High-Power Generation by Boron-Nitride-Nanopore Membranes

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The use of salinity-gradient power, based on the Gibbs free energy of mixing fresh and salt water, has been under intensive investigation for clean-energy harvesting from abundant environmental resources. However, the current reverse electrodialysis (RED) systems based on polymeric ion exchange membranes (IEMs) suffer from lower power density (approximately 1-3 W/m^2), low efficiencies, and high membrane cost. A recent experimental study on a membrane containing a single boron-nitride-nanotube pore showed electric currents as high as 1.2 nA. Extrapolating this result to a macroscopic membrane, with a boron-nitride pore density of ~10^{10} nanotubes/cm^2, would result in a power density of ~4 kW/m^2. However, no such large-surface-area vertically aligned boron-nitride-nanopore (VA-BNNP) membranes have ever been fabricated.

Here, for the first time, we demonstrate the power generation performance of macroscopic VA-BNNP membranes with high nanopore density, up to ~10^8 pores/cm^2. For the fabrication of VA-BNNP membranes, a thin hexagonal boron nitride (hBN) layer was deposited within the pores (~100 nm) of anodized alumina substrates by low-pressure chemical vapor deposition. Cross-sectional scanning-electron-microscope (SEM) images show the hBN layer (~35 nm) was uniformly deposited along the pores without excessive hBN on the top surface, ensuring that most pores remained open. In addition, the results of scanning confocal Raman spectroscopy and X-ray photoelectron spectroscopy (XPS) showed the high quality of the hBN layers in the AAO pores. We investigated the power generation of the macroscopic VA-BNNP membranes at different pH and salinity concentrations. The power generation per unit pore area increased as the salt concentration and pH increased. The highest power density of the membrane was up to ~100 W/m^2 which is two orders of magnitude higher than that of RED system based on IEMs or even nanofluidic channels. These findings indicate the great potential of large-area VA-BNNP membranes as next-generation nanostructured membranes for renewable energy harvesting.