Supplementary Information (SI) for ChemComm.

Supporting Information for

Moisture-Driven Power Generation in MXene Composite Membranes Regulated by Hygroscopic Ionic Liquids

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Supporting Notes

S1. Materials

MAX powder was purchased from Foshan Xinxi Technology Co., Ltd. Ionic liquids (ILs) were obtained from Qingdao Aolike New Materials Technology Co., Ltd. Nylon membranes (pore size 0.45 μm) were purchased from Tianjin Jinteng Experiment Equipment Co., Ltd. Electrode materials were supplied by Tianjin Aida Hengsheng Technology Development Co., Ltd.

S2. Preparation of MXene membrane

Dissolve LiF (3.2 g) in 40 mL of 9 M HCl, stirring at 600 rpm for 15 minutes in a Teflon-lined vessel at 40° C. MAX powder (2.0 g) was then added and etched for 48 hours to remove the aluminium layer. The resulting suspension was washed with deionized water and centrifuged at 3500 rpm for 1 minute per cycle until the supernatant reached neutral pH. The precipitate was redispersed in deionized water and sonicated for 1 hour in an ice bath under protective gas to obtain a stable MXene suspension.

S3. Preparation of IL/MXene membrane

Take 15 mL of MXene suspension, dilute to 20 mL with deionized water, mix thoroughly, and vacuum-filter through a nylon membrane to prepare the MXene membrane (MXene-M). Dry the membrane in a vacuum oven at 50° C. Subsequently, 1 mL of ionic liquid was uniformly coated onto the MXene surface using a squeegee technique. The membrane was then placed in a 50° C oven for one hour to obtain the final composite material, denoted as IL/MXene-M.

S4. Device assembly and performance measurements

IL/MXene-M was contacted on both sides with two Pt electrodes and clamped in a custom fixture to prevent displacement during testing. The fixture was mounted on a custom humidity chamber and connected to a digital multimeter (Fluke 289C). The open-circuit voltage U_{oc} was logged at 1-minute intervals. All data were recorded directly without postprocessing.

S5. Materials characterization

Morphology and elemental distributions were examined by scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS). X-ray diffraction (XRD) patterns were recorded on a Smart Lab 9 diffractometer using Cu Kα radiation (λ= 0.15406 nm). FT-IR spectra were collected on a Nicolet iS50 in attenuated total reflection (ATR) mode with 1 cm^{-1} resolution and 64 scans.

Supporting Figures and Captions:

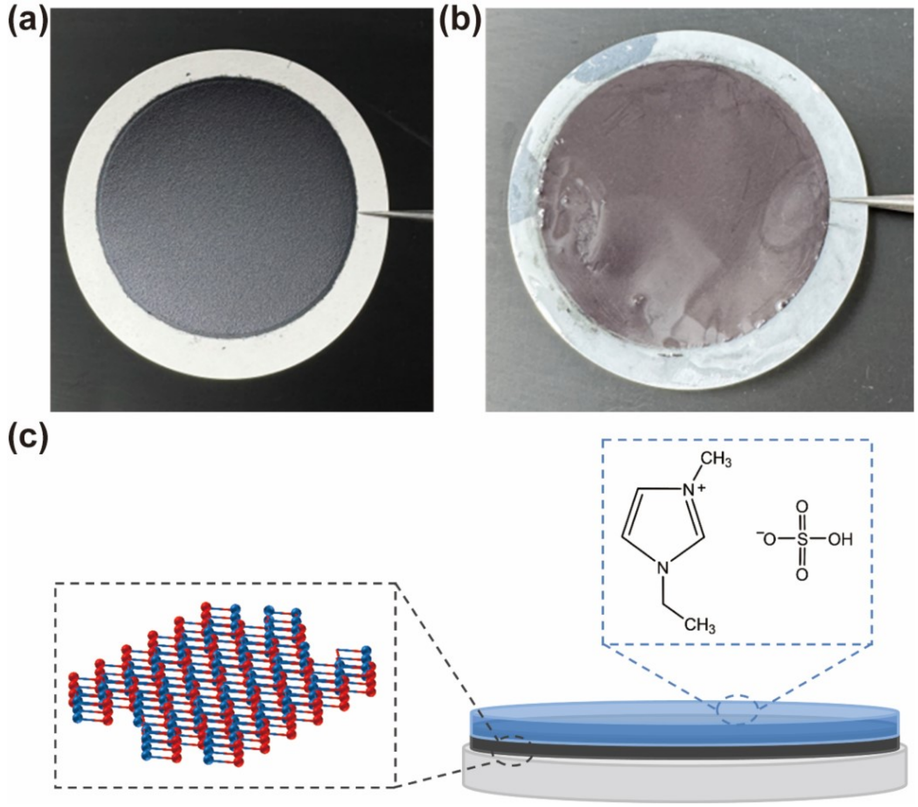


Figure S1. (a) Photo of MXene-M. (b) Photo of IL/MXene-M. (c)Schematic diagram of the IL/MXene-M composite membrane. From top to bottom: IL (e.g. $EMImHSO_4$), MXene, and nylon substrate.

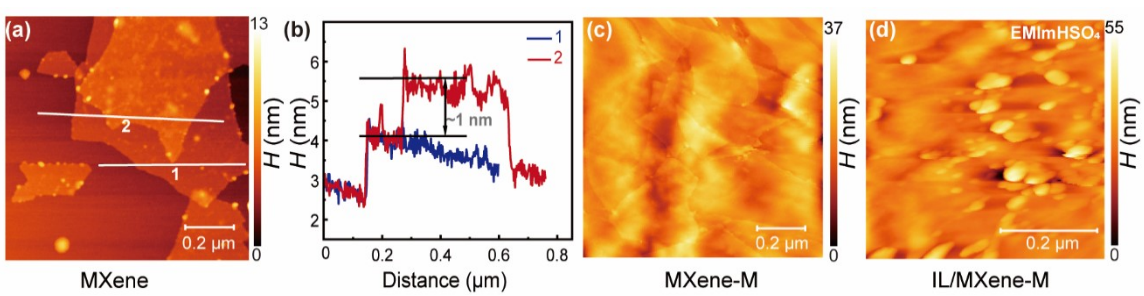


Figure S2. (a) AFM image of MXene sheets. (b) Height profile of the MXene flakes. (c) AFM image of the MXene-M surface. (d) AFM image of the IL/MXene-M surface.

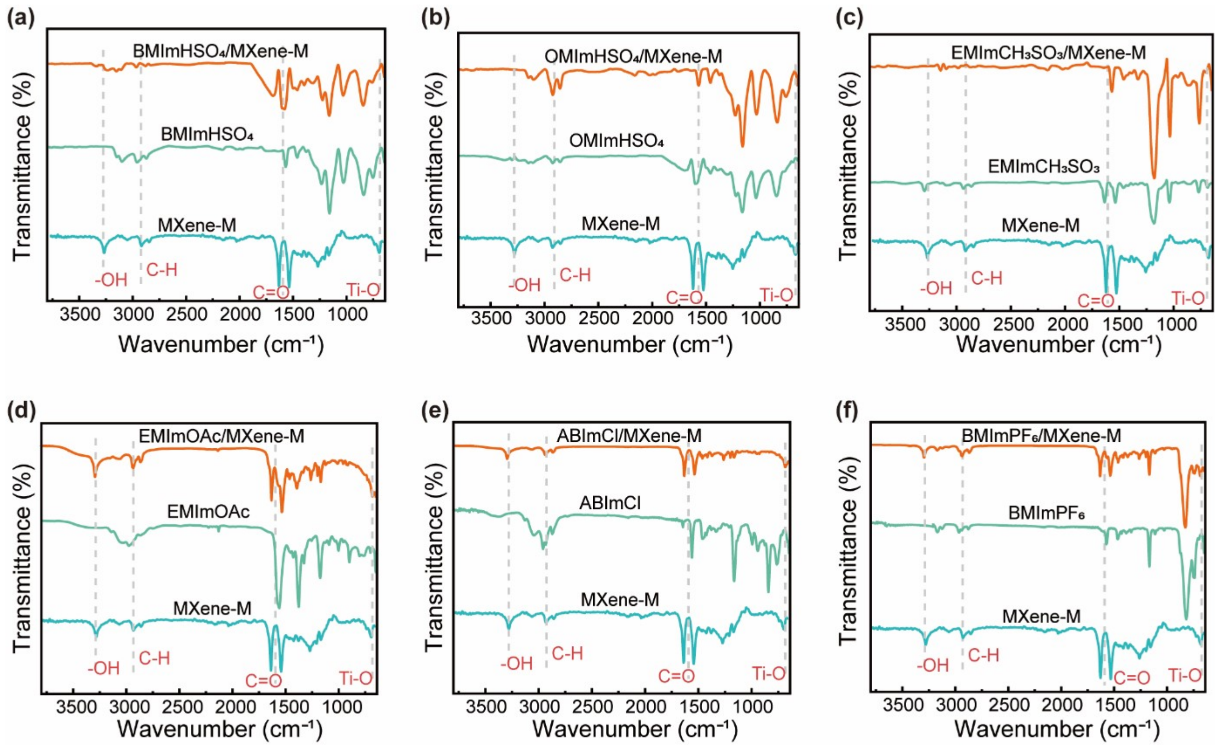


Figure S3. FTIR spectra of different composite membrane and corresponding ionic liquids. (a) $BMImHSO_4$/MXene-M. (b) $OMImHSO_4$/MXene-M. (c) $EMImCH_3SO_3$/MXene-M. (d) EMImOAc/MXene-M. (e) ABImCl/MXene-M. (f) $BMImPF_6$/MXene-M.

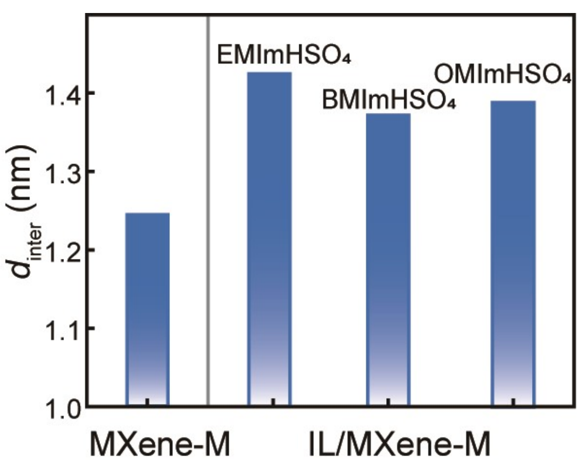


Figure S4. Interlayer spacing of MXene-M and different IL/MXene-M.

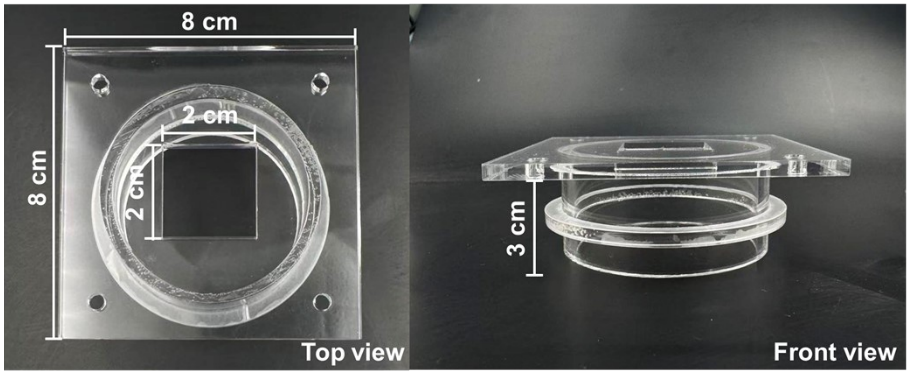


Figure S5. Physical image and dimensions of the mold used to test the power generation performance of composite membranes.

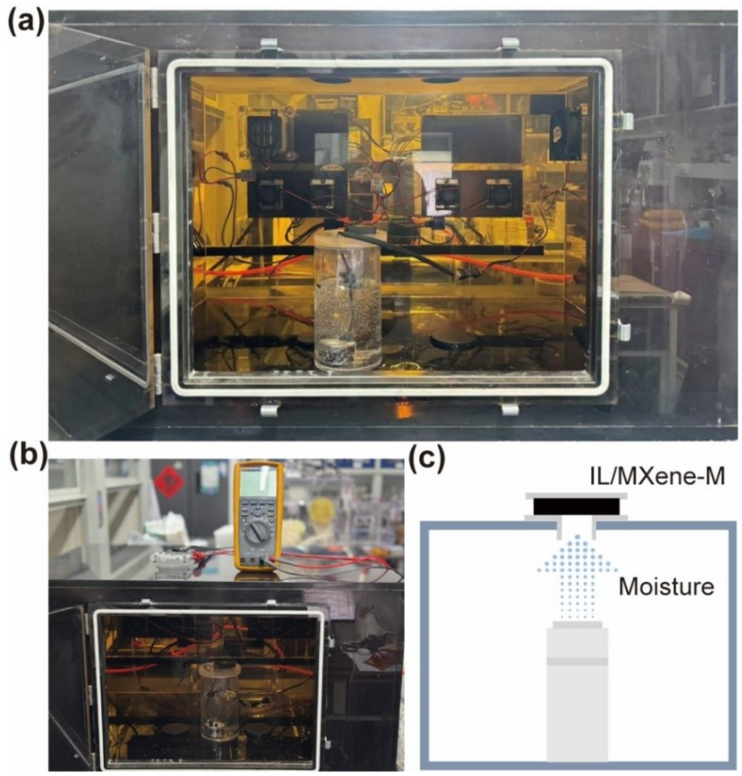


Figure S6. Photo of temperature and humidity monitoring equipment. (a) The overall dimensions of the cabinet are 70 cm × 50 cm × 40 cm. The main principle is to inject ultrapure water into the internal container, atomize it into fine droplets using an ultrasonic atomizer, and then blow it toward the top of the cabinet with a small fan. The cabinet is equipped with temperature and humidity sensor probes that can monitor humidity values in real time. Additionally, the exterior of the cabinet is designed with an air pump solenoid valve and desiccant, which dries the internal air by drawing it through the desiccant and then recirculates it into the cabinet to maintain a humidity environment. The humidity control range is 10%-90% RH, with a control deviation within ±1.5% RH. The indoor humidity is 45%. (b) IL/MXene-M actual power generation performance test image, with the testing mold placed on a temperature and humidity monitoring device. (c) A humidity differential exists between the humidity within the temperature and humidity monitoring equipment and the ambient humidity of the indoor environment, with moisture diffusing outwards.

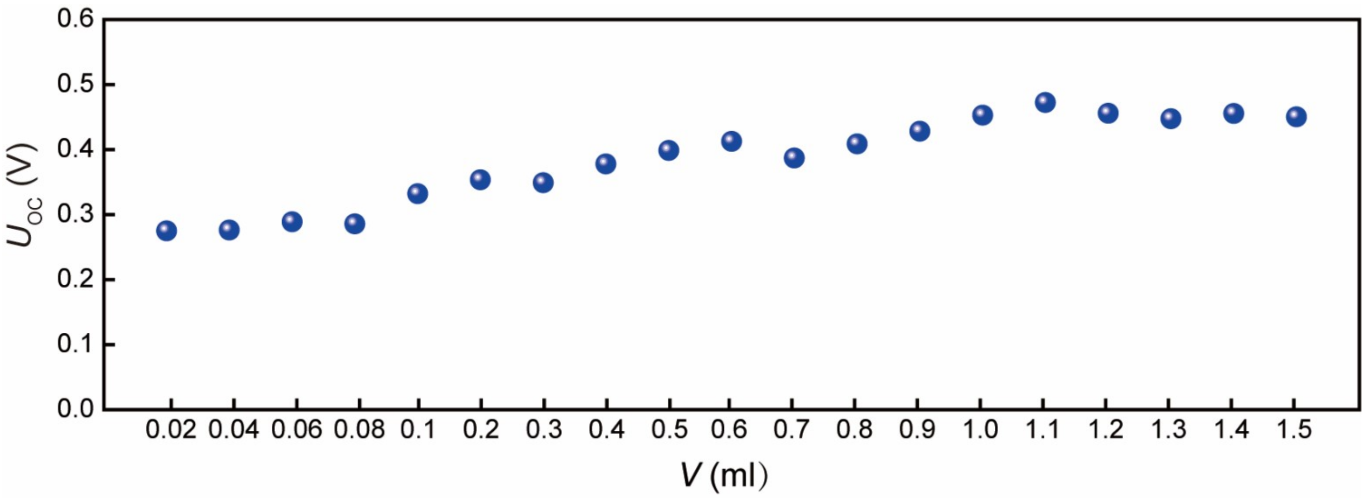
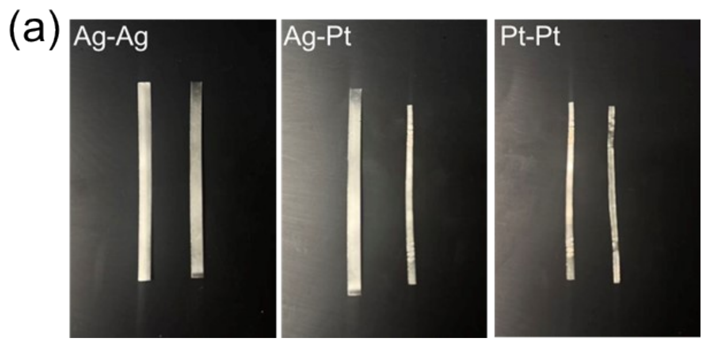


Figure S7. U_{oc} of the IL/MXene-M corresponding to different amount of $EMImHSO_4$, where the membrane is fully wetted upon the addition of 1 ml of the IL.



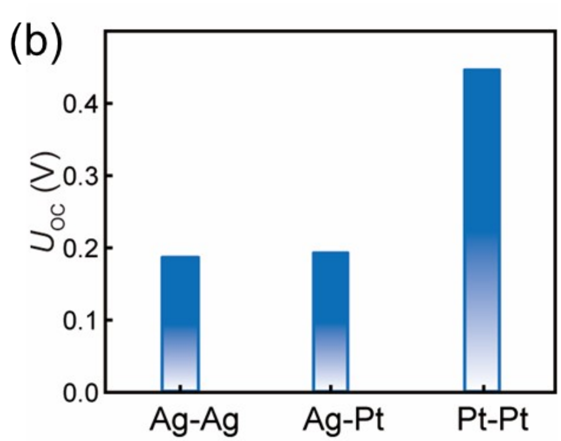


Figure S8. (a) Photos of different electrode pairs used in the test of power performance.
(b) *U*oc for the device with different electrode pairs

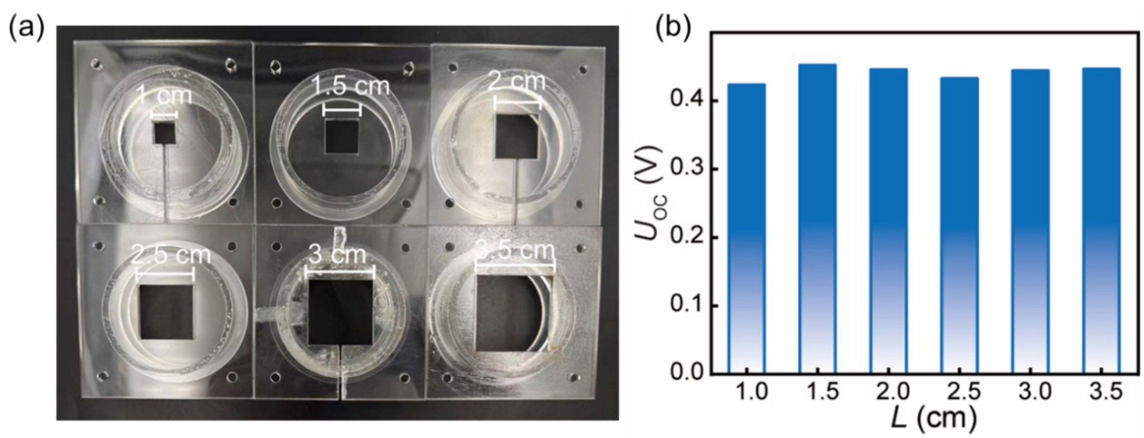


Figure S9. (a) Actual photos of molds for different window sizes. (b) *U*oc for the device with different moisture-exposure window sizes.

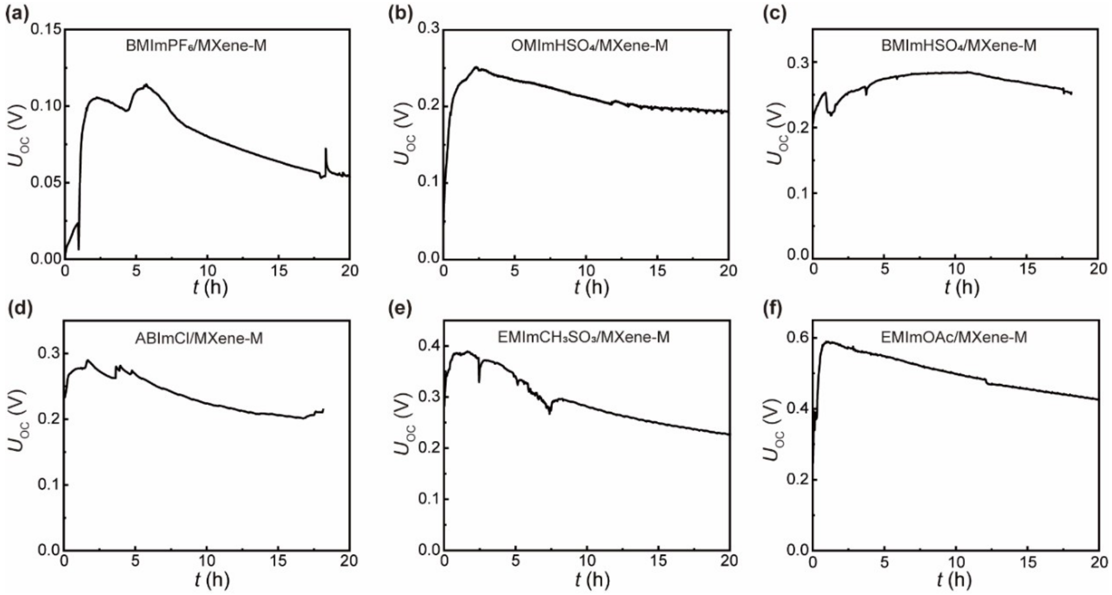


Figure S10. U_{oc} for the composite membrane with different ILs at 25°C and 90% humidity. (a) BMImPF$_6$/MXene-M. (b) OMImHSO$_4$/MXene-M. (c) BMImHSO$_4$/MXene-M. (d) ABImCl/MXene-M. (e) EMImCH$_3$SO$_3$/MXene-M. (f) EMImOAc/MXene-M.

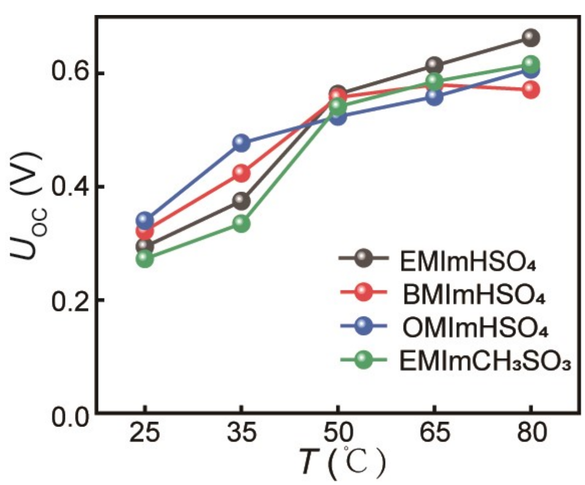


Figure S11. *U*oc at different temperatures.

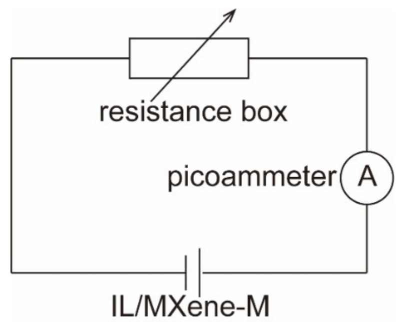


Figure S12. Test circuit for measuring areal power density of the MPG by connecting an external load resistor.

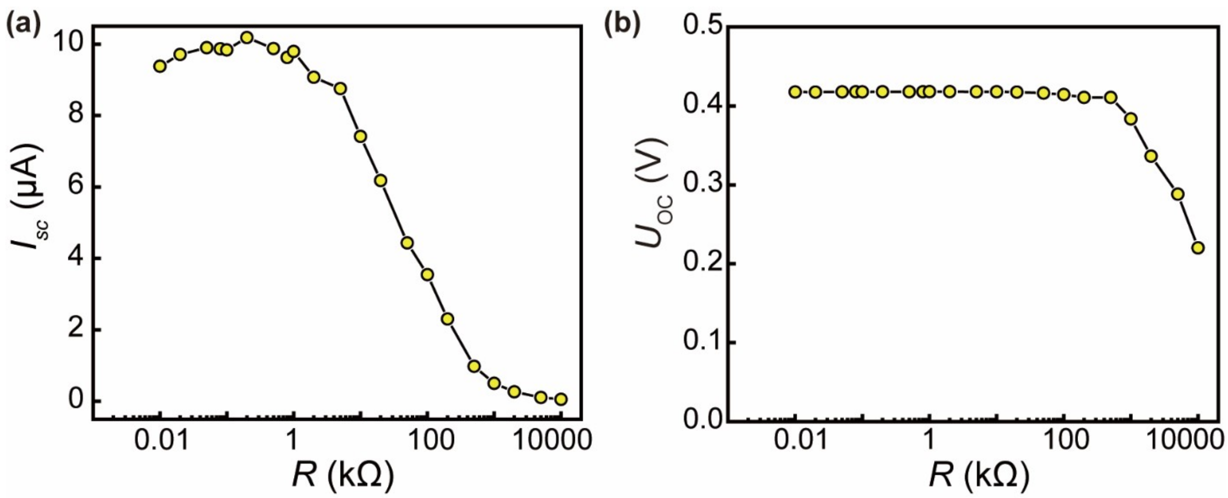


Figure S13. (a) I_{sc} corresponding to different external load resistances. (b) U_{oc} corresponding to different external load resistances.

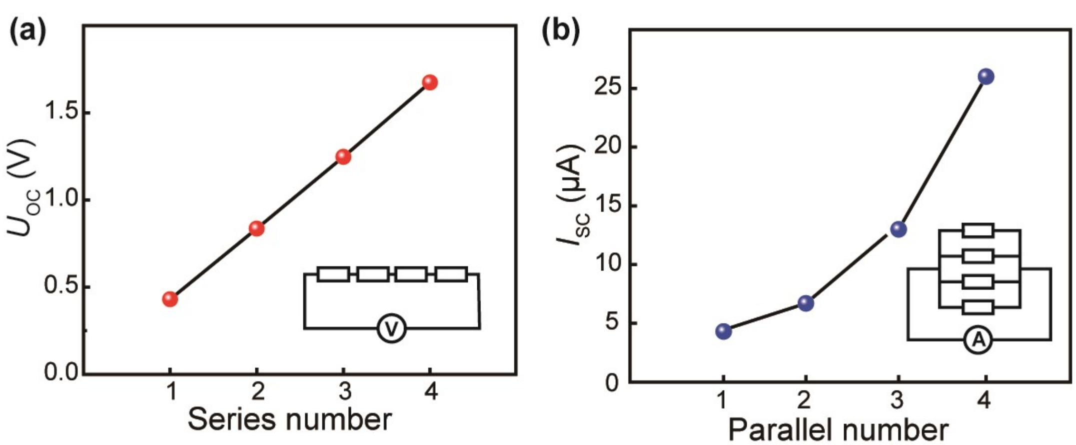


Figure S14. (a) *U*oc as a function of the serial number of device units. (b) *I*sc as a function of the parallel number of device units.

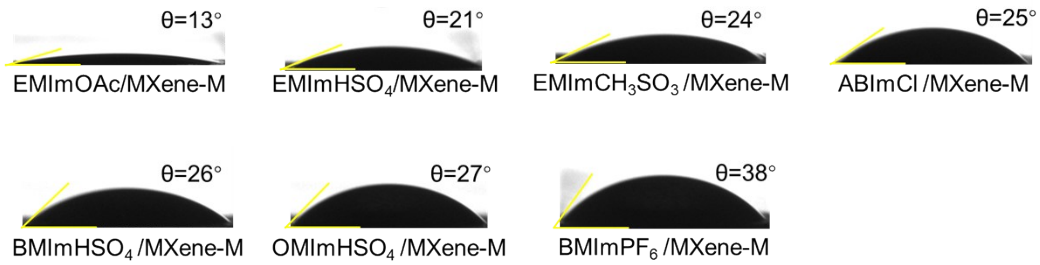


Figure S15. Water contact angles of different IL/MXene-M.

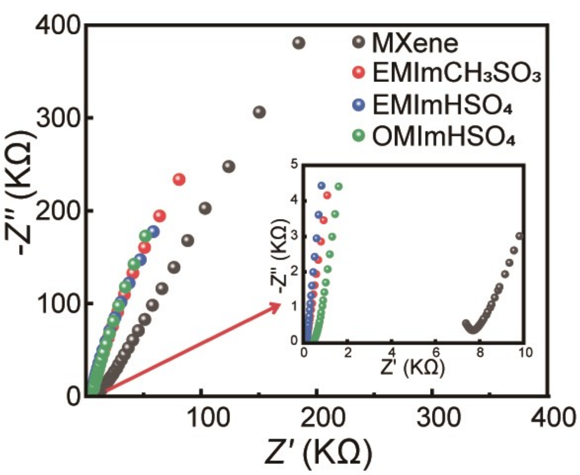


Figure S16. Nyquist impedance plots of MXene-M and IL/MXene-M.

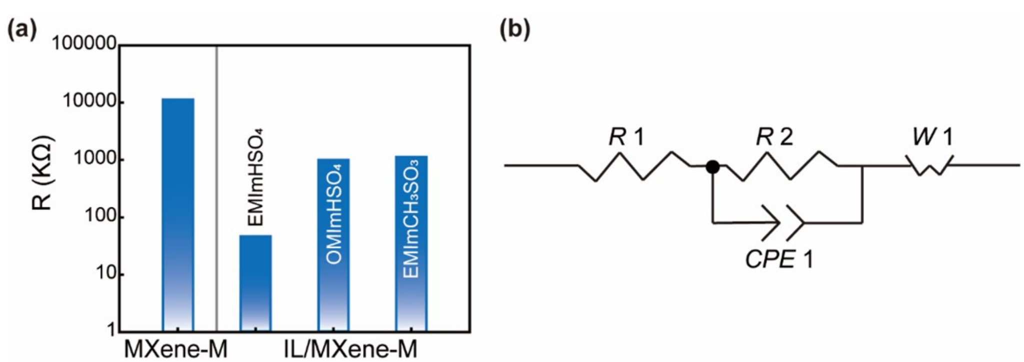
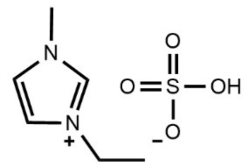
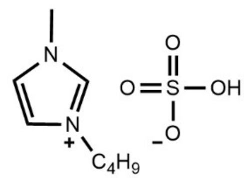
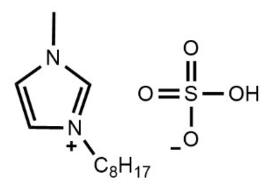
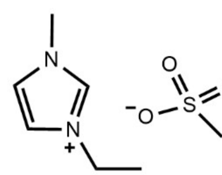
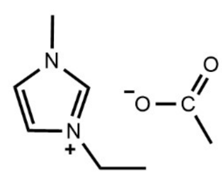
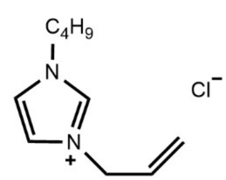


Figure S17. (a) The actual resistance value of IL/MXene-M measured using a multimeter. (b) The equivalent circuit diagram of EIS.

Supporting Table and Caption

Table S1. Summary table of the abbreviations, complete chemical names, and structural formulas of the ionic liquids referenced in this work.

abbreviation	full name	structural formula
$EMImHSO_4$	1-Ethyl-3-methylimidazolium hydrogen sulfate	
$BMImHSO_4$	1-butyl-3-methylimidazolium hydrogen sulfate	
$OMImHSO_4$	1-octyl-3-methylimidazolium hydrogen sulfate	
$EMImCH_3SO_3$	1-ethyl-3-methylimidazolium methanesulfonate	
EMImOAc	1-Ethyl-3-methylimidazolium acetate	
ABImCl	1-Allyl-3-butylimidazolium chloride	
$BMImPF_6$	1-butyl-3-methylimidazolium hexafluorophosphate