SUPPLEMENTARY INFORMATION

Out-of-plane ion concentration polarization for scalable water desalination

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SALT WATER MIXTURES

Salt water mixtures were comprised of deionized water with sodium chloride (20, 200, and 500 mM concentrations, EMD Chemicals Inc., Germany), and 0.25× TAE buffer. Fluorescein (Sigma Aldrich, St Louis, MO) and green fluorescing polymer microspheres (9.9 µm diameter, Duke Scientific Corp., Palo Alto, CA) were added to the source water stream to enable visualization.

MATERIALS AND DEVICE FABRICATION

The vertical nanoporous membrane was fabricated by cutting a slice through a piece of silicone rubber (McMaster Carr, Aurora, OH) using a CO_2 laser (Universal Laser Systems Inc., Scottsdale, AZ), (see Fig. S1). The slice was filled with a solution of 5% Nafion® 117 in a mixture of lower aliphatic alcohols (Sigma Aldrich, St Louis, MO), and placed in an oven to harden at 65 ºC for at least 30 minutes.

The microfluidic device was fabricated by micromachining the channels and reservoirs into PMMA using a CO_2 laser. The nanoporous membrane layer was held between PMMA layers by bolts. Producing out-of-plane microfluidic layers and nanoporous membranes with the CO_2 laser permits a wide range of dimensions; therefore, low cost desalination devices can be produced for various applications and capacity demands.

The out-of-plane design is also amenable to developing fabrication techniques, such as 3D printing. A 3D printing system capable of printing with nanoscale precision and multiple materials would be able to fabricate the out-of-plane devices.

DATA ACQUISITION AND ANALYSIS

Ion depletion was imaged using an inverted fluorescence microscope (DMI 6000B, Leica, NJ). Image sequences were obtained using a CCD camera (Orca AG, Hamamatsu, NJ), and processed in ImageJ. The fluorescence images were normalized by subtracting a dark field reference image that was created by flowing pure water through the device. Following the normalization procedure, the images were imported into Excel for processing and quantification. Average values were calculated over the region of interest, which encompassed the area downstream of the nanoporous membrane.

DIMENSIONS OF SCALED-UP DESALINATION DEVICES

For the single, double, and triple level devices the channels were ~500 µm wide, and the depth of the purified and concentrated channels was ~230 µm, with a ~270 µm layer between them. The incoming source channel had a depth equal to the sum of the two outgoing channels plus the layer between them for a total of 730 µm.

The wide device had channel widths of 2 cm, and the depth of the purified and concentrated channels was ~200 µm, with a ~1.3 mm layer between them. The incoming source channel had a depth of ~1.7 mm. The nanoporous membrane width for the larger device was ~250 µm, selected based on the nanoporous membrane width characterization data.

SUPPLEMENTARY FIGURES

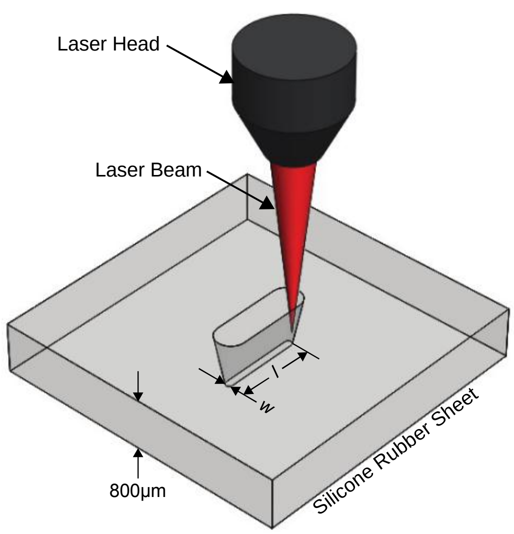

Fig. S1 Schematic of the procedure for producing the nanoporous membrane. The silicone sheet is cut with a CO_2 laser and the slice is filled with Nafion®. The result is a nanoporous membrane between the fluid layers with a width (*w*) and length (*l*) that can be controlled by the laser settings.

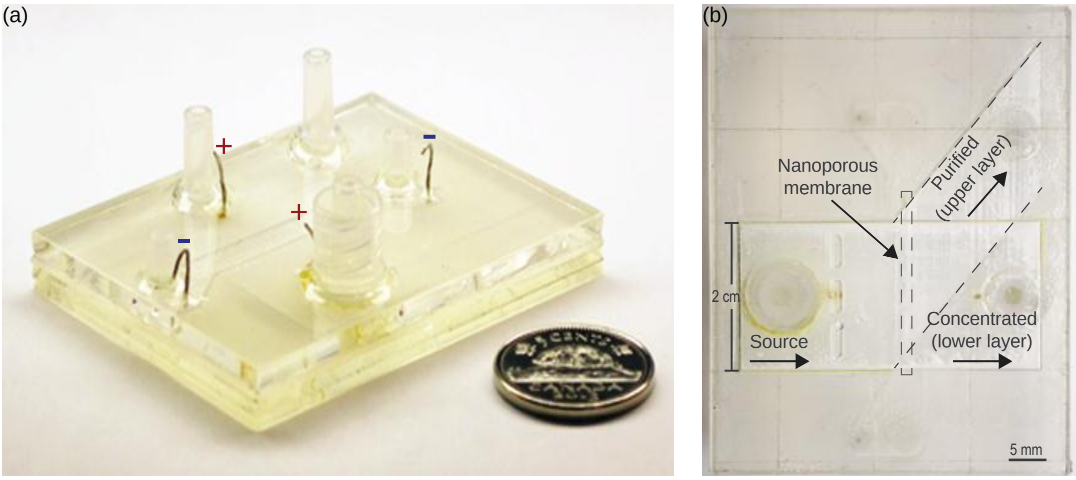

Fig. S2 Device with channel width of 2 cm. (a) Image of device beside a nickel for scale. (b) Image of the bottom of the device. The nanoporous membrane between the fluid layers is outlined by the dashed box. A 500 mM salt water mixture was used to test the device. Ion depletion was observed for a flow rate of 20 μL/min and applied voltage of 20 V (positive and negative electrodes are indicated by '+' and '-' in (a), respectively). Comparison of initial and depleted fluorescence intensity in the purified channel indicated ~90% removal of salt.