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4th **GRAPHENE NEW MATERIALS**
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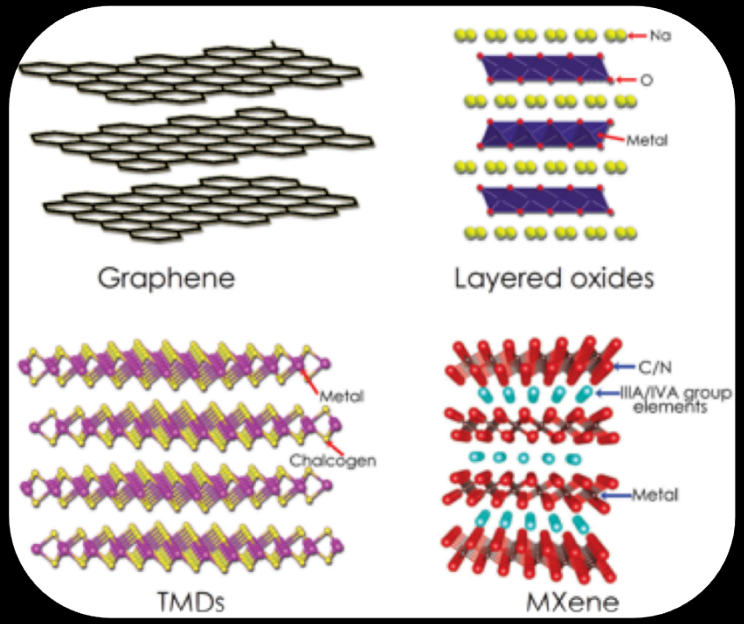

Latest Top 5 Breakthroughs and Research in Energy Storage 2D Materials

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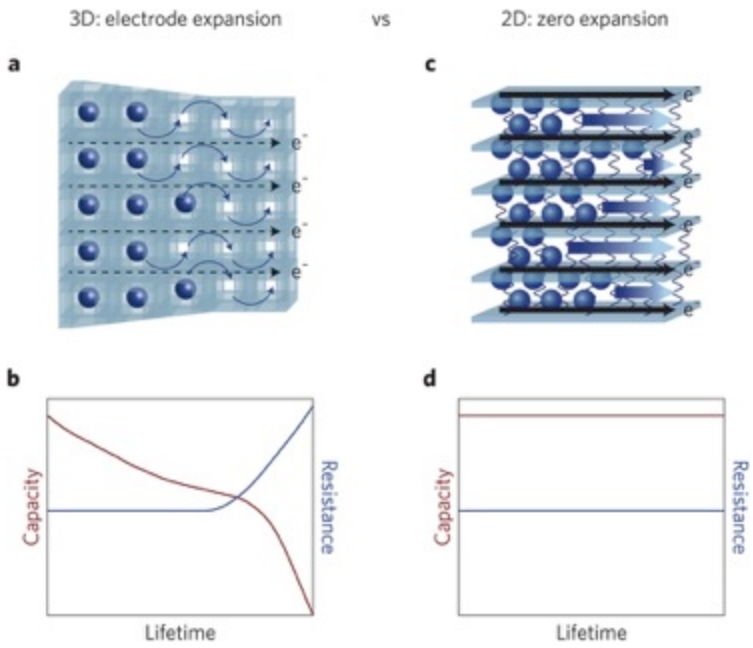
Chemistry Department
University of Cambridge

Nano Doctoral Training Centre Cambridge

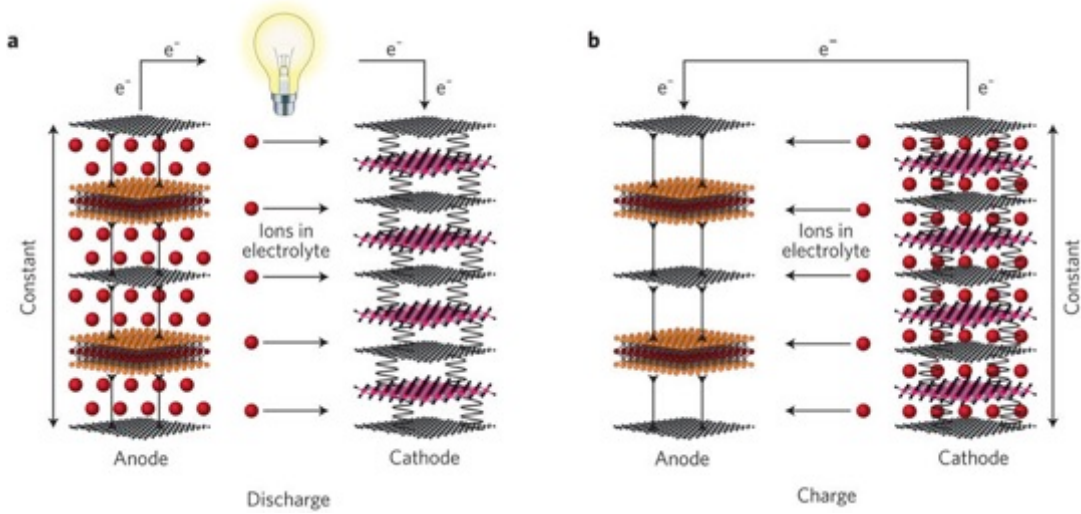
UNIVERSITY OF CAMBRIDGE

EPSRC
Engineering and Physical Sciences Research Council

2D Materials for Energy Storage



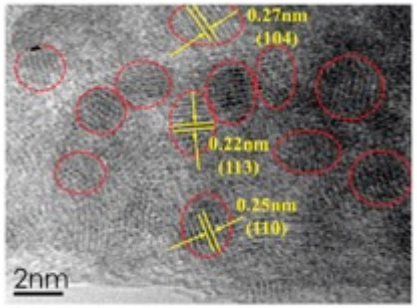
Overcoming limitations of current batteries by using 2D materials

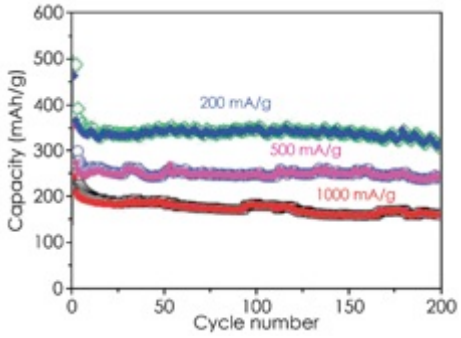


Schematic illustration of the electrochemical cycling process in a battery with 2D heterostructured pillared electrodes

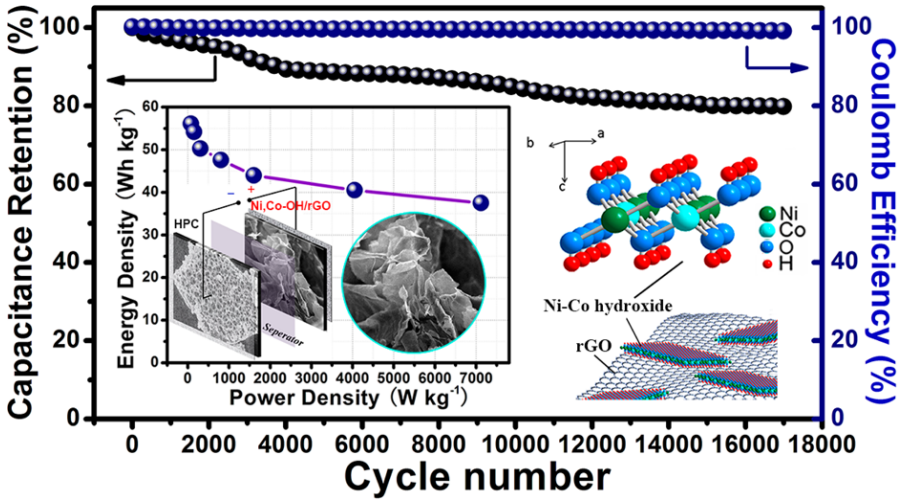
1. Pomerantseva, E., Gogotsi Y., *Nature Energy* 2, **2017**, 1-6

1. Graphene, Graphene Oxide, Reduced Graphene Oxide





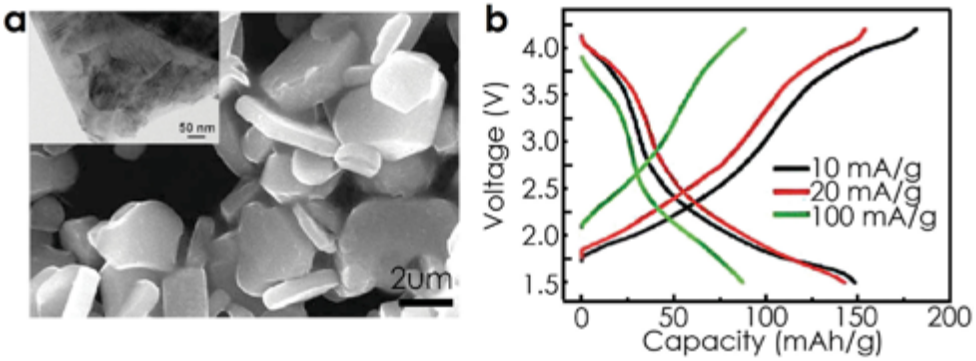
- Fe_2O_3 -Graphene nanosheets
- Capacity of 400 mAh g^{-1}
- Retained stable over 200 cycles at a current density of 100 mA g^{-1}
- Even at high current density of 1000 mA g^{-1}, capacity reaching 190 mAh g^{-1}
- Low-cost anode of SIBs
- Superior cycling and rate performance



- **Nickel Cobalt Hydroxide @ Reduced Graphene Oxide Hybrid**
- Application: High Performance Asymmetric Supercapacitor
- Remarkable cycling stability (80% retention after 17,000 cycles)
- High energy density 56.1 Wh kg^{-1}

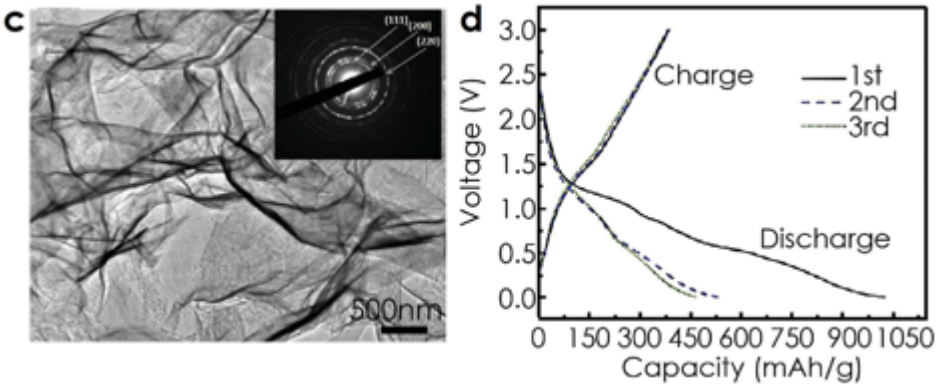
1. J. Materiomics, 2016, 2, 37-54
2. ACS Appl. Mater. Interfaces 2016, 8, 1992−2000
3. *Adv. Mater.* **2016**, *28*, 6104–6135
4. *Nat. Rev. Mater.*, 2016, 1, 1-14
5. *Adv. Energy Mater.* **2016**, *6*, 1600025

2. TMOs: Transition Metal Oxides



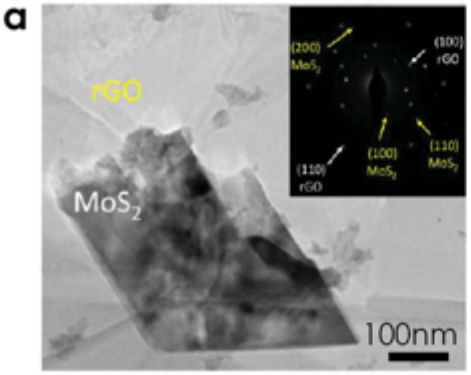
- **$Na_{0.4}Mn_{0.54}Co_{0.46}O_2$ nanosheets cathode**
- Superior cycling performance
- High reversible capacity of 151 mAh g^{-1} at current density of 20 mA g^{-1}
- After 65 cycles, still delivered reversible capacity of 120 mAh g^{-1}
- Promising rechargeable SIBs

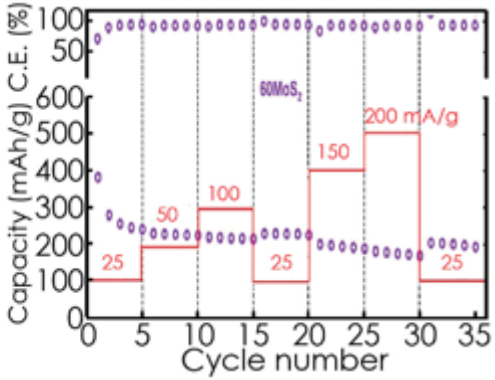
- **Ultrathin NiO nanosheets**
- Sodium storage: high reversible specific capacity of 299 mAh g^{-1} at 1 A g^{-1}
- Retained 154 mAh g^{-1} at 10 A g^{-1}
- Upon cycling, the specific capacity remained as high as 266 mAh g^{-1} after 100 cycle at 1A g^{-1}
- Attractive for high-rate SIBs



1. *Adv. Energy Mater.* **2016**, *6*, 1600025

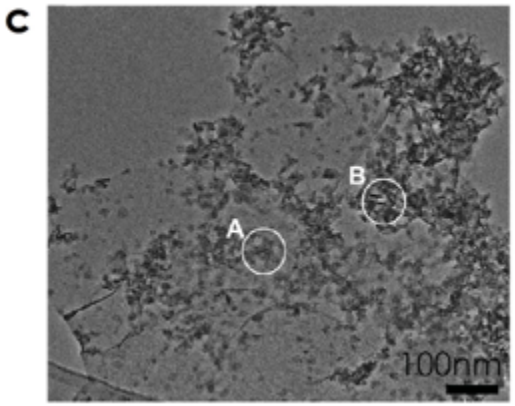
3. TMDs: Transition Metal Dichalcogenides

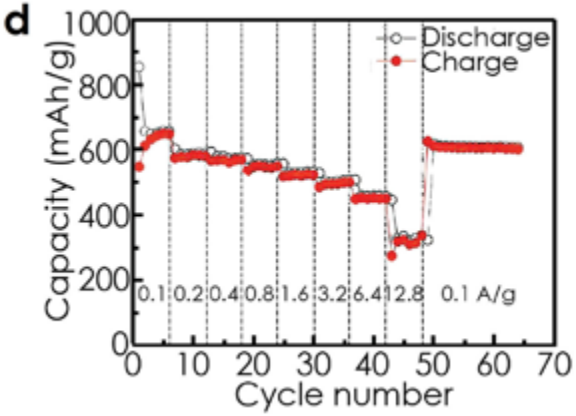




- **SnS_2-rGO hybrid**
- High capacity, long cycle life, excellent rate capability
- High charge capacity (649 mAh g^{-1} at current density 100 mA g^{-1})
- Current density up to 12.8 A g^{-1} (≈28 C) while still delivering charge capacity of 337 mAh g^{-1}

- **rGO/MoS_2 electrodes**
- Good cycling performance
- Stable charge capacity of 240 mAh g^{-1} at current density 25 mA g^{-1}
- Coulombic efficiency ≈99%
- Retaining 90% and 72% of this capacity at high current density (100 mA g^{-1} and 200 mA g^{-1})

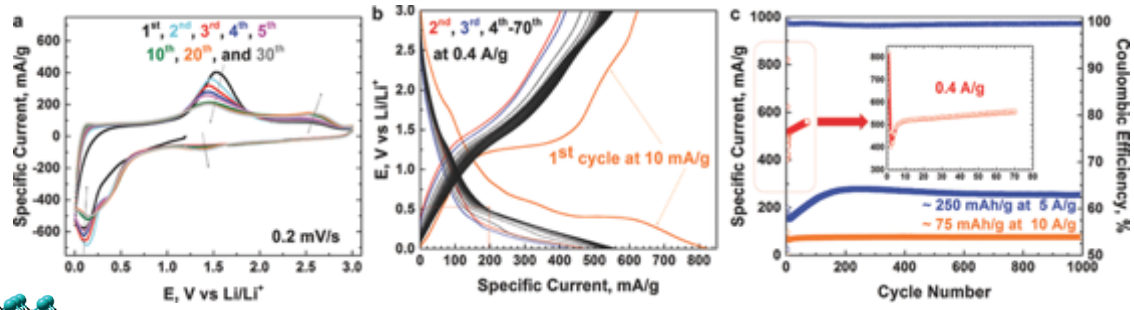




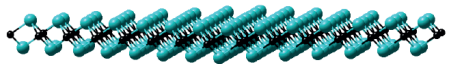
1. *Adv. Energy Mater.* **2016**, *6*, 1600025

4. MXenes: 2D Transition Metal Carbides, Carbonitrides and Nitrides

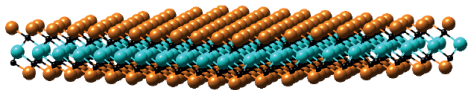
- **MXenes** expanded rapidly since the discovery of Ti_3C_2
- $M_{n+1}X_nT_x$: M (Ti, V, Cr, Mo), X (C / N), T (–O, – OH, –F)



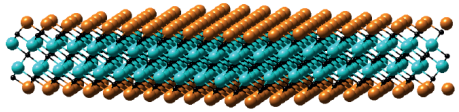
n = 1 Ti_2C

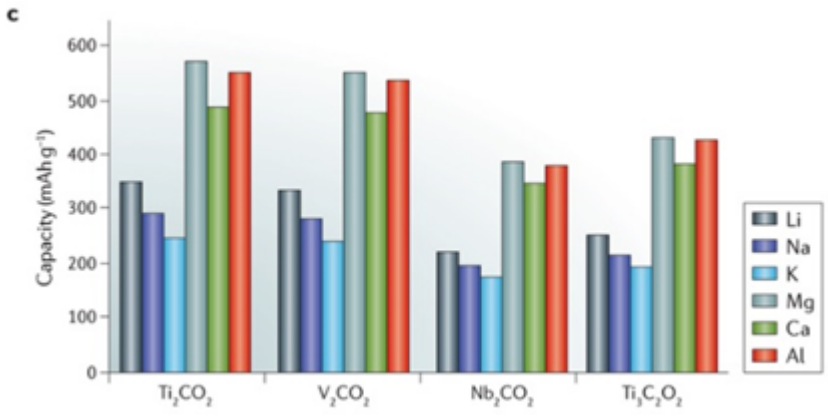


n = 2 $Ti_3(C,N)_2$



n = 3 Nb_4C_3



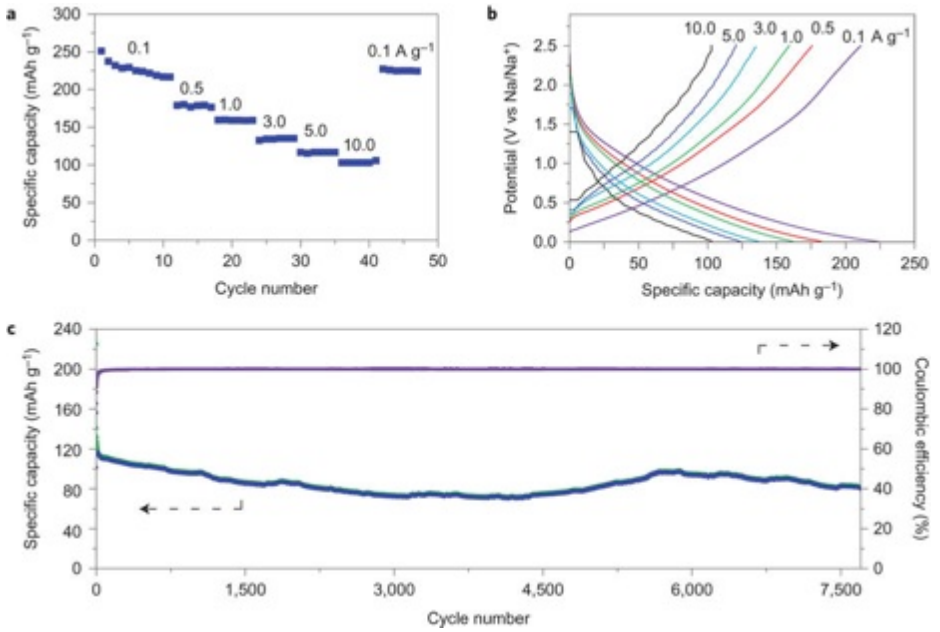


- **Free-standing Mo_2CT_x**
- Promising anode material for high power batteries and Li-ion capacitors
- High capacitance (700 F cm^{-3} in 1 M H_2SO_4)
- High capacity retention (10,000 cycles at 10 A g^{-1})
- Free-standing films (8 wt% CNTs)
- Stable reversible capacity of 250 mAh g^{-1} (20 C rate) achieved for over 1,000 cycles

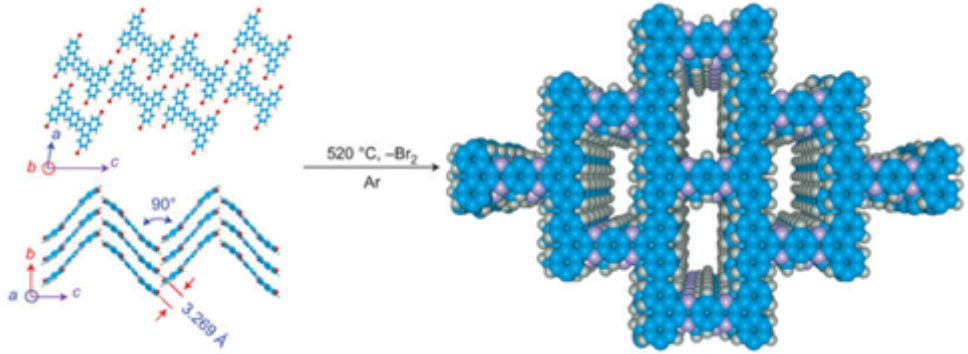
1. Anasori, B., Lukatskaya, M.R.,Gogotsi, Y., *Nat. Rev, Mater.*, **2017**, *16098, 2-17*
2. Cao, X. et al, *Adv. Mater.* **2016**, *28*, 6167–6196

5. Polymers: Crystalline 2D Conjugated Aromatic Polymers

- **Novel 2D graphene-like polymer sheets via C-C coupling**
- Application: electrode (anode) in sodium ion batteries
- Superior stability
- Quick charging and discharging at room temperature
- Worked well when tested in LIBs



Sodium storage performance of 2D-CAP electrode in the potential range 0.005–2.5 V (vs. Na/Na^+)



Retained 70% capacity after 7,700 charge cycles

1. Liu, W. et al, *Nature Chemistry* **2017**, 9, 563–570,