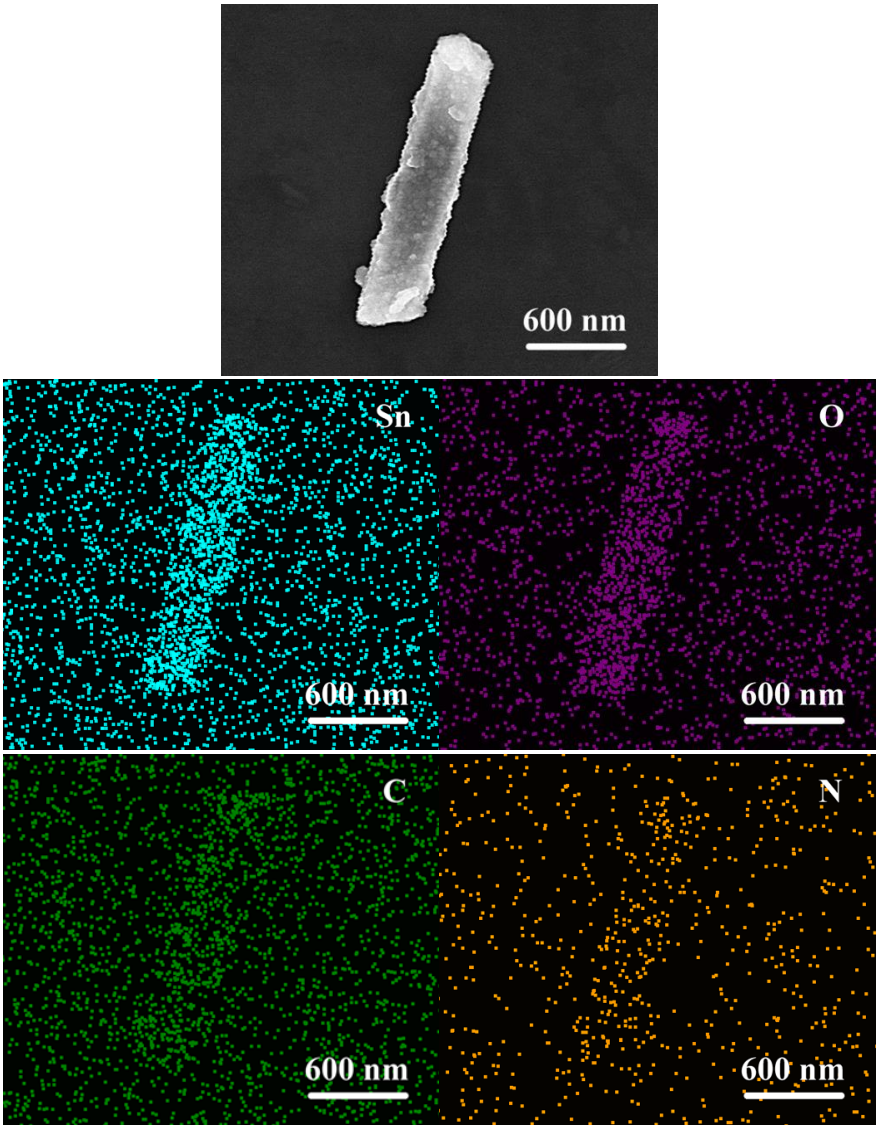

Fig. S2 Elemental mapping images of SnO_2@N-C NT.

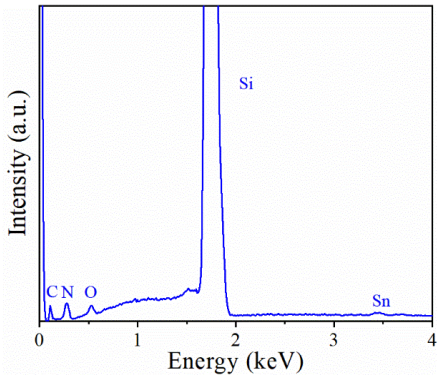

Fig. S3 EDS analysis of SnO_2@N-C NT.

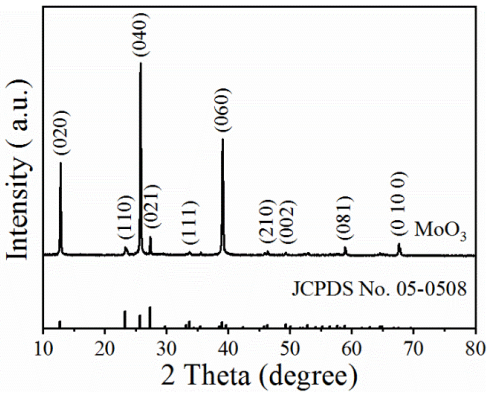

Fig. S4 XRD pattern of MoO_3 nanorods.

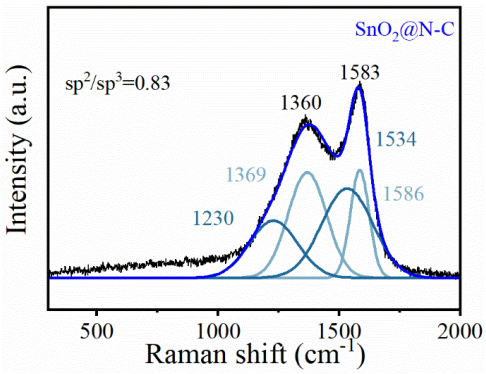

Fig. S5 Deconvoluted Raman spectra of D and G bands.

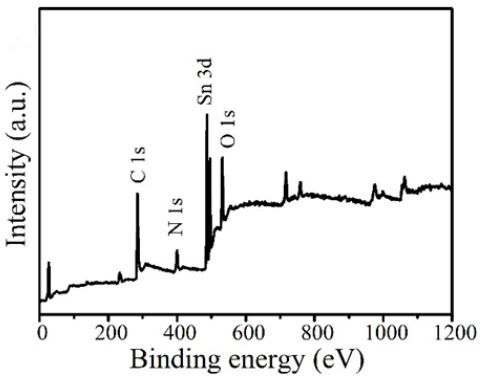

Fig. S6 XPS survey spectrum of SnO_2@N-C NTs.

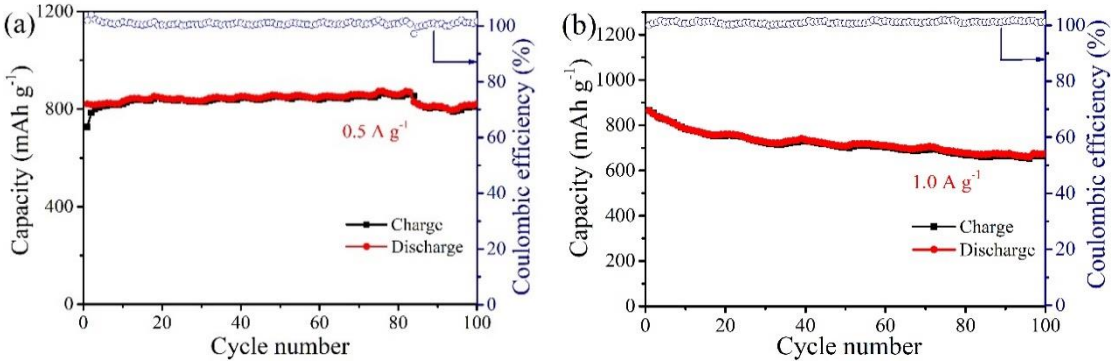

Fig. S7 Cycling stability of SnO_2@N-C NT anodes at current densities of **(a)** 0.5 $A \cdot g^{-1}$ and **(b)** 1.0 $A \cdot g^{-1}$.

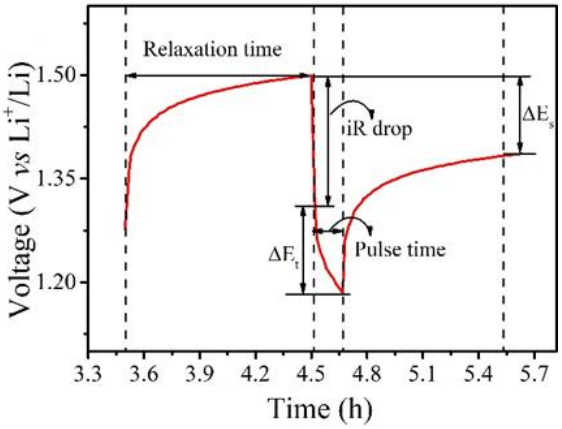

Fig. S8 Voltage response over time during a single current pulse.

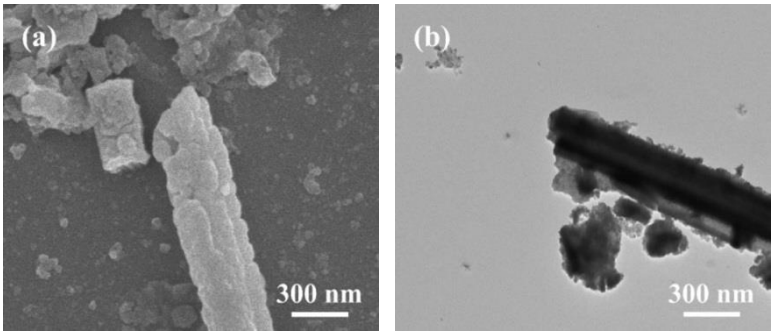

Fig. S9 (a) SEM and **(b)** TEM images of the SnO_2@N-C NT electrode after 100 cycles.

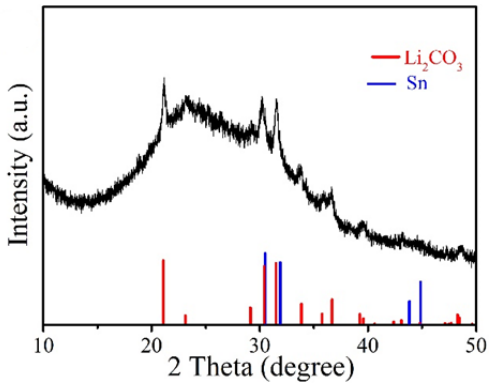

Fig. S10 XRD pattern of the SnO_2@N-C NT electrode after 100 cycles.

Table S1 Comparison of cyclic properties between synthetic materials and some other composites reported in literature

Electrode material	Current density/($A \cdot g^{-1}$)	Cycle number	Reversible capacity/($mAh \cdot g^{-1}$)	Ref.
SnO_2 microspheres	0.1	50	760.0	[38]
Co-SnO_2@GO nanosheets	0.1	90	1157.4	[39]
SnO_2@C nanowires	0.1	50	680.0	[40]
SnO_2@SnS_2	0.1	50	1068.0	[41]
SnO_2@FeOOH@C	1.0	160	262.2	[42]
SnO_2@PPy	1.0	100	591.0	[43]
SnO_2@MnO_2@GO	1.0	100	400.0	[44]
CoPPc@SnO_2 nanotubes	0.2	400	950	[17]
SnO_2@N-C nanotubes	0.1	100	1369.3	this work
	1.0	100	622.8	this work

Table S2 Simulation model with the estimated values

R/Ω	R_1	R_2	R_{ct}
SnO_2@N-C NT (fresh cell)	1.7	–	98.9
SnO_2@N-C NT (after 100 cycles)	3.7	3.7	11.4
SnO_2 NT (fresh cell)	1.6	–	279.1
SnO_2 NT (after 100 cycles)	8.7	58.7	44.2