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Research Article

MXene as a Cation-Selective Cathode Material for Asymmetric Capacitive Deionization

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Why I have chosen this paper?

- Currently, more than 300 million people around the world rely on desalinated water for part or all of their daily needs. That demand will only grow with larger populations and improved standards of living around the world.

- However, well-developed desalination processes such as reverse osmosis (RO), electrodialysis (ED), and distillation not only require large-scale infrastructure but also have a high cost for controlling fouling during operations. Therefore, it is desirable to develop a novel desalination technology with simple equipment, easy operation, and high energy efficiency.

- Among the various desalination technologies, capacitive deionization (CDI) is considered as one of the promising desalination technologies because of its energy-efficient, ecofriendly, facile operation.

What is this work about ?

- In this paper, an asymmetric CDI cell is assembled in which Na^+ intercalated $Ti_3C_2T_x$ (NaOH-$Ti_3C_2T_x$) serves as a cation-selective cathode, while the activated carbon (AC) serves as the anode and it used as a CDI electrode.

Relevance to the group or my work

- This paper shows how to prepare mxene and cation-selective electrodes has prepared by chemical modification. Also it can be used for different applications (*e.g.* sensor, CDI).

Background work…

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Article

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Xiaojie Shen, Yuecheng Xiong, Reti Hai, Fei Yu, and Jie Ma*

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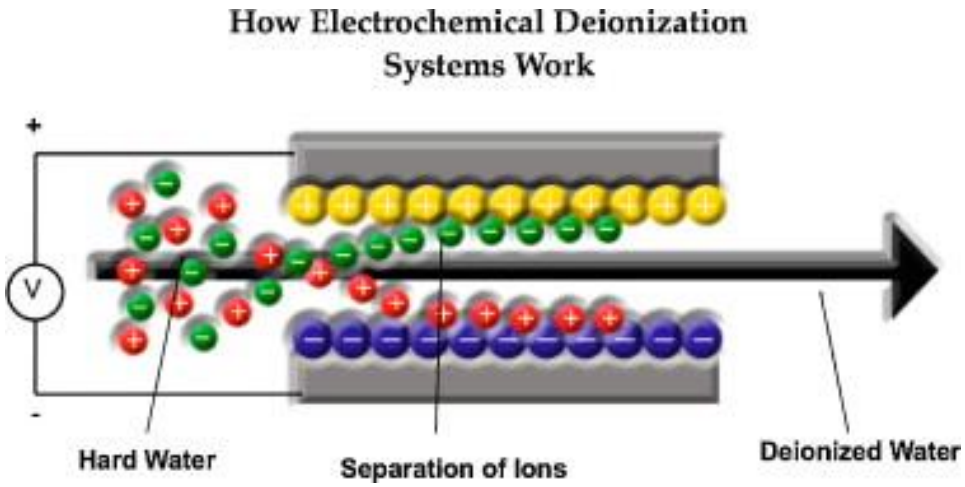
What is Mxenes?

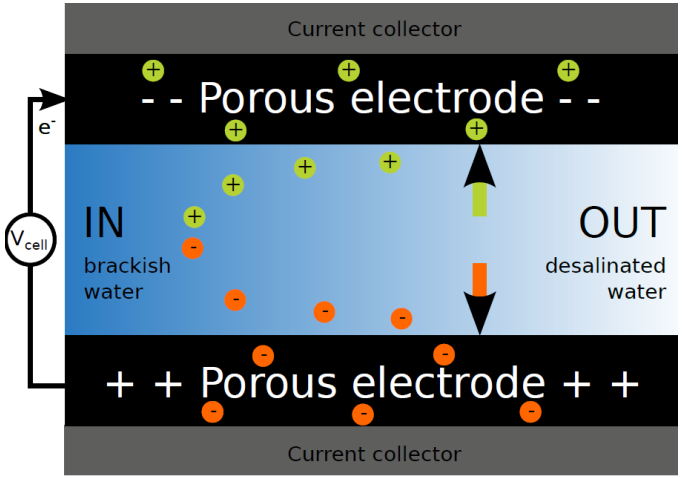
- In materials science, **MXenes** are a class of two-dimensional inorganic compounds. These materials consist of few-atoms-thick layers of transition metal carbides, nitrides, or carbonitrides. First described in 2011, MXenes combine metallic conductivity of transition metal carbides and hydrophilic nature because of their hydroxyl or oxygen terminated surfaces. The naming convention $M_{n+1}X_nT_x$ can be used, where T is a functional group (*e.g.* O, F, OH, Cl).

Applications

- MXenes, as conductive layered materials with tunable surface terminations, have been shown to be promising for energy storage applications (Li-ion batteries and supercapacitors), composites, photocatalysis, water purification, gas sensors, transparent conducting electrodes, neural electrodes, as a metamaterial, SERS substrate, photonic diode, electrochromic device, and triboelectric nanogenerator (TENGs), to name a few.

What is CDI?





- **Capacitive deionization (CDI)** is a technology to deionize water by applying an electrical potential difference over two porous carbon electrodes.
- Liquid is flowing between the high surface area electrode pairs having a potential difference of 1.0-2.0 V DC.

Image courtesy: M.A. Anderson *et al.*, Electrochimica Acta 2010, *55, 3845–3856*

In this paper….

- Water scarcity is becoming a serious issue across the world.
- However, well-developed desalination processes such as reverse osmosis (RO), electrodialysis (ED), and distillation not only require large-scale infrastructure but also have a high cost for controlling fouling during operations. Therefore, it is desirable to develop a novel desalination technology with simple equipment, easy operation, and high energy efficiency.
- Further applications of conventional CDI are limited due to its low salt adsorption capacity (0.1−15 mg g^{-1}), low charge efficiency (30−70%), and poor cycling stability.
- An innovative MCDI cell design based on two cation-selective electrodes and a single anion-selective membrane, and thereafter this design was experimentally validated by various authors.
- But MCDI electrode has issues due to decrease the conductivity of electrode surface.
- Na^+ -intercalated $Ti_3C_2T_x$ (NaOH-$Ti_3C_2T_x$) terminated with negatively charged groups (−OH, −O, and −F) was prepared by etching Ti_3AlC_2 in HF solution followed by treatment in NaOH solution.
- The desalination performance of NaOH-$Ti_3C_2T_x$ was tested by assembling an asymmetric CDI cell (AC // NaOH-$Ti_3C_2T_x$) in which an activated carbon (AC) electrode was employed as an anode and NaOH-$Ti_3C_2T_x$ as a cation-selective cathode.

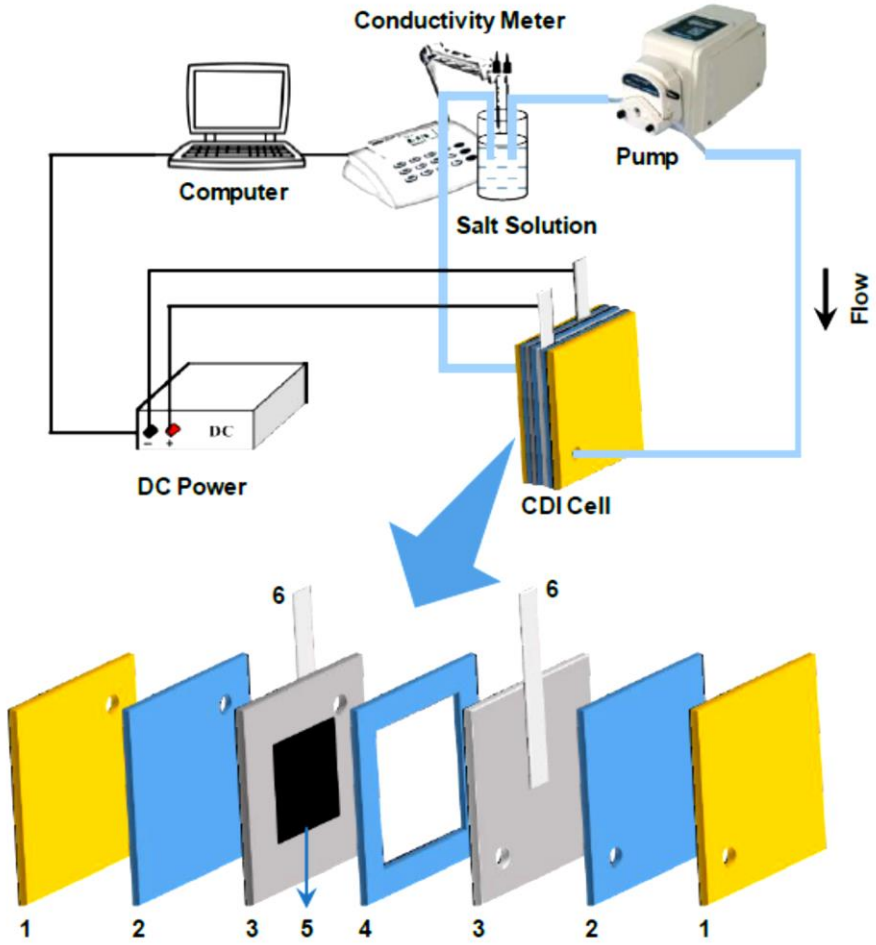


Figure 1. The schematic of the CDI measuring system. (1) epoxy plate, (2) silicon rubber slice, (3) titanium sheet, (4) silicon rubber, (5) electrode, and (6) titanium conductor.

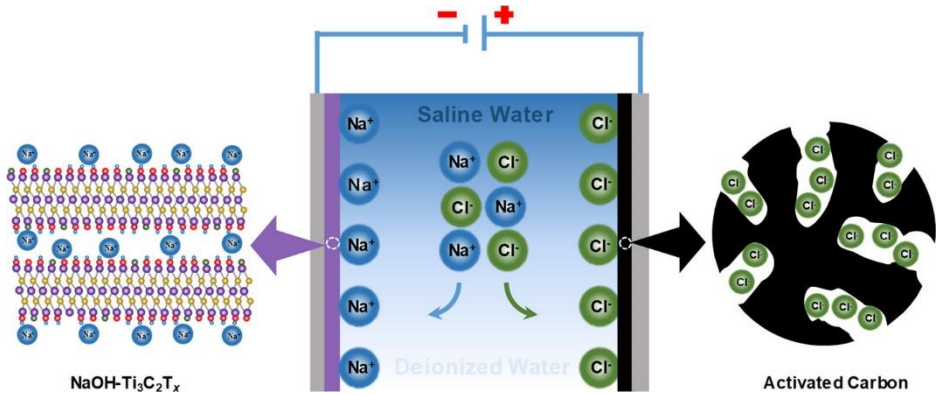


Figure 2. Schematic of the asymmetric CDI cell (AC // NaOH-$Ti_3C_2T_x$).

Results and discussion

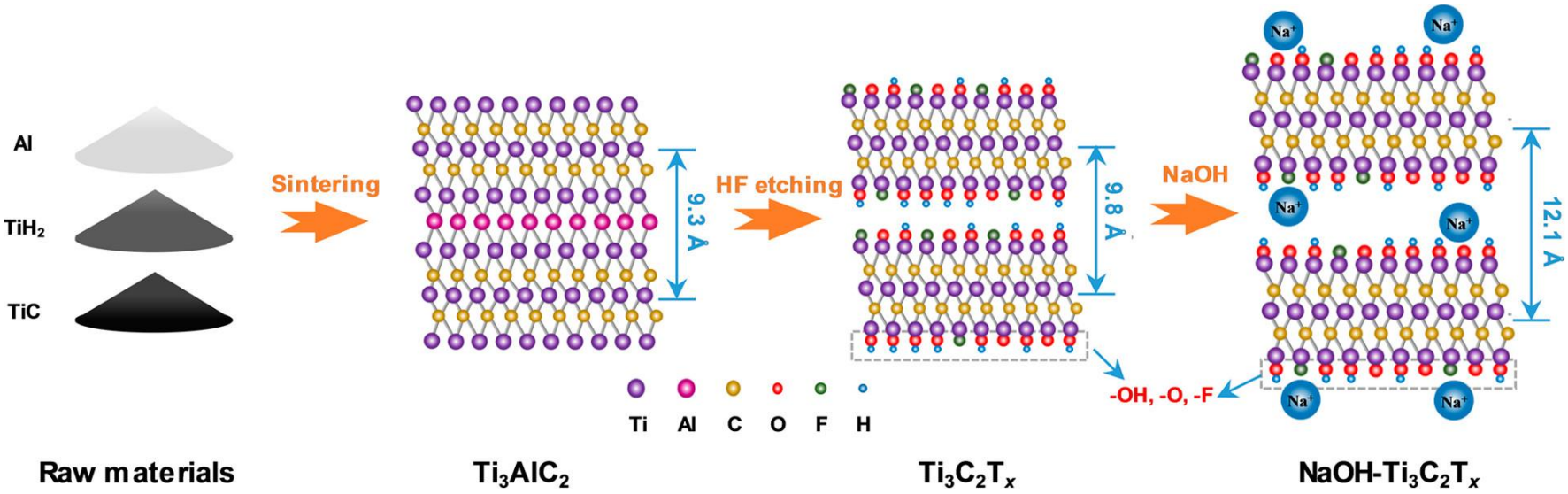


Figure 3. Schematic representation of synthesis procedures of NaOH-$Ti_3C_2T_x$.

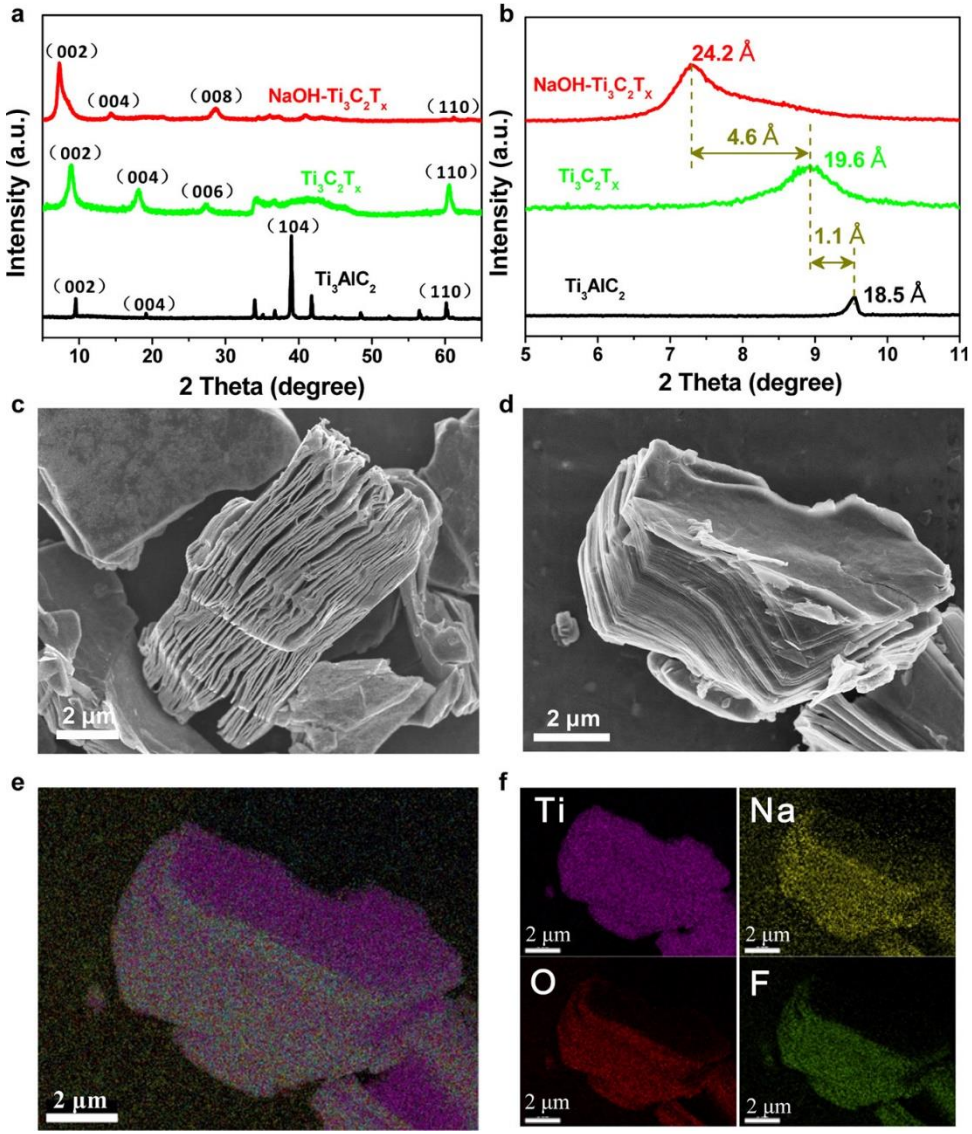


Figure 4. (a–b) XRD patterns of Ti_3AlC_2, $Ti_3C_2T_x$, and NaOH-$Ti_3C_2T_x$. (c) SEM graph of $Ti_3C_2T_x$. (d) SEM graph of NaOH-$Ti_3C_2T_x$. (e–f) EDX elemental distribution graphs of Ti, Na, O, and F of NaOH-$Ti_3C_2T_x$.

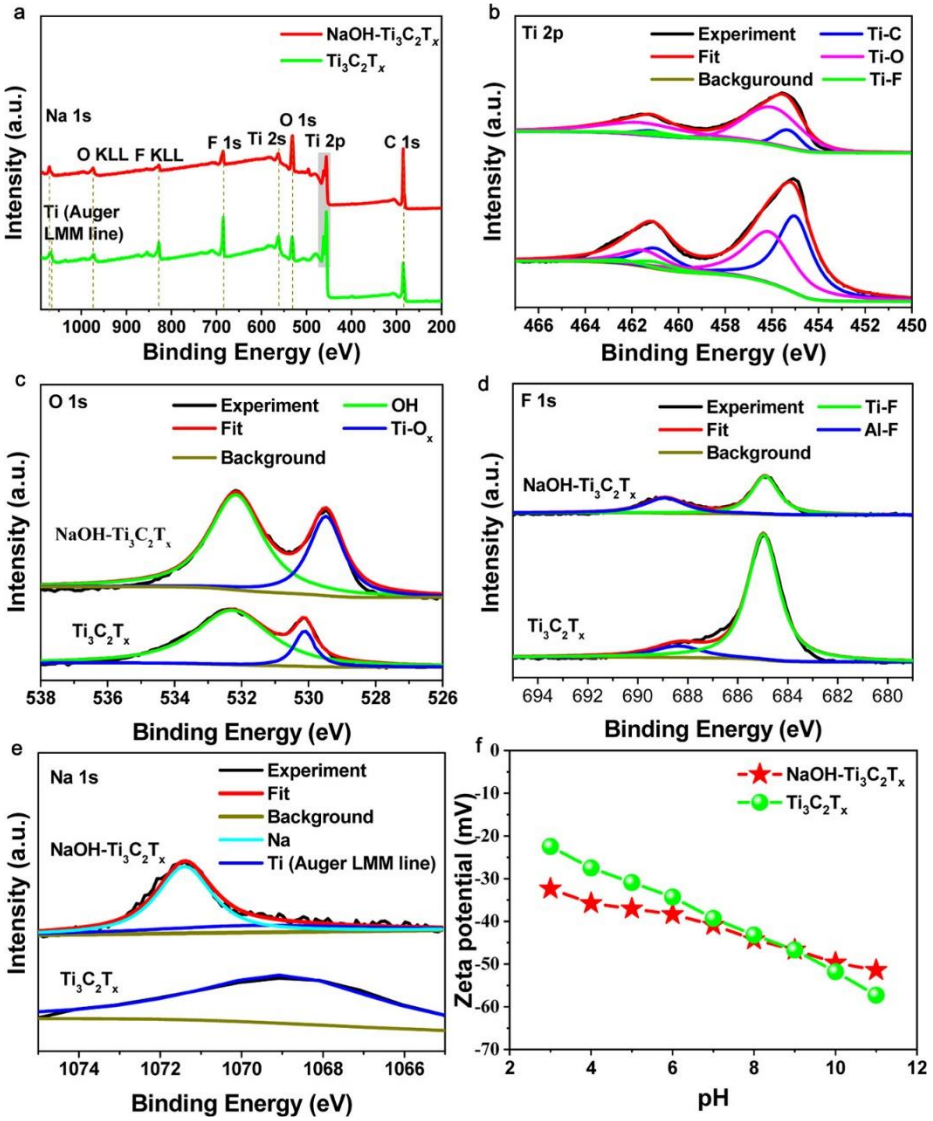


Figure 5. (a) XPS spectrum of $Ti_3C_2T_x$ and NaOH-$Ti_3C_2T_x$. (b−e) High-resolution XPS spectrum of $Ti_3C_2T_x$ and NaOH-$Ti_3C_2T_x$ in the (b) Ti 2p, (c) O 1s, (d) F 1s, and (e) Na 1s. (f) pH-dependent zeta potential of $Ti_3C_2T_x$ and NaOH-$Ti_3C_2T_x$.

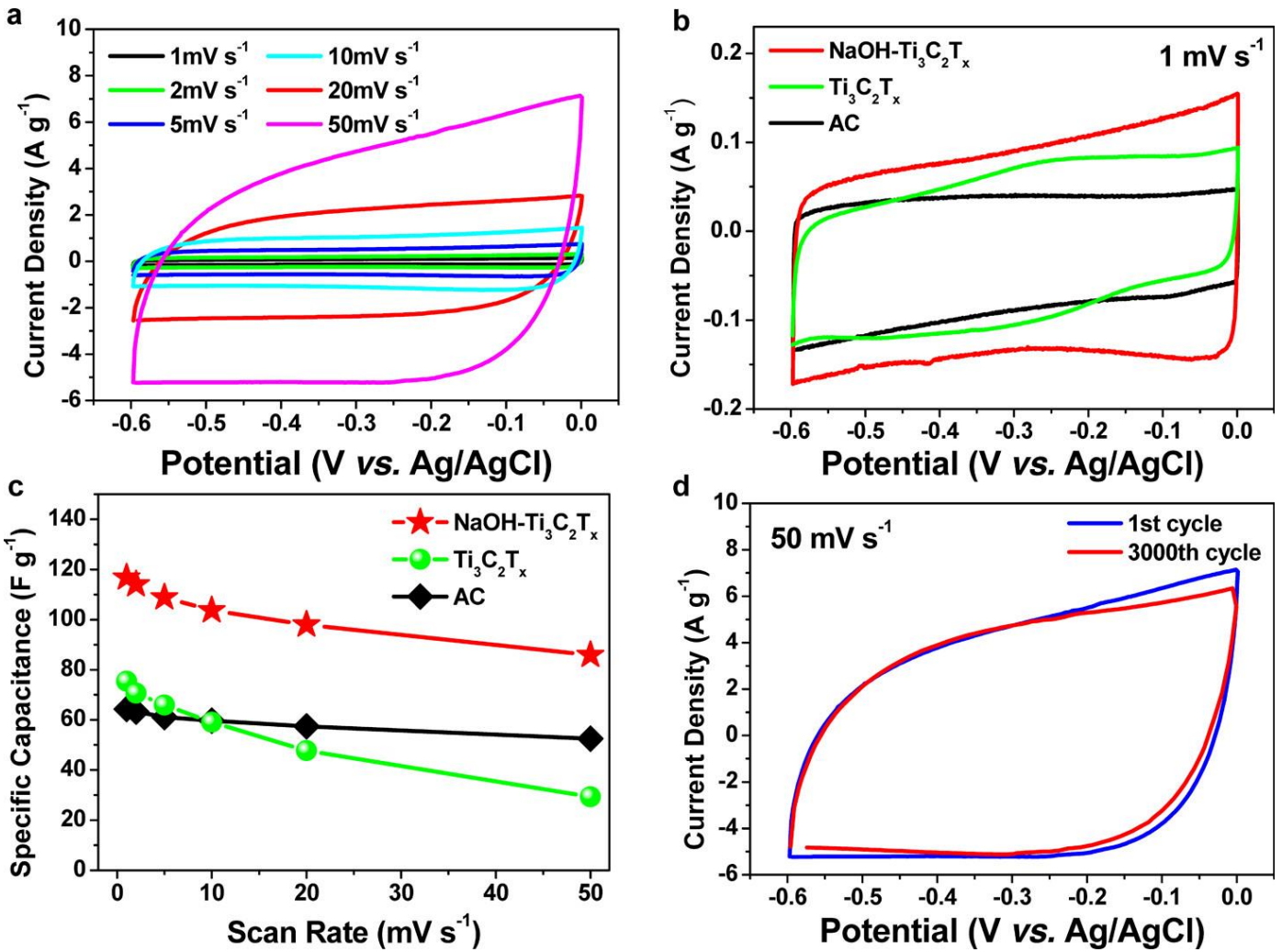


Figure 6. Electrochemical performance of NaOH-$Ti_3C_2T_x$, $Ti_3C_2T_x$, and AC electrodes. (a) CV curves of the NaOH-$Ti_3C_2T_x$ electrode at various scan rates. (b) CV curves for NaOH-$Ti_3C_2T_x$, $Ti_3C_2T_x$, and AC electrodes at a scan rate of 1 mV s^{-1}. (c) Specific capacitance of NaOH-$Ti_3C_2T_x$, $Ti_3C_2T_x$, and AC electrodes at various scan rates. (d) Cyclic stability of the NaOH-$Ti_3C_2T_x$ electrode at a scan rate of 50 mV s^{-1} for 3000 cycles.

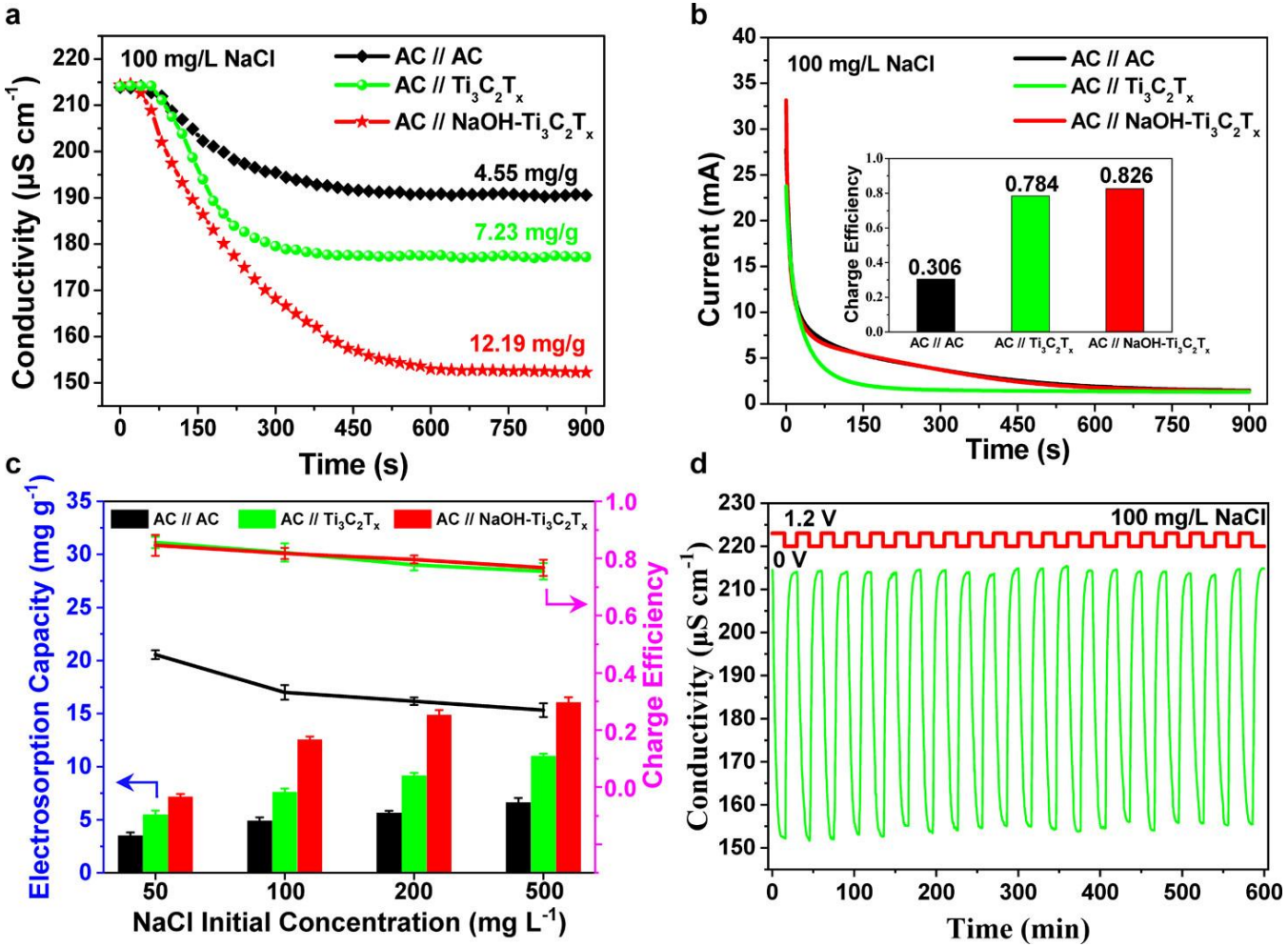


Figure 7. CDI characterizations of asymmetric and symmetric CDI cells. (a) Conductivity profiles of AC // NaOH-$Ti_3C_2T_x$, AC // $Ti_3C_2T_x$, and AC // AC in 100 mg L^{-1} NaCl solution. (b) Current and charge efficiency profiles of AC // NaOH-$Ti_3C_2T_x$, AC // $Ti_3C_2T_x$, and AC // AC in 100 mg L^{-1} NaCl solution. (c) Electrosorption capacity and charge efficiency of AC // NaOH-$Ti_3C_2T_x$, AC // $Ti_3C_2T_x$, and AC // AC at various NaCl concentrations. (d) Electrosorption−desorption profile of AC // NaOH-$Ti_3C_2T_x$ in 100 mg L^{-1} NaCl solution.

Conclusion

- In this paper, Na^+-intercalated $Ti_3C_2T_x$ (NaOH-$Ti_3C_2T_x$) with negatively charged groups (−OH, −O, and −F) and an expanded interlayer space was successfully synthesized via etching Ti_3AlC_2 in the concentrated HF and treatment in NaOH solution.

- An asymmetric CDI cell (AC // NaOH-$Ti_3C_2T_x$) was assembled where AC served as the anode and NaOH-$Ti_3C_2T_x$ as the cation-selective cathode.

- Compared to the symmetric one (AC // AC), the AC // NaOH-$Ti_3C_2T_x$ exhibits a significantly higher electrosorption capacity (12.19 mg g−1) and charge efficiency (0.826) in 100 mg L−1 NaCl solution.

- The AC // NaOH-$Ti_3C_2T_x$ cell shows excellent cyclic stability, which is more than 20 cycles.

- MXene has great potential as a candidate of a cation-selective cathode material in asymmetric capacitive deionization.


Thank You