Clean energy, Nanotechnology

Blue energy harvesting on ultra-thin nanopore membranes

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Abstract

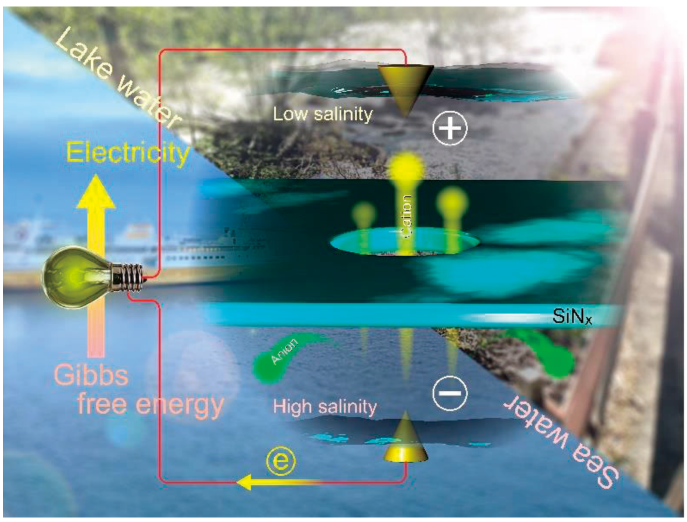
Intense research and development competition is underway for reverse electrodialysis power generation technology, which efficiently generates electrical energy from the difference in salinity between seawater and river water. Traditional technologies have used ion exchange resins for power generation. Due to the membranes being thicker than a few micrometers, however, they exhibit good ion selectivity but poor permeability, resulting in low energy conversion efficiency. To overcome this situation, we are advancing the research and development of ultra-thin nanopore membranes, which are several tens of nanometers thick and have nanosized pores, achieving both high ion selectivity and permeability.

Background & Results

Using semiconductor technology, we established a process to fabricate nanoscale pores with specified numbers, arrangements, and diameters within ultra-thin silicon nitride films that are less than 50 nm thick. Utilizing this technology, we first evaluated the reverse electrodialysis power generation performance of a single nanopore. As a result, we clarified that a nanopore with a diameter of 20 nm possesses a power generation performance of over 100 kW/m^2. On the other hand, when nanopores are accumulated into a two-dimensional array to create a multi-nanopore membrane, the power generation performance deteriorates with the increase in the membrane's porosity; however, we achieved a power density of approximately 100 W/m^2, significantly exceeding the target performance of 5 W/m^2 for social implementation. Furthermore, by investigating the causes of this performance deterioration, we revealed that in ultra-thin nanopore membranes, the distribution of salt concentration in the local space of closely spaced nanopores is affected by charge-selective ion diffusion transport, potentially reducing the effective salt concentration difference. To address this new challenge, we developed optimal designs for nanopore membranes concerning salt concentration difference power generation performance and methods to control ion selectivity in nanopore membranes using electric field effects, demonstrating the potential for large-area ultra-thin nanopore membranes to enable high-efficiency energy conversion. We are currently advancing the research and development of a new ultra-thin ion exchange membrane that combines these solid nanopores with conventional ion exchange resins.

Significance of the research and Future perspective

When there is a saline solution on one side and pure water on the other side of a semipermeable membrane, water molecules move from the pure water side to the saline side due to concentration diffusion, creating osmotic pressure. Research that aims to utilize this fundamental phenomenon learned in chemistry experiments for power generation is currently gaining significant attention. One such method is reverse electrodialysis technology, which uses ion exchange membranes that selectively allow either cations or anions to pass through to separate water of different salt concentrations. Just as in the osmotic pressure phenomenon studied in chemistry, ions migrate from the high-concentration side to the low-concentration side due to concentration diffusion. Since only cations or anions can pass through the membrane, a potential difference is generated as the ions move. This means that the Gibbs free energy of the ions is directly converted into electrical energy. By applying this power generation principle using the vast amounts of seawater and river water available on Earth, it is expected that we can achieve power generation equivalent to that of 1,000 nuclear power plants. Unlike wind or solar power, which are affected by weather conditions, this principle allows for power generation as long as there is a membrane and a difference in salinity, thus enabling a stable power supply system. By realizing high-efficiency reverse electrodialysis power generation with large-area ion exchange membranes using ultra-thin nanopore membranes, we can deliver sustainable clean energy from the rich marine resources in our country.



Patent

Treatise

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Keyword reverse electrodialysis, nanopore, ion exchange membrane