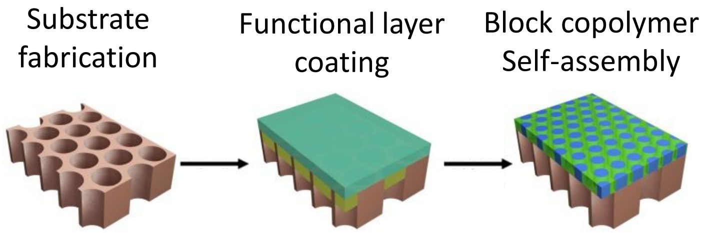
Bioinspired Asymmetric Membranes for Smart Ion Transport Control and Energy Conversion

Abstract

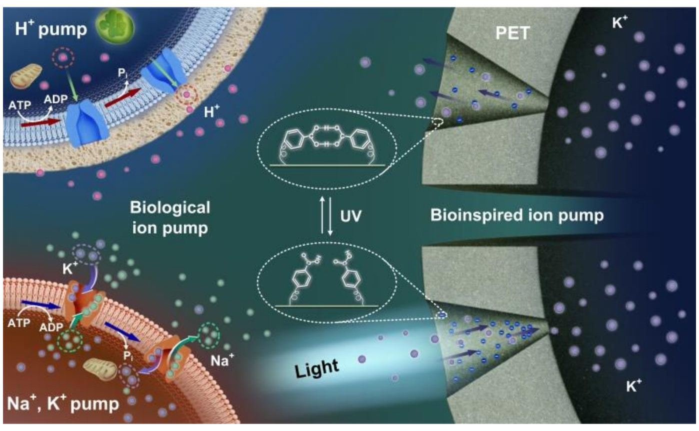
The salinity gradient energy existing in fluids is recognized as a promising "blue" energy source that can help solve the global issues of energy shortage and environmental pollution. The biological electric eels have the inherent skill to generate considerable bioelectricity from the salt content in fluids with highly selective asymmetric ion channels and pumps on cell membranes. Inspired from nature, we demonstrate a series of bioinspired asymmetric nanochannel systems as artificial ion pumps and apply them to harvest the salinity gradient energy between sea water and river water. The maximum power density can achieve 3.9 W/m^2, which largely outperforms the commercial ion exchange membranes. Our results shows the promising prospects of bioinspired asymmetric membranes in renewable energy applications.

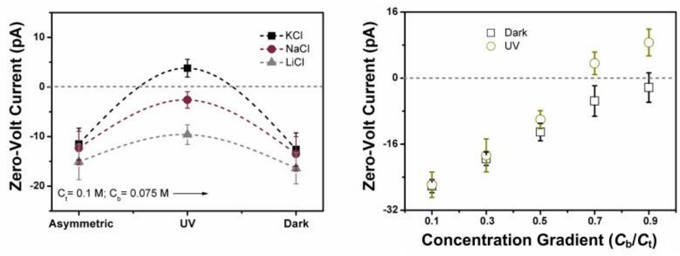
Methods



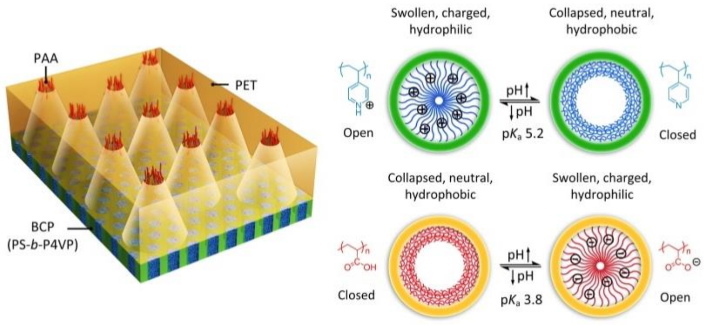
Results

Bioinspired ion pump system



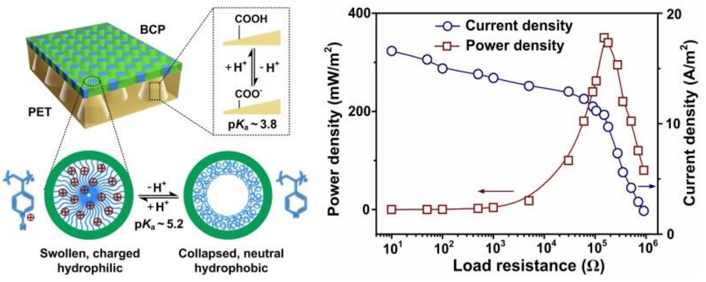


A bioinspired photo-driven ion pump based on single PET conical nanochannels is developed. The pumping process behaving as an inversion of zero-volt current can be realized by applying UV irradiation from the large opening. Enhanced electrostatic interaction between the ions and the charged groups on the inner wall is the key reason.

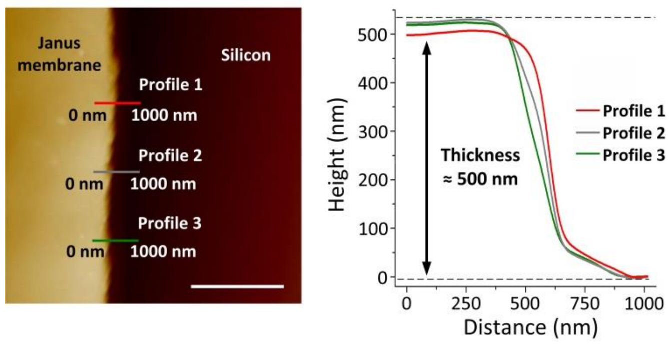


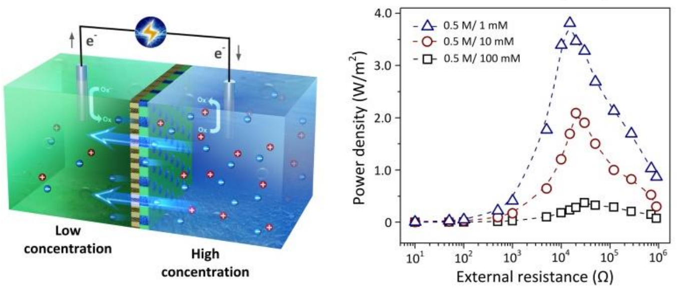
We then develop a bioinspired heterogeneous ion pump membrane with unidirectional selective ion pumping and efficient ion gating behaviors. Great controllability on the gating ability can be realized by tailoring the asymmetric pore distribution. These studies are an important step toward a procedure that mimics smart transport in life pump systems.

Salinity gradient power generation



We first develop a proof-of-concept asymmetric bipolar heterogeneous membrane system with ultrahigh ion rectification. The system can achieve a power density approximately 0.35 W/m^2 by mixing river water and sea water, which outperforms many commercial ion exchange membranes.





To expand to new avenues and stay economically attractive, membrane development must constantly strive for higher permeability and seek new and better selectivity. Next, we developed a block copolymer based ultrathin Janus membrane with excellent anion selectivity. The sub-micrometer scale thickness (≈ 500 nm) of the system provides very low ion resistance and high permeability, which enable an enhancement in the output density to approximately 3.9 W/m^2.

Conclusions

We successfully develop a series of bioinspired asymmetric membranes as artificial ion pump for smart ion transport control and demonstrated the feasibility of these membranes in the utilization of salinity gradient energy both experimentally and theoretically. These works can serve as a general guiding principle for the future design of membrane system for high-energy concentration cells.

Publications

1. Engineered Asymmetric Heterogeneous Membrane: A Concentration-Gradient-Driven Energy Harvesting Device. ***Journal of the American Chemical Society*** 2015, *137*, 14765-14772.
2. A Bioinspired Multifunctional Heterogeneous Membrane with Ultrahigh Ionic Rectification and Highly Efficient Selective Ionic Gating. ***Advanced Materials*** 2016, *28*, 144-150.
3. Asymmetric Multifunctional Heterogeneous Membranes for pH- and Temperature-Cooperative Smart Ion Transport Modulation. ***Advanced Materials*** 2016, *28*, 9613-9619.
4. "Uphill" Cation Transport: A Bioinspired Photo-Driven Ion Pump. ***Science Advances*** 2016, *2*, e1600689.
5. Ultrathin and Ion-Selective Janus Membranes for High-Performance Osmotic Energy Conversion. ***Journal of the American Chemical Society*** 2017, *139*, 8905-8914.
6. Bioinspired Heterogeneous Ion Pump Membranes: Controllable Ion Transport Triggered by Asymmetric Pore Distribution. 2017, Submitted.