

点亮高温燃料电池的“材料之火”

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高温燃料电池作为一种高效与清洁的电化学能量转换装置, 已成为“双碳”战略的关键技术之一。其核心优势在于燃料适应性广、能量转换效率高以及全固态结构稳定。这种燃料电池不仅可使用氢气作为燃料, 还能够直接利用碳氢化合物(如天然气、甲醇)和氨等多种燃料, 展现出良好的应用灵活性与能源兼容性。与传统的内燃机发电技术相比, 高温燃料电池通过电化学反应直接将化学能转化为电能, 其发电效率可超过 60%。若进一步利用反应过程中产生的余热, 采用热电联供的方式, 整体能源利用效率可进一步提升至 80%以上。高温燃料电池技术中, 关键部件材料始终是与其商业化进程紧密相关的核心命题。特别是开发在高温严苛环境下能够长期稳定工作的部件材料, 是目前制约高温燃料电池进步的瓶颈。该项技术的突破将为高温燃料电池的未来发展奠定基石。

传统高温燃料电池依赖于氧化钇稳定氧化锆(YSZ)电解质、镍-YSZ 金属陶瓷阳极以及镧锶锰(LSM)氧化物阴极等经典材料体系。这些材料在高温条件下表现出优异的电化学活性和离子电导率, 为高效能量转换提供了重要保障。尽管如此, 随着操作温度降低至中低温范围(400~700 °C), 传统材料体系的氧离子迁移速率和电极反应动力学显著下降, 导致电池的电化学性能明显衰减。在保持效率和稳定性的前提下, 为实现高温燃料电池的中低温运行, 全球研究人员正致力于开发具有高离子电导率的新型电解质材料和高催化活性的电极材料, 以推动高温燃料电池技术在新一代能源体系中的广泛应用。

受《无机材料学报》编辑部的邀请, 本人组织编撰了“高温燃料电池关键材料”专栏, 特别邀请到来自哈尔滨工业大学、西安交通大学、北京怀柔实验室、武汉工程大学等单位的国内知名研究团体, 旨在分析高温燃料电池相关材料在基础研究、制备工艺、性能优化与机理研究方面的最新进展。

期望本专栏能够帮助科研人员更深入地理解高温燃料电池的内涵, 为他们提供了解该领域最新发展动态的窗口, 并积极推动高温燃料电池材料发展和学科进步。在此, 衷心感谢各位专家在百忙之中为本专栏撰稿, 是他们的辛勤付出和大力支持使得本专栏得以顺利出版。

Kindling the “Material Fire” in High-temperature Fuel Cells

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High-temperature fuel cells, as highly efficient and clean electrochemical energy conversion devices, represent a kind of key technology for achieving “dual carbon” energy strategies. Their core appeal lies in the broad fuel adaptability, high energy conversion efficiency and stable all-solid-state structure. Fuel cells can utilize not only hydrogen as fuel but also directly employ diverse fuels such as hydrocarbons (*e.g.*, natural gas, methanol) and ammonia, demonstrating excellent application flexibility and energy compatibility. Compared to conventional internal

combustion engine power generation, high-temperature fuel cells directly convert chemical energy into electricity through electrochemical reactions, achieving power generation efficiencies exceeding 60%. Furthermore, by utilizing waste heat from the reaction process for combined heat and power generation, overall energy utilization efficiency can be elevated to over 80%. However, commercialization of high-temperature fuel cell technology remains intrinsically tied to a core challenge—key component materials. Specifically, developing component materials capable of long-term stable operation under harsh conditions of high temperatures is currently the bottleneck that restricts advancement of high-temperature fuel cells. Breakthroughs in this area will lay cornerstone for development of high-temperature fuel cell technology in the future.

Conventional high-temperature fuel cells rely on classic material systems such as yttria-stabilized zirconia (YSZ) electrolytes, nickel-YSZ metal-ceramic anodes, and lanthanum-strontium-manganese (LSM) oxide cathodes. These materials exhibit outstanding electrochemical activity and ionic conductivity under high-temperature conditions, providing a crucial foundation for achieving efficient energy conversion. However, as operating temperatures are reduced to the medium-to-low range (400–700 °C), the oxygen ion migration rate and electrode reaction kinetics of conventional material systems significantly decline, markedly deteriorating the electrochemical performance of the cells. To enable the operation of high-temperature fuel cells at lower temperatures while maintaining efficiency and stability, researchers are actively developing novel electrolyte materials with high ionic conductivity and highly catalytically active electrode materials. This advancement aims to promote the widespread application of high-temperature fuel cell technology within next-generation energy systems.

At the invitation of the editorial board of *Journal of Inorganic Materials*, I served as a guest editor to organize and compile this topical section on “Key Materials for High-temperature Fuel Cells”. Renowned domestic research groups from institutions including Harbin Institute of Technology, Xi’an Jiaotong University, Beijing Huairou Laboratory, and Wuhan Institute of Technology have dedicated themselves to analyzing the latest advances in fundamental research, preparation techniques, performance optimization, and mechanism studies concerning materials for high-temperature fuel cells.

This topical section is intended to provide researchers with a deeper understanding of high-temperature fuel cells, serving as a window into the latest developments within the field, and actively promoting advancement of materials for high-temperature fuel cells as well as progress in the discipline. I extend my heartfelt gratitude to all experts who contributed to this topical section amidst their busy schedules. It is through their diligent efforts and generous support that this publication has come to fruition.

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研发计划政府间国际创新合作、国家自然科学基金面上项目、江苏省自然科学基金杰出青年项目等 20 多项。在 *Advanced Materials*, *Applied Catalysis B: Environmental*, *Advanced Functional Materials* 等期刊发表论文 150 余篇, 授权发明专利 10 余项。主要研究方向为煤基燃料电池及高效制氢、CO₂ 高温电解及碳基燃料合成等。

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