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Superionic conductor and semiconductor-ionic materials for advanced solid oxide fuel cell (SOFC): Challenges and opportunities

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The superionic conductors (SC) have characteristics of highly disordered or liquid state of the mobile ions which can fastly transport through network channels, not individual ionic hopping. The SCs are used primarily as the electrolytes in solid oxide fuel cells (SOFCs) and widely for electrochemical devices. In a long history, the SOFC has been dominated by yttrium stabilized zirconia (YSZ) which is based on oxygen vacancy created in the structure and the O_2- transport phenomenon relies on the hopping of ions through a fluorite solid structure at high temperature (e.g. 1000°C). The YSZ is in principle not the SC. In order to develop advanced SOFCs for low enough temperatures and technical usefulness, Goodenough proposed the "Oxide-ion conductors by design" (1). However, the proposed structure and doping approach have put strong constraints for SOFC material design and development. Our approach is based on the superionic conduction mechanism on the ionic networking conduction to create the artificial liquid state and superionic channels through interfaces between a rigid solid phase, e.g. oxide-ion ceria structure and a 2nd phase which can be molten or soften at a suitable temperature ≤ 500°C. Typical examples are ceria-carbonate composite materials. These materials have successfully reached 0.1 S/cm at around 300°C (to be comparable to YSZ at 1000°C), resulting in great successes for low temperature SOFCs, e.g. more than 1000 mW/cm_2 at ≤ 500°C. Latest developments showed more advanced novel functional semiconductor-ionic materials (SIM) in which the ionic conductivity can be greatly enhanced by strongly correlation between electrons and ions. More interestingly, such SIMs can function for fuel cell anode, electrolyte and cathode, "Three in one" (2), thus creating single-layer electrolyte-free fuel cells (EFFCs) as a revolutionary breakthrough. Therefore, many new opportunities for SOFC R&D have been explored.

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