Fuel Processing in Microfabricated Chemical Systems

Personnel

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Chemical fuels store substantially more energy per unit weight (and volume) than the most advanced batteries currently available. For this reason, portable fuel cell systems operating on chemical fuels have received a great deal of attention in hopes of outperforming batteries in low-power, portable electronics. Given the current state of the art in fuel cell technology, a feed of pure hydrogen (in air) is desirable to reach optimal fuel cell efficiencies. However, hydrogen storage presents a challenge due to safety concerns and its low compressibility. Point-of-use hydrogen generation from a conveniently stored liquid fuel (e.g., butane) is a desirable albeit challenging solution to this problem. Our research program investigates the potential of MEMS (micro-electro-mechanical systems) microfabrication technology to make safe, portable, efficient chemical fuel processors for point-of-use hydrogen generation.

We have developed a microfabricated fuel processor (Figure) comprised mainly of thin-walled silicon nitride tubes that directly addresses the most significant problem in small-scale fuel processors: thermal management. The reactor has been demonstrated to operate at temperatures over 900°C with a high degree of thermal isolation and mechanical stability. Chemical reactions we have carried out in this reactor include catalytic ammonia cracking (using integrated thin-film heaters) and autothermal butane combustion. In addition to on-demand hydrogen production, this reactor can potentially be used as an efficient combustor/recuperator in a thermoelectric or thermophotovoltaic generator. Our ongoing research effort can be divided into four major components: fuel processor design and testing, fabrication and packaging technology, heterogeneous catalysis in microchannels, and reactor testing/overall system assessment.

Fuel processor design and modeling. The optimization of the reactor design is a very important and challenging aspect of the research effort. The most important consideration in reactor design is thermal management, which in this application means being able to integrate exothermic combustion and endothermic hydrogen-producing reactions such that they exchange heat with each other but lose little heat to the environment. Other reactor design issues include the ability to provide adequate surface area for coatings of heterogeneous catalyst and incorporation of thin-film heater materials that are stable for extended periods of time at high temperature. Detailed computational fluid dynamics (CFD) and heat transfer modeling is an important component of the reactor design effort, as these models provide insight into the microscale phenomena occurring in the fuel processor.

Fabrication and packaging technology. Improving fabrication and packaging technology is another key aspect of the research program. A great deal of effort has gone into developing the fabrication process to make the suspended-tube structure. In particular, optimization of the isotropic silicon etch to release the suspended tubes has been very challenging. The development of a strategy and system for vacuum packaging of the fuel processor is currently underway and is of marked importance in the near future.

Heterogeneous catalysis in microchannels. Heterogeneous catalysis, specifically as it applies to reactions in the micro fuel processor, is an essential component of the research effort. Our catalysis research focuses on (1) investigation of methods for the controlled deposition of high-surface-area porous catalyst films (washcoats) into the microchannel structures, (2) development of accurate techniques to characterize these catalyst washcoats in situ (for measurement of active surface area, adhesion to substrate, etc.) before and after carrying out high-temperature chemical reactions, (3) examination of catalyst performance (rate, selectivity, deactivation, etc.) for high temperature fuel reforming and H2 production reactions, and (4) implications of catalysis (catalyst selection, reaction scheme, etc.) on the optimization of the fuel processor system.

Reactor testing and overall system assessment. The microfabricated fuel processor will be tested in a variety of hydrogen production schemes to properly assess its potential in portable fuel cell systems. Fuels include butane, methanol, and ammonia, and reaction pathways include partial oxidation, and combustion coupled with thermal decomposition or steam reforming. These reactions must be studied in the context of systems issues. For instance, CO level in the product stream must be carefully monitored, as even modest levels of CO will poison the electrocatalysts in low-temperature polymer electrolyte fuel cells. The need for separations systems and auxiliary equipment, such as pumps, valves, sensors, control systems and plumbing are also being evaluated.

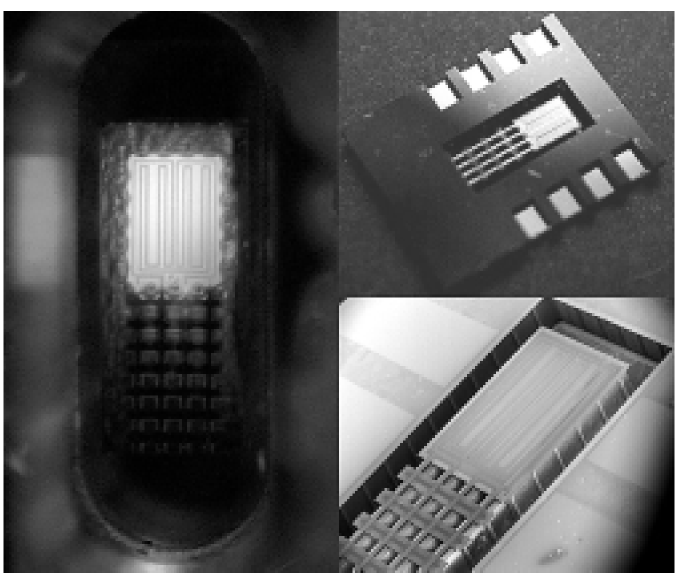

Fig. 44: Microfuel processor. Photograph of device (upper right) Electron micrograph of reactor-heat exchanger section (lower right). Reactor heated to ~900°C (left) (Note, that the tubes and surroundings remain at low temperatures)