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Research Highlight

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Nanoscale redox reaction unlocking the next-generation low temperature fuel cell

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Solid oxide fuel cells (SOFCs) represent a next-generation energy platform technology. Lowering the operating temperature has become a hot topic in SOFC research and is pivotal to their commercialization, since lower temperatures improve the sealing and durability, as well as reducing costs. However, the lower oxide-ion diffusion and transport in the electrolyte and electrodes at low temperatures seriously inhibit the electrochemical performance and practical applications of SOFCs. Therefore, the design of new structural and functional materials with high ionic conductivity and high electrocatalytic activity is crucial to the development of next-generation low temperature fuel cells.

To face this challenge, Zhu *et al.*[1] have developed semiconductor-ionic materials (SIMs), which enable the production of new advanced SOFCs known as semiconductor membrane fuel cells (SMFCs), which link semiconductor physics and fuel cell electrochemistry at the nanoscale. In contrast to traditional SOFCs, the SMFC concept is proposed to replace the traditional electrolyte by a SIM or semiconductor membrane and it can deliver superior performance even at a lower temperature range (300-500 °C).

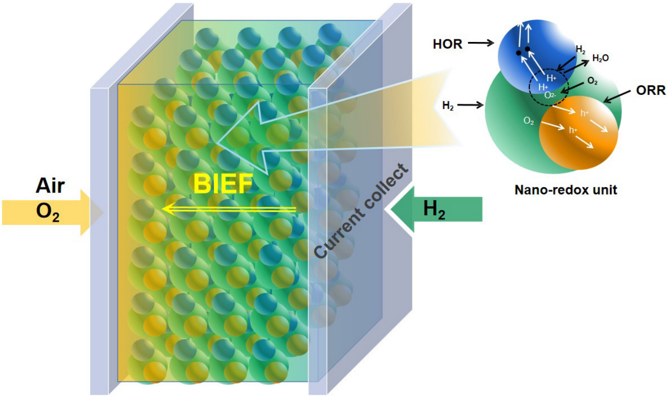

Figure 1. Nano-redox units used to build a macroscale fuel cell device. HOR: Hydrogen oxidation reaction; ORR: oxygen reduction reaction.

In such a special design, the p- and n-type layers/zones of the SMFC can be regarded as the cathode and anode of a traditional SOFC, respectively, where the electrolyte layer used to separate the hydrogen oxidation reaction (HOR) and oxygen reduction reaction (ORR) is not required. Meanwhile, the p-n junctions of SMFCs can realize the charge separation function under a built-in or internal electric field (IEF). They can block the electron flow to prevent the short-circuiting risk of SMFCs. This indicates that a physically separated electrolyte layer may not actually be an indispensable component for SOFC operation. In fact, the feasibility of the single-layer fuel cell constructed by a bulk p-n heterojunction consisting of ionic and p- and n-type semiconductor nanocomposite materials and a double layer fuel cell by the cathode and anode with a planar p-n junction has been demonstrated earlier[1-5].

Furthermore, this strategy can integrate the cathode, electrolyte and anode into a nano-redox unit consisting of ionic and n- and p-type particles. This means that the nano-redox unit[6], which suggests that SMFC devices can be constructed at the nanoparticle scale, as shown in Figure 1. By doing so, it can obviously promote the fuel cell HOR and ORR reactions in situ without the traditional separation by the electrolyte layer. In addition, the IEF caused by the p-n junction can drive the transport of the ions, e.g., H^+ and O^{2-}, thus increasing the ionic conductivity and output current/power. All of these can minimize or even avoid the interfacial polarization that is critical for traditional SOFCs, especially those operating at low temperature. Moreover, the electrolyte limitations of SOFC technology can be overcome to bring about a new pathway for SOFC commercialization.

Finally, this perspective focuses on the nano-redox mechanism and generation principle. Zhu *et al.*[7] have presented a next-generation fuel cell technology using a triple conducting oxide (TCO) single-layer device, which is able to conduct three mobile charge carriers, thereby exhibiting three types of conductivities: oxygen ions, electrons and protons. TCOs are very useful for various scientific areas and potential applications in electrochemical devices, such as membranes and reactors for hydrogen or oxygen separation, or electrodes for SOFCs and protonic ceramic fuel cells. The proposed TCO single device will not only benefit fuel cells but is also meaningful for other relevant energy technologies, such as water electrolysis, CO_2 electrochemical reduction and electrochemical nitrogen fixation.

DECLARATIONS

Authors' contributions

Wrote the manuscript: Fan Q, Yan S

Discussed and commented on the manuscript: Fan Q, Yan S, Wang H

Availability of data and materials

Not applicable.

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Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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