Electronic Supplementary Information

High performance asymmetric supercapacitors based on Ti$_3$C$_2$Tx MXene and electrodeposited spinel NiCo$_2$S$_4$ nanostructures

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**Electrochemical measurements:**

The specific capacitance calculated using cyclic voltammetry,

\[ C_{sp} = \frac{\int I(V) \, dv}{[2m \, s \, \Delta V]} \]

Where, \( m \) is the mass of electrode deposited on substrate, \( s \) is the scan rate, \( \Delta V \) is the potential window and \( \int I(V) \, dV \) represents area under the curve.

Specific capacitance calculated using charge-discharge cycle,

\[ C_{sp} = \frac{I \Delta t}{m \Delta V} \]

Where, \( I \) is the current, \( m \) is the mass of electrode, \( \Delta t \) is discharge time and \( \Delta V \) is the potential window. Current/mass is given by current density i.e. A/g and discharge time/ potential window can be obtained by the slope of the discharging curve from galvanostatic charge-discharge plot (\( \Delta t/\Delta V \)).

Energy density of symmetric cell is calculated using following formula,

\[ E_d = \frac{1}{2} C_{sp} x (\Delta V)^2 \]

Where, \( C_{sp} \) is a specific capacitance calculated from GCD and \( \Delta V \) is the potential window. (Wh/kg)

Power density of symmetric cell is calculated by using following formula,

\[ P_d = \frac{E_d \times 3600}{\Delta t} \]

Where, \( E_d \) is the energy density and \( \Delta t \) is the discharging time. (W/kg) [13,39].
To achieve the charge balance $Q^+ = Q^-$, a mass balance is required and given by following eq,

$$\frac{m_+}{m_-} = \frac{C_- \cdot \Delta V_-}{C_+ \cdot \Delta V_+}$$

The average mass ratio between the two electrodes $m^+/m^-$ can be adjusted to get the optimal performance of an asymmetric supercapacitor.[40].

Areal capacitance calculated using cyclic voltammetry,

$$C_a = \frac{\int I(V) dV}{A \cdot s \cdot \Delta V}$$

Where, $A$ is the active area of the electrode, $s$ is the scan rate, $\Delta V$ is the potential window and $\int I(V) dV$ represents area under the curve. Unit is given by (mF/cm$^2$).

Areal capacitance calculated using charge-discharge cycle,

$$C_a = \frac{I \Delta t}{A \Delta V}$$

Where, $I$ is the current, $A$ is the geometrical area of the electrode, $\Delta t$ is discharge time and $\Delta V$ is the potential window. Current/geometrical area of the electrode is given by current density i.e. mA/cm$^2$ and discharge time/potential window can be obtained by the slope of the discharging curve from galvanostatic charge-discharge plot ($\Delta t/\Delta V$), unit is given by (mF/cm$^2$).

Energy density of asymmetric cell is calculated using following formula,

$$Ed = \frac{1}{2} C_a \times (\Delta V)^2$$

Where, $C_a$ is a specific capacitance calculated from GCD and $\Delta V$ is the potential window. (mWh/cm$^2$)
Power density of asymmetric cell is calculated by using following formula,

\[ Pd = \frac{Ed \times 3600}{\Delta t} \]

Where, Ed is the energy density and \( \Delta t \) is the discharging time. (mW/ cm\(^2\)). [41,42].

**Figure S1**
**Fig-S1:** FESEM image of (a) vertical graphene (VG) (b) magnified image VG, (e) MXene Sheets after HF etching and (d) image of HF etched MXene sheets at high magnification. Inset shows 2D sheets like structure after HF etching; XRD pattern of (e) MXene Sheets after HF etching, (f) vertical graphene (VG).
**Figure S2**

**Fig-S2:** (a-b) the CV and GCD curves of NCS on substrate, (c-d) CV and GCD curve of NCS on VG substrate; (e-f) CV and GCD curve of NCS on CF substrate- in 3 electrode cells set up (Vs. Ag/AgCl) 0.5M K₂SO₄ electrolyte
Fig-S3: (a-b) the CV and GCD curves of NCS on substrate, (c-d) CV and GCD curve of NCS on VG substrate; (e-f) CV and GCD curve of NCS on CF substrate and (g) Ragone plots of all the supercapacitor electrodes of NCS grown on VG, CF and NF substrate.
Figure S4

(a) the CV cures of Ti$_3$C$_2$T$_x$, (b) GCD curve of Ti$_3$C$_2$T$_x$ in 3 electrode system (Vs. AG/AgCl) and (c) comparative CV cycles of NCS grown on CF/NF/VG substrates and Ti$_3$C$_2$T$_x$ in 0.5M K$_2$SO$_4$ electrolyte
Figure S5

Fig-S5: (a-b) the CV and GCD curves of NF-NCS//Ti$_3$C$_2$T$_x$, (c-d) CV and GCD curve of VG-NCS//Ti$_3$C$_2$T$_x$; (e-f) CV and GCD curve of CF-NCS//Ti$_3$C$_2$T$_x$ Asymmetric assembly
Figure S6: (a) comparative Ragone plot- areal energy density (mWh/cm²) vs. areal power density (mW/cm²) and (b) gravimetric energy density (Wh/kg) vs. power density (W/kg) of all the supercapacitor electrodes of NCS grown on VG, CF and NF substrate.
**Table S1:** Comparison of electrochemical performance of Nickel cobalt sulfides and its supercapacitor performance in symmetric and asymmetric assembly.

| Material          | Specific capacitance (F/g) | Areal capacitance (mF/cm²) | Energy density (Wh/kg) | Power density (W/kg) | Areal Energy density (mWh/cm²) | Areal Power density (mW/cm²) | Cycling stability %/cycles |
|-------------------|-----------------------------|----------------------------|------------------------|----------------------|--------------------------------|-------------------------------|--------------------------|
| CF-NCS // CF-NCS | 167.28                      | -                          | 11.38                  | 8550                 | -                              | -                            | 66/3000                  |
| NF-NCS // NF-NCS | 116.62                      | -                          | 4.5                    | 5170                 | -                              | -                            | 61/3000                  |
| VG-NCS // VG-NCS | 64.26                       | -                          | 1.5                    | 2177                 | -                              | -                            | 81/3000                  |
| CF-NCS // TCX     | 54.57                       | 48.6                       | 14.86                  | 28870                | 13.22                          | 25412                        | 79/5000                  |
| NF-NCS // TCX     | 49                          | 45                         | 8.76                   | 9051                 | 8.74                           | 8050                         | 77/5000                  |
| VG-NCS // TCX     | 47                          | 42.83                      | 8.61                   | 2555                 | 8.57                           | 2290                         | 85/5000                  |