Supporting Information

2D $Ti_3C_2T_x$ MXene/GO hybrid membranes for highly efficient osmotic power generation

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Supporting information includes 7 pages with the following figures and tables, as cross referenced throughout the main article:

Synthesis of MXene and GO nanosheets

$Ti_3C_2T_x$ MXene nanosheets was obtained by selective etching of the Al layer from the Ti_3AlC_2 (MAX phase) using in situ hydrofluoric (HF) forming etchant, lithium fluoride (LiF) and hydrochloric acid (HCl) (shown as Figure S1). [1] MAX powder was obtained from Luoyang Tongrun Info Technology Co., Ltd, China. LiF of 1.32 grams was dissolved in 20 mL of 6 M HCl solution under stirring for 10 min. Then, 2 g Ti_3AlC_2 power (MAX) was slowly added to avoid initial overheating of the exothermic reaction.[2] After etching at 40 ℃ for 60 h under magnetic stirring, the resulting solution was washed with deionized water through several cycles of centrifugation (5 min for each cycle at 3500 rpm), until the pH value of the supernatant reached ~ 6. To delaminate $Ti_3C_2T_x$ into 2D nanosheets (*d*- $Ti_3C_2T_x$ MXene), the obtained precipitates were redispersed into 100 mL of DI water followed by ultrasonication for 2 h under flowing Argon gas. The stable MXene colloidal solution in a dark green color was collected after centrifugation at 3500 rpm for 1h.

Graphene oxide (GO) was synthesized based on a modified Hummer's method.[3] The synthesis steps in detail are as follows: three grams of graphite and 1.5 g of sodium nitrate were added into 75 mL concentrated sulfuric acid under stirring in an ice bath at 0 ℃ for 1h. Afterwards, 9.0 g $KMnO_4$ was carefully added over the course of 20 min with temperature kept below 20 ℃. The temperature was subsequently increased to 35 ℃ and kept at 35 ± 3 ℃ for 30 min. Afterwards, 150 mL DI water was added slowly into the mixture with an elevated temperature of 98 ℃ for another hour. Finally, the mixture was cooled to room temperature followed by the addition of 400 mL DI water and 9 mL H_2O_2 (30% wt %) to stop the oxidation reaction. The obtained product was washed with 1 M HCl solution and a large amount of DI water until reaching a pH ~ 5. The yellowish GO colloidal solution was collected with the aid of a centrifuge at 3000 rpm for 30 min.

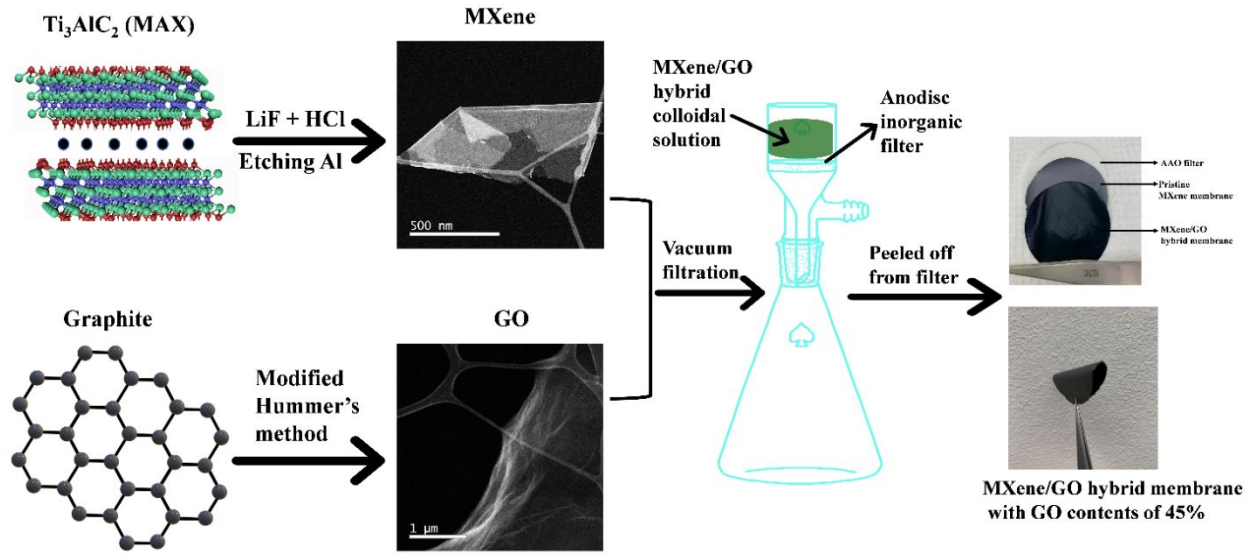

Figure S1. The fabrication procedure of the MXene/GO hybrid membranes.

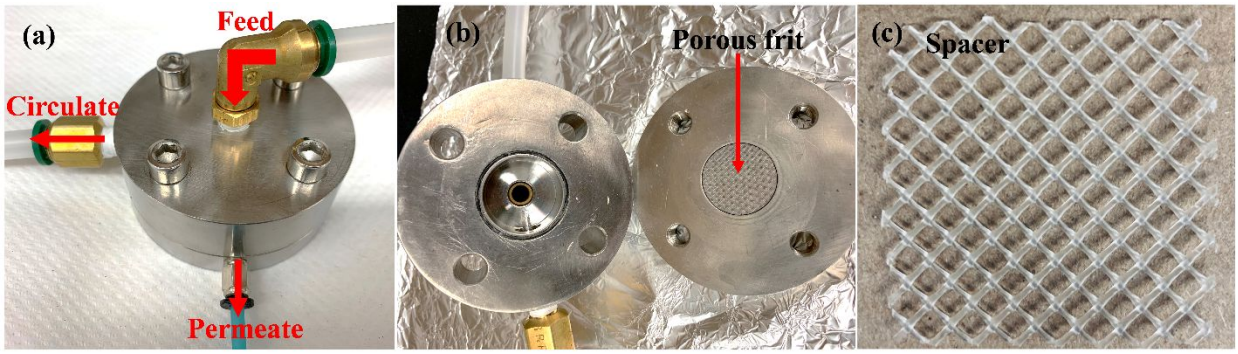

Figure S2. The membrane testing cells. (a). the modified RO testing cell, (b) the porous frit in the RO cell, and (c) the spacer used to replace the porous frit.

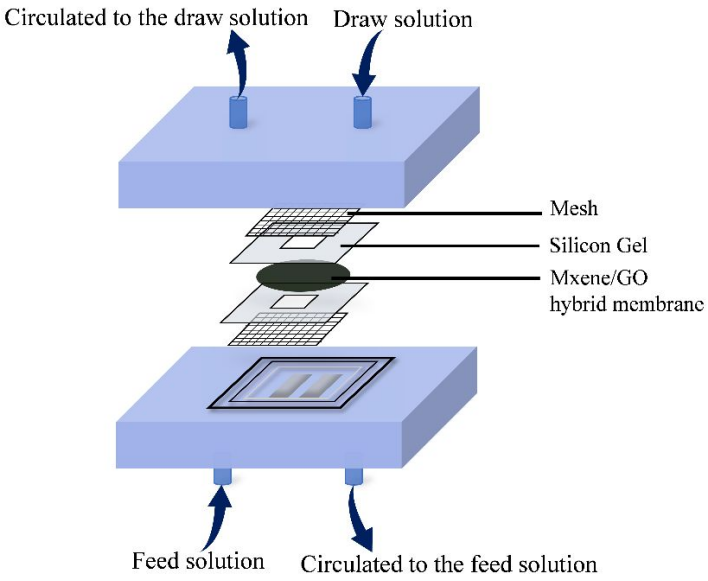

Figure S3. The schematic of a FO cell under the crossflow mode.

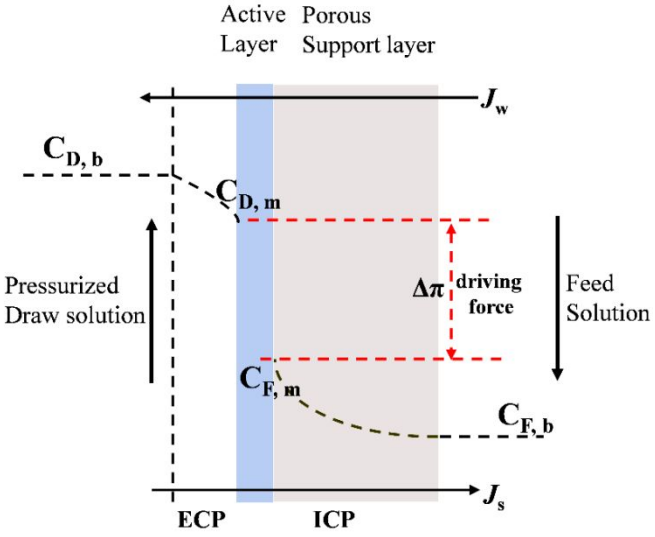

Figure S4. A schematic diagram of the salt concentration profile across a PRO membrane.

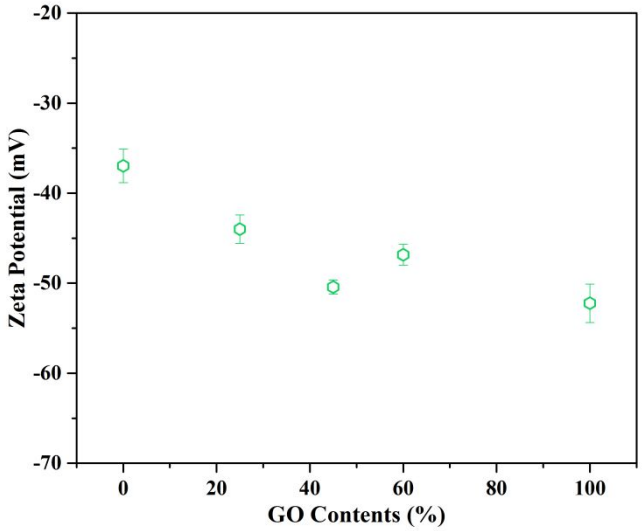

Figure S5. Zeta potential of MXene/GO solutions as a function of GO contents (%).

Table S1. The mechanical properties of the membranes.

Membrane	Tensile strength (Mpa)	Young's Modulus (Gpa)	Strain to failure (%)
d-$Ti_3C_2T_x$-0	19.3±1.5	3.47±0.1	1.2 ± 0.2
d-$Ti_3C_2T_x$-25	33.1 ± 2.0	2.58 ± 0.3	2.0 ± 0.3
d-$Ti_3C_2T_x$-45	94.0 ± 4.2	4.1 ± 0.5	9.1 ± 0.1

Table S2. The intrinsic characteristics of the membranes.

Membranes	A (L m^{-2} h^{-1} bar^{-1})	B (L m^{-2} h^{-1})	S (μm)
d-$Ti_3C_2T_x$-45	7.76	13.47	57.0 ± 2.1
CTA	1.09	1.06	476.1 ± 10.5

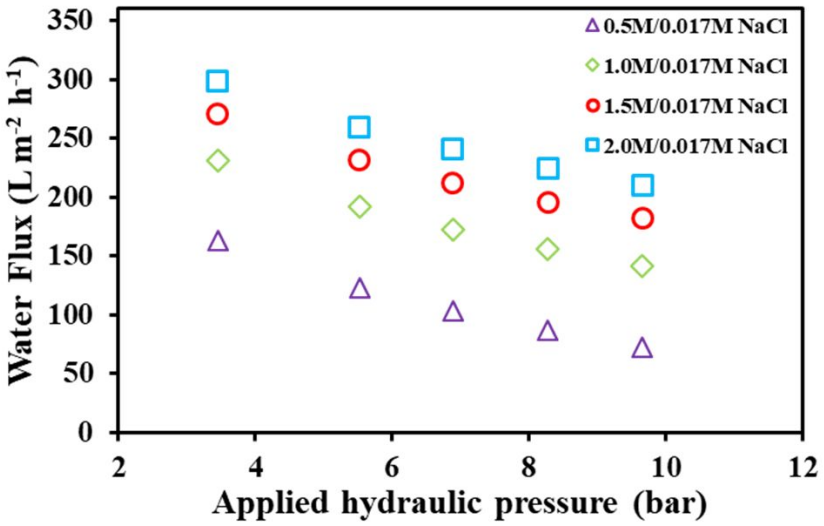

Figure S6. The calculated theoretical water flux as a function of applied hydraulic pressure.

Table S3. Power generation performance of MXene/GO hybrid membrane compared with state-of-art flat-sheet PRO membrane.

Membrane	Feed Solution (NaCl)	Draw Solution (NaCl)	ΔP (bar)	Power Density (W m^{-2})	Reference
MP#1 (TFC-PRO membrane)	0.017 M	0.5 M	12.5	10.0	[1]
TFC200 (TFC-PRO membrane)	DI water	0.59 M	13.0	9.0	[2]
TFC200 (TFC-PRO membrane)	0.01 M	1.0 M	15.0	10.0	[2]
TNC-2 (TNC-PRO membrane)	0.08 M	1.06 M	15.2	15.2	[3]
TNC-2 (TNC-PRO membrane)	0.0009 M	1.06 M	15.2	21.3	[3]
Freestanding GO membrane	0.017 M	0.5 M	6.89	6.8	[4]
Freestanding GO membrane	0.017 M	1.0 M	6.89	12.8	[4]
Freestanding MXene/GO-45	0.017 M	0.5 M	9.66	19.4	This work
Freestanding MXene/GO-45	0.017 M	1.0 M	9.66	38.1	This work

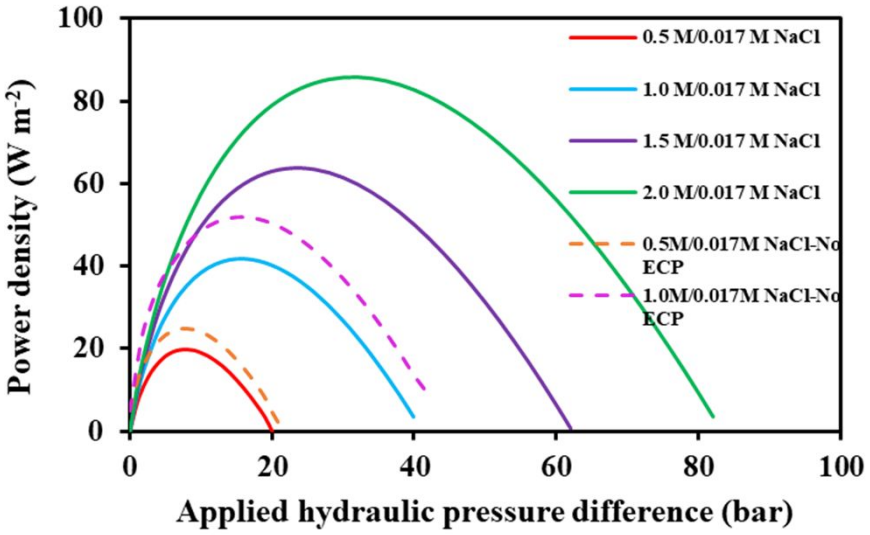

Figure S7. The calculated theoretical power density as a function of applied hydraulic pressure difference.

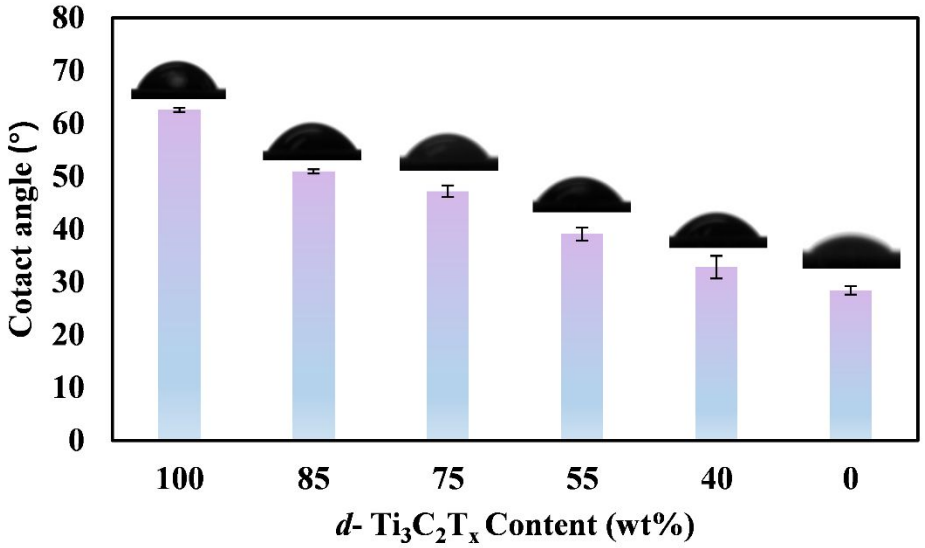

Figure S8. Contact angle of MXene/GO membrane with different MXene contents.

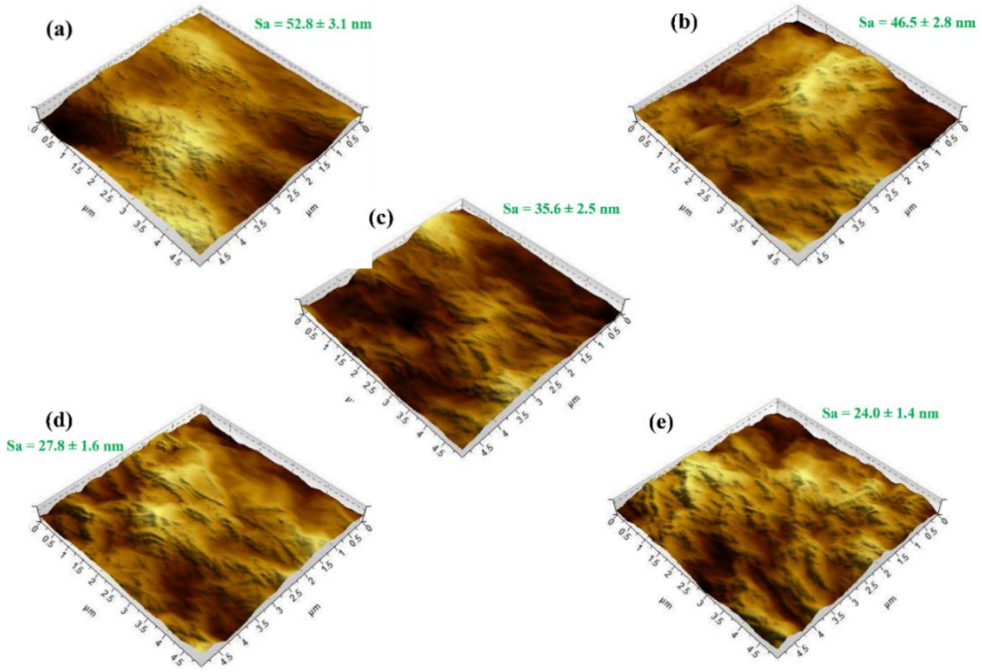

Figure S9. AFM images of membrane surface roughness (a) *d*-$Ti_3C_2T_x$/GO-0, (b) *d*-$Ti_3C_2T_x$/GO-15, (c) *d*-$Ti_3C_2T_x$/GO-25, (d) *d*-$Ti_3C_2T_x$/GO-45, and (e) *d*-$Ti_3C_2T_x$/GO-60.

References

1. Liang, C.; Wang, Z.-S.; Bruell, C. J., Influence of pH on persulfate oxidation of TCE at ambient temperatures. *Chemosphere* **2007,** *66*, (1), 106-113.
2. Ghidiu, M.; Lukatskaya, M. R.; Zhao, M.-Q.; Gogotsi, Y.; Barsoum, M. W., Conductive two-dimensional titanium carbide 'clay'with high volumetric capacitance. *Nature* **2014,** *516*, (7529), 78.
3. Xu, Y.; Bai, H.; Lu, G.; Li, C.; Shi, G., Flexible Graphene Films via the Filtration of Water-Soluble Noncovalent Functionalized Graphene Sheets. *Journal of the American Chemical Society* **2008,** *130*, (18), 5856-5857.