FAST MOVING FRONTS - 2010

May 2010

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Ashish V. Pattekar & Mayuresh V. Kothare talk with *ScienceWatch.com* and answer a few questions about this month's Fast Moving Fronts paper in the field of Engineering. The authors have also sent along images of their work.

Article: A microreactor for hydrogen production in micro fuel cell applications
Authors: **Pattekar, AV;Kothare, MV**
Journal: J MICROELECTROMECHANICAL SYST, 13 (1): 7-18 FEB 2004
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SW: Why do you think your paper is highly cited?

This paper describes one of the earliest attempts to integrate an entire chemical reactor on a silicon chip, namely, a miniaturized hydrogen production chemical-plant-on-a-chip for micro fuel cell applications.

As rechargeable battery technology has matured in recent years, it seems to be hitting a plateau in terms of improvements in energy storage capacity and density. Miniaturized fuel cells have been considered as a possible alternative power source for portable electronics and also as stationary electricity generators/ auxiliary power units (APUs)—with theoretical energy storage densities up to 10 times those of current battery technology.

However, a major challenge with portable fuel cells has been the difficulty and hazards involved in the storage and handling of hydrogen, which is used as the fuel for producing electricity.

Through the work described in this paper, we successfully demonstrated a micro-reactor on a silicon chip that could chemically convert an easy to carry and package liquid fuel, methanol, to hydrogen for the fuel cell on an as-needed and on-demand basis—thus helping to close an important gap in the realization of this next-generation portable power source.

SW: Does it describe a new discovery, methodology, or synthesis of knowledge?

This paper describes a novel methodology for realizing a truly chip-scale chemical reactor by synthesizing the knowledge of diverse concepts from the fields of chemical, mechanical, and electrical engineering, microelectromechanical system (MEMS) design and fabrication, and modeling and implementation/optimization of microfluidic flows in silicon microchannel networks using computational fluid dynamics (CFD).

An important aspect of this work is the customized fluidic interconnects and integrated on-chip heaters and temperature sensors that we developed specifically for this project: to enable reliable fluidic connections to our device and the ability to control the device operation without increasing the overall footprint—a critical issue in portable applications.

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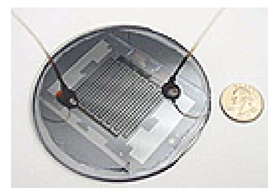
Also, we were able to optimize the design of our microfluidic channel network by modeling and simulating the flow of the reacting fluids using a computer—thus enabling us to further minimize the device footprint without sacrificing throughput (hydrogen production rate).

These developments represent an important contribution to furthering knowledge in the field of microreaction technology (MRT), specifically for application to micro fuel cell systems.



"A view of the fabricated chip-scale methanol reforming microreactor for micro fuel cell applications."

View/download three accompanying figures and descriptions.

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SW: Would you summarize the significance of your paper in layman's terms?

Imagine a power source for your laptop computer that can last 8 to 10 times as long as today's rechargeable batteries, without any increase in size and weight. Or imagine reducing the weight of the batteries that a soldier has to carry in the field today, from up to 40 pounds (yes—that's how much the batteries weigh which need to be hauled around in order to power the on-person electronics that today's soldiers carry!) to less than 5 pounds. This is the scale of the impact that miniaturized fuel cell systems could have on portable power applications in the future.

Our paper addresses one of the key challenges associated with realizing such a high-energy-density fuel cell-based power source: the problem of how to supply the hydrogen needed for fueling a miniature fuel cell. Hydrogen is extremely difficult to carry and store in pure form.

For example, even at an extremely high storage pressure of 10,000 psi, one can only store about 0.04 gm of H_2 per cubic centimeter (cc). Even as liquid hydrogen, the density is only about 0.07 gm of H_2 per cc—and these numbers don't include the added space and weight requirements of the high-pressure cylinder or the cryogenic storage overheads.

Other approaches such as metal hydrides and carbon nanotube based H_2 storage have also been explored in the past, but without much improvement in actual storage capacity. Compared to this, liquid hydrocarbons such as methanol are pretty easy to store and handle, and for each cc of methanol that is reformed in our microreactor we can produce nearly 0.15 gm of hydrogen through the reforming reaction.

Of course, one needs to account for the fact that we need to supply steam for the reforming reaction (which can actually come from the exhaust of the fuel cell) and the additional volume of the hydrogen-generating microreactor. Even with these considerations, however, a reformed hydrogen fuel cell could provide an order-of-magnitude increase in energy storage density over today's batteries—a very good improvement overall.

Our paper provides a very practical way of enabling such a reformed hydrogen fuel cell based power source, and, more generally, demonstrates how an entire chemical plant could be shrunk down to the size of a single silicon chip.

SW: How did you become involved in this research and were any particular problems encountered along the way?

This program began through a grant that Lehigh University received from the US National Science Foundation through their solicitation titled "Engineering Microsystems: XYZ-on-a-chip" in 1999. At that time, miniaturization of a host of traditional engineering scale systems to a "silicon chip scale" size was a rapidly emerging area of research.

As chemical engineers, we proposed the miniaturization of an entire chemical plant to a chip-scale device and proposed to demonstrate this concept through a micro-scale hydrogen generation chemical plant.

Some of the difficulties that we encountered were involved with the actual fabrication of the devices on silicon and tuning the various semiconductor processing/MEMS fabrication techniques to realize a fluidic microreactor device.

We were fortunate to be able to use the facilities at the Cornell Nanofabrication Facility (CNF) at Cornell University to implement our designs, and were provided lots of helpful advice on selecting the most suitable techniques for making our test devices by the CNF staff.

Perhaps some of the greatest difficulties we encountered were in the area of microfluidic interconnections, i.e., making reliable and leak-proof fluid delivery ports for introducing and removing fluids from such a microreactor system working at elevated temperatures and pressures.

When we found that state-of-the-art techniques for plumbing fluids to and from these miniature devices would not satisfy our temperature and pressure requirements, we ended up inventing our own designs for implementing such "building blocks" for our microreactor system. This work has also been published earlier, in a separate publication.

SW: Where do you see your research leading in the future?

Since publishing the work referenced in this paper, we actually published an improved design—building on many of the same concepts first demonstrated here, but providing a 2X increase in throughput capacity and an 18X to 20X improvement in performance in terms of pressure loss versus production rate: thus moving this chip-based microreactor one step closer to the intended micro fuel cell application.

This follow-up work was published in a paper titled "A radial microfluidic fuel processor," (Pattekar AV; Kothare MV, *Journal of Power Sources*147 [1-2]: 116-27, September 2005).

"This paper describes one of the earliest attempts to integrate an entire chemical reactor on a silicon chip, namely, a miniaturized hydrogen production chemical-plant-on-a-chip for micro fuel cell applications."

Regarding where our research might lead in the future, we are actively seeking funding for further work in this area, to combine our microreactor fuel reformer with a micro fuel cell and highly efficient, customized power electronics to actually demonstrate a fully integrated micro-fuel-cell-based power source with an order-of-magnitude improvement in performance versus conventional batteries.

It is well known that micro fuel cells as alternative portable power systems have generated a lot of interest, but have remained elusive thus far due to various technical challenges. Several research groups, including ours, are actively working on resolving these issues.

We certainly expect this work to eventually lead to the "power source of the future"—one that lasts many times longer than today's batteries, and enables a "truly wireless" world where portable devices do not have to be plugged into a power outlet every so often.

One of us, Ashish V. Pattekar, is currently at PARC, which has an active cleantech program. In a recent analysis, we have compared this approach to that of the current recharging-discharging model of supplying portable power using batteries.

It turns out that, on a per watt-hour basis, the overall cycle of generating electricity in a coal-fired power plant and then converting to low-voltage DC for recharging at the point-of-use results in almost twice as much CO_2 emissions overall, compared to the production and use of methanol in a portable fuel cell as discussed in our publication—leading to significant environmental benefits as well, apart from the performance improvements over today's rechargeable battery technology.

SW: Do you foresee any social or political implications for your research?

Perhaps the greatest societal implication of the work may be in reducing our dependence on electric grid-based power for portable device charging and instead using fully portable and decentralized autonomous power supplies.

Additionally, our preliminary calculations indicate that this technology, if fully realized, could also reduce net greenhouse gas (CO_2) emissions.

Another significant impact area of this work would be through a somewhat scaled-up application as auxiliary power units (APUs) for large vehicles such as transportation trucks and recreational vehicles (RVs) that currently need to keep their engines running to supply electricity requirements (e.g., refrigeration of perishables during transport, other electrical equipment for use by personnel on the vehicle)—even while the vehicle is parked.

After a typical 11-hour shift, truck drivers are required by federal law to rest at least 10 hours. Idling trucks consume an estimated one gallon of fuel each hour and emit carbon dioxide, nitrogen oxides (NOx), carbon monoxide, particulate matter, and volatile organic compounds (VOCs).

Successful development of this technology for vehicle APUs would have a significant impact on these idling vehicle emissions and related fuel consumption by eliminating such inefficiencies as well.

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KEYWORDS: fuel cell; lab-on-a-chip; micro fuel cells; microfluidics; microreactor; microreformer; system-on-chip; METHANOL; CATALYST; REACTORS.

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2010 : May 2010 - Fast Moving Fronts : Ashish V. Pattekar & Mayuresh V. Kothare Discuss Microreactor Technology