

Supplementary information

Carbon-coated $\text{MoS}_{1.5}\text{Te}_{0.5}$ nanocables for efficient sodium-ion storage in non-aqueous dual-ion batteries

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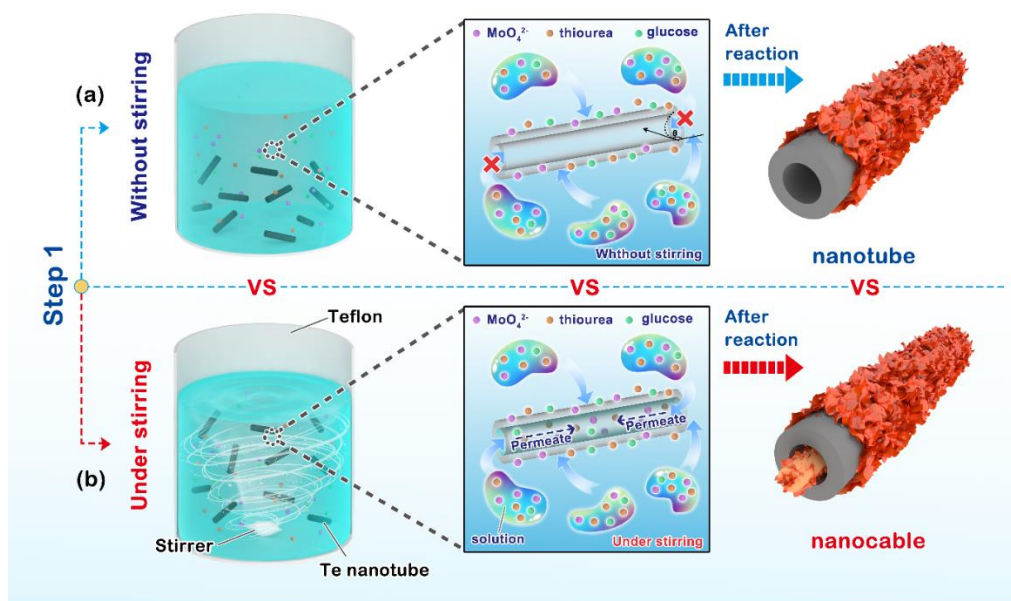
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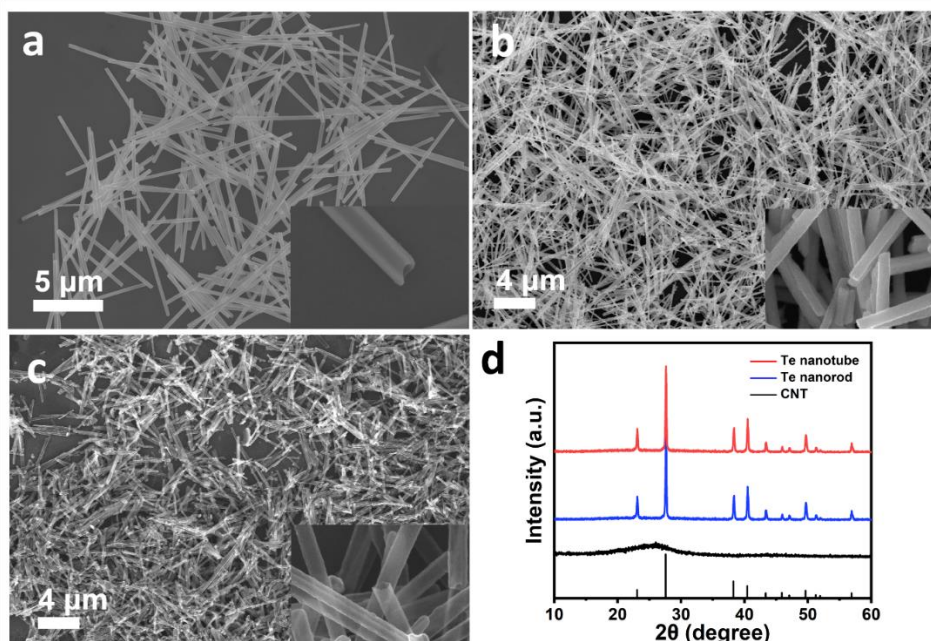
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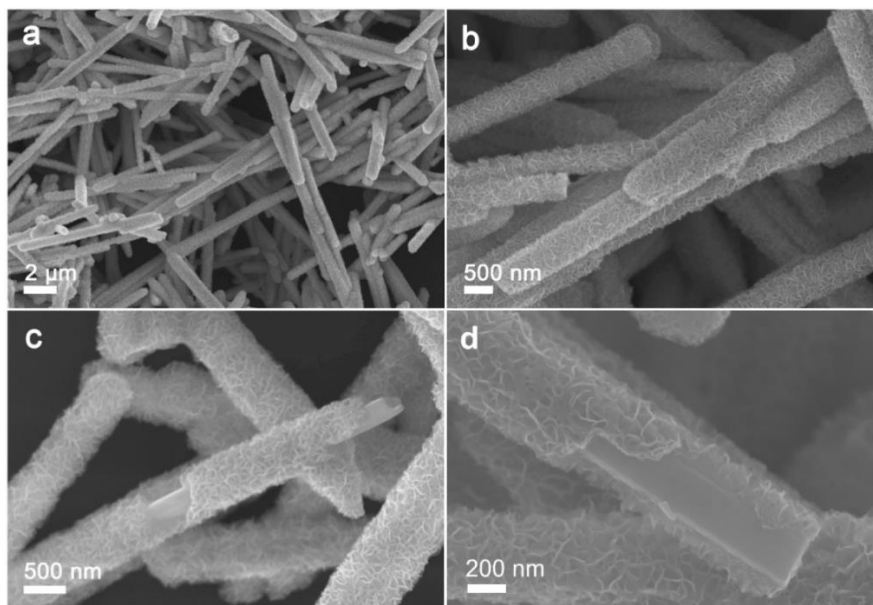
Supplementary Figures



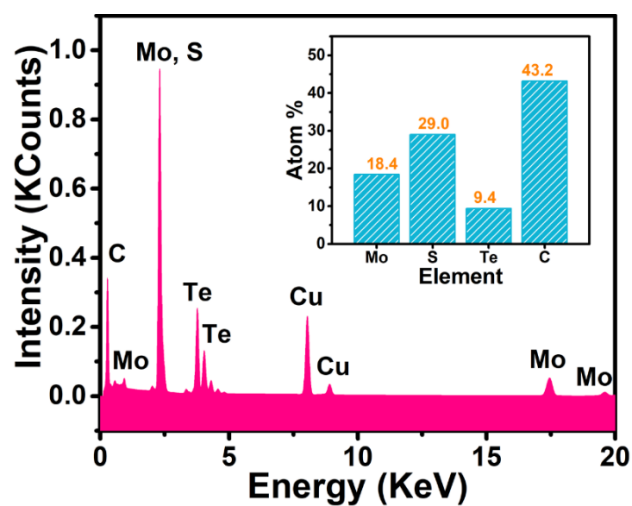
Supplementary Figure 1. Schematic illustration of the formation process of nanotube and nanocable structures under normal and stirring hydrothermal processes (Step 1) at 180 °C for 10 h respectively.



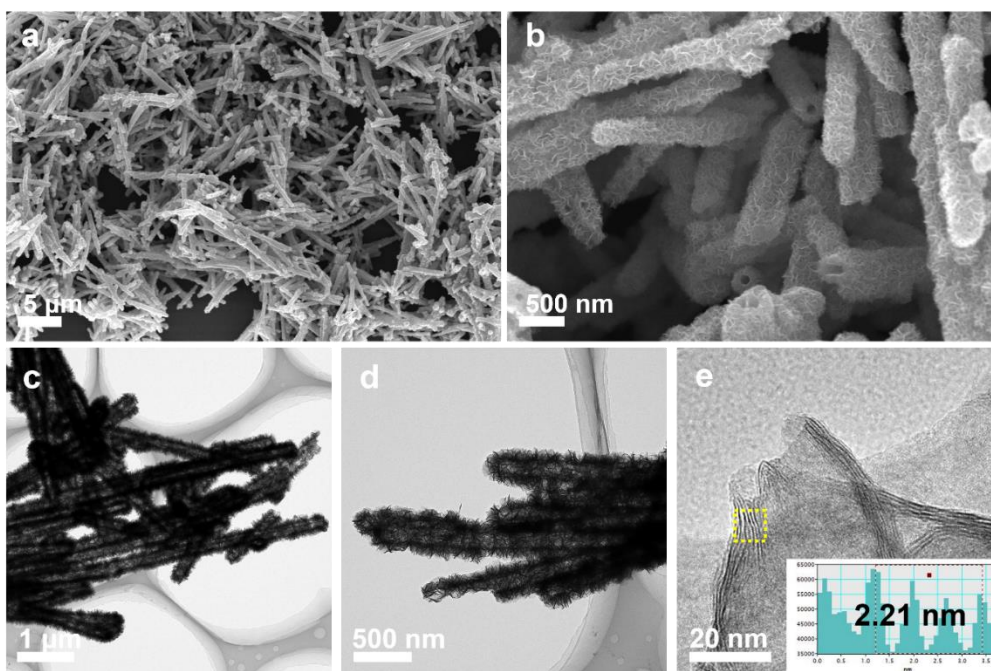
Supplementary Figure 2. SEM images of (a) Te nanotubes, (d) Te nanorods and (c) CNT and corresponding XRD pattern.



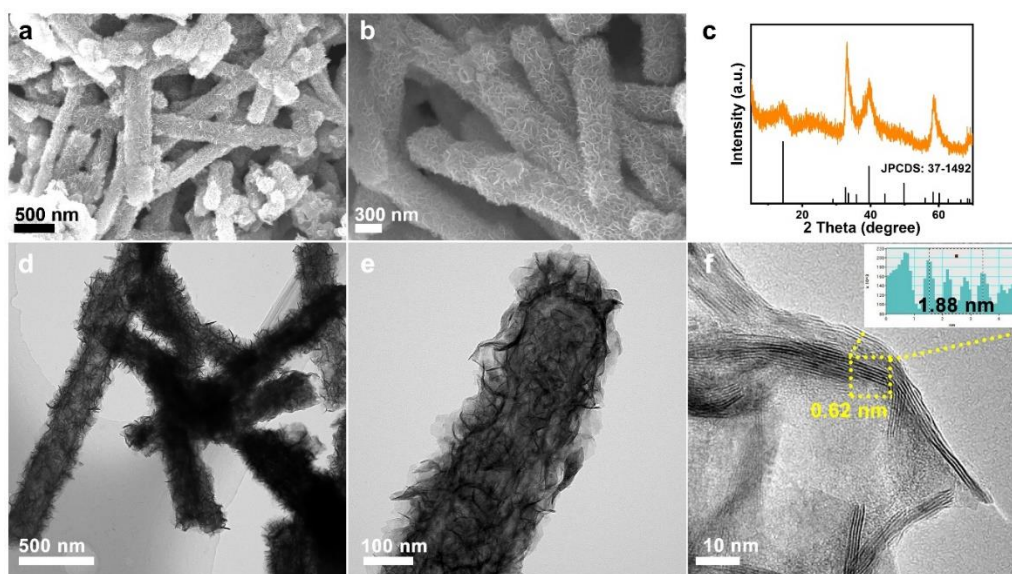
Supplementary Figure 3. (a-c) SEM images of Te@C/MoS₂.



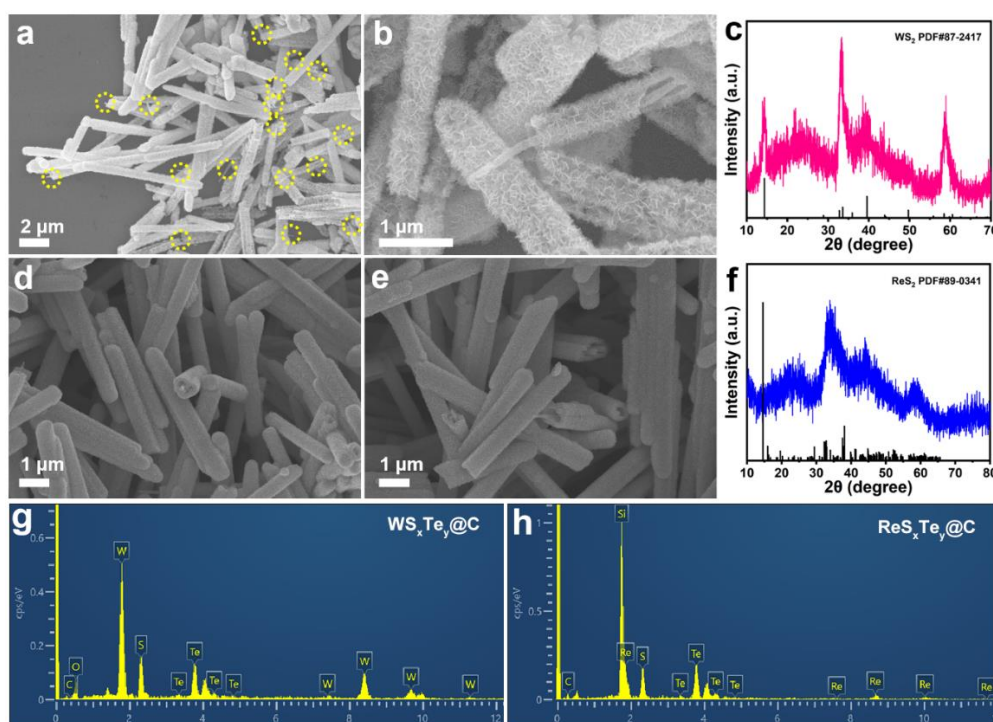
Supplementary Figure 4. EDS spectrum and table (inset) illustrating the element content contained in $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanocables.



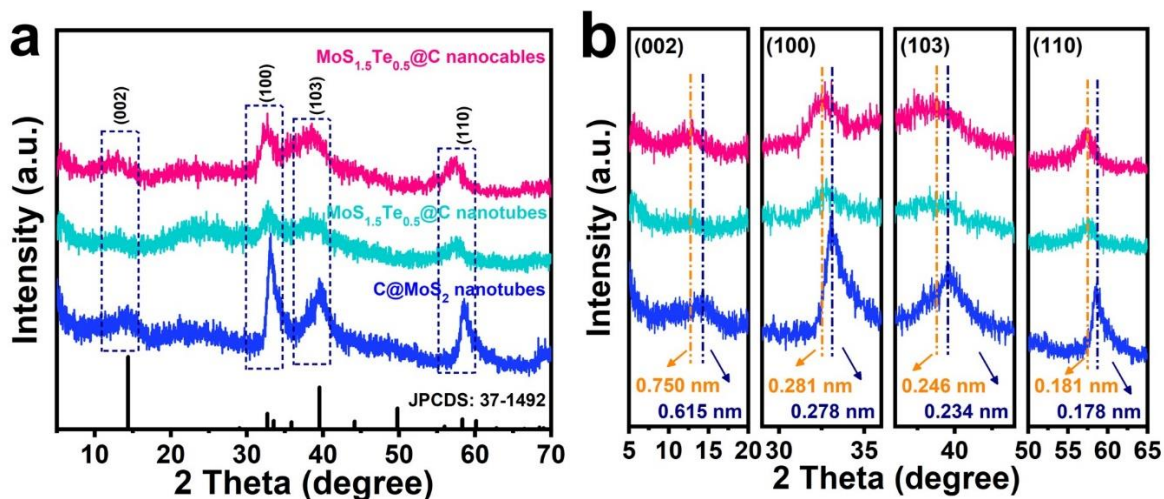
Supplementary Figure 5. (a-b) SEM images and (c-e) TEM images of $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanotubes.



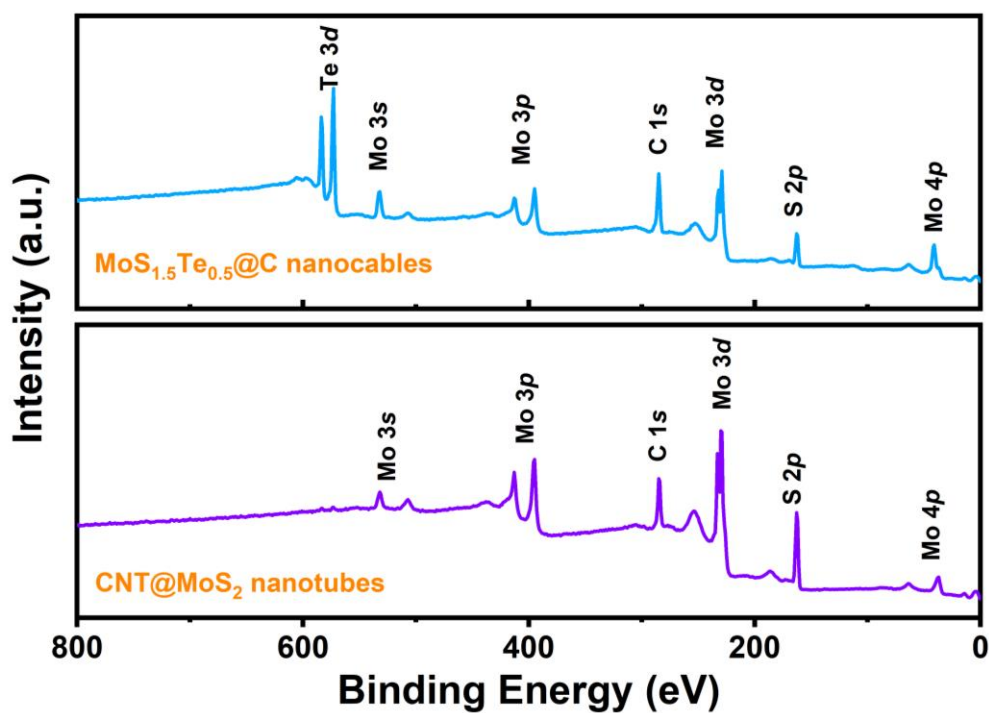
Supplementary Figure 6. (a,b) SEM images, (c) XRD pattern and (d-f) TEM images of CNT@MoS₂ nanotubes.



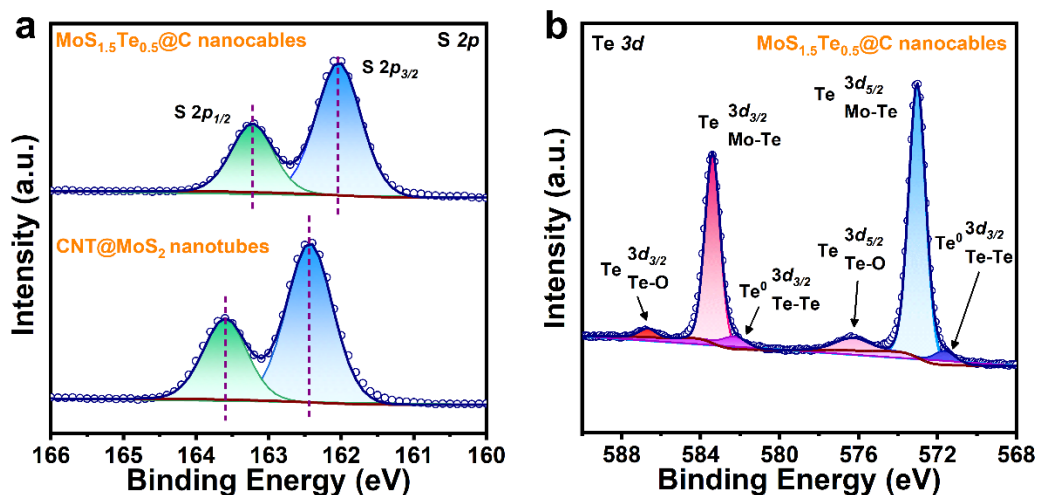
Supplementary Figure 7. The SEM images of (a,b) wire-in-tube WS_xTe_y@C nanocables and (d,e) wire-in-tube ReS_xTe_y@C nanocables. XRD results of (c) wire-in-tube WS_xTe_y@C nanocables and (f) wire-in-tube ReS_xTe_y@C nanocables. EDX spectrum of the WS_xTe_y@C nanocables (g) and ReS_xTe_y@C nanocables (h).



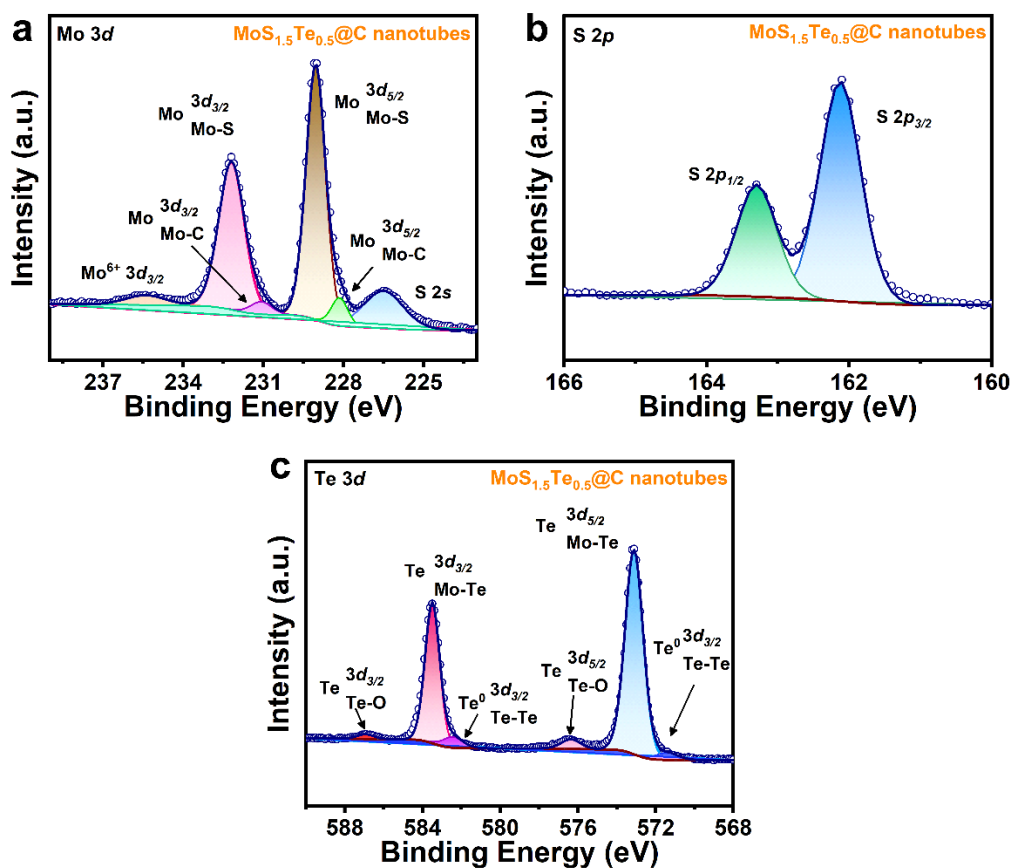
Supplementary Figure 8. XRD patterns of $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanocables, $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanotubes, and $\text{CNT}@\text{MoS}_2$ nanotubes composites.



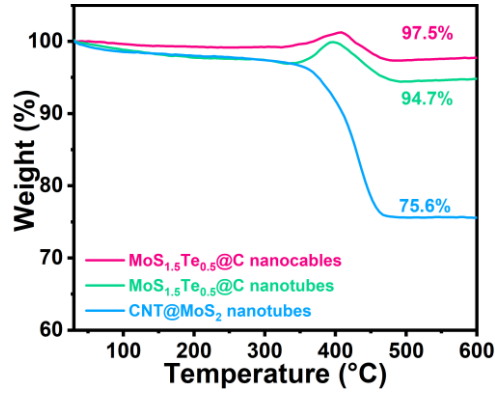
Supplementary Figure 9. The survey XPS spectrum of the $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanocables and the $\text{CNT}@\text{MoS}_2$ composites.



Supplementary Figure 10. High-resolution XPS spectra for (a) S 2p and (b) Te 3d of $\text{MoS}_{1.5}\text{Te}_{0.5}@C$ nanocables composites.



Supplementary Figure 11. High-resolution XPS spectra for (a) Mo 3d, (b) S 2p and (c) Te 3d of $\text{MoS}_{1.5}\text{Te}_{0.5}@C$ nanotubes composites.



Supplementary Figure 12. TGA curves of MoS_{1.5}Te_{0.5}@C nanocables, MoS_{1.5}Te_{0.5}@C nanotubes and CNT@MoS₂ nanotubes samples under air atmosphere.

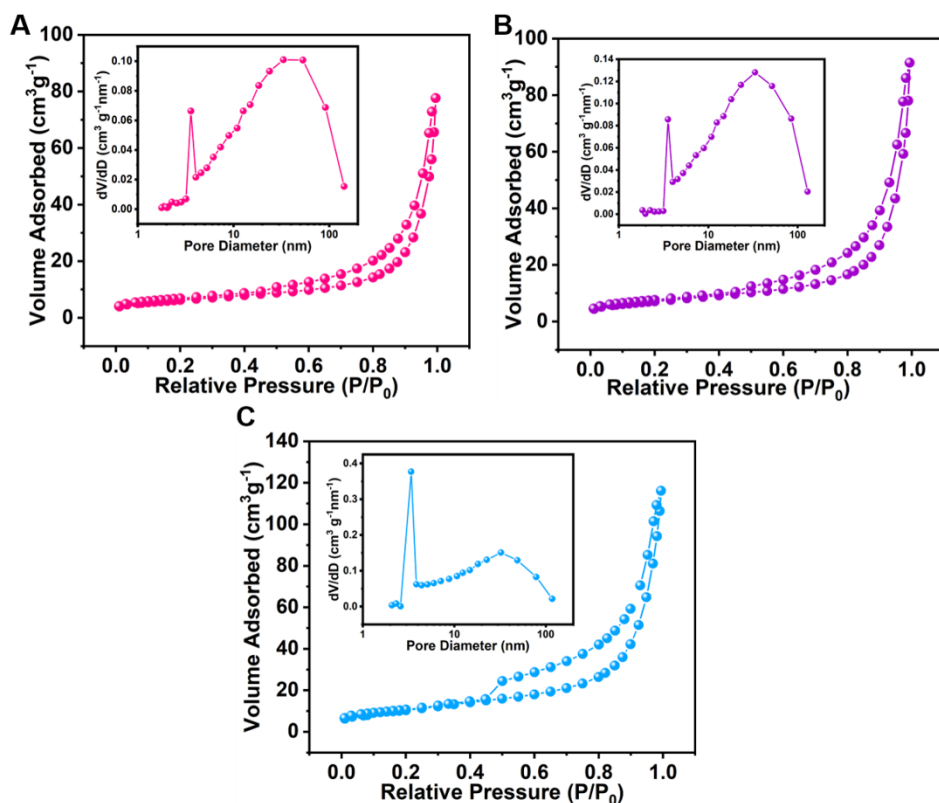
An initial weight loss below 200 °C is attributed to the evaporation and desorption of surface adsorbed water molecules. The second weight loss between 200-700 °C is the oxidation of active substance MoS_{1.5}Te_{0.5} in the composite into MoO₃, SO₂, and TeO₂, and the carbon is transformed into CO₂. It's worth noting that the weight increase in 200-400 °C is attributed with the generation of TeO₂. Form the above, the residual weight percent of MoS_{1.5}Te_{0.5}@C nanocables, MoS_{1.5}Te_{0.5}@C nanotubes and CNT@MoS₂ nanotubes samples at 650 °C are 97.5%, 94.7% and 75.6%, respectively. The content of MoS_{1.5}Te_{0.5} ($\omega_{\text{MoS}_{1.5}\text{Te}_{0.5}}$) in the MoS_{1.5}Te_{0.5}@C nanocables and MoS_{1.5}Te_{0.5}@C nanotubes samples are calculated from the Supplementary Equation (1), and the content of MoS₂ (ω_{MoS_2}) in the CNT@MoS₂ nanotubes also could be obtained from the Supplementary Equation (2):

$$\omega_{\text{MoS}_{1.5}\text{Te}_{0.5}} = \frac{M_{\text{MoS}_{1.5}\text{Te}_{0.5}}}{M_{(\text{MoO}_3 + \text{TeO}_2)}} * \omega_{(\text{MoO}_3 + \text{TeO}_2)} \quad (1)$$

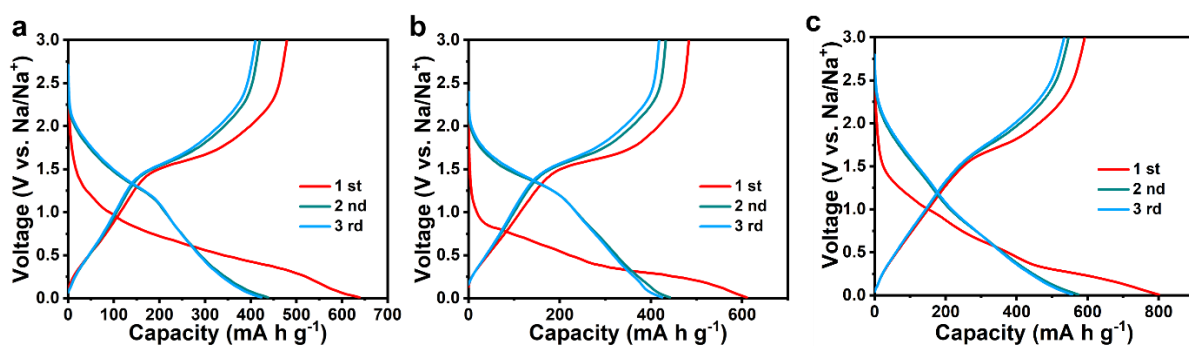
$$\omega_{\text{MoS}_2} = \frac{M_{\text{MoS}_2}}{M_{\text{MoO}_3}} * \omega_{(\text{MoO}_3)} \quad (2)$$

$$\omega_{\text{Te}} = \frac{M_{\text{Te}}}{M_{\text{MoS}_{1.5}\text{Te}_{0.5}}} * \omega_{\text{MoS}_{1.5}\text{Te}_{0.5}} \quad (3)$$

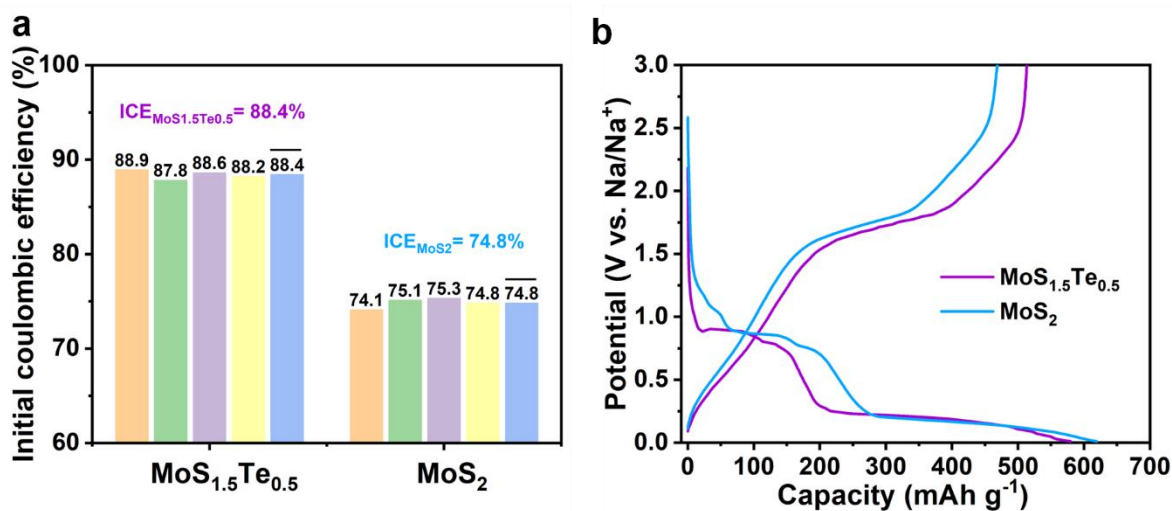
Thus, the active substance content in MoS_{1.5}Te_{0.5}@C nanocables, MoS_{1.5}Te_{0.5}@C nanotubes and CNT@MoS₂ nanotubes samples are calculated at 90.9 %, 87.9 % and 84.1 %, respectively. On the other hand, the corresponding carbon content in the three samples is 9.1 %, 12.1 %, and 15.9 %, respectively. Impressively, the Te atoms doping with a high loading (~30 wt%) in the MoS_{1.5}Te_{0.5}@C nanocables could be achieved (Supplementary Equation (3)).



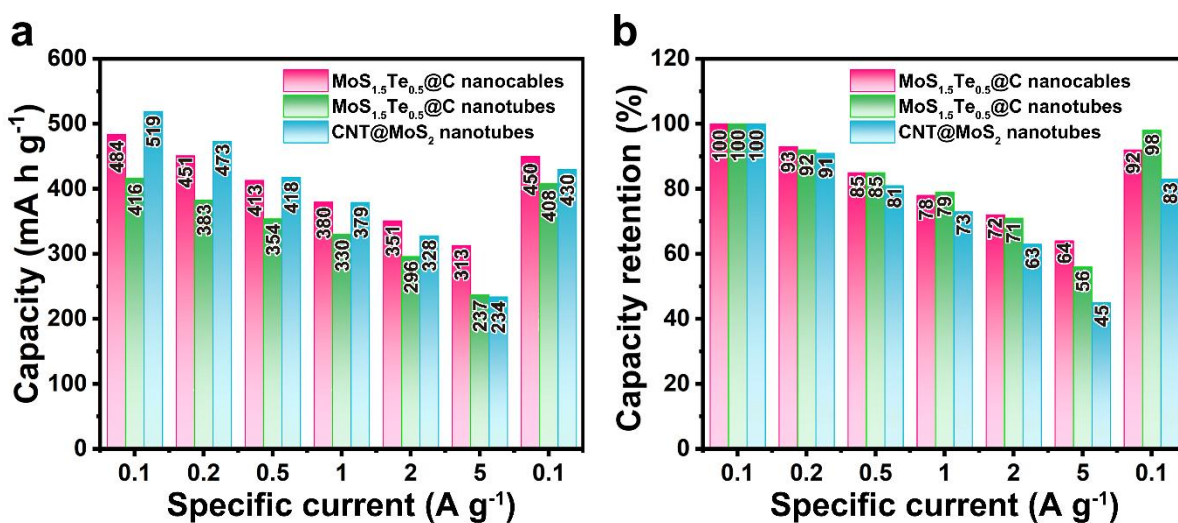
Supplementary Figure 13. Nitrogen adsorption-desorption isothermal curves (inset: pore size distribution) for (a) $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanocables, (b) $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanotubes and (c) $\text{CNT}@\text{MoS}_2$ nanotubes.



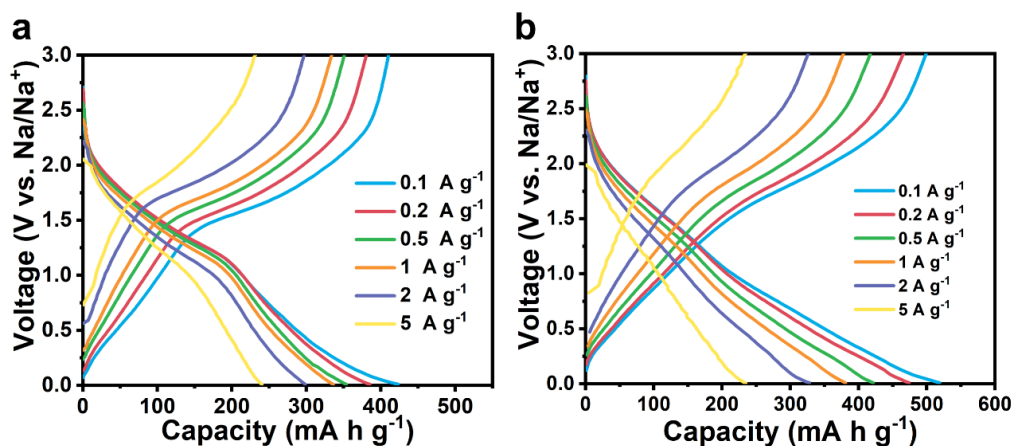
Supplementary Figure 14. Charge-discharge profiles of (a) the $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanocables, (b) the $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanotubes and (c) the $\text{CNT}@\text{MoS}_2$ electrodes tested in combination with Na metal electrode at a specific current of 0.1 A g^{-1} . The electrochemical measurements were carried out using a 1 M NaPF_6 in EC/EMC/DMC (1:1:1, by volume) electrolyte solution at 25°C .



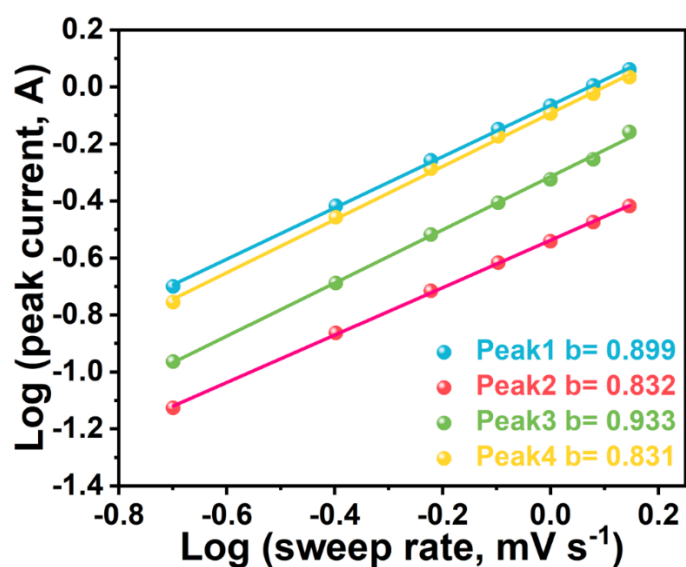
Supplementary Figure 15. a) ICE for two different set of electrochemical experiments comprising five different Na metal|| $\text{MoS}_{1.5}\text{Te}_{0.5}$ and Na metal|| MoS_2 cells each and, b) the 1st sodiation/desodiation potential profiles of the $\text{MoS}_{1.5}\text{Te}_{0.5}$ - and MoS_2 -based electrodes. The electrochemical measurements were carried out using a 1 M NaPF_6 in EC/EMC/DMC (1:1:1, by volume) electrolyte solution at 100 mA g⁻¹ and 25 °C.



Supplementary Figure 16. (a) The average capacities and (b) the capacity retention rate of the MoS_{1.5}Te_{0.5}@C nanocables, MoS_{1.5}Te_{0.5}@C nanotubes and CNT@MoS₂ nanotubes electrodes sampled at the 5th discharge cycles for Na metal half-cell testing at various current rates based on the data used for Figure 3d.

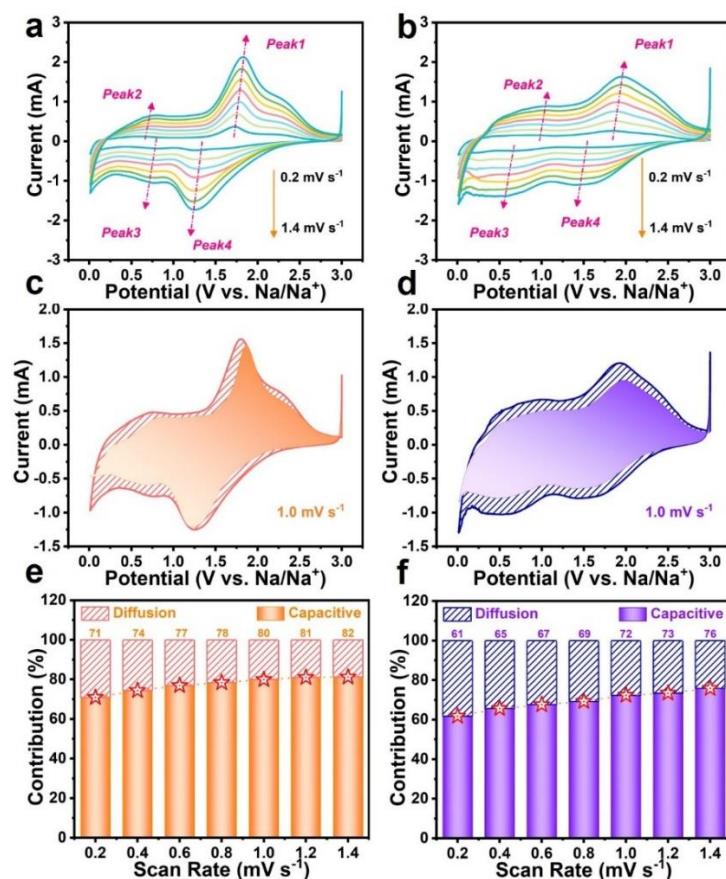


Supplementary Figure 17. Charge-discharge profiles of (a) the MoS_{1.5}Te_{0.5}@C nanotubes and (b) the CNT@MoS₂ electrodes tested in combination with a Na metal counter electrode at various specific currents (from 0.1 to 5.0 A g⁻¹). The electrochemical measurements were carried out using a 1 M NaPF₆ in EC/EMC/DMC (1:1:1, by volume) electrolyte solution at 25 °C.



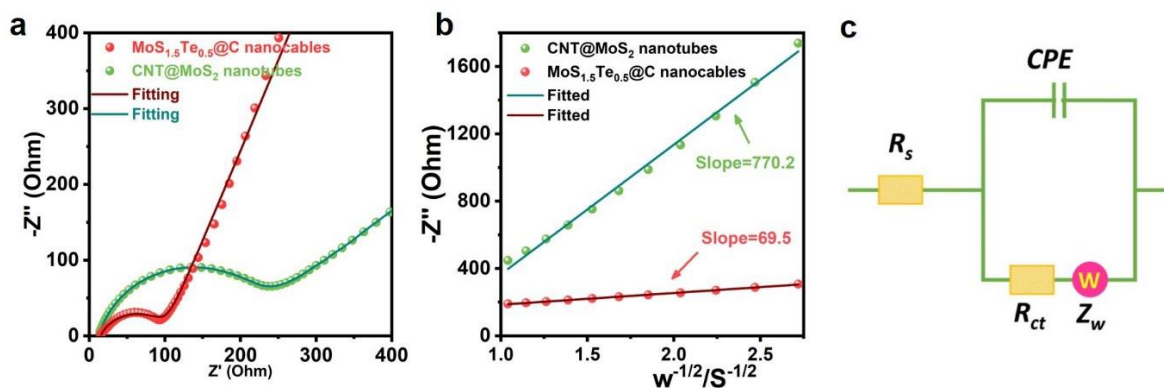
Supplementary Figure 18. Log (i) versus log (v) plots at different redox peaks of the MoS_{1.5}Te_{0.5}@C nanocables.

The calculated b-value for MoS_{1.5}Te_{0.5}@C nanocables electrode based on the linear fitting of log(v) against log(i) are 0.89, 0.83, 0.93 and 0.83 in the corresponding redox peaks, respectively, indicating the Na⁺ storage behavior in MoS_{1.5}Te_{0.5}@C nanocables electrode is mainly dominated by a capacitive charge storage behavior.



Supplementary Figure 19. (a,b) CV curves at various scan rates, (c,d) Capacitive contribution at 1.0 mV s⁻¹, (e,f) the percentages of capacitive and diffusion-controlled capacities at different scan rates of the MoS_{1.5}Te_{0.5}@C nanotubes and the CNT@MoS₂ respectively.

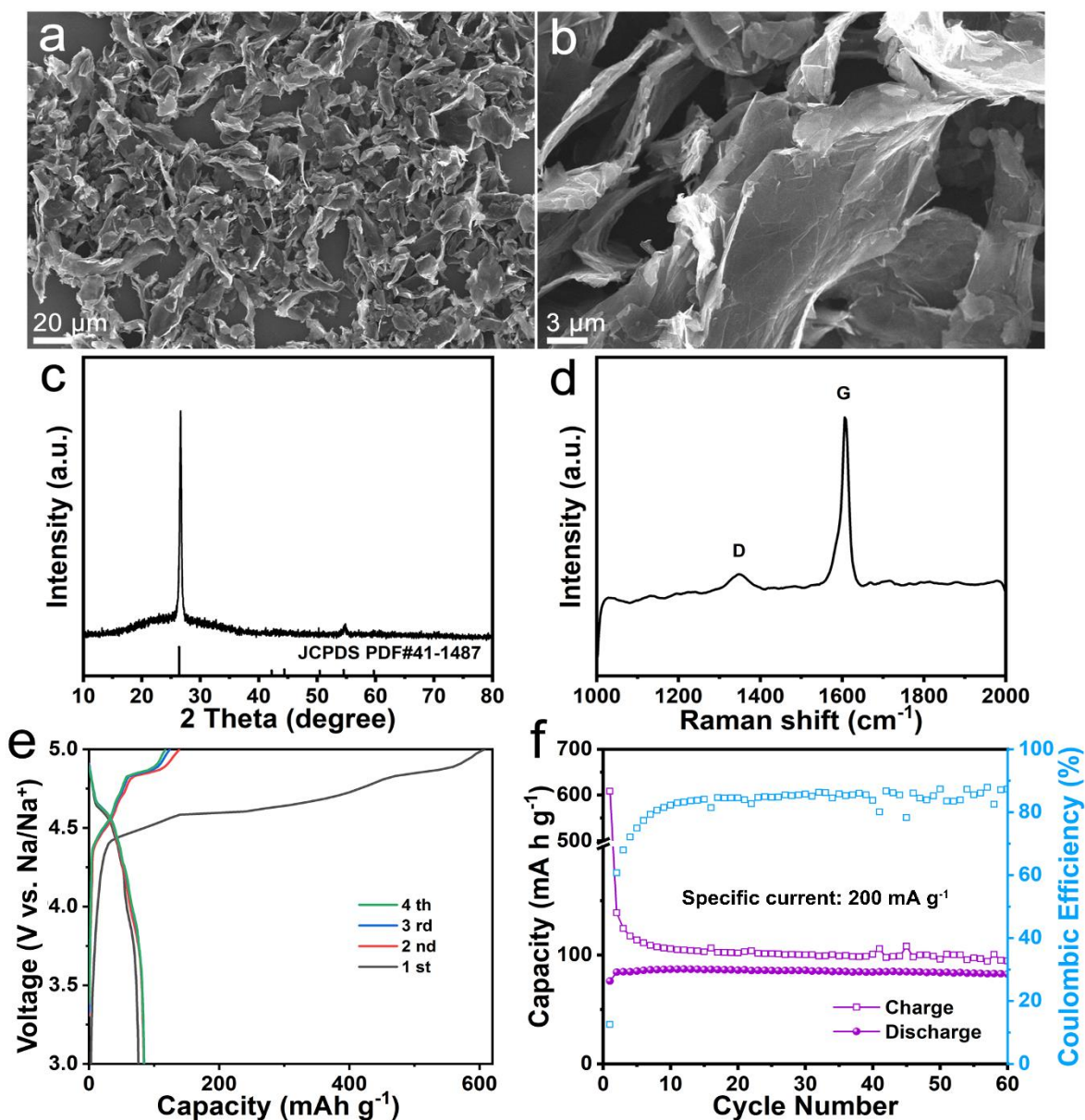
As shown in Figure 3f, Supplementary Figure 19, one can observe that the MoS_{1.5}Te_{0.5}@C nanocables show a more positive cathodic peak and a more negative anodic peak, as well as enhanced peaks intensity than that of the CNT@MoS₂ nanotubes electrode, implying the accelerated conversion reaction kinetics and dramatically decreased polarization of liquid-solid conversion by Te-doping. Such significantly enhanced reaction kinetics could be ascribed to these following factors: (1) The anionic Te doping to form S_{1.5}Te_{0.5} interlayer ligands narrow interlayer energy band of MoS₂ and thus achieve advanced metallic properties, improve the electrical conductivity of materials. (2) The weakened Mo-Te interaction is easier to break than that of Mo-S bands, leading to the reversible conversion reaction dynamics and reversibility.



Supplementary Figure 20. (a) Electrochemical impedance spectra (EIS) of the MoS_{1.5}Te_{0.5}@C nanocables and the CNT@MoS₂ electrodes and (b) linear fits of the Z' versus $\omega^{-1/2}$ ($\omega = 2\pi f$) in the low-frequency region. (c) the corresponding equivalent circuit model.

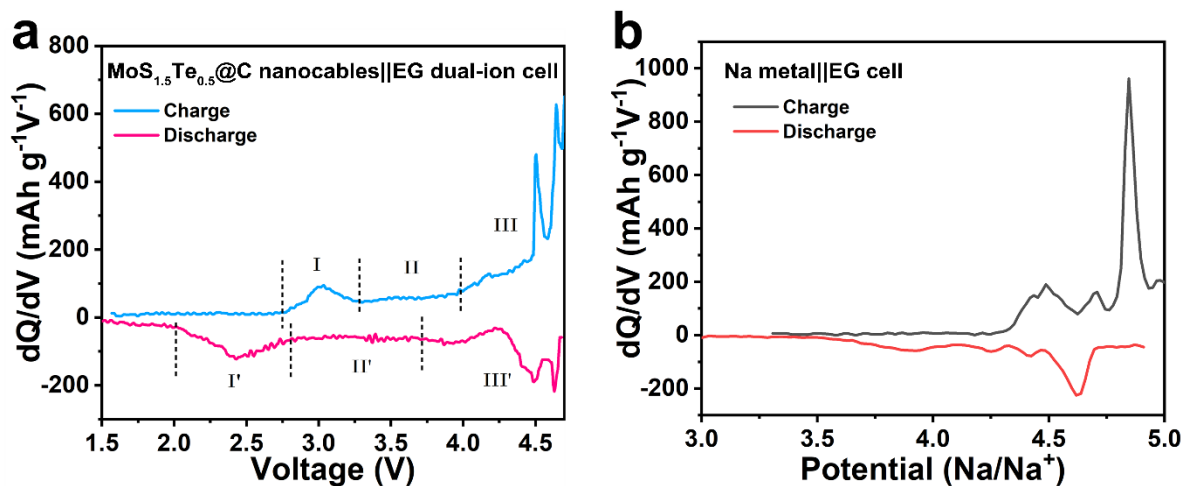
The Na⁺ diffusion coefficient (D_{Na^+}) in MoS_{1.5}Te_{0.5}@C nanocables electrode is higher than these in the CNT@MoS₂ nanotubes electrodes basing on the slope of the oblique line in [Supplementary Figure 20b](#).

The equivalent circuit of EIS spectra was modeled to fit the Nyquist plots, where R_s , R_{ct} and R_f represent the total ohmic resistance of the electrode system, charge-transfer resistance in the middle-frequency region and SEI films resistance in the high-frequency region, respectively. Z_w is the Warburg impedance for Na⁺ diffusion in the bulk of the electrode materials associated with the straight sloping line at low frequency region. CPE related to the surface capacitance.

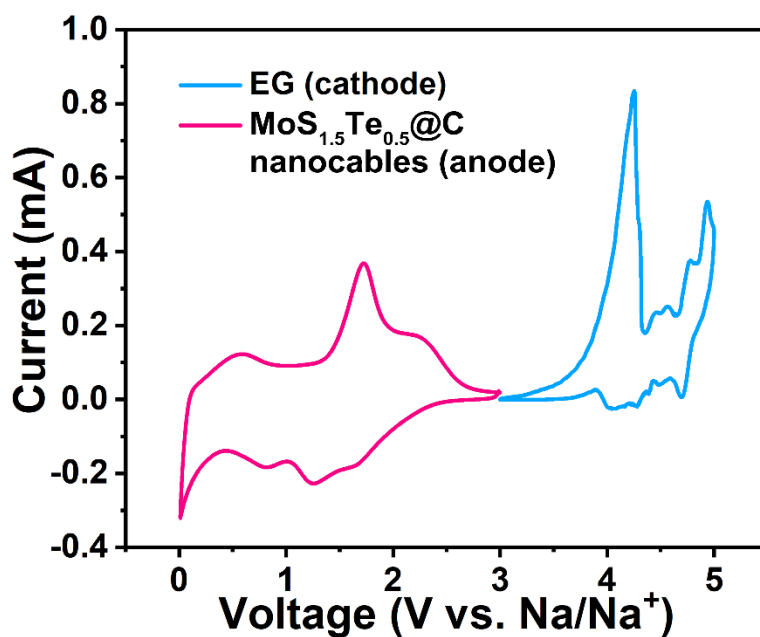


Supplementary Figure 21. (a, b) FE-SEM, (c) XRD peaks, (d) Raman spectrum of EG. (e) Charge-discharge curves at the initial three cycles and (f) Cycling performance under 200 mA g⁻¹ for the Na metal||EG cell. The electrochemical measurements were carried out using a 3 M NaPF₆ in EC/EMC/DMC (1:1:1, by volume) electrolyte solution at 25 °C.

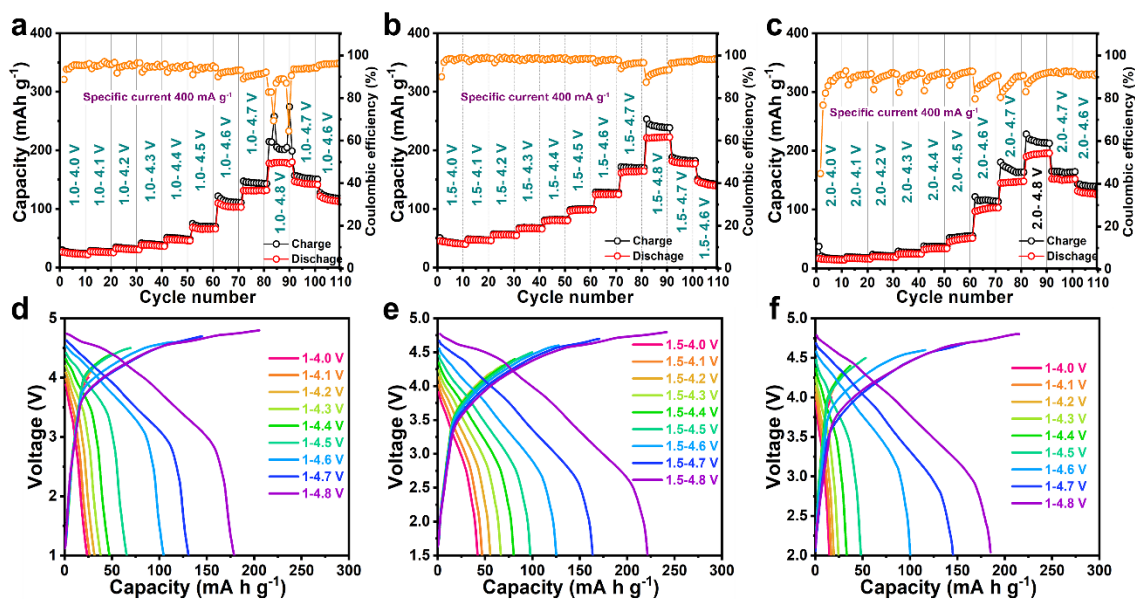
For the anion-hosting cathodes, the low CE of EG cathode could be attributed to the partially irreversibly side reactions occurs during the anion intercalation reaction with the large size of anions and the decomposition of electrolyte at a high voltage.



Supplementary Figure 22. The dQ/dV differential curve of (a) the $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanocables||EG dual-ion cell and (b) Na metal||EG cell.

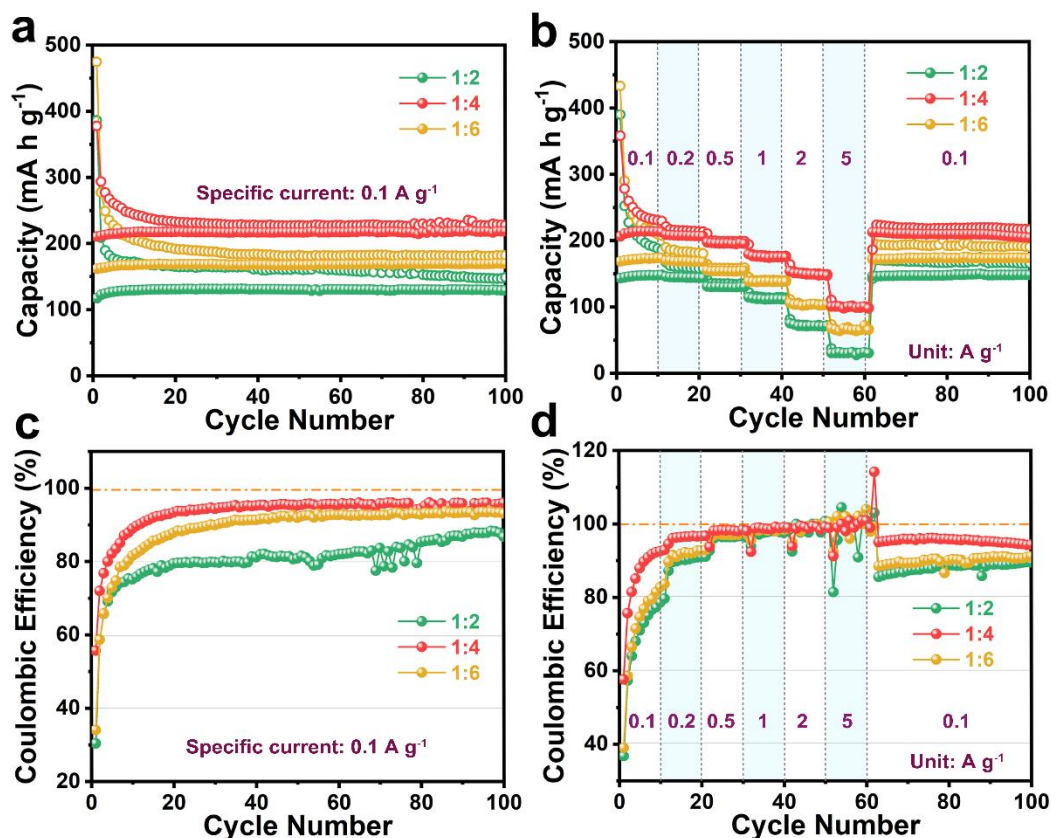


Supplementary Figure 23. The CV curves of the $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanocables and EG half-cells with the device configuration of Na metal|| $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanocables and Na metal||EG cells at a scan rate of 0.1 mV s^{-1} .



Supplementary Figure 24. The cycling behaviour of various MoS_{1.5}Te_{0.5}@C nanocables||EG dual-ion cells with same charge voltage cut-off from 4.0 to 4.8 V and various discharge voltage cut-off under 1.0 V (a), 1.5 V (b), and 2.0 V (c). (d-f) corresponding charge-discharge curves at different voltage windows. The electrochemical measurements were carried out using a 1 M NaPF₆ in EC/EMC/DMC (1:1:1, by volume) electrolyte solution at 25 °C.

In order to legitimately explore the suitable voltage window in this SDIB system, various charge cut-off voltages are paired with identical discharge cut-off voltage at 1.0 V, 1.5 V and 2.0 V, respectively (Supplementary Figure 24). It is noted that the SDIBs exhibit a much low capacity, when the charge cut-off voltage below 4.6 V. However, if the charge cut-off voltage exceeds 4.8 V, there is an obvious capacity gap between charge/discharge curves. In other words, the CE begins to decay owing to the side reaction, which could be attributed by the decomposition of electrolyte under high voltage. Thus, value of 4.7 V is chosen as the charge cut-off voltage due to its high CE and higher capacity. Therefore, we apply the fixed charge cut-off voltage of 4.7 V to match different discharge cut-off voltage. For the discharge cut-off voltage at 1.0 V, the SDIBs fail to get a satisfactory capacity; while for such value at 2.0 V, one can observe that the CE is almost below 90 % at various rates. Therefore, we select an optimized operating voltage windows range from 1.5 V to 4.7 V for subsequent test.

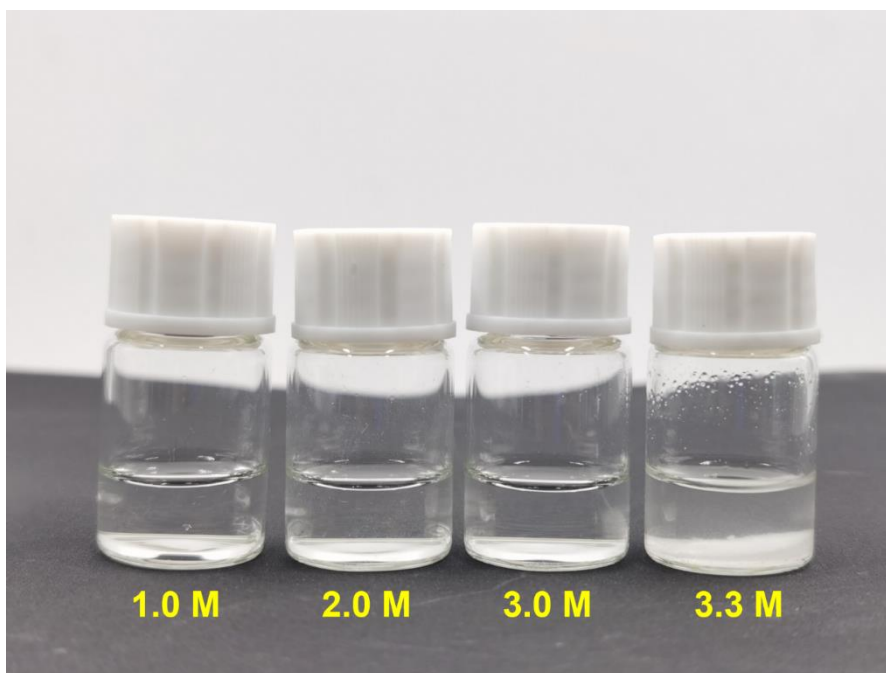


Supplementary Figure 25. (a) Cycling stability under specific current of 0.1 A g^{-1} and (b) rate performance profiles under various rates (from 0.1 A g^{-1} to 5 A g^{-1}) for $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanocables||EG dual-ion cells with different anode/cathode mass ratio (1:2, 1:4 and 1:6). Corresponding Coulombic efficiency for cycle performance (c) and rate capability (d). The electrochemical measurements were carried out using a 3 M NaPF_6 in EC/EMC/DMC (1:1:1, by volume) electrolyte solution at 25°C .

To obtain the desired electrochemical performance, we must balance the capacity between cathode and anode. The $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanocables anode showed a specific capacity of around 450 mAh g^{-1} , and the graphite cathode exhibited a specific capacity of around 100 mAh g^{-1} , thus the mass ratio of the EG cathode to $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanocables anode was optimized to be 4:1 according to the charge balance Supplementary Equation (4):

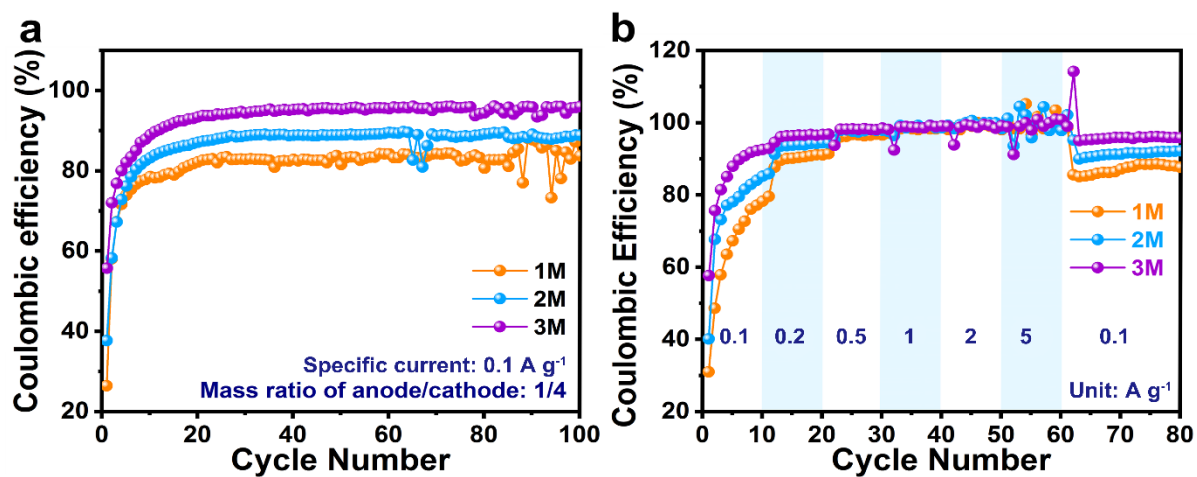
$$C_{\text{cathode}} \times m_{\text{cathode}} = C_{\text{anode}} \times m_{\text{anode}} \quad (4)$$

where C (mAh g^{-1}) and m (mg) are the specific capacity of both electrodes and the mass of active materials, respectively. Meanwhile, we also tested the cells with different anode/cathode mass ratios (1:2, 1:4 and 1:6) in a 3 M NaPF_6 in EC/EMC/DMC (1:1:1, by volume) electrolyte solution.

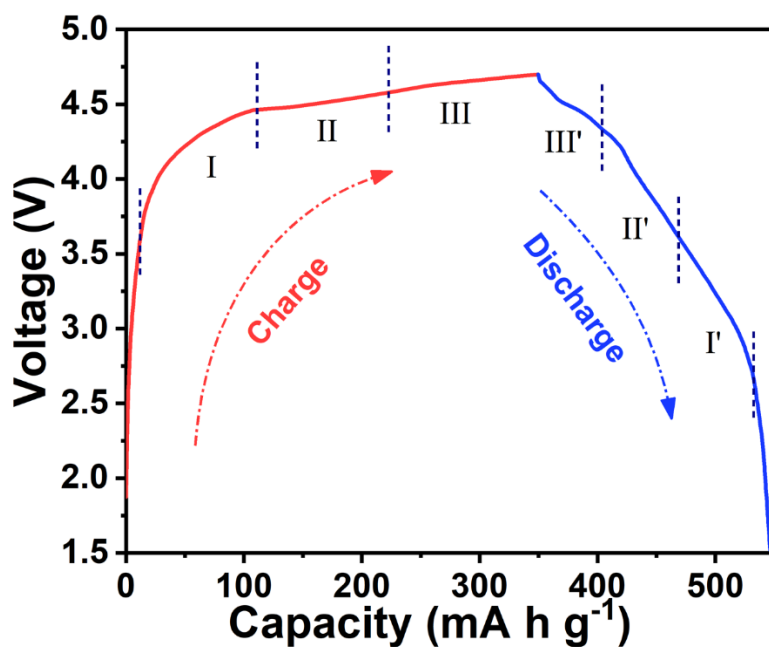


Supplementary Figure 26. The digital photographs with different concentration electrolytes. (1.0, 2.0, 3.0 and 3.3 M NaPF_6 in EC/DMC/DEC mixture (1:1:1, by volume)).

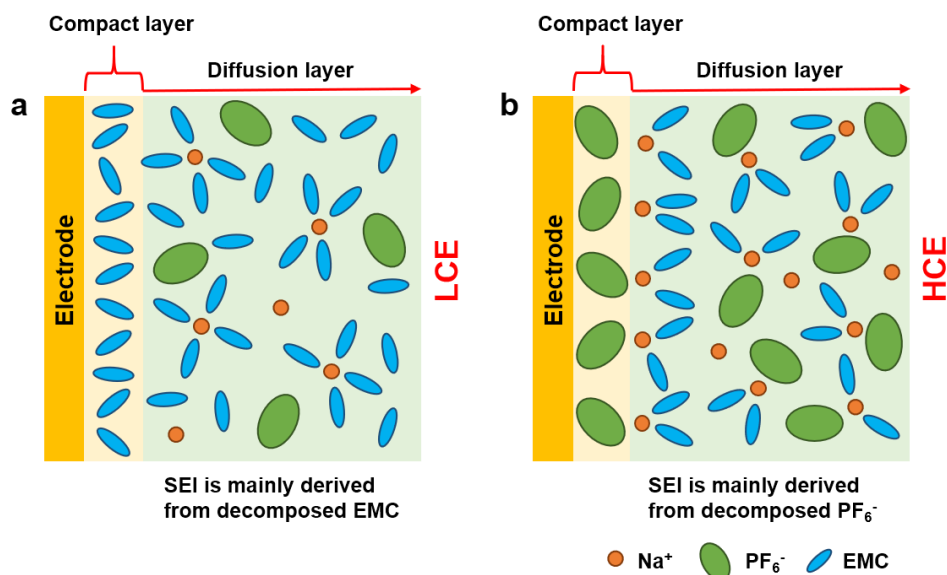
It should be noted that the solubility of NaPF_6 in alkyl carbonates is relatively limited at room temperature. When the concentration exceeds 3.3 M, the electrolyte solution is saturated, and a white precipitate can be noticed in the vial.



Supplementary Figure 27. Corresponding coulombic efficiency of the MoS_{1.5}Te_{0.5}@C nanocables||EG dual-ion cells for (a) cycling performance and (b) Rate performance using different electrolyte concentrations (i.e., 1.0, 2.0 and 3.0 M NaPF₆ in EC/DMC/DEC mixture (1:1:1, by volume)).

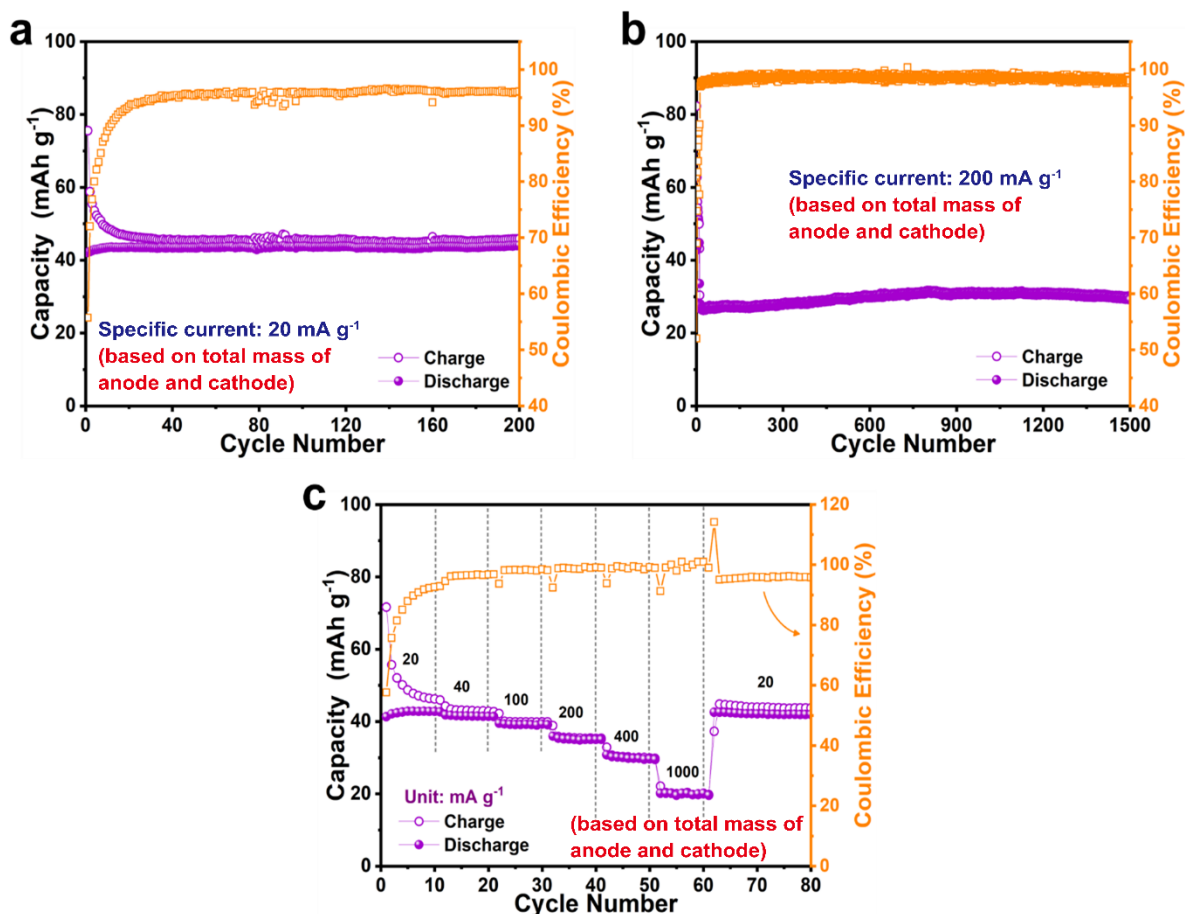


Supplementary Figure 28. 1st charge/discharge cycle of the MoS_{1.5}Te_{0.5}@C nanocables||EG dual-ion cell cycle at 0.1 A g⁻¹ and 25 °C.



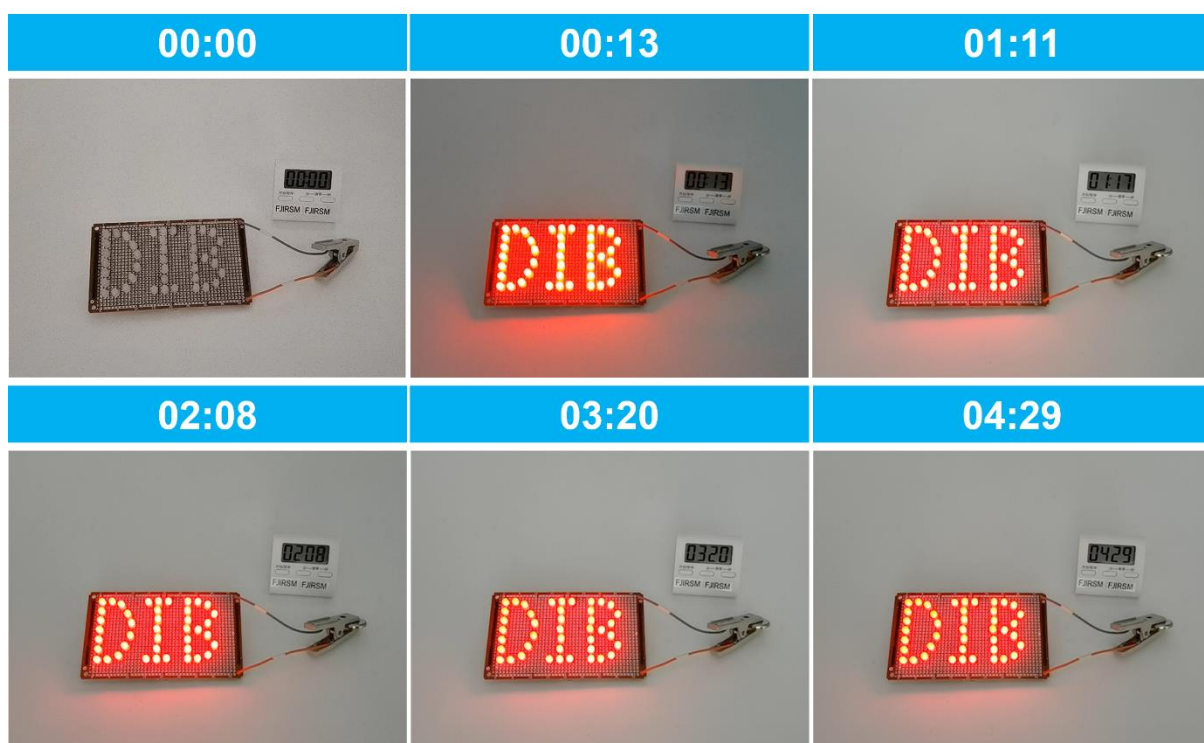
Supplementary Figure 29. The SEI layer formation mechanism in SDIBs using (a) low concentrated electrolyte and (b) high concentrated electrolyte.

The compositions of SEI layer in low concentrated electrolyte (LCE) and high concentrated electrolyte (HCE) are quite different (Supplementary Figure 29). In LCE, the SEI layer is mainly originated from the decomposition of solvents, which is loose and thermodynamically unstable, thus inevitably aggravating continuation of side reaction and decreasing the coulombic efficiency. However, the association between Na^+ ions and the anions in HCE can be enhanced by the high concentrated Na salts, reducing the presence of the free solvent molecules. Therefore, the SEI layer is mainly derived from by the anions of Na salts. This is thinner, more compact, and thermodynamically stable, which can effectively further suppress the decomposition of electrolyte and ensure high reversibility for ions intercalation/deintercalation, which is benefit for maintaining high coulombic efficiency and durable cycling performance of SDIBs.¹

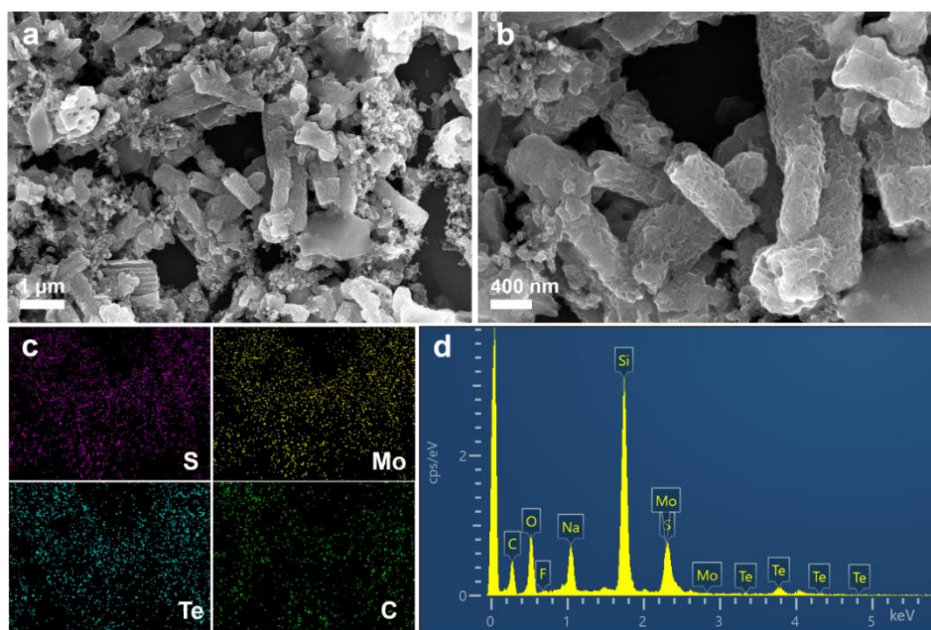


Supplementary Figure 30. The cycling performance at (a) 20 mA g⁻¹ and (b) 200 mA g⁻¹ and (c) the rate performance of the MoS_{1.5}Te_{0.5}@C nanocables||EG dual-ion cells (The specific capacity and specific current were calculated based on the total mass of the cathode and anode active materials).

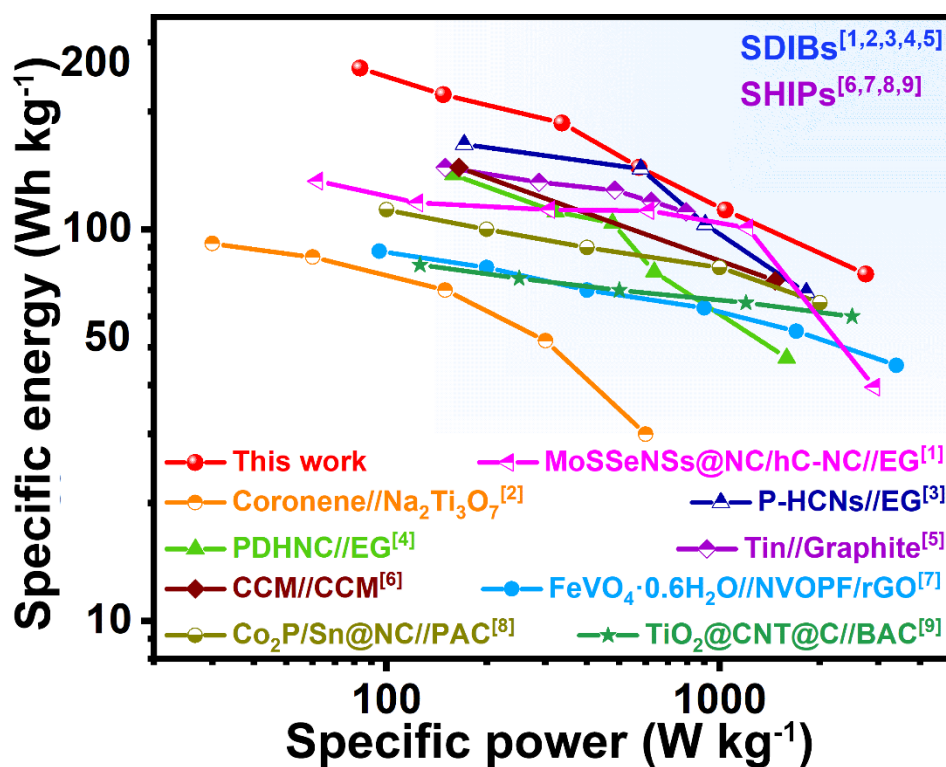
The initial specific capacity of the MoS_{1.5}Te_{0.5}@C nanocables||EG dual-ion cell is about 216.8 mAh g⁻¹ based on the anode material. By counting in the cathode material mass, which is about 4 times of the anode material mass, the capacity calculated based on total mass of cathode and anode is about 43.4 mAh g⁻¹ (= 216.8 mAh g⁻¹/(1 + 4)).



Supplementary Figure 31. Digital photographs of the “DIB” logo composing of 42 light-emitting-diodes (LEDs) light up by one single $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanocables||EG dual-ion cell at different times.

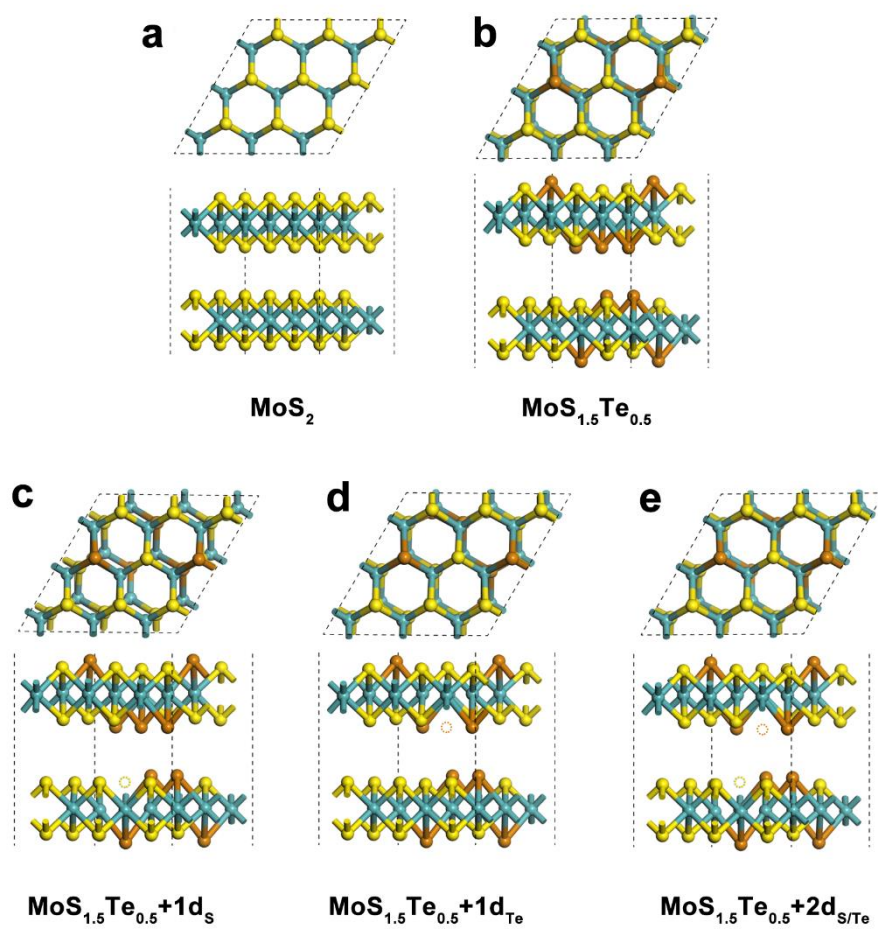


Supplementary Figure 32. (a,b) SEM images, (c) element mapping and (d) EDS analysis of a postmortem $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanocables electrode cycled 1500 times at 1 A g^{-1} in $\text{MoS}_{1.5}\text{Te}_{0.5}@\text{C}$ nanocables||EG dual-ion cell configuration.

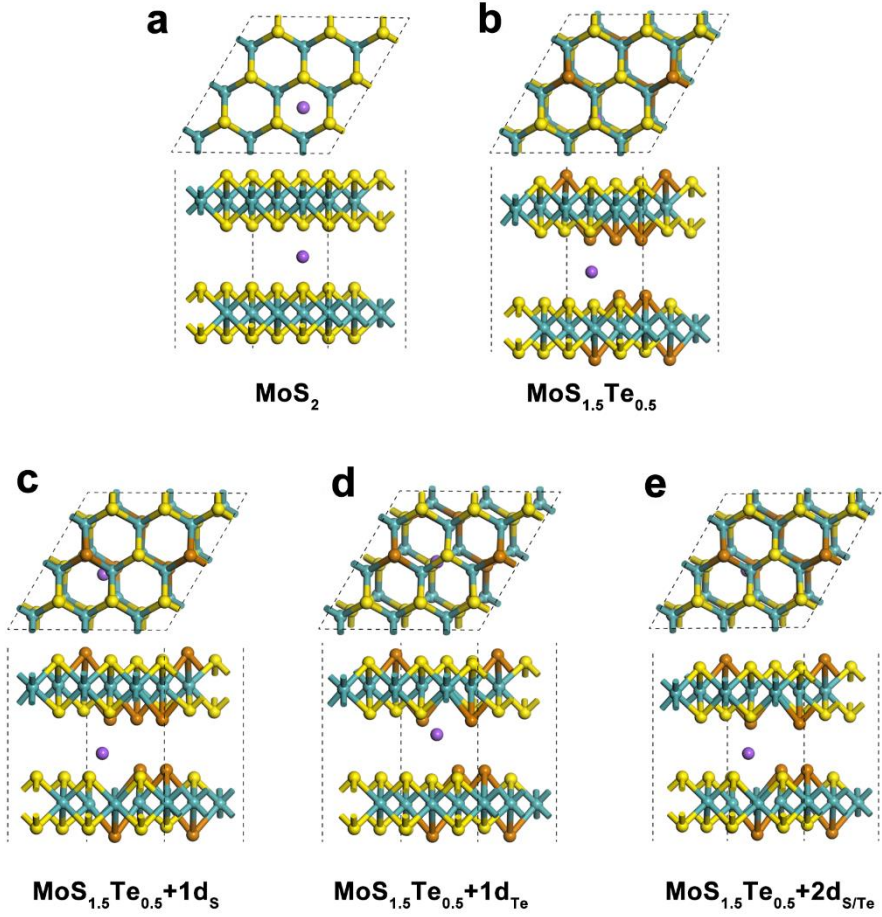


Supplementary Figure 33. Specific energy and power of our prepared MoS_{1.5}Te_{0.5}@C nanocables||EG dual-ion cells in comparison with those of previously reported sodium-based devices (the specific energy and specific power of SDIBs are based on the total mass of both anode and cathode materials).

As shown in [Supplementary Figure 33](#), the MoS_{1.5}Te_{0.5}@C nanocables||EG dual-ion cells deliver high specific energy of 192, 183.7, 171.4, 151, 125.5 and 70.1 Wh kg⁻¹ at the specific power of 61.9, 123.2, 305, 601, 1168, 2500 W kg⁻¹, respectively.²⁻¹³



Supplementary Figure 34. Top and side view of the optimized structure of (a) MoS₂ and (b) MoS_{1.5}Te_{0.5}, (c) MoS_{1.5}Te_{0.5}+1d_S, (d) MoS_{1.5}Te_{0.5}+1d_{Te} and (e) MoS_{1.5}Te_{0.5}+2d_{S/Te}.

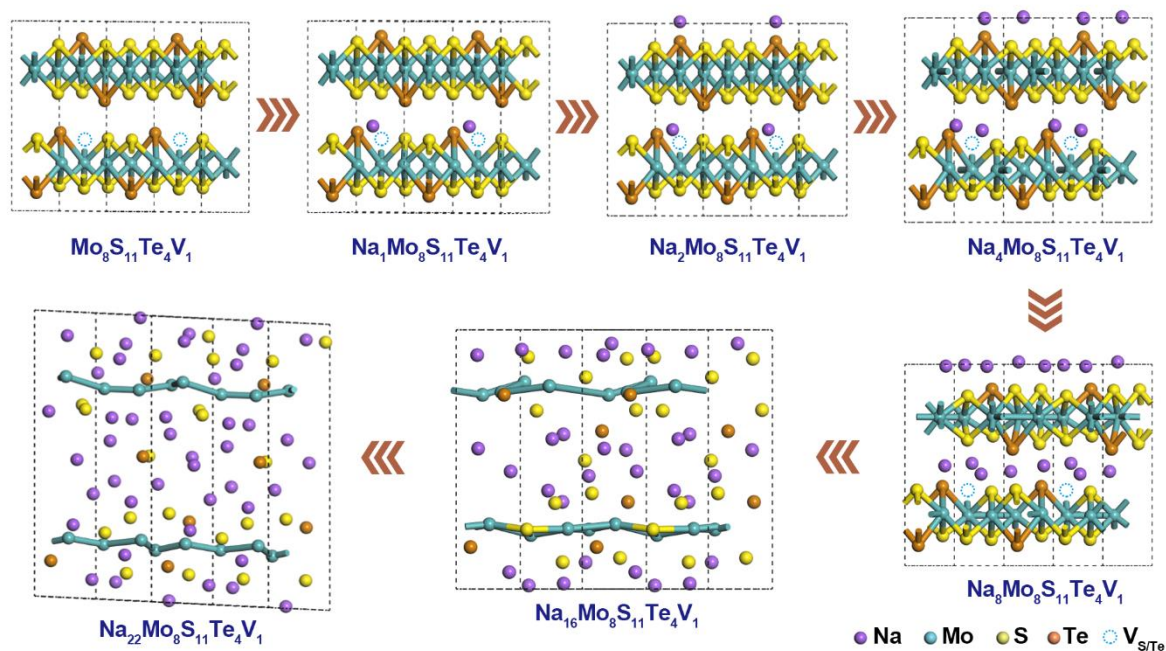


Supplementary Figure 35. Top and side illustration of simulations for one adsorbed Na^+ in the (a) MoS_2 and (b) $\text{MoS}_{1.5}\text{Te}_{0.5}$, (c) $\text{MoS}_{1.5}\text{Te}_{0.5}+1\text{d}_\text{S}$, (d) $\text{MoS}_{1.5}\text{Te}_{0.5}+1\text{d}_\text{Te}$ and (e) $\text{MoS}_{1.5}\text{Te}_{0.5}+2\text{d}_{\text{S/Te}}$.

The corresponding adsorption energy (ΔE_a) for sodium ions is calculated by adding a single Na^+ in each model and then relaxing the optimized geometry structures again (Supplementary Figure 35), according to the following Supplementary Equation (5):

$$\Delta E_a = E_{\text{tot}} - E_{\text{Na}} - E_{\text{str}} \quad (5)$$

where E_{tot} is the total energy of compound, E_{Na} is the energy of per atom in pure Na metal, and E_{str} is the energy of each structure.



Supplementary Figure 36. Calculated sodiation process of MoS_{1.5}Te_{0.5} by DFT. In sodiation process, the corresponding intermediates are identified by DFT.

As shown in [Supplementary Figure 36](#), several intermediate sodium-ion intercalated phases are predicted and identified according to DFT calculations. During the initial sodiation process, the anion defect sites present stronger electron deficiency characteristics, so that Na⁺ tend to insert at anion defect sites, since the anion defects are more likely to gain electrons from Na atoms. The Na⁺ intercalated MoS_{1.5}Te_{0.5} lattice would form an intercalated structure when the number of sodium ions is less than or equal to the number of Mo ions. Above the thresholds, Mo ions start to be reduced and the conversion reaction will occur. The final phase after Na⁺ insertion includes Mo, Na₂S and Na₂Te.

Supplementary Table 1. Contents of Mo, Te, S, and C in MoS_{1.5}Te_{0.5}@C nanocables and MoS_{1.5}Te_{0.5}@C nanotubes

Element	MoS _{1.5} Te _{0.5} @C	MoS _{1.5} Te _{0.5} @C
	nanocables (wt%)	nanotubes (wt%)
Mo ^{a)}	45.3	43.0
Te ^{a)}	28.7	27.1
S ^{b)}	19.8	18.2
C ^{b)}	9.1	12.8

a) The element results were analyzed by ICP-AES.

b) The element results were analyzed by EA.

Supplementary Table 2. Specific surface area and pore volume of three different Mo-containing active materials

Sample	S _{BET} (m ² g ⁻¹)	V _{pore} (cm ³ g ⁻¹)
MoS _{1.5} Te _{0.5} @C nanocables	21.9	0.77
MoS _{1.5} Te _{0.5} @C nanotubes	24.9	0.091
CNT@MoS ₂ nanotubes	36.7	0.12

Supplementary Table 3. The error between the raw and fitted data in the equivalent circuit.

Element	MoS _{1.5} Te _{0.5} @C nanocable		CNT@MoS ₂ nanotube	
	Value	Error%	Value	Error%
R _s	14.75	1.23	19.83	0.94
R _{ct}	90.71	1.49	210.10	2.66
W ₁ -R	4140	2.55	12311	5.67
W ₁ -T	1.80	4.35	30.17	7.70
W ₁ -P	0.69	0.84	0.75	0.50
CPE-T	2.54E-5	8.05	4.59E-5	7.69
CPE-P	0.79	1.15	0.705	1.20

Supplementary Table 4. The EIS fitting parameters of the MoS_{1.5}Te_{0.5}@C nanocables and the CNT@MoS₂ electrodes.

Sample	R _{ct} (Ohm)	Error (%)
MoS _{1.5} Te _{0.5} @C nanocables	90.7	1.23
CNT@MoS ₂ nanotubes	210.1	1.06

Supplementary Table 5. Cycle performance comparison of MoS_{1.5}Te_{0.5}@C nanocables||EG dual-ion cells with various recently reported dual-ion cells (The capacities were calculated based on the mass of anode).

Materials	Voltage range (V)	Specific current (mA g ⁻¹)	Cycle number	Specific capacity (mAh g ⁻¹)	m _{anode} /m _{cathode} (mg)	The type of electrolytes	Reference
MoS _{1.5} Te _{0.5} @C nanocables EG <u>Na-based dual-ion cells</u>	1.5-4.7	100	100	216.8	1.0/4.0	3.0 M NaPF ₆ EC/DMC/DEC (1:1:1, v:v:v)	This work
		1000	1500	145.7			
Soft carbon graphite <u>Na-based dual-ion cells</u>	2.0-4.7	1000	800	54	1.5/2.5-3.0	1 M NaPF ₆ EC/DMC (6:4, v/v)	(14)
Coronene Na ₂ Ti ₃ O ₇ <u>Na-based dual-ion cells</u>	1.5-3.5	500	5000	78	0.9/4.5	1 M NaPF ₆ EC/DMC (1:1, v/v)	(6)
P-doped hollow carbon EG <u>Na-based dual-ion cells</u>	2.0-4.7	500	1500	121	1.0/4.0	1 M NaPF ₆ EC/DMC (4:6, v/v)	(7)
N,S-doped MoS ₂ @C nanosheets EG <u>Na-based dual-ion cells</u>	1.0-4.0	100	300	60	1.5/2.0	1 M NaPF ₆ EC/DMC/DEC (1:1:1, v:v:v)	(15)
		1000	5000	39.3			
P-doped soft carbon graphite <u>Na-based dual-ion cells</u>	2.0-4.7	500	100	110	1.0/3.0	1 M NaPF ₆ EC/DMC (6:4, v/v)	(16)
		1000	900	81			
Soft carbon nanosheets EG <u>Na-based dual-ion cells</u>	3.5-4.7	100	350	56.6	1.5/2.0	1 M NaPF ₆ EC/DMC (6:4, m/m)	(17)
WS ₂ graphite <u>Li-based dual-ion cells</u>	0.01-4.0	100	30	47	1.5/6.0	1 M LiPF ₆ EC/EMC (1:1, v/v)	(18)

Porous N-doped CNF graphite <u>K-based dual-ion cells</u>	3.0-5.0	100	346	65	0.5/3.0- 4.0	1 M KPF ₆ EC/DMC (1:1, m/m)	(19)
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Supplementary Table 6. Cycle performance comparison of MoS_{1.5}Te_{0.5}@C nanocables||EG dual-ion cells with various recently reported sodium based dual-ion batteries. (The specific capacity and specific current were calculated based on the total mass of the cathode and anode active materials)

Materials	Voltage range (V)	Specific current (mA g ⁻¹)	Cycle number	Specific capacity (mAh g ⁻¹)	m _{anode} /m _{cathode} (mg)	The type of electrolyte	Reference
MoS _{1.5} Te _{0.5} @C nanocables EG <u>Na-based dual-ion cells</u>	1.5-4.7	20	100	43.4	1.0/4.0	3.0 M NaPF ₆ EC/DMC/DEC (1:1:1, v:v:v)	This work
		200	1500	29.2			
Soft carbon graphite <u>Na-based dual-ion cells</u>	2.0-4.7	333	800	18	1.5/2.5- 3.0	1 M NaPF ₆ EC/DMC (6:4, v/v)	(14)
Hard carbon graphite <u>Na-based dual-ion cells</u>	2.0-4.7	500	200	22.2	1.0/1.8	2.55 M NaTFSI in TMP	(20)
Coronene Na ₂ Ti ₃ O ₇ <u>Na-based dual-ion cells</u>	1.5-3.5	100	5000	19.3	0.9/4.5	1 M NaPF ₆ EC/DMC (1:1, v/v)	(6)
P-doped hollow carbon EG <u>Na-based dual-ion cells</u>	2.0-4.7	100	1500	24.2	1.0/4.0	1 M NaPF ₆ EC/DMC (6:4, m/m)	(7)
N,S-doped MoS ₂ @C	1.0-4.0	42.9	300	25.7	1.5/2.0	1 M NaPF ₆ EC/DMC/DEC	(15)

nanosheets EG <u>Na-based dual-ion cells</u>		428.5	5000	16.8		(1:1:1, v:v:v)	
P-doped soft carbon graphite <u>Na-based dual-ion cells</u>	2.0-4.7	125	100	27.5	1.0/3.0	1 M NaPF ₆ EC/DMC (6:4, v/v)	(16)
		250	900	20.2			
MoS ₂ /C-G EG <u>Na-based dual-ion cells</u>	1.0-4.0	100	200	27.5	1.0/1.0	1 M NaPF ₆ EC/DMC/DEC (1:1:1, v:v:v)	(21)
Hard carbon graphite <u>Na-based dual-ion cells</u>	1.5-4.8	45	100	21.8	1.0/1.2	1 M NaClO ₄ PC	(22)

Supplementary Table 7. The calculated values for the ex situ X-ray diffraction measurements of charged PF₆⁻EG electrodes of the different cell setups (data corresponding to [Figure 5c](#) in in the revised manuscript).

Cell Setup	EG electrodes
$d_{(n+2)}/d_{(n+1)}$ ratio	1.20
$2\theta_{(n+1)}$ [°]	25.3
$2\theta_{(n+2)}$ [°]	30.5
Dominant stage [n]	3
Periodic repeat distance (I_c) [nm]	1.457
PF ₆ ⁻ gallery height (d_i) [nm]	0.788
PF ₆ ⁻ gallery height (Δd) [nm]	0.453

According to the Bragg's Law formula, the graphite layers was expanded to 0.35 nm from the initial value (0.335 nm) when charging voltage to 4.7 V. The determined stages (n) in the formed PF₆⁻-GIC could be related to the periodic repeating distance (I_c), the gallery height (d_i), and the gallery expansion (Δd), according to the Supplementary Equation (6):

$$I_c = d_i + 0.335 \text{ nm} \times (n-1) = \Delta d + 0.335 \text{ nm} \times n = l \times d_{\text{obs}} \quad (6)$$

where l represents the index of (00 l) oriented in the stacking direction, d_{obs} describes the observed value of the spacing between two graphitic layers, which can be calculated from diffraction angles by Bragg's Law.^{23,24}

Based on the above results ([Supplementary Table 7](#)), the stage-3 GIC can be formed when the charging voltage approached 4.7 V, implying quite a lot of PF₆⁻ anions can be stored in graphite space.

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