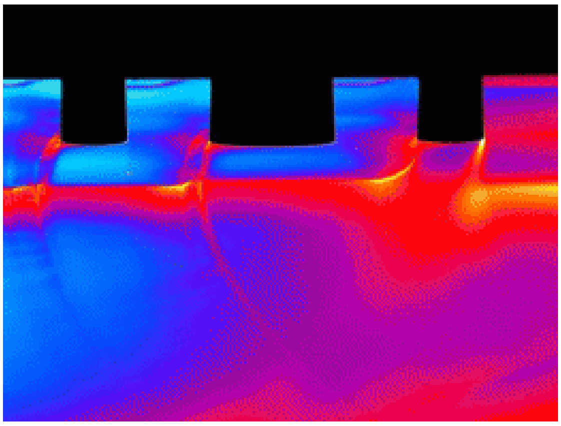
Micro Fuel Cells Get Closer to Replacing Batteries

17 November 2008, By Lisa Zyga



Close-up image of silicon microchannels. In microDMFC fuel cells, methanol and air circulate in microscopic microchannels etched in silicon wafers, as shown here. Image credit: Steve Arscott.

(PhysOrg.com) -- Mobile electronics have the potential to offer digital luxuries beyond our imagination, but they will never get there on today's lithium ion batteries. Power has been the weak spot in the development of more advanced mobile electronics, and the need for power will become even more important as devices feature more energy-sapping applications.

One alternative to lithium ion batteries is fuel cells, due to their advantage of a high energy density – potentially, sixteen times higher than lithium ion batteries. Although researchers have been working on fuel cells for several years, they still face several challenges.

In a recent study, a team of researchers has developed micro-sized direct methanol fuel cells (microDMFC) that achieve significantly improved fuel efficiency and maintain a good power density while operating at room temperature. The energy density (measured in watt-hours per liter) of the new fuel cells is 385 Wh/L, which is superior to lithium ions batteries' value of 270 Wh/L.

The research, led by Dr. Steve Arscott at the Institute of Electronics, Microelectronics and Nanotechnology (IEMN) in France, working in collaboration with SHARP Corporation in Nara, Japan, is published in a recent issue of the *Journal of Micromechanics and Microengineering,* and a second study has been accepted to the *Journal of Power Sources.*

Both studies use methanol fuel cells, in which methanol is the fuel and serves as the anode, while air is the oxidant and serves as the cathode. The methanol and air circulate through the fuel cell in microscopic microchannels etched in silicon wafers. When the methanol and air react in the presence of an electrolyte, electricity is produced.

In their second study, the researchers inserted a novel macroporous layer into the silicon-based microfuel cell. This design helped them improve the fuel efficiency from an already high 20 percent in their first study to 75 percent, while operating at room temperature. At this efficiency, the cells had a power density of 4.3 mW/cm^2 and 9.25 mW/cm^2 in the two respective studies. By adding a little bit more fuel, the researchers could increase the cells' power density to 12.7 mW/cm^2, although the efficiency then dropped to 20 percent (numbers are from the second study).

While previous fuel cells have achieved higher power density (up to 47.2 mW/cm^2, by Yen et al), they haven't operated at room temperature, which is absolutely essential for a commercial product.

Part of the reason that the new fuel cell achieves unprecedented fuel efficiency is because it uses a small amount of fuel (as little as 1.38 microliters per minute, or 550 nanoliters per minute, in the first and second study, respectively). By using a minimal amount of fuel, it's possible to eliminate components such as pumps, which in turn would lower the cell's energy consumption. However, as the researchers demonstrated, a minimum amount of fuel is necessary to maintain a steady fuel concentration across the cell to achieve maximum efficiency.

From the design perspective, the key to achieving high power density at room temperature is reducing both the fuel cell size and microchannel cross-sections. These modifications resulted in overall device miniaturization to a size of 0.18 cm^2, with a thickness of 0.17 cm, corresponding to a tiny cell volume of 0.03 cm^3 and a weight of about 110 milligrams. According to Arscott, these microcells are the smallest and lightest high-performance microDMFC working at room temperature to date.

Despite these improvements, challenges still remain, as Arscott highlighted.

"The biggest challenges facing micro fuel cells are: (i) high-performance room-temperature operation, (ii) miniaturization for on-chip use, (iii) compatibility with existing system fabrication (CMOS, for example), (iv) avoidance of complicated pumps for fuel and air which use energy themselves, (v) use of an efficient silicon-based proton exchange membrane and diffusion layers (novel porous layers for example), (vi) full integration with a microchannel architecture and also (vii) fuel storage," he told *PhysOrg.com*. "On the latter point, obviously the more fuel efficient the cell, the less fuel needs to be stored for a given working period."

In addition to applications in mobile consumer devices, the fuel cells could also be integrated as on-chip energy sources for autonomous MEMS and NEMS devices, as well as for sensors and actuators in silicon microelectronics, where efficient fuel use will be important. Arscott explained that different kinds of applications will require different kinds of fuel cells.

"In terms of fuel cells and energy sources, one must compare like with like: on one hand, fuel cells which will be one day be used for automobiles will be large and will have to supply a high power and have an energy density for a long journey," he said. "On the other hand, micro fuel cells for a new generation of autonomous MEMS/NEMS-based sensors and actuators will require compact, on-chip, very efficient, high energy density energy sources which can supply micro and milliwatts for a long time. In the latter case, the energy required will be to drive the sensor and to communicate with the environment (for example, send a signal which says 'forest fire here!'). I don't think there will be one dominant fuel cell for all applications, but there is likely to be one dominant fuel cell per application, for example, the hydrogen cell for cars or the methanol cell for portable and autonomous micro/nanosystems."

Based on the progress of fuel cell research, fuel cells may begin widely replacing lithium ion batteries in consumer devices in the near future.

"From a research point of view, prediction is very hard," Arscott said. "One can see fuel cells powering consumer electronics (iPod, Blackberry, etc.) in the next few years; one can see fuel cells powering automobiles in the next 20 years (or not, if we find huge resources of petrol in the Arctic, for example). The popularity and success of something is based on many factors – for example, cost (energy/dollar), availability, performance and the lawmakers. For instance, a ban on existing polluting batteries that contain heavy metals would favor fuel cells.

"One thing is sure," he added. "Like everyone, I think that energy is about to become very important and, as Mark Twain (of who I'm a big fan) said, 'What is a government without energy? And what is a man without energy? Nothing, nothing at all...'"

More information: Kamitani, Ai; Morishita, Satoshi; Kotaki, Hiroshi; and Arscott, Steve. "Miniaturized microDMFC using silicon microsystems techniques: performances at low fuel flow rates." *J. Micromech. Microeng.* 18 (2008) 125019 (9pp)

Kamitani, Ai; Morishita, Satoshi; Kotaki, Hiroshi; and Arscott, Steve. "Improved fuel use efficiency in microchannel based DMFC using a hydrophilic macroporous layer." *J. Power Sources.* To be published.