Neah's Silicon-Based Fuel Cell Electrodes Leading the Pack

By Vinh Chung, Director of Business Development, Neah Power Systems, Inc.

The proton exchange membrane (PEM) has been a key component enabling fuel cell miniaturization for portable applications. It is an elegant design, combining the requirement of catalyst support, physical and electrical isolations, and ion transport all into one structure. It is a polymer based material that can be made in volume quantities through thermoplastic extrusion on reels and rolls. However, as attractive as these benefits may be, there is a list of challenges associated with the used of PEM for fuel cell applications. Issues such as water management, durability, and methanol crossover are recognized and have been discussed at length in many scientific papers and articles. In a departure from this technology path, Neah Power Systems, Inc. has devised an electrode and cell technology unique in its ability to address many of these issues.

The idea of producing electrode structures using MEMS based concepts was the brainchild of founder Leroy Ohlsen, a University of Washington graduate. He envisioned a structure that was engineered to produce the high surface area necessary for high power generation in a compact, highly manufacturable form factor. From this vision, the design of a methanol based fuel cell system based on high surface area silicon electrode structures was developed.

"It was a leap of faith, but given the feedback we had from individuals we talked to, we knew we were on to something big," reflected Ohlsen.

Figure 1.0 Leroy Ohlsen, Co-founder, Member, Board of Directors.

In classic entrepreneurial fashion, Mr. Ohlsen secured enough Angel funding to assemble a small technical team for preliminary proof of concept development. The concept of the electrode structures were thought through in detail and the initial work leading to the core patent portfolio was accomplished.

When it came to fuel cell design concepts, Ohlsen encouraged the team to come up with any creative ideas and quickly run them to ground. The outcomes from these ideas had to meet three conditions; (1) has the potential to be the top industry performer, (2) is scalable and amendable to miniaturization, and (3) is applicable to outsourcing models for volume manufacturing.

There were two design paths to consider. A passive design gives a smaller device footprint but lower power output. Conversely, an active design with pumps and other auxiliary components, though making the over device size larger, can offer a greater range of output. However these auxiliary components draw power so the stack of cells has to be sized larger to compensate for the hotel load. Ohlsen opted for the active design in order to go after a wider range of applications in the future.

One way to keep the stack volume the same (or even reduce it) but still account for the hotel load is to generate higher power densities from the individual cells. In order to achieve this, a higher catalyst surface area is typically needed.

“This was the main attractiveness with using silicon. The semiconductor industry has built up decades of experience manipulating this material down to the micro and now the nano level. With the tools and processes in place, we just needed to come up with the design, fabricate, and then test it. What we had in mind for making this structure was to punch hundreds of millions of tiny holes in the silicon wafer and then coat them with our catalyst. If you add up all the surface areas of these tiny holes you are going to have a whole lot of catalyst sites working for you!” described Ohlsen.

The 3D micro channel silicon structure has many beneficial attributes over the traditional PEM cell configuration. The cartoon diagram showing a cross sectional view of a single cell in Figure 2.0 illustrates the differences of the two designs. Power generation in the 3D structure of the Neah electrode design along with the liquid electrolyte coverage of that surface results in significantly more surface area available for power generation than the corresponding 2D surface. Since electrical current is produced from the chemical reactions that occur when the fuel, electrolyte, and catalyst come together, the PEM design has significantly less useable reaction sites.

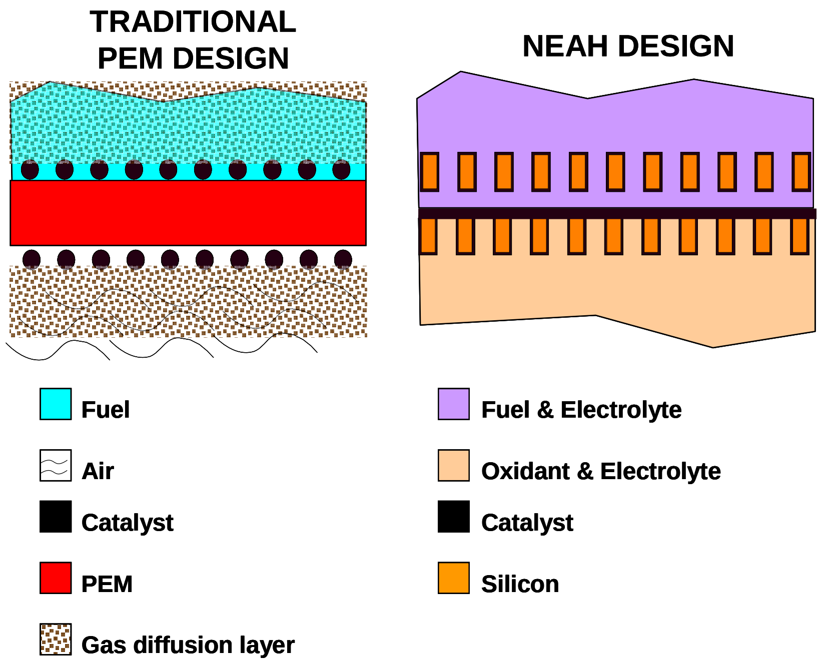

Figure 2.0 Side-by-side comparison of PEM vs. Neah cell designs (not to scale).

The liquid system drives other design differences from a traditional PEM based design. The gas diffusion layer required by PEM systems is not a requirement any longer as the ordered pore structure of the Neah electrode allows for uniform fuel/electrolyte distribution. Ultimately, the MEMS based design techniques available for silicon based structures will allow more and more functionality to be built directly into the electrode structure as the technology continues to mature.

The final performance enhancement observed with Neah's approach is found in the chemistry of the fuel. Neah uses methanol as the fuel on the anode side but have replaced oxygen in air with a liquid oxidant. The pH of both fuel and oxidant is lowered with an electrolyte to enhance the propagation of protons. Because protons can readily migrate from anode to cathode the potential loss between the two electrodes is minimized. Further, the liquid oxidant also allows Neah to use non-platinum catalyst, reducing cost. Neah identified a metal that is not only cheaper but is also non-reactive with methanol, thus avoiding issues associated with methanol crossover. This metal compliments the liquid oxidant to give very favorable activation energies for cathodic reactions.

When all of these improvements are combined together, the net result is impressive power output per given apparent area. Figure 3.0 is a polarization curve for a single cell measured at room temperature, showing a power density value as high as 140 mW/cm^2.

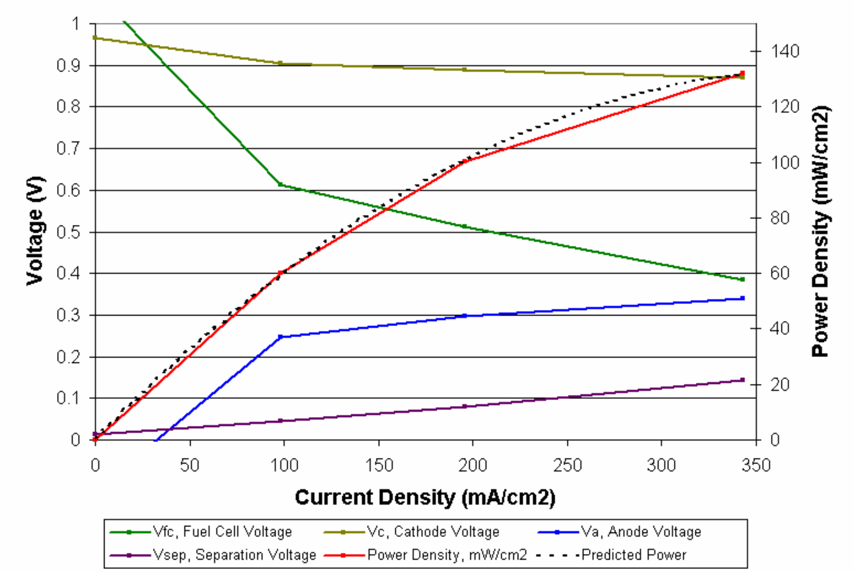

Figure 3.0 Neah single fuel cell polarization curve at room temperature.

Such a novel design was not conceived over night. Creating the micro channels was especially challenging at the start. There are only a handful of ways to create micro silicon structures. The preferred method was to perform plasma etching with a process called 'Deep Reactive Ion Etching' (DRIE). The two mechanisms for removing silicon using DRIE involve chemical reactions and physical obliteration, much like sand blasting but with high energized ions. In order to achieve high aspect ratio (etched depth divided by etched width or span) channels, the side wall etch rate must be substantially less than that normal to the surface. Two technologies offering high aspect ratio etching are Cryogenic and Bosch DRIE. Back in 2000, neither of these technologies could produce the desired structure.

One option that was available however was a lesser known technique known as anodic etching. With anodic etching, channels with 80:1 aspect ratios or higher are achievable. This electrochemical process is the reverse of electroplating in that material is removed in a controlled fashion rather than deposited. Unlike DRIE, it is a wet process so the setup is less demanding and is very similar to that of a plating bath.

Commercial equipment was not available at the time so the Neah team constructed their own through collaboration with academic researchers in the field. They eventually set up enough anodic etch systems to give them the throughput needed to support R&D work. Just as producing high aspect ratio structures is challenging, so is the uniform deposition of material on these structures. Figure 4.0 are SEM images of Neah's silicon-based fuel cell electrodes. With the development of techniques that could reliably deposit uniform layers within the porous structures the engineering of a fuel cell system could begin in earnest.

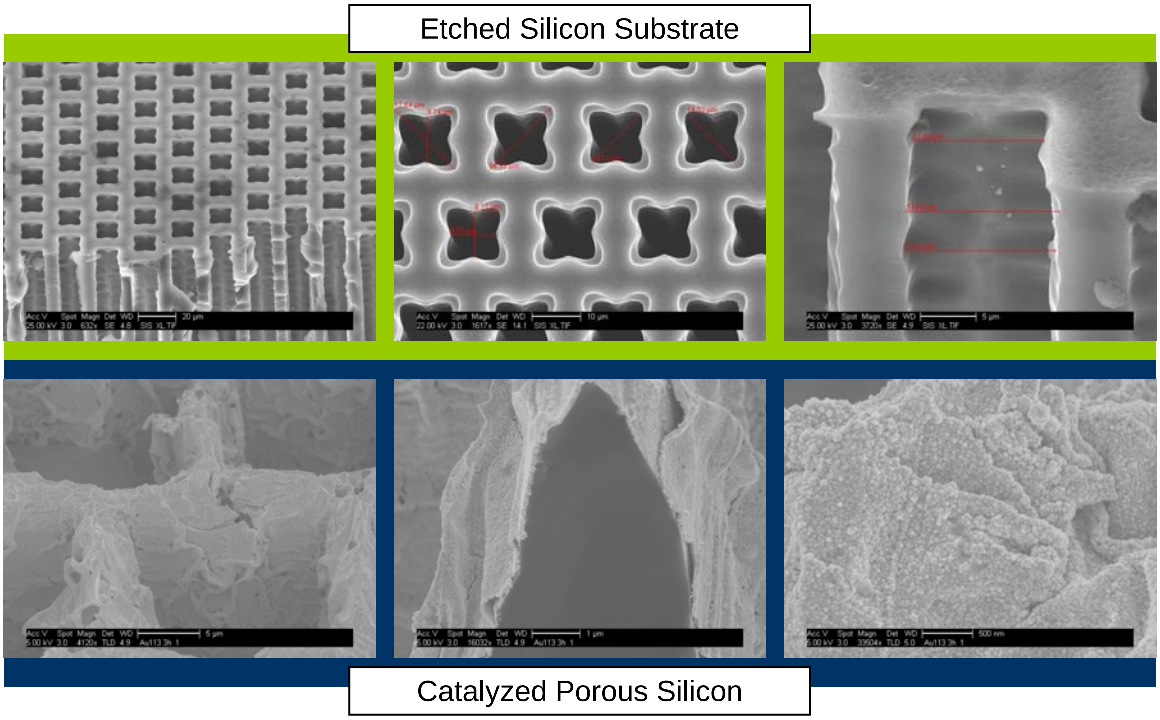

Figure 4.0. SEM Images of Neah's electrode characteristics.

While these prototype processes allowed for the early stage concept development, it was understood that the key to a product would be to define processes that could eventually result in a viable path to commercialization. The explosion in MEMS based production has provided that opportunity with improved capability and processes that promise to revolutionize the field. Neah Power Systems is rapidly adopting these techniques to produce electrode structures with greater capability, lower variability and lower cost.

In September of 2007, the development efforts culminated in the first integrated test of a liquid electrolyte fuel cell based on the Neah electrode structure. "Neah's September 2007 prototype was a critical accomplishment. It signifies the transition from development and engineering to manufacturing. Neah Power systems has the unique ability to leverage mainstream semiconductor processes and the world class electronics manufacturing systems (EMS) infrastructure to bring our product to market. This is a key differentiator for Neah Power Systems," explains Chris D'Couto, Ph.D. President and CEO.

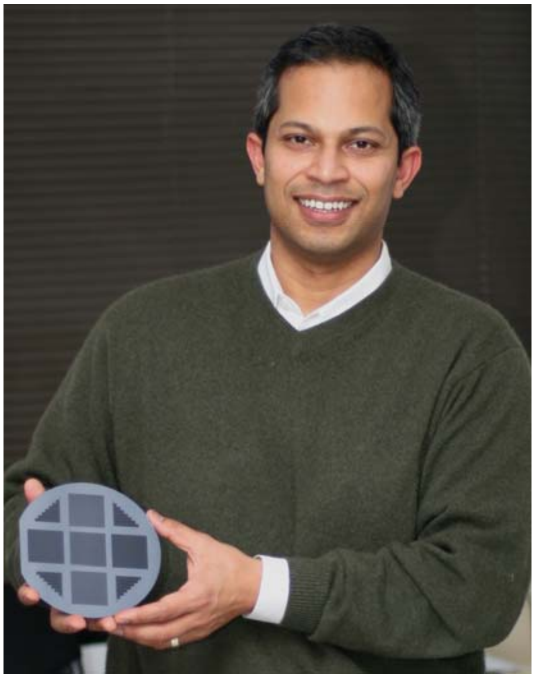
Figure 5.0 Chris D'Couto, Neah CEO & President.

"A lot of these companies that are now major players in the fuel-cell market, most of them began as tiny underfunded startups," said Greg Dolan, former deputy executive director of the U.S. Fuel Cell Council. "In an industry like the fuel-cell industry, if you have a better widget, you'll find a market for it."

It's an exciting time for Neah. Look for future articles on Neah's technologies and go to our website, www.neahpower.com for more information.