Decarbonizing the Fossil Fuel Sector Through High-Temperature Materials for Solid Oxide Fuel Cells

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Abstract

Global fossil fuel CO_2 emissions total approximately 35 gigatons per year, with around half originating from coal. Achieving net-zero emissions necessitates significant reductions, requiring disruptive technologies such as zero-emission coal and third-generation power systems. This transition relies on the development of innovative catalyst materials for effective fuel utilization and CO_2 reduction. Towards this, high-temperature solid oxide fuel cells (SOFCs) offer several advantages, facilitating efficient energy production and CO_2 reduction through reversible operation. However, advancing effective electrode materials for zero-emission coal or SOFC-integrated power systems presents a significant technological bottleneck **[1-2]**. To tackle these material design challenges, we adopt a combined experimental and theoretical approach, analysing the rate-limiting processes in the materials **[3]**. We propose rational tailoring of the electrode material through nanostructuring approaches, which could lead to breakthroughs in SOFC electrode design **[2]**.

Inorganic perovskite materials are touted as the next generation of electrode materials for energy conversion in high temperature electrolyzers and SOFCs owing to its significantly high electronic and ionic conductivity. In search of a suitable composition of the perovskite material, several combinations of cations are proposed to design the perovskite, which can match the desired conductivity and stability in the high temperature electrochemical device (electrolyzes or a fuel cell). Herein a bottom-up approach in designing the composition of cations and dopants is presented to come up with a rationale to discover new materials for oxygen reduction reaction in SOFCs. More specifically, material stability in oxidizing environment is probed to design high performance electrodes wherein mechanistic elucidations of the rate-limiting processes is leading to the rational electrode design. For example, in a geometrically well-defined experiment, cation segregation to the surface is observed to limit the SOFC performance. This acts as a stumbling block in the commercial success of the SOFCs. Following which, strategies are proposed to control cation segregation at the molecular level, which may significantly improve the electrochemical performance. This is elucidated in nanostructured fabrication of the electrode material as a thin film **[3]** or a nanoparticle **[2].**

References

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Figures

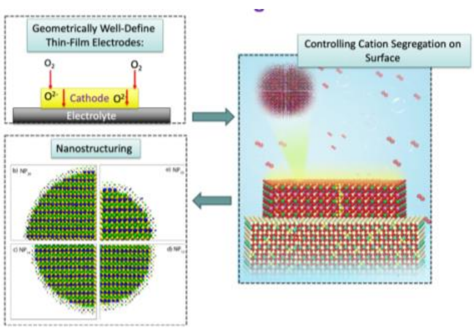

Figure 1: Mechanistic and rational design of high-temperature materials for solid oxide cells.

Biosketch: Prof. M. Ali Haider is working as a Vice Provost Research and External Engagement at the Indian Institute of Technology Delhi- Abu Dhabi. He holds an M.S. and PhD in Chemical Engineering from the University of Virginia, as well as a B.Tech. from the Indian Institute of Technology (IIT) Guwahati. Prof. Haider serves as an Editorial Advisory Board member for the journal ACS Sustainable Chemistry & Engineering. In 2023, he visited the Catalysis Research Center, Technical University Munich, as an Alexander von Humboldt fellow. The Royal Society of Chemistry has recognized his research contributions on various occasions, designating him as the 'Emerging Investigator' in the Reaction Chemistry & Engineering journal, a 'Highly Cited Author' in the Green Chemistry journal, and as part of the 'Editor's Choice Collection' in the Journal of Materials Chemistry A. He was a visiting fellow at the Catalysis Center for Energy Innovation at the University of Delaware, supported by the 'Bioenergy-Award for Cutting Edge Research' sponsored by the Indo–US Science and Technology Forum. For his research work in utilizing high-performance computing (HPC) to solve problems related to sustainability and climate change, Hewlett Packard Enterprise and Intel have bestowed upon him the 'Dr. A.P.J Abdul Kalam HPC Award for R&D in HPC Application'. He is a member of The National Academy of Sciences, India (NASI) and the Indian National Young Academy of Sciences (INYAS), actively engaging in delivering motivational and popular science lectures on sustainability, climate change, nanoscale catalysis, and renewable energy.