PROPERTIES OF SAMARIUM STRONTIUM COBALT OXIDE BASED COMPOSITE CATHODE WITH DIFFERENT ELECTROLYTES FOR INTERMEDIATE TEMPERATURE SOLID OXIDE FUEL CELL: A SHORT REVIEW

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Abstract. Solid oxide fuel cell (SOFC) is a promising technology for energy conversion efficiency. Electrochemical processes convert the chemical energy of a variety of substances into direct current power. Typically, these reactions occur at temperatures between 400 and 1000 °C. In recent years, a substantial quantity of research has been conducted on intermediate temperature SOFCs (IT-SOFCs), with a particular emphasis on the cathodes. However, the effect of electrolyte on composite cathodes has not been studied as thoroughly. Current SOFC research focuses on enhancing cell performance by decreasing operating temperature. It is crucial in this context to analyze the efficacy of various electrolytes. Gadolinium-doped ceria (GDC) and samarium-doped zirconia (SDC) are two such electrolytes that can be coupled with samarium strontium cobalt oxide (SSC) cathodes. In SSC-based cathodes, the electrolyte material strengthens the triple phase boundary, thereby enhancing cell performance. Chemically compatible with altered ceria electrolyte materials, SSC is appropriate for SOFCs operating at intermediate temperatures. Specifically, SSC nanofiber-GDC electrolyte composite cathodes exhibit superior thermal stability. In addition, their cathode polarization resistance at 650 °C is only 0.024 cm^2. This review indicates that perovskite SSC is a formidable candidate for use in IT-SOFCs. To optimize cell efficacy, however, additional research is required. This research should center on the chemical, physical, and electrochemical compatibility of cathode materials. In conclusion, the future of SOFCs depends on the optimization of these factors, and the potential of SSC-based cathodes in this sector is an exciting prospect.

Keywords: Cathode, composite, gadolinium doped ceria, samarium doped ceria

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Introduction

Global energy demand necessitates global-benefitting alternative power sources. A fuel cell instantaneously converts fuel chemical energy into electrical energy [1]. SOFCs outperform others. It supports 400–1000 °C kinetic processes. 700–900 °C SOFC operation may lower system efficiency. The working temperature restricts compounds and adds costs, making SOFC uncommercial [2]. Lowering the working temperature to 600–800 °C fixes this [3]. Lowering SOFC operating temperatures makes them more adaptable. These fuel cells promise energy-conversion technology. Material deterioration, construction stability, service life, and processing costs may decrease [4]. However, a lower-temperature electrolyte material (IT-SOFC) could diminish cathode catalytic performance for the oxygen reduction reaction (ORR) process and intermediate SOFC electrochemical performance [4-5]. Therefore, IT-SOFC electrolyte study [3]. Traditional SOFCs using oxygen-ion conductors like yttrium-stabilized zirconia (YSZ) run at 800–1000 °C, increasing system costs and decreasing durability. Lowering fuel cell device operating temperatures solves these issues. [6]. Because of their lower activation energy and better protonic conductivity than YSZ, proton-conducting oxides like $Ce_{0.8}Sm_{0.2}O_2$-(SDC), $Ce_{0.9}Gd_{0.1}O_2$-(GDC), and $La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_3$-(LSGM) make good ITSOFC electrolytes. Electrolytes must meet certain parameters. High conductivity, chemical stability, sintering, and low grain boundary resistance. Selecting a cerium-based electrolyte carefully increases electrode chemical compatibility [6-7]. SOFC electrolytes need excellent ionic conductivity, density exceeding 95%, and thermal stability [8].

Composite cathodes help develop SOFC component materials [2]. The mixture expands the triple phase boundary (TPB) to optimize electrochemical activity. Cathode-electrolyte thermal mismatch improved [9]. SOFC development aims to lower the operating temperature to 400-600 °C to increase the availability of high-performance perovskite cathode materials such samarium strontium cobalt oxide ($Sm_{0.5}Sr_{0.5}CoO_{3-}$) (SSC). Thus, Jiang et al. and Lee et al. [10] said that mixed ionic electronic conductivity (MIEC) materials generated from cobalt oxide, such as samarium strontium cobalt oxide (SSC), have gained interest as cathodes due to their good mixed ionic and electronic conductivities at low temperature. SSC cathodes have 1000 Scm^{-1} mixed conductivity at 200–800 °C [11]. SSC SOFC cathodes have low polarization resistance [12]. SSC-based composite cathode SOFCs with ionic conducting electrolytes as SDC, YSZ, GDC, and CGO are more stable and perform better. Sintering, operating temperature, particle size and porosity, thermal expansion mismatch, and composite cathode composition affect SSC cathode performance. High SOFC power density and performance with low polarization resistance require these [17].

GDC Electrolyte

Intermediate temperatures use gadolinium- and samarium-doped ceria electrolytes. GDC, like SDC, has good ionic conductivity for electrolyte IT-SOFC [18]. High numbers indicate good cathodes. Most cathode composites use electrolyte materials like SDC and GDC because they operate better at intermediate and low temperatures [18]. GDC-doped ceria is a promising intermediate temperature SOFC material. Ball mills and solid-state technologies make GDC. Simple and cheap, it makes finer particles. Ball milling and solid-state synthesis produced gadolinium-doped cerium. Powders were dried and calcined at 600 °C, 700 °C, and 800 °C. Calcination temperature altered intermediate solid oxide fuel cell electrolyte [8].

SDC Electrolyte

SOFC electrolytes must resist oxidizing and reducing conditions and have good ionic conductivity at cell operating temperature. Gas cross-leakage needs rich electrolytes. Chemically compatible TECs prevent cracking and delamination. Electrolytes varied. Researchers prefer pure cathode SDC electrolytes. SDC powder densified when pressed uniaxially at 200-400 MPa and sintered at 1350-1400 °C for 4 h. SDC electrolyte-based anode-supported SOFCs perform well at 500–600 °C [19]. SDC is completely ionic at high oxygen partial pressures, but at lower pressures, it considerably lowers at the anode side, resulting in a considerable volume proportion of electronic conductivity [19]. High numbers indicate good cathodes. Most cathode composites include electrolyte materials like SDC and GDC because they operate better at intermediate and low temperatures [20].

SDCC Electrolyte

Samarium-doped ceria carbonate (SDCC) composite electrolytes' carbonate mix impacts the secondary phase. SDC improves all composite cathodes, making carbonate acceptable [21]. Many publications recommend SDCC compound electrolyte. According to Wu et al. [22], carbonates melt at 500 °C, which increases the mobility of many ions (Na^+, Li^+, H^+, CO_3^{2-}, and O^{2-}) and causes superionic conduction. CO_3^{2-} transfers H^+ and O^{2-} ions between carbonate ions. Both binary carbonates allow superionic conduction at two-phase material interactions. [22].

SSC-GDC Composite Cathode Characteristics

X-Ray Diffraction (XRD) Analysis of SSC-GDC

GDC and SDC interlayers prohibit YSZ electrolyte-porous SSC cathode interactions. Their mismatches decrease. Composition, microstructure (grain size and porosity), and sintering temperature affect cathode performance [23]. GDC in the porous SSC cathode may close the electrolyte-cathode thermal expansion coefficient gap. Stopping SSC-YSZ reactions requires GDC [12]. X-ray diffraction patterns show SSC stability with GDC in Figure 1. SOFC can operate at SSC GDC temperatures below 900 °C. GDC is being studied as an SSC barrier layer since it is stable [23]. Figure 2 shows SSC-GDC composite cathode-created SOFC cross-sections. SOFCs have 4–7–11 mm porous GDC barrier layers. SOFCs have 20–30-mm cathode layers. Cathode-electrolyte stability is needed. SSC reacts with YSZ, and the second resistive phase peaks, like $SrZrO_3$ and $Sm_2Zr_2O_7$, developed at 800 °C [24].

Electrochemical Properties of SSC-GDC

- ***Conductivity***

Table 1 shows the ionic conductivity of sintered GDC pellets calcined at various temperatures. Sintering was done at 1350 °C, which was lower than previous researchers. As expected, operating temperature increased conductivity. Sintering temperature increased relative density and grain size. Ionic conductivity then decreased [24].

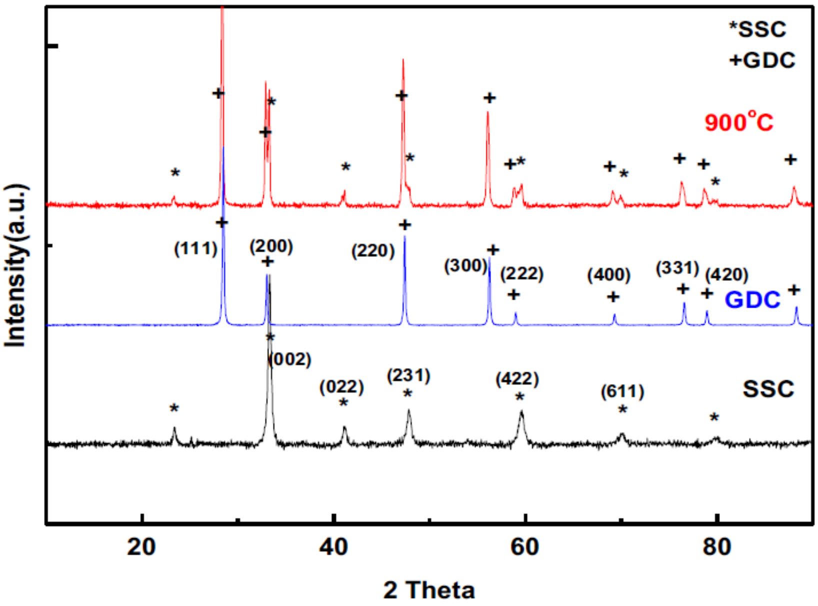

Figure 1: Patterns of X-ray diffraction of SSC and GDC mixed [23].

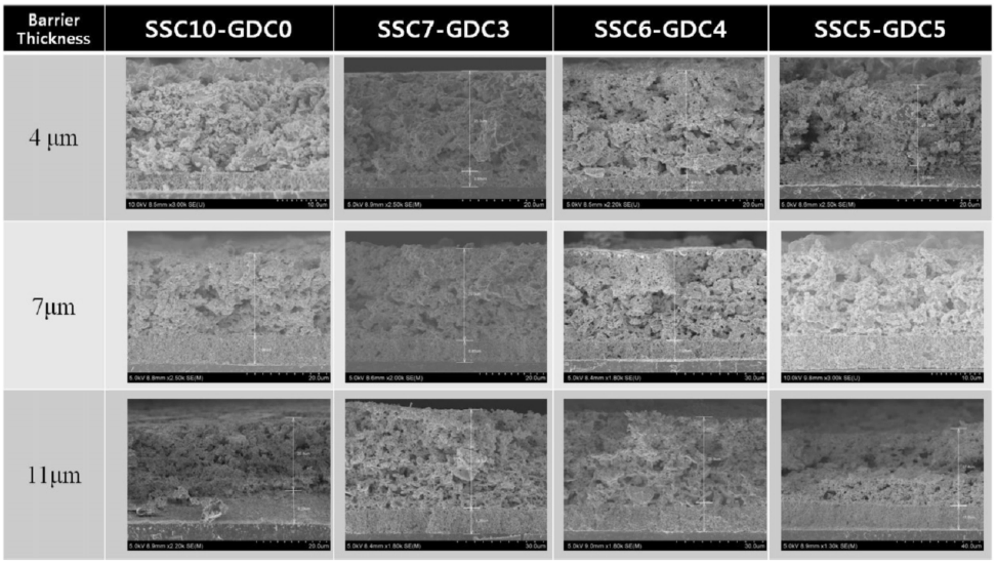

Figure 2: Cross-sectional images of SSC-GDC [24].

Table 1: Ionic conductivity of GDC pellet at various calcination temperatures [23].

Operating temperature (°C)	**Ionic conductivity at calcination temperature (Scm^{-1})**		
	600 °C	700 °C	800 °C
400	0.00010	0.00010	0.000076
450	0.00028	0.00048	0.00025
500	0.00082	0.00093	0.00063
550	0.0018	0.0018	0.0013
600	0.0024	0.0031	0.0024
650	0.0047	0.0052	0.0040
700	0.0077	0.0071	0.0058
750	0.0110	0.0095	0.0076
800	0.0153	0.0115	0.0091

The solid oxide electrolyte needs at least 0.01 Scm^{-1} conductivity at its operating temperature [24]. GDC10 pellet calcined at 600 °C meets the requirements with a conductivity of 0.011 and 0.0153 Scm^{-1} at 750 °C and 800 °C. Pellet's operating temperature was measured. When heated to 800 °C, the 700 °C calcined powder only produced 0.0115 Scm^{-1} ionic conductivity. Despite the 800 °C calcination temperature, the ionic conductivity was below 0.01 Scm^{-1} at all operating temperatures. The greatest ionic conductivity was 0.0153 Scm^{-1} at 600 °C calcination at 800 °C. Azim et al. observed the highest ionic conductivity of 0.184 Scm^{-1} at 800 °C, lower than scandia-stabilized zirconia [24].

SSC-SDC Composite Cathode Characteristics

X-Ray Diffraction (XRD) Analysis of SSC-SDC

Figure 3 shows as-prepared sample XRD patterns. SDC has a similar XRD pattern to pure CeO_2, with a little variation in the direction of the considerably higher angles for the 2 values. SSC is more structurally compatible with SDC electrolyte than SSC alone [25]. SDC samples have CeO_2 cubic fluorite structures. Sm_2O_3 was doped into the CeO_2 lattice because its phases cannot be detected. SSC follows $Sm_{0.5}Sr_{0.5}CoO_3$, a perovskite. The sintered SDC-SSC composite material shows two-phase diffractions that can be recognized as SDC or SSC phases. Two hours at 600 °C sintered the material. No by-product phases were found, suggesting that the SSC and SDC phases do not interact and form a composite type [26].

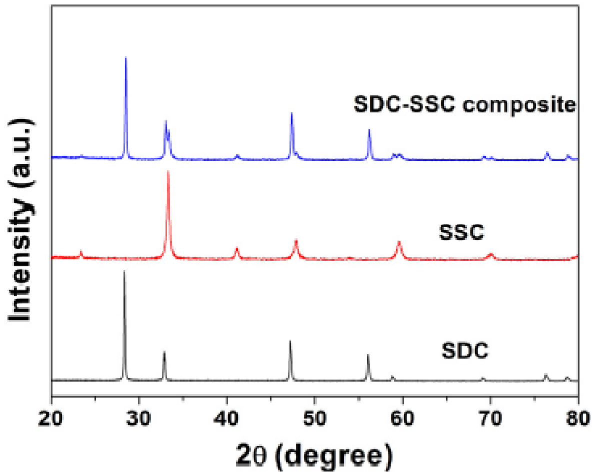

Figure 3: XRD patterns of SDC, SSC, and SDC-SSC (6:4) composites [26].

Microstructure Analysis of SSC-SDC

Figure 4 shows SEM pictures of the SDC sample (a). SDC particles are 50–200 nm wide. Figure 4(b) shows that SSC particles have a unique bulk aggregation and a non-uniform size distribution from nanometer to micrometer. Third Figure (c) SEM pictures of the SDC-SSC composite reveal a consistent distribution of two phases (SDC and SSC) in the composite, which is corroborated by elemental mappings in Figure 4(d) to (h). For both ionic and semiconducting phases, the as-produced SDC-SSC composite material meets the essential conditions for continuous networks and charge transport channels in electrolyte free fuel cells [26]. Because of the consistency of the created material.

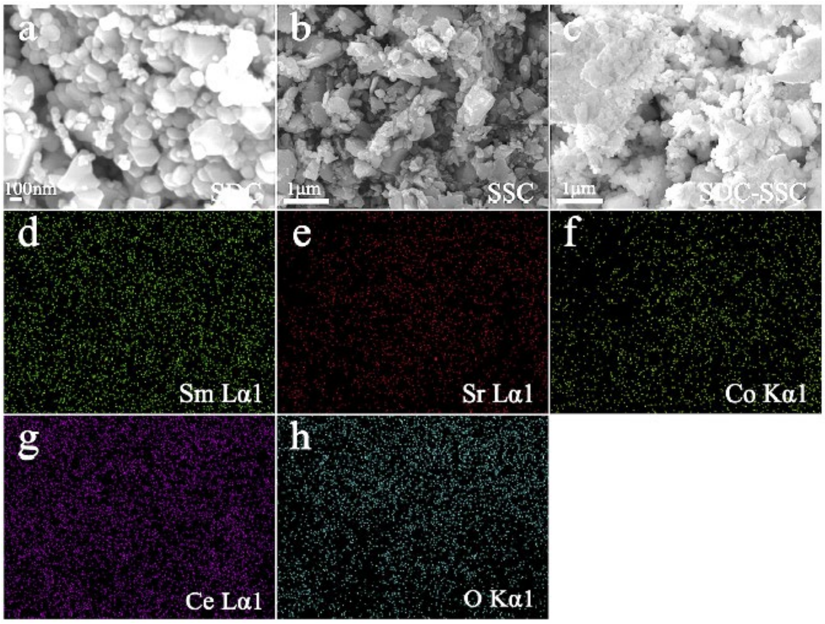

Figure 4: Scanning electron microscope images of (a) SDC, (b) SSC and (c) SDC-SSC composite samples. (d) Sm, (e) Sr, (f) Co, (g) Ce and (h) O [26].

Electrochemical Properties of SSC-SDC

Conductivity

The cathode must retain strong ionic conductivity and avoid thermal mismatch. SSC's catalytic activity and electronic conductivity battle for composition dependency. The SDC-SSC composite cathode has active sites in the cathode reaction zones, which increases current/power outputs [18]. The linear zone in the center of I-V curves largely represents the IR loss of the electrolyte, which may be used to calculate the ionic conductivity of the SDC electrolyte or SDC-SCC layer. Table 2 summarizes the findings. Table 2 shows that 40% SSC composites are roughly three times SDC. Unlike the TPB effect, the interfacial space charge effect between the oxide phases promotes ionic conductivity [27].

Table 2: Resistances are given in U cm^2 while ionic conductivity is given in S. [27].

Cell	R_0	R_1	Q_1	n_1	R_2	Q_2	n_2	R_3	Q_3	n_3	σ_1
SDC	0.245	0.136	5.1E-5	1	0.576	0.44	0.88	0.771	0.99	0.37	0.072
20% SSC	0.150	0.020	4.6E-3	0.78	0.148	3.9	0.8	0.760	1.86	0.38	0.175
40% SSC	0.114	0.008	1.2E-3	1	0.203	0.51	0.55	0.316	3.3	0.83	0.229
60% SSC	0.057	0.006	1.8E-2	0.94	0.007	0.16	1	0.070	2.7	0.49	0.177

SSC-SDCC Composite Cathode Characteristics

X-Ray Diffraction (XRD) of SSC-SDCC

Figure 5 depicts X-ray diffraction measurements of pure SSC and pure SDCC samples prior to and after calcination at temperatures ranging from 600 °C to 750 °C. Pure SDC carbonate has the same equivalency as JCPDS75-0158 and a cubic fluorite structure like pure SDC [28]. The binary carbonate content (SDCC) examination of the carbonate phase revealed that the crystallite peak of the SDC pure fluorite type structure was equivalent to the pure SDC structure.

This proved that the composite cathode powder had high SSC and SDC crystallinity. Phase and chemical stability affected low-temperature solid oxide fuel cell (LTSOFC) electrochemical performance over time. The electrochemical performance and chemical and structural stability of SSC cathode LTSOFCs have been determined [30]. This shows that SDCC composite cathodes maintain chemical and structural phase stability, which will improve LTSOFC performance. SDCC is a promising composite electrolyte for composite cathode development, and XRD pattern demonstrates that SDCC peak position is unaffected by pure SDC [18].

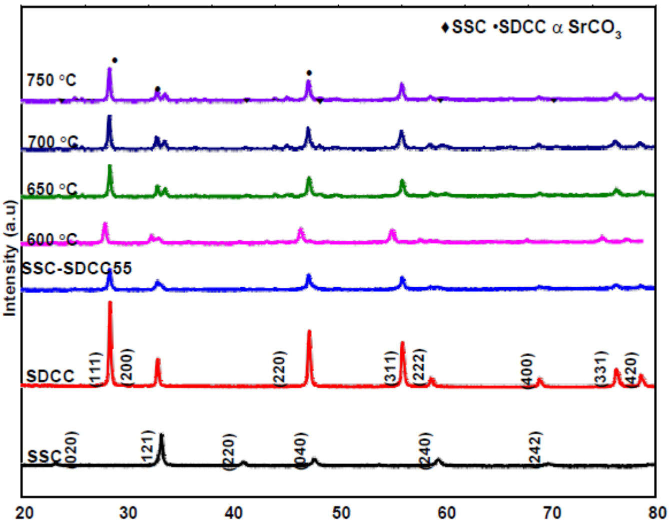

Figure 5: X-ray diffractograms for commercial SSC, SDCC and calcined composite cathode SSC-SDCC5 [28].

Microstructure Analysis of SSC-SDCC

SSC-SDCC composite cathode microstructures are critical to LTSOFC electrochemical performance. Figure 6 shows SEM images of calcined SSC-SDCC55 sintered composite pellets' structural and physical stability. The pellet form of composite cathode is essential to observe SSC-SDCC performance as a single cell during LTSOFC cell operation. Oxygen diffuses to the porous cathode's triple phase boundary (TPB) and is electrochemically reduced to oxygen ions. Anode, electrolyte, and cathode comprise the cell. This is called the oxygen reduction reaction (ORR) [28].

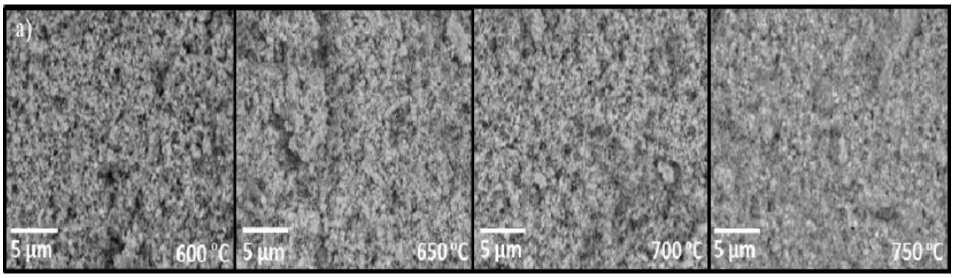

Figure 6: Backscattered image for the cross section composite cathode pellet of calcined SSCB55 [28].

This study demonstrates the significance of milling parameters, calcination temperatures, and sintering temperatures in the production of SSC-SDCC composite cathode. The pellet morphology drawings showed a consistent particle distribution and appearance [28]. Carbonate in SSC and matching these components improved pellet microstructure stability without increasing aberrant grain formation [29].

Electrochemical Properties of SSC-SDCC

- ***Conductivity***

Composite cathode composition and carbonate concentration affect conductivity. In conclusion, for low-temperature solid oxide fuel cells (400-600 °C), SDCC composite electrolytes outperform SDC electrolytes. They offer stronger ionic conductivity, lower cost, and better mechanical stability. Figure 7 compares SDC and SDCC electrolytes briefly.

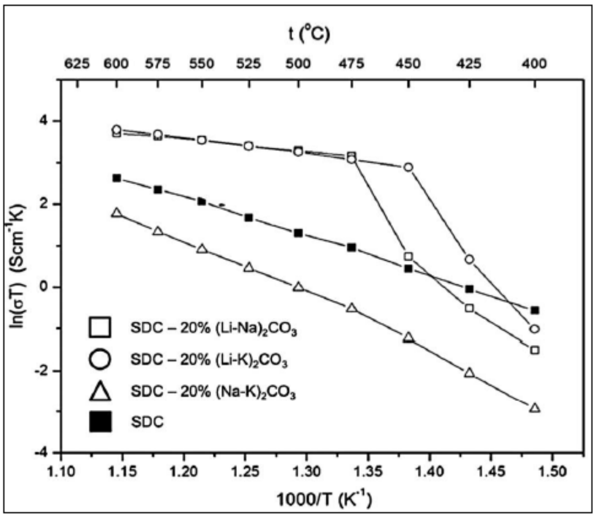

Figure 7: Total conductivity of SDCC composite electrolytes with various salt compositions [19].

Conclusions

The SDC-SSC composite performs well due to its higher ionic conductivity and SSC-enhanced catalytic activity. These results show that the SDC-SSC composite is promising for next-generation LT-SOFCs. This study found that calcination temperature affects solid-state gadolinium-doped cerium (GDC). XRD showed that CeO_2 has a single-phase structure with crystallite size increasing with calcination temperature and lattice parameter decreasing. Calcination temperature increased particle size. Calcination temperature impacts ionic conductivity. This study shows that particle size and calcination temperature can optimize ionic conductivity, phase formation, and physical stability. However, more comprehensive electrochemical impedance spectroscopy testing of calcination temperatures and secondary phase is needed to identify how secondary phase affects LTSOFC performance.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare.

Compliance with Ethical Standards

The work is compliant with ethical standards.

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