New fuel cells that can operate at temperatures between -20 to 200°C

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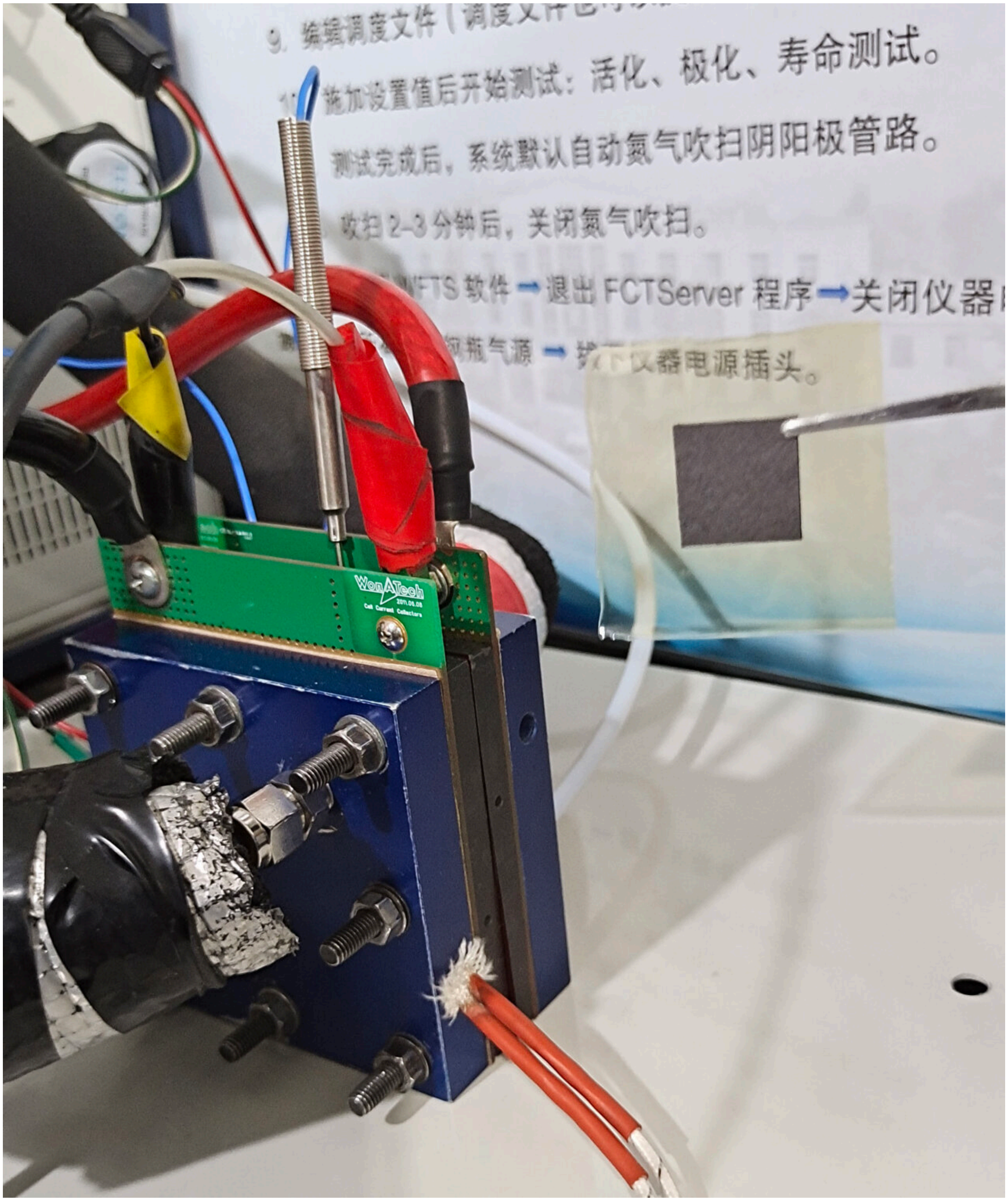

One of the researchers’ fuel’s cells as it was being tested. . Credit: Tang et al.

Proton exchange membrane fuel cells (PEMFCs) are power cells that can transform the chemical energy produced during the electrochemical reaction between hydrogen and oxygen into electrical energy. While these cells could be highly promising energy solutions, most of them can only operate at limited temperature ranges, such as 80 to 90 degrees Celsius or 140 to 180 degrees Fahrenheit.

Researchers at the Chinese Academy of Sciences, Tianjin Normal University and Tianjin University have recently designed a new type of PEMFCs that can operate across a far wider range of temperatures, specifically from -20 to 200 degrees Celsius. Their paper, published in *Nature Energy*, could facilitate the widespread use of PEMFC technology, while also reducing its fabrication costs.

"When we think about the leakage of phosphoric acid (PA) from a polybenzimidazole (PBI) membrane, we believe that one molecule of benzimidazole would absorb one molecule of PA, according to the concept of acid-base interactions," Nanwen Li, one of the authors of the paper, told TechXplore. "All other PA molecules in the PBI membrane, on the other hand, are mostly retained by hydrogen-bonding interactions. This is like a dog chain that restrains a dog, so that other dogs just follow this dog by kinship. However, if we can create a dog kennel, all the dogs in this kennel would not be able to come out easily if the front door is closed."

The primary aim of the recent study conducted by Li and his colleagues was to create a membrane that could absorb PA. To further strengthen its ability to capture PA, the researchers leveraged what is known as the 'capillary siphoning effect," an effect through which liquids can be easilyabsorbed.

When applying the capillary siphoning effect to a conventional membrane, liquid might still not be easily released. Therefore, the team decided to fabricate the membrane using Tröger's base (TB) polymers, materials with an ultra-high intrinsic microporosity.

"The ultra-micropores in the TB polymer act as capillaries for the PA absorption and retention, like in the dog kennel metaphor," Li explained. "By adjusting the chemical structure of the monomer, the polymer membrane pore size and distribution could be controlled. One membrane with the pore size of about 3.5 Å showed the best siphoning effect of PA molecules, and thus the best conductivity stability and fuel cell performance under a broad range of operating temperatures."

The membranes' fabrication process. Credit: Tang et al.

Fuel cells typically work by electrochemically oxidizing fuels, such as hydrogen, in the presence of air or oxygen, ultimately producing electrical energy and water. The proton conductive membrane contained in PEMFCs is coated with a catalytic substance on each side, to trigger electrochemical reactions between the anode (hydrogen) and cathode (oxygen) inside a cell.

"Among others, there are two primary functions of the membrane: one is to conduct the protons catalytically produced at the anode to transport them to the cathode and combine them with oxygen, ultimately producing water, while the other is to force the electrons (i.e., electrical energy) produced catalytically at the anode, through an exterior circuit, where they complete the circuit and produce water," Li said. "One can think of fuel cells as a highly controlled catalytic combustion of hydrogen and oxygen, which does not explode as it would if ignited, but releases electrical energy on demand. Electrolysis, or the splitting of water, is really just the reverse, where you input electrical energy to split water into hydrogen and oxygen."

Using the PA-doped ultra-microporous membrane they created, Li and his colleagues were able to fabricate fuel cells that can operate at a very broad range of temperatures. This is a remarkable achievement, as previously developed PEMFCs can only operate at restricted temperature ranges.

"Using our design, the fuel cell stack would be simplified significantly," Li said. "We believe that the siphoning effect for the PA absorption into the ultra-micropores is significant for the development of highly performing high-temperature PEMFCs and also would improve the overall fuel cell system, allowing it to be operated without auxiliary heating systems."

The new membrane and cell design could soon lead to the development of better-performing PEMFCs, while also significantly reducing their fabrication costs. In their next studies, Li and his colleagues plan to apply the capillary siphoning effect to the catalyst layer too, to improve its effectiveness and reduce catalyst loading.

In addition, they will be focusing on micro-tuning the size of the membrane's pores and the distribution of the blending, co-polymerization and crosslinking. This could ultimately help to improve the stability and conductivity of the fuel cells further.

"We would also like to design and prepare PBI systems with the same kind of ultra-microporosity as the membranes we used, which could be easier to apply in the energy industry," Li added. "Moreover, the same siphoning effect we produced could also be utilized in the catalyst layer, to hold the PA molecules within the catalyst layer and thus avoid the adverse impact of phosphate poisoning of the Pt catalyst. Therefore, we anticipate that high catalyst utilization and thus low catalyst loading will be achieved for high temperature proton exchange membrane fuel cells."

More information: Hongying Tang et al, Fuel cells with an operational range of –20 °C to 200 °C enabled by phosphoric acid-doped intrinsically ultramicroporous membranes, *Nature Energy* (2022). DOI: 10.1038/s41560-021-00956-w

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