New fuel-cell technology could help power future vehicles

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In the lab and classroom of Stanford mechanical engineering Professor Fritz Prinz, fuel cell technology is cooler than ever — literally and figuratively. In four papers presented at an Electrochemical Society conference in Los Angeles Oct. 16-21, Prinz and students are announcing innovations that drastically reduce the operating temperature of a promising type of fuel cell, an advance that could help them power future vehicles.

Within a month, Prinz and co-authors will release a fuel cell textbook, filling a void for students eager to learn about the up-and-coming technology.

"Fuel cells today are not economically producible and cannot compete with the traditional combustion engine," says Fritz Prinz, who is the chair of the Mechanical Engineering Department and the Rodney H. Adams Professor in the School of Engineering. "But there are significant opportunities to improve the performance and the economics of fuel cells."

Because they can provide plentiful electric power to buildings, cars and electronics without hurting the environment, fuel cells, including the solid oxide fuel cells that Prinz's group works on, are a hot technology. Solid oxide fuel cells generate electricity through a pair of chemical reactions that conduct negative charge around a circuit. One side of the cell takes in oxygen in from the air and combines it with electrons to form negative oxygen ions. Those ions are conducted through a solid electrolytic layer in the middle to the other side of the cell, where the ions combine with hydrogen gas fuel to form water. That reaction frees up electrons, which pass through whatever the fuel cell is powering to return to the first side, completing the circuit. Along the way, the cell has taken in hydrogen and oxygen to produce only water and electricity. Fuel cells are different than batteries in that they don't lose their charge. They keep running as long as there is hydrogen fuel and oxygen.

Compared to other fuel cells, solid oxide fuel cells are especially good candidates for powering homes and cars because they can deliver more total power with relatively high efficiency. But their high running temperature—more than 1,300 F (about 700 C)—is a huge drawback for use in cars, which would overheat at those temperatures. One of the reasons for the high temperature has to do with the electrolyte layer. The best electrolytes to date have had trouble conducting the negative oxygen ions without producing a lot of heat. But Prinz's group is changing all that.

Thin is in

The Prinz group has improved ion conductivity through the electrolyte layer—a membrane of yttria stabilized zirconia (YSZ)—by making it as thin as 50 nanometers. To build a membrane that thin, yet durable enough to operate reliably, is a huge mechanical challenge. Why? The inputs of the fuel cell are gases (hydrogen and oxygen), so as much of the membrane as possible has to be exposed to them rather than blocked off by supporting structures. Meanwhile, as thin as the membrane is, it has to be strong enough to withstand forces such as differences in gas pressures on either side of it. (While layers of platinum catalyst on each side provide little support, they are loosely packed to allow the gases to permeate.)

Prinz's group has addressed this problem by experimenting with manufacturing techniques similar to those employed by the semiconductor industry. The group has successfully built a YSZ membrane atop a silicon mesh that makes it durable enough to work, yet leaves much of the membrane exposed to the gases.

The effort has paid off handsomely, yielding a fuel cell that delivers a power density of 400 milliwatts per square centimeter at 750 F (about 400 C) in individual openings in the silicon mesh. (A typical car needs 15,000 watts to run, but stacks of cells with a total membrane surface area of 4 square meters could produce that much power.) Typical solid oxide fuel cells generate comparable power densities at more than 1,300 F degrees (700 C), meaning Prinz's group has cut the temperature almost in half without sacrificing any power.

"To my knowledge this is the solid oxide fuel cell which delivers the highest power density and can run at the lowest temperature at the same time," Prinz says.

In two other papers at the electrochemical society conference, Prinz and his students will show how they strive to improve the membrane's conductivity in another way: by bombarding the membrane's crystalline structure with positive argon ions and then heating the charged membrane to 1,470 F (800 C). This procedure has the effect of opening up or dilating the crystal structure, boosting ion conductivity by as much as 34 percent.

Another paper describes a method for analyzing both the structure and conductivity of a membrane.

Overall the research, supported by Japanese automaker Honda, is part of a larger collaboration with materials science and engineering Associate Professor Paul McIntyre and chemical engineering Professor Stacey Bent to produce fuel cells usable in cars.

Serving students

While the research results represent important advances in the technology, the upcoming textbook, Fuel Cell Fundamentals, is a complementary advance in teaching. Prinz collaborated on the book with former students Ryan O'Hayre and Suk-Won Cha and civil and environmental engineering postdoctoral fellow Whitney Colella.

To be published this year by John Wiley, the book fills an important void by providing a comprehensive text and homework sets for advanced undergraduates and early graduate students eager to learn more about fuel cells, Prinz says. Few texts are dedicated to fuel cells and virtually none have homework problems to help students hone their skills and theoretical understanding. The book has more than 100 homework problems.

"The research and teaching environment at Stanford puts a lot of emphasis on how we can improve our energy situation," he says. "We certainly would like to broaden the background of students in this area and open their horizons to what's possible. We have needed to increase our educational offerings in this area."

Soruce: Stanford University

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