Nanoporous silicon as a proton exchange membrane for micro-scale fuel cells

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Silicon-based fuel cells are under active development to supply chip-scale electrical power supply. The most widely used commercial proton conducting membrane material in silicon microscale fuel cells is Nafion®. This perflourocarbon polymer with sulfonic acide side chains has many drawbacks. Among the biggest of these is that it is not readily integrated with standard microfabrication techniques used in making micro fuel cells, other microchemical systems, or MEMS based devices. Nafion® cannot be easily patterned using photolithography and bonding it to silicon is often problematic in working fuel cell conditions, due to its volumetric changes with changes in hydration level. It would be desirable to develop a solid state protonic conductor that could be readily incorporated into silicon-based devices that still has performance comparable to that of Nafion®.

We have demonstrated the use of nanoporous silicon as a material for micro-fuel cell applications. Nanoprous silicon is compatible with standard microfabrication techniques and will not exhibit volumetric changes with changes in the level of hydration as is observed with Nafion®. Proton conductivities were measured using impedance spectroscopy. Nanoporous silicon membranes with thicknesses of 40 to 70 microns were observed to have proton conductivities (0.0068-0.33 S/cm) comparable to, and in some cases better than, Nafion® (0.05 S/cm), as shown in Figure 1. Additionally, the permeability of formic acid was measured using a standard permeation cell. At room temperature the crossover of 5M formic acid through nanoporous silicon membranes was found to be similar to that of Nafion® membranes. Increasing formic acid permeability was observed with increasing anodization current density and consequently with increasing pore size, from $4.3x10^{-8}$ to $3.9x10^{-7}$ mol/s·cm$^2$ as compared to $1.23x10^{-7}$ mol/s·cm$^2$ for Nafion® 117, as shown in Figure 2. Data indicate that the mechanism by which nanoporous silicon conducts protons and rejects formic acid is distinctly different from that of Nafion®. Nanoporous silicon membranes were also tested in a direct formic acid fuel cell and showed comparable performance to Nafion®. These results represent the discovery of a new class of protonic conductor that can be integrated into standard silicon microfabrication processes.

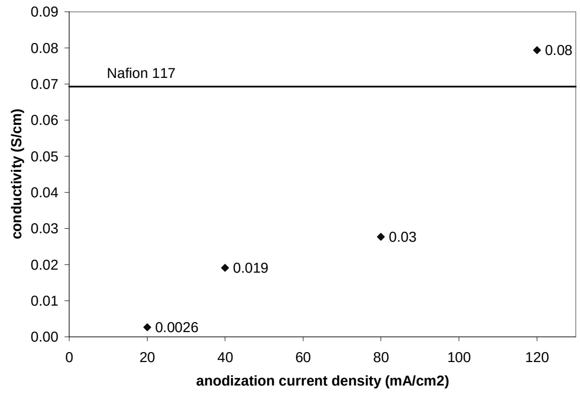
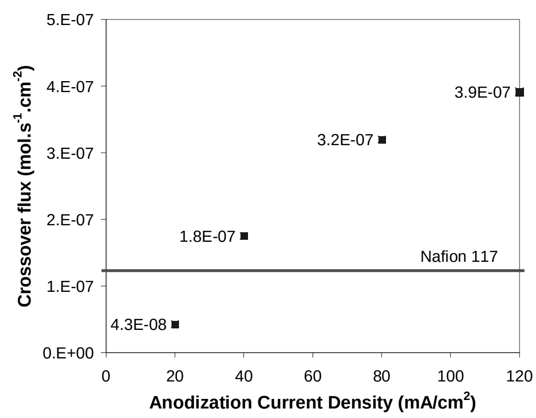



Figure 1. Proton conductivity of nanoporous silicon membranes as a function of anodization current density




Crossover of 5M formic acid through nanoporous silicon membranes as a function of anodization current density