

### SS5A : 차세대 SOFC 연구주역

#### SS5A-1 | 직접 CO<sub>2</sub> 전해전지용 고효율/고안정성의 더블 페로브스카이트 기반 전극 개발

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Solid oxide electrochemical cells (SOCs) hold great promise as highly efficient energy conversion devices for the electrochemical reduction of CO<sub>2</sub> into valuable fuels. However, the practical application of SOCs for CO<sub>2</sub> reduction is significantly hampered by the sluggish reaction kinetics and poor stability of the fuel electrodes. Here, we report on a novel Pr<sub>4/3</sub>Ba<sub>2/3</sub>Co<sub>2/3</sub>Fe<sub>2/3</sub>Mn<sub>2/3</sub>O<sub>5+δ</sub> (PBCFM) with a double perovskite structure, which is highly active and durable for electrochemical reactions of H<sub>2</sub> oxidation and CO<sub>2</sub> reduction. Co-doping of Fe and Mn into the B-site of PrBaCo<sub>2</sub>O<sub>5+δ</sub> improved its structural stability, thereby preventing Ba segregation and carbonate formation under pure CO<sub>2</sub> atmospheres and enabling the exsolution of CoFe alloy without phase decomposition. The SOC with the PBCFM electrode exhibited superior performance of 2.04 W cm<sup>-2</sup> in peak power density in the fuel cell mode with H<sub>2</sub> and a current density of 3.76 A cm<sup>-2</sup> at 1.5 V in the CO<sub>2</sub> electrolysis cell mode at 850 °C. Furthermore, the PBCFM electrode exhibited excellent long-term durability without any carbon coking or degradation. These results demonstrate the feasibility of the novel PBCFM as a robust and efficient catalyst for direct CO<sub>2</sub> electrolysis.

#### SS5A-2 | Highly bendable and thin solid oxide fuel cells via phase control of scandia doped zirconia

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Flexible solid oxide fuel cells (SOFCs) have gained increasing attention due to their superior mechanical durability in withstanding external stresses. A pivotal component in the development of flexible SOFCs is transformable tetragonal (t-) zirconia, but there remain some difficulties in practical applications due to a lack of performance improvement. Addressing this concern, we present our work on flexible electrolyte supports designed to exhibit improved ionic conductivity. This enhancement is achieved by investigating different doping levels of the zirconia-scandia system within the range of 3–9 mol% Sc<sub>2</sub>O<sub>3</sub>. Notably, 5 mol% scandia-stabilized zirconia demonstrates transformable tetragonality (>1.010), exceptional flexibility- mechanical strength behavior and more than twice the conductivity (0.082

S/cm, @ 900 °C) compared to the flexible Y<sub>2</sub>O<sub>3</sub>-ZrO<sub>2</sub> system. Finally, we successfully fabricate a highly flexible SOFC (with a total thickness of 2 μm at 900 °C under wet H<sub>2</sub> with general cermet electrodes, Ni-ScSZ (anode) and LSM-ScSZ (cathode), and displays exceptional long-term stability (350 h).

#### SS5A-3 | Fabrication of large-area sub-micron thick proton ceramic electrolytes by inkjet printing

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Recent developments in proton ceramics have garnered considerable attention, especially as an electrolyte for fuel cells and water electrolysis cells. This interest stems from their impressive ionic conductivity at relatively low temperatures, surpassing that of oxygen-ion conducting ceramics. Proton diffusion, with an activation energy of about 0.3–0.5 eV, is more efficient compared to the 0.8–1.0 eV needed for oxygen ion conduction. One of the challenges in fuel cell and electrolysis cell operation is the energy loss that occurs during ion conduction through the electrolyte membrane. To minimize this, there is a push to make the electrolyte as thin as possible. Several attempts have been made to produce thin electrolytes suitable for commercial-scale cells. Traditional methods such as screen-printing or spraying, however, have only managed to achieve thicknesses in the several-micron range. In contrast, inkjet printing, already a staple in creating large-scale thin ceramic products like displays and capacitors, offers promising potential. The key lies in devising the perfect printable ink blend – one that combines functional materials and auxiliary agents optimally. Our team has pioneered a top-notch ceramic ink tailored for fuel cells and electrolyzers. We have crafted large-area proton ceramic electrolytes with a sub-micron thickness. Notably, our output is free from pinholes, ensuring a high open circuit voltage almost on par with theoretical values. Moreover, our printing technique guarantees sharp patterns without any blurring along the edges. Our sub-micron-thick inkjet-printed proton ceramic was tested as a fuel cell electrolyte and the results were impressive with a peak power of approximately 0.6 W cm<sup>-2</sup> at 500 °C and a low ohmic resistance of under 0.1 Ω cm<sup>2</sup>. The material showed remarkable durability with negligible degradation over a long-term operation. These findings underscore the potential of inkjet printing as a viable commercial method for producing high-performance thin ceramic membranes.

#### SS5A-4 | Exploring Effective Ceria Doping for Buffer Layers in LSCF Cathode of Solid Oxide Cells

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<sup>1</sup>Korea Institute of Ceramic Engineering and Technology, <sup>2</sup>National University, <sup>3</sup>Korea Institute of Energy Research LSCF ( $\text{La}_x\text{Sr}_{1-x}\text{Co}_y\text{Fe}_{1-y}\text{O}_{3-\delta}$ ) which contains lanthanum ferrite doped with strontium and cobalt, is a commonly employed cathode material in solid oxide fuel cell (SOFC). Nevertheless, LSCF cathodes have the potential to react with the YSZ electrolyte, leading to the formation of insulating secondary phases such as  $\text{La}_2\text{Zr}_2\text{O}_7$  and  $\text{SrZrO}_3$ . Consequently, the necessity for a buffer layer arises to act as a protective barrier, preventing this secondary phase formation reaction between the electrolyte and the electrode within SOFC. Typically, gadolinium-doped ceria (GDC) is used as the buffer layer. Nonetheless, it faces challenges in achieving high density due to the requirement for elevated sintering temperatures, and it introduces a Ce-Zr solid solution characterized by limited ionic conductivity. In this study, we explored the potential of GYBC ( $\text{Gd}_{0.135}\text{Yb}_{0.015}\text{Bi}_{0.02}\text{Ce}_{0.83}\text{O}_{1.915}$ ) as a novel material with enhanced conductivity and sintering properties compared to GDC for use as a buffer layer. Furthermore, we also confirmed the microstructure performed by scanning electron microscopy (SEM) and evaluated the influence of the buffer layer by electrochemical analysis.

#### SS5A-5 | 암모니아 직접 구동을 위한 금속지지체형 SOFC의 개발

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수소의 낮은 저장밀도로 인해 다양한 저장매체 후보군이 연구되고 있는 가운데, 최근 암모니아 형태로 수소를 활용하고자 하는 연구가 활발히 이뤄지고 있다. 암모니아의 경우, 상온에서 약 10기압 정도에서 쉽게 액화가 되며, 탄소 성분을 포함하지 않아 새로운 연료로써 주목받고 있다. 특히, 암모니아는 고온에서 적절한 촉매 하에 쉽게 질소와 수소로 분해되는 특징이 있기 때문에 고체산화물연료전지(SOFC)의 연료로 사용되기에 적합하다. 그러나, 고온 암모니아 환경에서는 금속의 빠른 질화로 인해 기계적 안정성이 급격히 떨어지며, 이로 인해 금속의 물성 변화 및 파단으로 인한 문제가 발생할 수 있다. 따라서 이를 대응하기 위해, 질화에 강건한 금속 소재를 적용하고, 이러한 금속 소재에 맞는 셀의 구성을 설계할 필요가 있다. 본 연구에서는, 고온 암모니아 환경이 스테인리스 스틸, 니켈 초합금 등의 내열 합금 소재에 어떤 변화를 일으키는지 분석하고, 이를 통해 암모니아 환경에서 구동하는 금속지지체형 SOFC 제작에 적합한 소재를 찾고자 하였다. 또한, 선정된 금속 소재의 열팽창계수 등의 물성과 높은 정합성을 가지고, 연료극에서 암모니아를 분해할 수 있는 촉매층

을 가질 수 있는 셀 구성을 설계하였다. 이를 통해, 고온의 암모니아 환경에서도 안정적으로 구동될 수 있는 금속지지체형 SOFC를 개발하고자 한다.

#### SS5A-6 | Observation of Rheological Properties of NiO-8YSZ Composite Tape Casting Slurry with Variation in Powder Volume Fraction and Chemical Additives

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The anode substrate is a crucial element in a fuel cell, both in terms of electrochemistry and mechanical aspects. It serves as a foundation for constructing a multi-layered stack and provides a physically stable porous structure, making it a pivotal component for hydrogen diffusion, water supply, and various electrode reactions. However, despite its significance, only a limited number of studies have explored the correlation between the rheological characteristics of the tape casting slurry and the properties of tape. In this study, based on the optimized NiO-8YSZ tape casting recipe, it was accomplished to understand the influence of particle volume fraction and various chemical additives on the rheological perspective. As a result, viscosity behavior with shear rate due to various parameters, intrinsic viscosity, yield stress, and the fractal dimension and shear-dependent constant were investigated. Additionally, aggregation behavior using various models was observed. Lastly, the selected slurry composition was used to cast actual tapes, and the properties following heat treatment were analyzed.

#### SS5A-7 | Phase stability of perovskite oxide materials based on dense bulk electrode for solid oxide fuel cell

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The perovskite-based materials are typically used as the electrodes of solid oxide cells (SOCs) due to their high catalytic activities of oxygen exchange reactions. The durability of SOCs, resulted from cation redistribution of perovskite-based electrode, has been considered the main bottleneck for the commercialization of SOCs application. However, the detailed surface chemistry associated with perovskite-based electrodes and their impact on electrode performance in real operating environments are not fully understood. Herein, we

## Oral Presentations

derived a correlation with applied voltage, surface features, and electrochemical property in perovskite-based electrode under the operating condition of actual SOFCs. Consequently, from the perspective of the actual operating conditions of SOFCs, this study suggests that the phase stability associated with elements in the B-site in perovskite electrodes becomes increasingly important to improve the cell performance, breaking away from studies that focused only on A-site segregation behaviour of perovskite-based materials. This approach can pave a new perspective for enhancing the performance and stability of devices in electrochemical application using perovskite materials.

### SS5A-8 | Nano-scale architectural design of air electrode for high-performance and robust reversible solid oxide cells

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In this study, we report an innovatively synthesized  $\text{La}_{0.6}\text{Sr}_{0.4}\text{CoO}_3$  (LSC) nanostructured air electrode, demonstrating superior catalytic activity and exceptional durability against critical interfacial delamination-induced degradation. A ~50 nm thin LSC air electrode adorned a porosity graded  $\text{Gd}_{0.1}\text{Ce}_{0.9}\text{O}_2$  backbone via ultrasonic-assisted infiltration showing significantly flourished ORR and OER kinetics with prolific electrochemical performance compared to the cell with conventional LSC air electrode. The SOC exhibited maximum power density of  $2.24 \text{ W cm}^{-2}$  in the fuel cell mode and maximum current density of  $4.57 \text{ A cm}^{-2}$  at an operating voltage of 1.6 V in the electrolysis mode at 750 °C. The results of reversible cycling stability test indicate excellent durability which is attributed to elimination of detrimental  $\text{O}_2$  pressure evolved at the air electrode/electrolyte interface. Sited among highest performances till date, this study provides a smart strategy to realize a tremendously durable SOC design for the production of green hydrogen and electricity.