Supporting information

Bio-inspired Transpiration Ion Pump Based on MXene

Experimental Section

Fabrication of Lamellar MXene Membranes.
1.3 g LiF (Aladdin) was dissolved in 25 mL HCl solution (9 M) and magnetic stirring for 15 min. Then, 0.5 g Ti_3AlC_2 (200 mesh, Materials Research Centre, Ukraine) was slowly added in the solution over 30 min and then reacting at 37 °C for 24h. The resulting suspension was washed with DI water and centrifugated at 4000 rpm several times until the pH of the supernatant was ~ 6. The sediment was then dispersed into DI water with ultrasonication for 20 min. Finally, a colloidal solution of $Ti_3C_2T_x$ MXene nanosheets were obtained after the suspension was centrifuged at 4000 rpm for 15 min. The MXene membranes were prepared by vacuum-assisted filtration of liquid exfoliated MXene solution with a certain amount on a polypropylene filter membrane (Celgard 2400) and then peeled off the substrate after drying.

Characterization of MXene Nanosheets and Membranes.
X-ray photoelectron spectroscopy (XPS) was gained by Physical Electronics PHI5802 instrument using a magnesium anode (monochromatic Kα X-rays at 253.6 eV) as the source. The binding energy in the XPS spectra was calibrated with a carbon signal (C 1s at 284.6 eV). Scanning electron microscopy (SEM) images of MXene membranes were taken with Hitachi S4800. Transmission electron microscopy (TEM) images were obtained using a JEOL JEM-2100F microscope with an acceleration voltage of 200 kV. X-ray di□raction patterns were carried out on DX-27 mini with Cu Kα radiation.

Ion pump and energy conversion Measurement.
The ion pump and energy conversion devices were conducted with a home-made apparatus with two reservoirs. A certain volume of electrolyte solution was filled in each reservoir. A piece of rectangular MXene membrane (15 mm × 8 mm) was placed flat and the two ends were in contact with each solution. Ag/AgCl electrodes were inserted into both reservoirs to measure zero-volt current and open circuit voltage under IR illumination. Zero-volt current and open circuit voltage were recorded by a Keithley 2400 instrument.

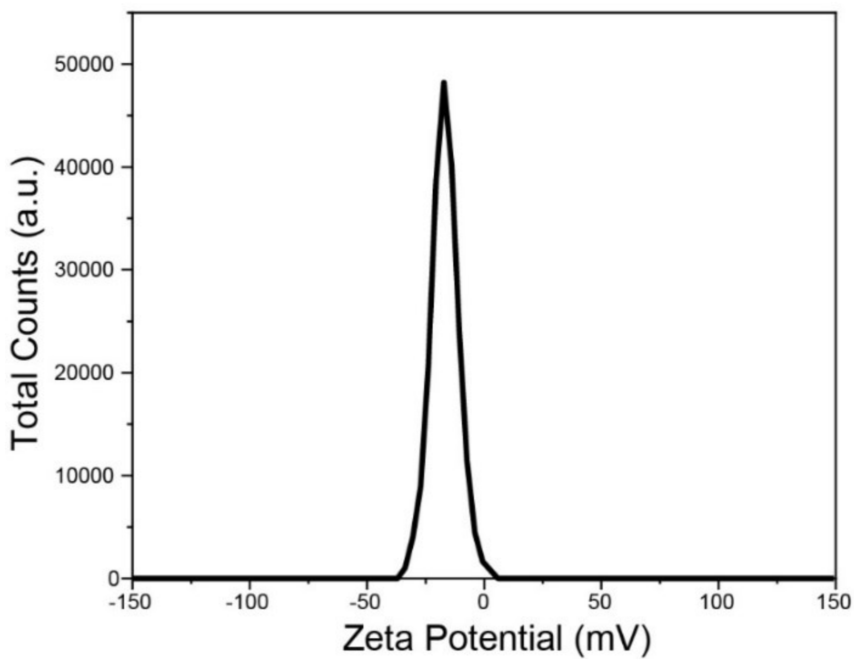

Fig. S1. Negative zeta potential of MXene nanosheets, confirming its negative surface charge (-20 mV).

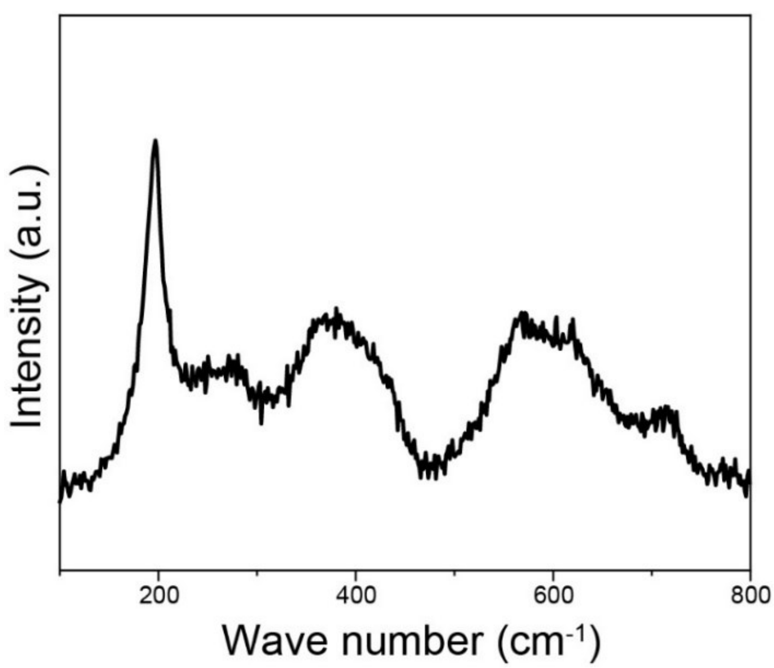

Fig. S2. Raman spectroscopy shows the main peaks of the MXene Ti_3C_2Tx.

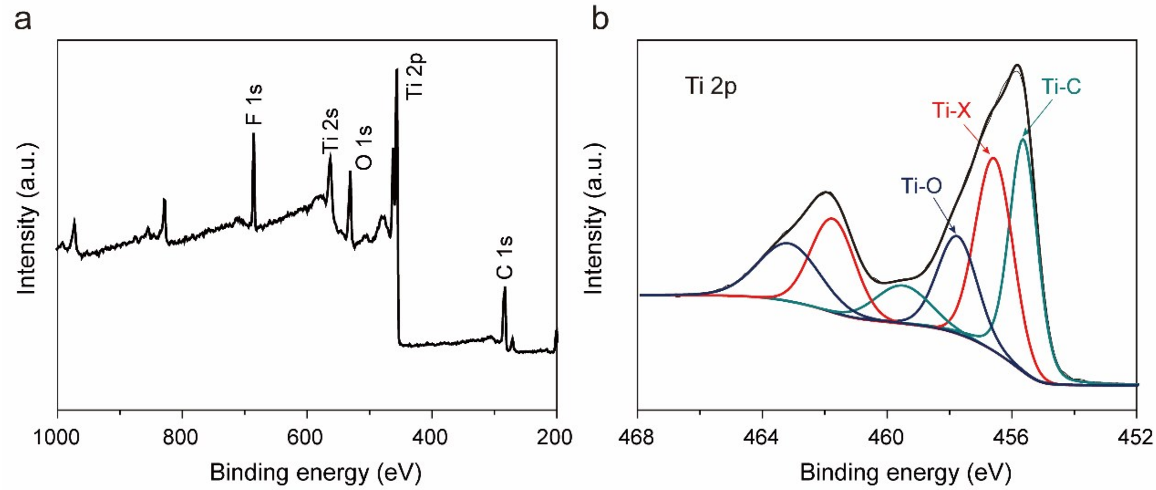

Fig. S3. XPS spectra of Ti_3C_2Tx nanosheets. **(a)** Full XPS spectrum and **(b)** High-resolution Ti 2p spectrum show the existence of C, Ti, O and F, indicating the formation of $Ti_3C_2T_x$ MXene.

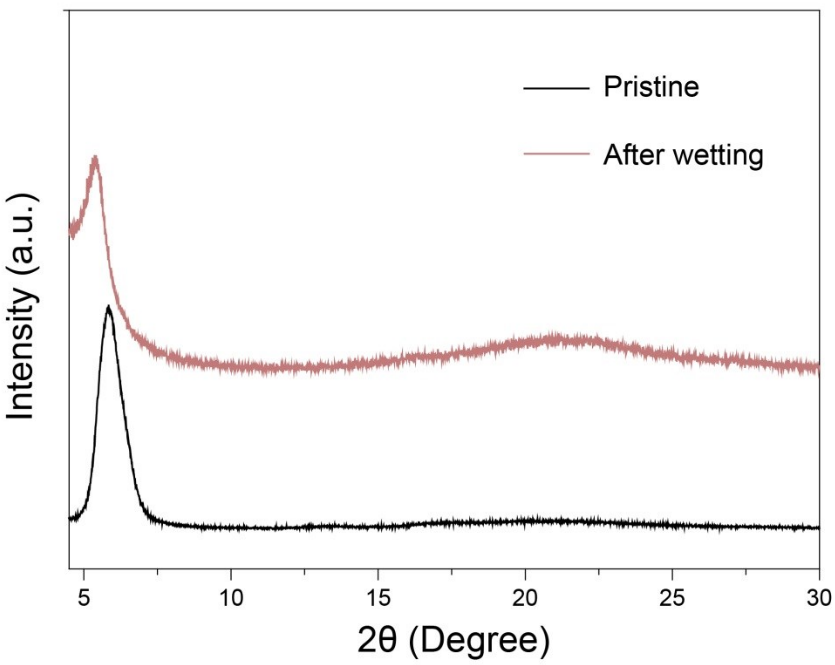

Fig. S4. X-ray di□raction patterns of $Ti_3C_2T_x$ membranes under drying and after wetting, showing the (0002) peak shifted from 5.8 ° to 5.4° after water swelling.

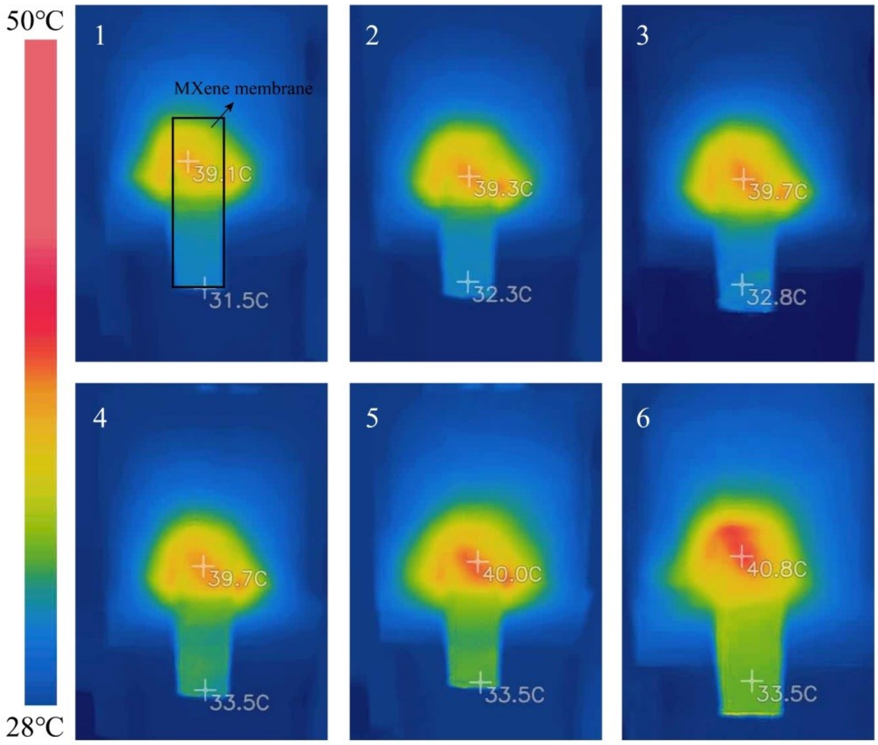

Fig. S5. IR thermal images of MXene $Ti_3C_2T_x$ membrane when one side was radiated by 600 mW/cm^2 power of IR illumination, showing a temperature difference of 7.3 ℃ between the sides within 30min. MXene film was placed flat and the two ends were in contact with solutions in two reservoirs respectively.

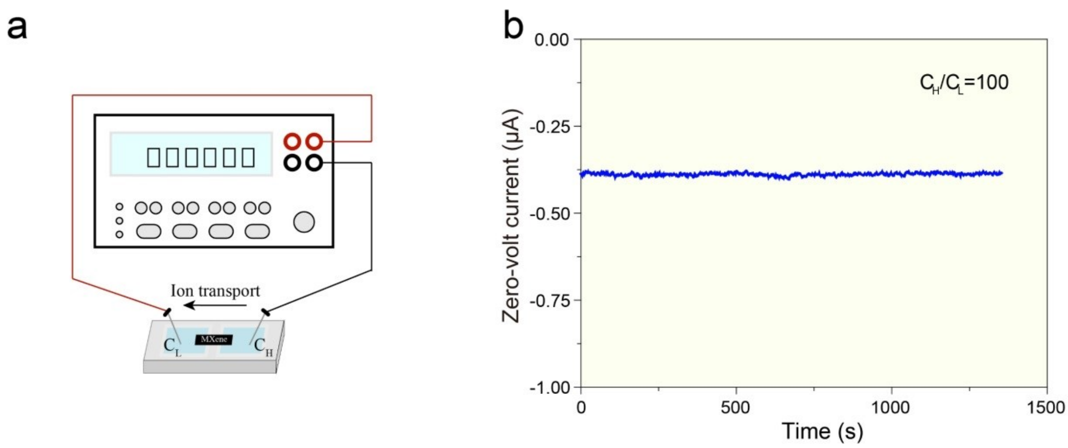

Fig. S6. Illustration of the appearance of ionic current. (a) Schematic of measurement. The positive (red) and negative (black) probes of Keithley 2400 were connected with Ag/AgCl electrodes that inserted into the left and right reservoirs. Ion diffusion current was measured at I-T mode when the left and right reservoirs were filled with solutions of C_L and C_H, respectively. (b) Ion diffusion current under 100-fold (C_H

=0.01 M; C_L =0.0001 M) KCl concentration. [41]

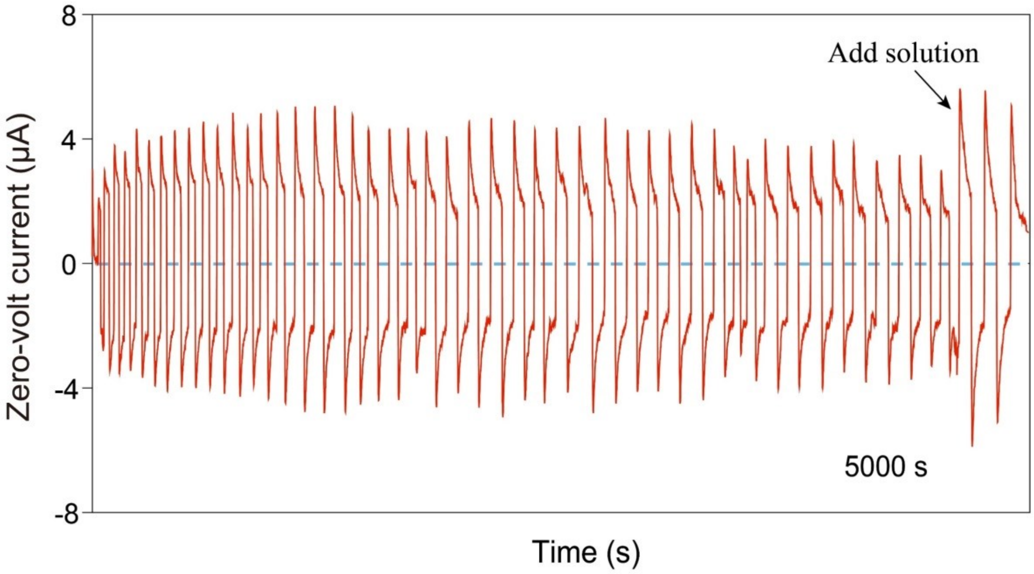

Fig. S7. Zero-volt current through $Ti_3C_2T_X$ membrane within 5000 seconds when the illumination was applied to the left or right side of the membrane, showing the good stability and repeatability of ion pump device.

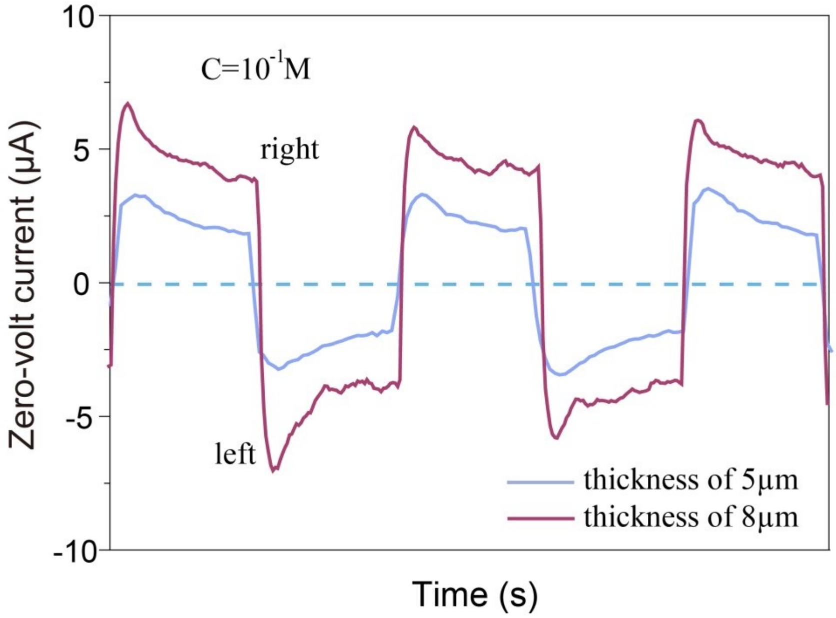

Fig. S8. The comparison of zero-volt current curves when the thickness of the $Ti_3C_2T_X$ membrane is about 5μm and 8μm.

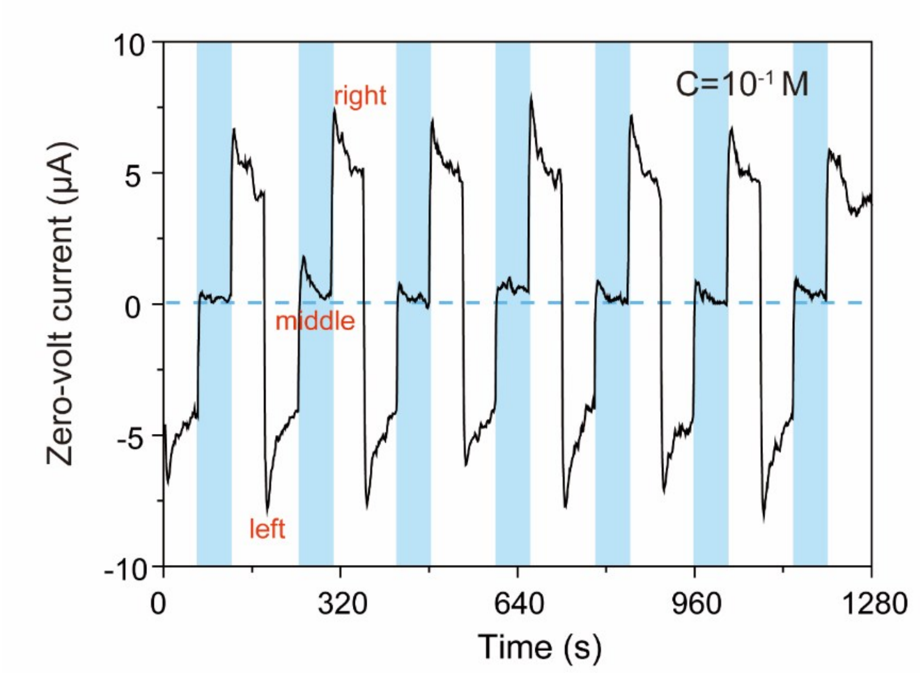

Fig. S9. Zero-volt current curves under several cycles when the light illumination was applied separately on different positions (left, middle and right) of MXene membrane.

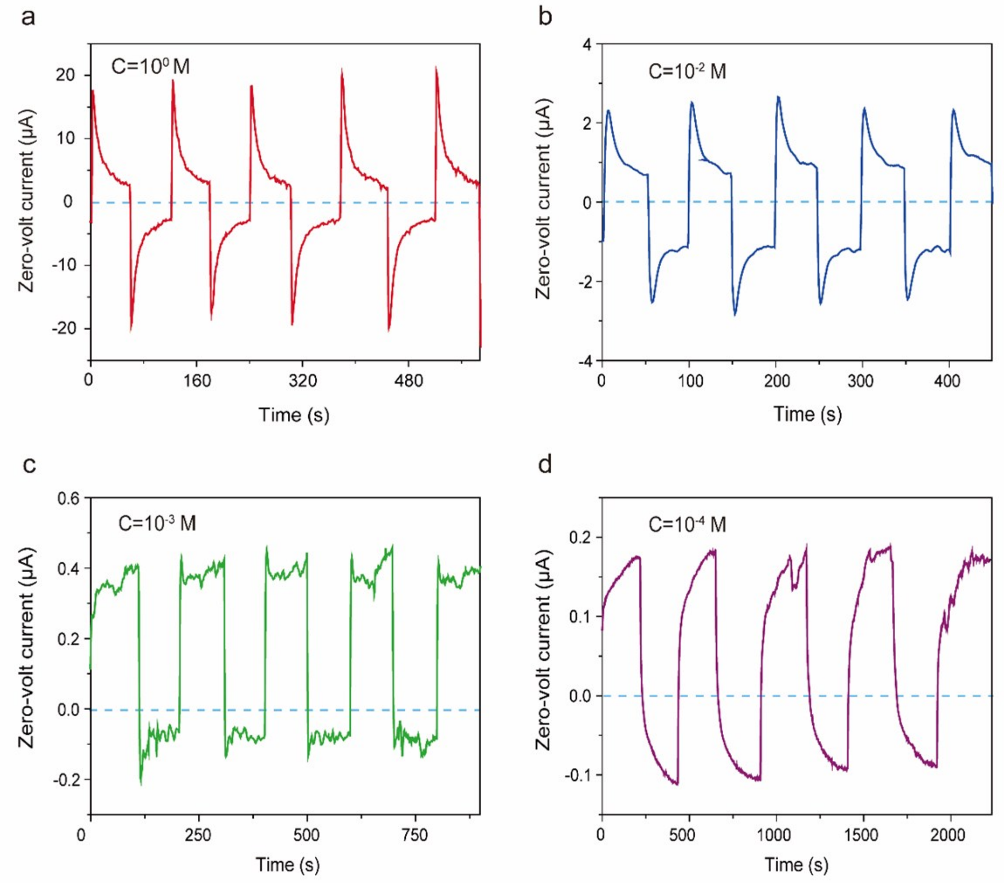

Fig. S10. Zero-volt current curves with different values and waveforms under different KCl concentrations. (a-d) The concentrations of KCl solution is 10^0 M, 10^{-2} M, 10^{-3} M and 10^{-4} M respectively.

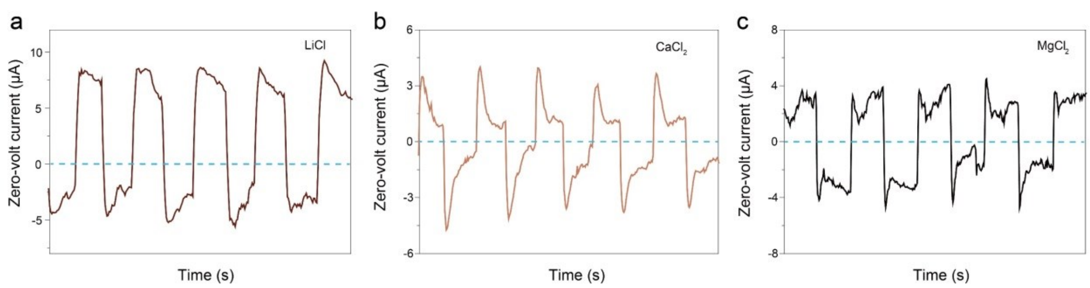

Fig. S11. Zero-volt current curves of LiCl, $CaCl_2$ and $MgCl_2$ solution. The electrolyte solution concentrations were 0.1 M.

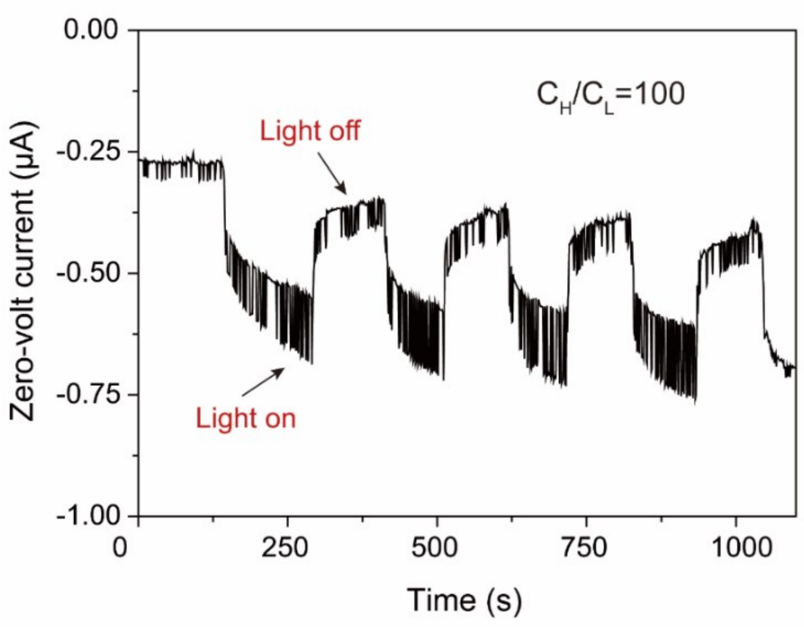

Fig. S12. Zero-volt current curves with the alternating light illumination at 100-fold (C_H =0.01 M; C_L =0.0001 M) KCl concentration. The illumination was applied to low concentration side.

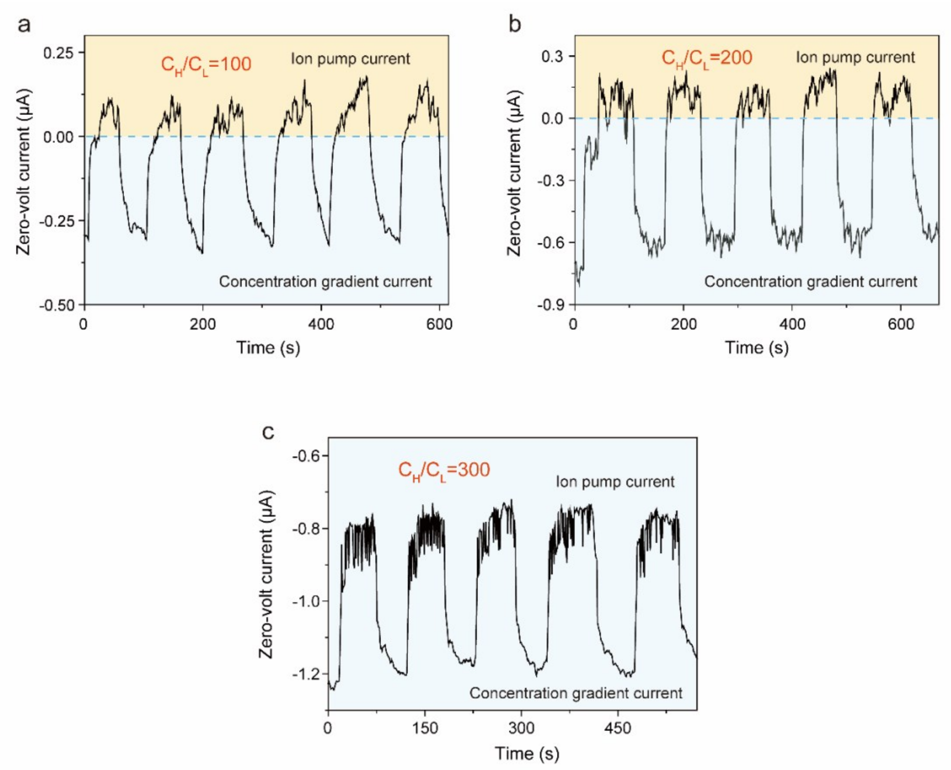

Fig. S13. Anti-gradient ion transport. Zero-volt current curves at KCl solution concentration gradient of **(a)** 100-fold, **(b)** 200-fold and **(c)** 300-fold upon regulated light intensity. The low concentration (C_L) of KCl solution is 0.0001 M.