Review Article

Investigating the Potential of GDC Electrolyte for High-Efficiency ITSOFC Applications: Short Review

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Abstract: *Solid Oxide Fuel Cells (SOFCs) hold immense promise for clean and efficient power generation. However, conventional high-temperature SOFCs require operating temperatures exceeding 800°C, leading to material degradation and increased system complexity. Intermediate-Temperature SOFCs (ITSOFCs) offer a compelling solution, operating at lower temperatures (500-700°C) with benefits like faster startup, improved durability, and reduced system costs. A critical factor for achieving high efficiency in ITSOFCs is the electrolyte material. Gadolinium-doped Ceria (GDC) emerges as a promising candidate due to its high ionic conductivity at lower temperatures. This review explores the potential of GDC as an ITSOFC electrolyte, examining its advantages in conductivity, compatibility with operating temperatures, and its impact on overall cell efficiency. We discuss the challenges associated with GDC, such as limitations in achieving dense thin films and potential degradation issues. Additionally, the review highlights ongoing research efforts to address these challenges, including co-doping strategies and advanced thin film deposition techniques. By overcoming these obstacles, GDC-based electrolytes have the potential to revolutionize ITSOFC technology, paving the way for a more commercially viable and environmentally friendly future for fuel cell technology.*

Keywords: ITSOFC, GDC Electrolyte, Solid Oxide Fuel Cells.

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1. INTRODUCTION

1.1 Introduction of solid oxide fuel cells (SOFCs)

The development of alternative power sources is necessary to reduce global energy consumption in a wide range of ways (Ghani, et al., 2023). Thus, an electrochemical system is a reliable fuel cell that can efficiently and cleanly transform chemical energy into electrical energy with less pollution (Jaidi, et al., 2023). SOFCs, which stand for solid oxide fuel cells, are a promising technology for the conversion of energy due to the great efficiency they possess and the environmental benefits they offer. Solid oxide fuel cells (SOFCs) have garnered significant interest for their notable efficiency, ability to use many fuels, and environmentally friendly nature (Roslan & Karim, 2023). According to Gao et al. (2016), solid oxide fuel cells (SOFCs) are capable of operating in a variety of modes, including the conversion of chemical energy to electrical power (fuel cell mode) and the conversion of electrical energy to chemical energy (electrolysis mode). According to Zhang et al. (2017), these cells are well-known for their capacity to immediately transform the chemical energy that is derived from fuels into electric power with a high degree of efficiency. With their high efficiency, solid oxide fuel cells (SOFCs) are becoming increasingly appealing for use in power production, particularly in the context of carbon neutralization (Tew et al., 2022).

A considerable number of scholars are currently investigating the hybridization of aluminium matrix composites due to their commercial viability, enhanced characteristics, and potential applications in the fabrication of aircraft, automobiles, and marine vessels. Microstructure, capacity, homogeneity, isotropy, particle size, dispersion level, and matrix-particle interface all influence the properties of a composite (Kamaruddin et al., 2024). Acquiring the requisite properties of manufactured AMCs is facilitated by selecting the proper fabrication technique, optimizing its process parameters, and selecting the appropriate form of reinforcement (Kamaruddin et al., 2023). Aerospace, automotive defense, and thermal management in sports and recreation are among the functional and structural high-tech applications in which AMC is utilized (Roslan, Farahin, et al., 2023).

According to Huang (2024), one of the most significant benefits of solid oxide fuel cells (SOFCs) is their fuel adaptability, which enables them to make effective use of a diverse variety of fuels, including low-quality fuels such as coalbed methane. According to the findings of current study (Tew et al., 2022) this adaptability is very necessary in order to make the transition to a carbon-neutral economical system. The capacity of solid oxide fuel cells (SOFCs) to create electricity while emitting a low amount of pollution is another reason why they are considered a clean energy technology (Wang, 2023).

The performance of solid oxide fuel cells (SOFCs) has been the subject of investigation by researchers. (Zhang et al., 2017) As shown in Figure 1, research has been conducted to examine improved materials that can run solid oxide fuel cells (SOFCs) at lower temperatures, hence broadening the potential uses of these devices. Nanotechnology has been utilized to boost the electrochemical performance of solid oxide fuel cells (SOFCs), which is a demonstration of the continuous attempts to improve the efficiency of these devices (Wang, 2023). In addition, the utilization of exsolved nanoparticles has been suggested as a means of enhancing the reduction of oxygen in solid oxide fuel cells (SOFCs), with the objective of further enhancing their efficiency (Zhu et al., 2015).

The use of solid oxide fuel cells (SOFCs) has attracted interest not only for stationary power production but also for uses in transportation. This technology has been shown to be extremely versatile, as seen by the research that has been conducted on the design of SOFC systems for automobiles (Ma et al., 2021). According to Ma et al. (2021), the adaptability and broad possibilities for energy conversion of solid oxide fuel cells (SOFCs) are highlighted by their prospective uses in both stationary and mobile applications.

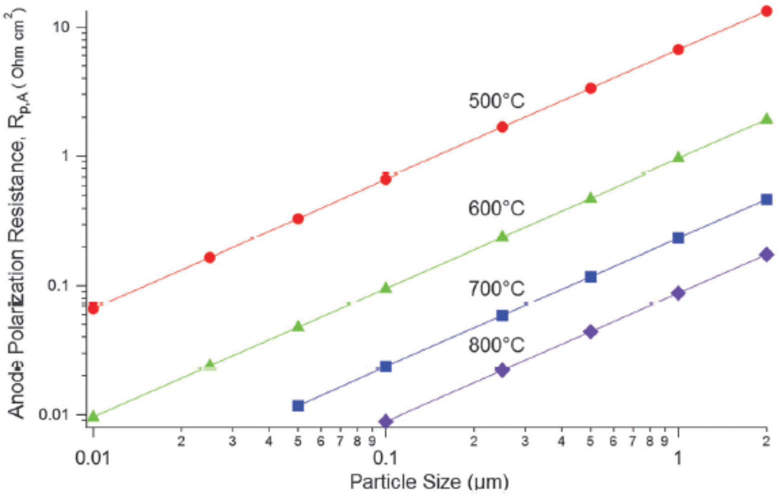

Figure 1. Ni-YSZ anode polarization resistance versus feature size, assuming equal sizes for Ni and YSZ, for temperatures from 500 to 800 °C (Gao et al., 2016)

In conclusion, solid oxide fuel cells provide a compelling alternative for the conversion of energy in a reliable and environmentally friendly manner. The great efficiency, fuel flexibility, and low emissions that they produce make them an important technology for a future that is focused on sustainable energy.

1.2 Advantages of Intermediate-Temperature SOFCs (ITSOFCs)

There are a number of benefits that may be gained from using intermediate-temperature solid oxide fuel cells (ITSOFCs) as opposed to traditional high-temperature SOFCs. Compared to the higher temperatures that are required by conventional solid oxide fuel cells (SOFCs), the working temperature range of these batteries is typically between 500 and 700 degrees Celsius, which is a significant advantage (Ma et al., 2022). 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 (Roslan, Rahman, et al., 2023). This lower working temperature presents various benefits, including increased cell durability, easier handling, assembly, and disassembly, as well as cost reduction, which can considerably boost the practicality and commercial viability of ITSOFCs (Zakaria et al., 2019). Figure 2 demonstrated that these benefits are presented.

Furthermore, it has been demonstrated that ITSOFCs have qualities that are associated with improved performance. It has been established through research that it is possible for ITSOFCs to reach higher power densities in comparison to high-temperature SOFCs. Studies have reported that operating at a lower temperature of 1073 K can result in an increase of up to 10.68% in power density (Kumar et al., 2022). This higher performance can be ascribed to the optimal operating conditions of ITSOFCs, which allow for more efficient energy conversion processes within the cell (Kumar et al., 2022). Information regarding this improvement can be found here.

Additionally, because ITSOFCs operate at a lower temperature, they are able to make use of innovative materials and design configurations that might not be possible at higher temperatures. For example, the creation of highly ion-conducting electrolytes that are based on perovskite oxides has demonstrated that it has the ability to be used in practical low-temperature SOFCs. This exemplifies the potential for innovation and advancement in the field of ITSOFC technology (Chen et al., 2019).

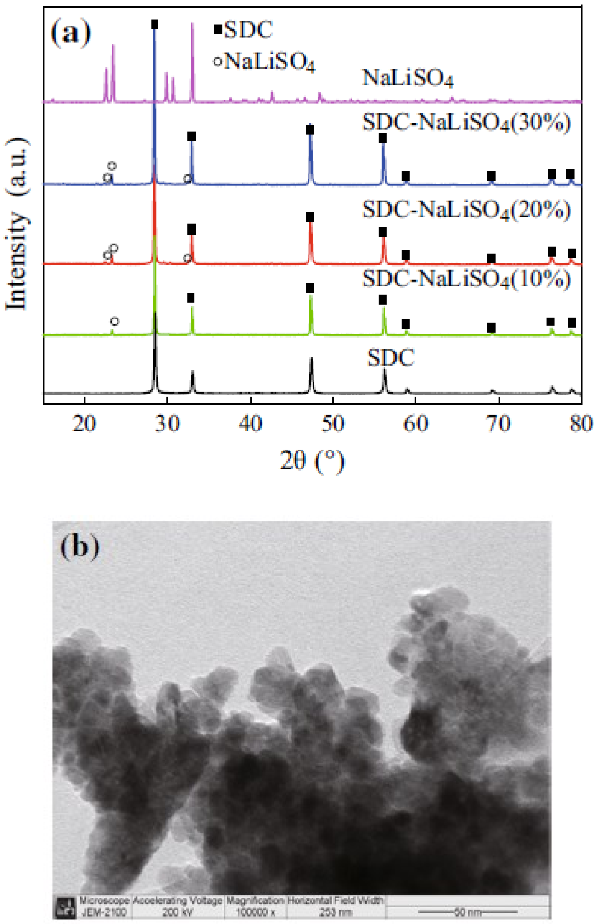

Figure 2. a XRD patterns of pure LiNaSO4, SDC, and SDC–LiNaSO4 (10–30 wt%) wafers sintered at 950 °C for 0.5 h; b TEM image of SDC–LiNaSO4 (20 wt%) powders calcined at 750 °C for 1h (Lv et al., 2015).

Additionally, the operational flexibility of ITSOFCs offers up prospects for a wide range of applications, such as portable power sources and distributed energy systems. These applications are able to achieve a balance between efficiency and practicability thanks to the ability of ITSOFCs to function at intermediate temperatures (Ma et al., 2022). This adaptability in application scenarios highlights the great potential of hybrid solid-state fuel cells (ITSOFCs) to address a variety of energy needs in an economical and environmentally responsible manner.

In conclusion, Intermediate-Temperature Solid Oxide Fuel Cells offer a variety of benefits in comparison to conventional high-temperature SOFCs. These benefits include improved durability, enhanced performance, opportunities for innovation, and operational flexibility. These advantages position them as a promising technology for the conversion of energy in a manner that is both clean and efficient..

1.3 Importance of the electrolyte material in SOFCs

When it comes to Solid Oxide Fuel Cells (SOFCs), the selection of the electrolyte material holds a significant amount of importance in determining the efficiency of the cells. It is crucial for the efficient transport of ions that are required for the electrochemical reactions that take place in SOFCs (Zhang et al., 2022). The selection of the electrolyte material has a direct influence on the ionic conductivity that occurs within the cell. As a result of their strong ionic conductivity at intermediate temperatures, typically around 600 degrees Celsius, proton-conducting oxides have emerged as attractive electrolyte materials for solid oxide fuel cells (SOFCs) (Zhang et al., 2022). The utilization of these materials results in an improvement in both performance and overall efficiency, as they allow the efficient transit of ions inside the cell.

The second generation of solid oxide fuel cells (SOFCs) have been designed to contain advanced oxygen-ion conducting electrolytes, such as samarium-doped ceria (SDC), which enables them to function at temperatures as low as approximately 600 degrees Celsius (Duan et al., 2015). When the operating temperature of solid oxide fuel cells (SOFCs) is lowered by the use of new electrolyte materials, not only is efficiency increased, but also the operational expenses and issues that are associated with high-temperature operation are reduced.

The selection of the electrolyte material has an effect on the stability and durability of solid oxide fuel cells (SOFCs). To ensure the cells' continued efficiency and dependability over the long term, it is essential to make an informed choice regarding the electrolyte material chosen. Research suggests that the development of efficient electrolytes with high ionic conductivity is essential for improving the performance of solid oxide fuel cells (SOFCs), particularly in applications such as CO-fueled SOFCs (Zhang & Hu, 2023).

In addition, the electrolyte material used in SOFCs has an effect on the overall design of the cell as well as the operational properties involved. There has been research conducted on alternative ion-conducting electrolytes with the aim of enhancing the performance of solid oxide fuel cells (SOFCs) at lower working temperatures. This has the potential to give prospects for increased efficiency and versatility in a variety of application situations (Filonova & Medvedev, 2022). (Кутербеков et al., 2022) Extensive research has been undertaken on thin electrolytes that possess sophisticated architectures. The objective of these investigations is to permit lower operating temperatures, hence further enhancing the efficiency of solid oxide fuel cells (SOFCs).

To summarize, the selection of the electrolyte material in solid oxide fuel cells (SOFCs) is of the utmost importance in defining the efficiency, performance, and durability of the cells. Electrolyte materials have seen major advancements, such as proton-conducting oxides and oxygen-ion conducting electrolytes, which have greatly contributed to the enhancement of the efficiency and practicability of solid oxide fuel cell technology at the same time..

1.4 Introduce Gadolinium-doped Ceria (GDC) as a potential electrolyte material for ITSOFCs

Due to the outstanding qualities that it possesses, Gadolinium-doped Ceria (GDC) is a material that has the potential to become an electrolyte for Intermediate-Temperature Solid Oxide Fuel Cells (ITSOFCs). GDC, specifically Ce0.9Gd0.1O1.95, is widely acknowledged for its exceptional oxygen-ion conductivity, which can reach up to 10^-2 S·cm^-1. This exceptional conductivity makes it an outstanding option for the functioning of ITSOFCs at temperatures about 500°C, as stated by Yu (2023). This high ionic conductivity of GDC is critical for supporting effective ion movement within the cell, which ultimately results in an improvement in the overall performance and efficiency of ITSOFCs.

Moreover, GDC displays low electrical conductivity, which is vital for limiting electronic leakage within the cell and preserving the purity of the electrochemical processes (Yu, 2023). According to Wachsman et al. (2014), the utilization of GDC as an electrolyte material in ITSOFCs has the potential to contribute to the reduction of overpotentials within the cell, hence enhancing the overall efficiency of the cell.

In addition, the compatibility of GDC with the thermal expansion coefficients of associated components in SOFCs improves the stability and durability of the cells, which in turn ensures that they carry out their functions for an extended period of time (Zhang, 2024). The integration of GDC into solid oxide fuel cells (SOFCs), such as in a three-layer GDC/Y0.148Zr0.852O1.926/GDC electrolyte system, has been demonstrated to improve the performance of the cells at intermediate temperatures (Zhang et al., 2022).

In addition, GDC has been recognized as a promising innovative anode material for solid oxide fuel cells (SOFCs). It provides enhanced resistance to hydrogen sulfide (H2S) poisoning, which is essential for ensuring that the cells continue to function effectively and for a longer period of time (Herzig et al., 2022). It is a critical electrolyte material for developing the efficiency and practicality of ITSOFC technology because of its unique qualities, which include its strong ionic conductivity, low electronic conductivity, and compatibility with other cell components. These properties place GDC as a key factor in the advancement of the technology.

In conclusion, Gadolinium-doped Ceria (GDC) stands out as a potential electrolyte material for Intermediate-Temperature Solid Oxide Fuel Cells (ITSOFCs). Additionally, it provides superior oxygen-ion conductivity, electronic insulation, compatibility with thermal expansion coefficients, and resistance to poisoning. All of these characteristics are essential for improving the efficiency and performance of ITSOFCs.

2. BACKGROUND

2.1 Working principle of SOFCs, focusing on the role of the electrolyte in conducting oxygen ions

The operation of solid oxide fuel cells, also known as SOFCs, is based on the principle of conversion of fuel into energy through electrochemical reactions. In solid oxide fuel cells (SOFCs), the electrolyte is an essential component that plays a crucial part in the process of conducting oxygen ions. To ease the movement of oxygen ions from the cathode to the anode within the cell, oxygen-ion conducting electrolytes, such as Gadolinium-doped Ceria (GDC), are utilized. (2015), Wang et al. report.

A voltage gradient is supplied to the electrolyte in a solid oxide fuel cell (SOFC), which causes oxygen ions to move through the device. The oxygen molecules that are present in the air are broken down into oxygen ions at the cathode. These oxygen ions then make their way to the anode by way of the electrolyte. The oxygen ions undergo a reaction with the fuel (such as hydrogen or hydrocarbons) at the anode, which results in the production of water and the release of electrons. Based on the findings of Bi et al. (2018), these electrons travel through an external circuit, which results in the generation of electrical power, and then they recombine with the oxygen ions at the cathode.

It is absolutely necessary for the electrolyte material to have a high oxygen-ion conductivity in order to move ions within the SOFC in an effective manner. It makes it possible for oxygen ions to migrate quickly, which in turn lowers the internal resistance of the cell and increases the overall efficiency of the cell. In addition, the electrolyte's capacity to selectively conduct oxygen ions while simultaneously preventing electrical conduction maintains the purity of the electrochemical reactions that take place within the cell, which in turn improves the performance of the cell (Zakaria et al., 2019).

For solid oxide fuel cells (SOFCs), the electrolyte material must be chemically stable, mechanically strong, and compatible with the other components of the cell in order to guarantee its continued functioning over an extended period of time. According to Mei et al.'s 2019 research, so-called solid oxide fuel cells (SOFCs) that are based on oxygen-ion conducting electrolytes can have their performance greatly improved by using nanoparticles to customize the cathode-electrolyte interface.

In conclusion, the electrolyte plays a crucial part in the efficient operation of solid oxide fuel cells because of its involvement in conducting oxygen ions. Oxygen-ion conducting electrolytes, such as GDC, significantly contribute to the facilitation of ion transport, the preservation of cell purity, and the guarantee of the overall performance and lifetime of solid oxide fuel cells (SOFCs)..

2.2 Key properties desired in an ITSOFC electrolyte material, such as high ionic conductivity, chemical and mechanical stability, and compatibility with other cell components

The electrolyte material for an Intermediate-Temperature Solid Oxide Fuel Cell (ITSOFC) should have a high ionic conductivity, chemical and mechanical stability, and compatibility with other cell components. These are the primary features that are desired. It is essential to have a high ionic conductivity in order to have effective ion transport within the cell. This allows for quick oxygen ion migration and reduces internal resistance, which ultimately results in an increase in the overall efficiency of the cell. 2018 research by Asano et al. According to Han et al. (2016), chemical stability is a crucial factor in ensuring the long-term performance of the electrolyte material. It helps to prevent degradation and ensures that functionality is maintained over longer periods of time. According to Lv et al. (2015), mechanical stability is necessary in order to endure thermal and mechanical stresses that occur during operation. This helps to ensure that the cell maintains its structural integrity.

In addition, compatibility with other cell components is essential in order to guarantee the ITSOFC's capability of achieving optimal performance and smooth integration. In order to prevent unfavorable interactions that could impact the efficiency and longevity of the cell, the electrolyte material should demonstrate a high level of compatibility with the electrodes, interlayers, and other components (Li et al., 2022). In addition, thermal stability is necessary in order to successfully survive changes in operating temperature as well as thermal cycling, which guarantees constant performance over the course of time (Lv et al., 2015).

Furthermore, the electrolyte material should have great electrochemical stability in order to keep its integrity and functioning intact under a wide range of working circumstances, which will contribute to the overall reliability of the ITSOFC (Han et al., 2016). In order to achieve efficient and long-lasting energy conversion in practical applications of ITSOFC, it is vital to have the ability to retain high ionic conductivity, chemical and mechanical stability, and compatibility with other components (Li et al., 2022).

To summarize, the optimum material for the electrolyte of an ITSOFC should have a high ionic conductivity, chemical and mechanical stability, compatibility with other cell components, thermal stability, and electrochemical stability. This is necessary to guarantee the fuel cell system's optimal performance, lifetime, and reliability..

2.3 Review the commonly used electrolyte materials for SOFCs, highlighting their limitations, particularly regarding operating temperature limitations

Electrolyte materials play an essential function in Solid Oxide Fuel Cells (SOFCs), and a number of electrolytes that are routinely utilized have distinct limits, particularly with regard to the temperature constraints that are imposed by the operating environment. The solid electrolyte known as yttria-stabilized zirconia (YSZ) is utilized extensively in solid oxide fuel cells (SOFCs) because to its strong ionic conductivity, chemical stability, and mechanical robustness, as stated by Zakaria and Kamarudin (2020). YSZ, on the other hand, is often required to undergo sintering at temperatures over 1550 degrees Celsius during the cell production process, which restricts its use in low-temperature solid oxide fuel cells (Song et al., 2022).

Perovskite materials, like $\mathrm{BaZr0.8Y0.2O3}-\delta$ and $\mathrm{BaZr1}-\mathrm{xCexO3}-\delta$, have garnered attention for application in solid oxide fuel cells (SOFCs). However, due to the presence of low oxygen vacancies, these materials display proton conduction, which hinders their utilization as electrolytes in conventional SOFCs (Irshad et al., 2021). However, their drawbacks may include high sintering temperatures and deleterious phase interactions between the anode and electrolyte (Zhang et al., 2022). Proton-conducting oxides have been proposed as electrolytes for solid oxide fuel cells (SOFCs) due to their strong ionic conductivity at 600 degrees Celsius.

The actual implementation of cobalt-free perovskite cathode materials in solid oxide fuel cell technology is limited due to problems such as low structural stability, excessive thermal expansion coefficients, and inadequate compatibility with the electrolyte (Song et al., 2020). Despite their efficiency, these materials can have limitations that make them less efficient. In an effort to overcome the restrictions that are associated with high-temperature electrolytes, the goal of reducing the operating temperature of solid oxide fuel cells (SOFCs) below 800 degrees Celsius has been to improve the ionic conductivity while simultaneously minimizing the resistance (Zakaria et al., 2019).

In conclusion, although electrolyte materials that are routinely utilized, such as YSZ, have outstanding features, their employment in low-temperature SOFCs is restricted due to the high-temperature processing requirements demanded by these materials. Perovskite materials and proton-conducting oxides have shown promise, but they face issues related to proton conduction and high sintering temperatures. This highlights the need for electrolyte materials with enhanced characteristics in order to expand the scope of applications for solid oxide fuel cells (SOFC).

3. GDC ELECTROLYTE FOR ITSOFCS

3.1 Crystal structure and doping mechanism of GDC

Due to the fact that it has a high oxygen-ion conductivity, gadolinium-doped ceria, often known as GDC, is a substance that is frequently utilized as an electrolyte in Intermediate-Temperature Solid Oxide Fuel Cells (ITSOFCs). According to Chen et al.'s 2019 research, the crystal structure of GDC is commonly classified as cubic fluorite. This is because gadolinium ions are doped into the ceria lattice, which results in the creation of oxygen vacancies that promote oxygen-ion conduction. The process of doping involves the substitution of cerium ions with gadolinium ions, which results in the production of oxygen vacancies. These oxygen vacancies act as channels for the movement of oxygen ions throughout the material (Kaur et al., 2022).

The nanocrystalline structure of GDC has been demonstrated to display surface or grain boundary conduction mechanisms, which contribute to an extraordinarily high ionic conductivity of 0.37 S·cm^−1 at a temperature of 550°C (Chen et al., 2019). The efficiency of oxygen-ion transport inside the electrolyte is improved as a result of this one-of-a-kind structure, which in turn leads to an improvement in the overall performance of ITSOFCs.

An investigation of the sintering process and the microstructure of GDC electrolytes has also been carried out in order to optimize the crystal structure and surface morphology of these electrolytes, as demonstrated in Figure 3. The crystal structure and surface features of GDC barrier layers can be modified to improve their performance in IT-Solid Oxide Cells (Coppola et al., 2018). This is accomplished by adjusting the temperature ramp that occurs during the post-growth annealing process.

The incorporation of transition metals into GDC has also been investigated as a potential method for modifying the sintering and electrochemical properties of the material. Doping with transition metals, such as cobalt, copper, iron, manganese, or zinc, can have an effect on the crystal structure and conductivity of graphene dioxide (GDC), which presents chances to improve its functioning as an electrolyte material in solid oxide fuel cells (SOFCs) (Rehman et al., 2020).

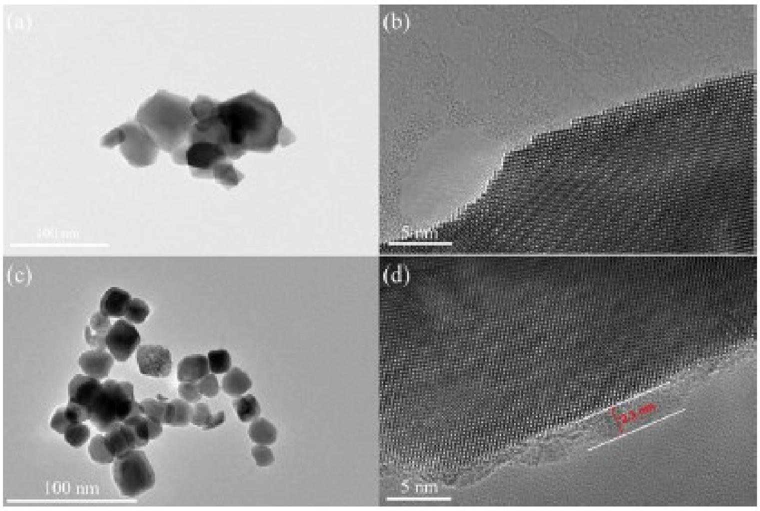

Figure 3. TEM images of the GDC powder in cell with nanocrystalline GDC electrolyte before and after the performance test: (a,b) HRTEM images of GDC raw powders, (c,d) TEM images of the GDC powder scraped and ground from the GDC electrolyte in cell with nanocrystalline GDC electrolyte after the performance test (Chen et al., 2019).

In a nutshell, the crystal structure of GDC in ITSOFC electrolytes is generally cubic fluorite. Gadolinium doping makes it possible for oxygen-ion conduction to occur by triggering the formation of oxygen vacancies. In the context of solid oxide fuel cell (SOFC) applications, the nanocrystalline structure of graphene dioxide (GDC) and the possibility of transition metal doping present opportunities for enhanced performance and conductivity..

3.2 Effect of gadolinium doping on the ionic conductivity of ceria and its suitability for ITSOFC operating temperatures

The ionic conductivity of ceria is considerably improved through gadolinium modification, rendering it a viable substance to be used as an electrolyte in Intermediate-Temperature Solid Oxide Fuel Cells (ITSOFCs). Oxygen vacancies are created within ceria through the incorporation of gadolinium; these vacancies serve as oxygen-ion transport pathways within the material, consequently enhancing its ionic conductivity (Kaur et al., 2022). Research has indicated that gadolinium-doped ceria (GDC) possesses a notable ionic conductivity ranging from 0.005 to 0.02 S·cm^-1 at intermediate temperatures. This characteristic establishes GDC as a potentially effective electrolyte material for ITSOFCs (Kulkarni et al., 2015).

The conductivity of the material, generation of oxygen vacancies, and particle size are all influenced by the doping mechanism of gadolinium in ceria (Kaur et al., 2022). ITSOFCs have identified GDC as a prospective material for the electrolyte and electrode components on account of its exceptional ionic conductivity across a temperature range of 300-700°C (Poozhikunnath et al., 2016). It has been documented that the inclusion of gadolinium in ceria solid solutions substantially improves the material's ionic characteristics, thereby serving as a viable dopant to enhance the conductivity of ceria-based electrolytes (Accardo et al., 2016).

In addition, research has indicated that GDC demonstrates exceptional ionic conductivity at temperatures below 700°C, rendering it a desirable option for ITSOFC applications (Arabac, 2019). Due to the presence of gadolinium dopants, GDC possesses a high ionic conductivity, which facilitates the transport of oxygen ions efficiently within the electrolyte. This property enhances the overall performance and efficacy of ITSOFCs (Zhang, 2024).

In summary, the introduction of gadolinium doping into ceria results in an increase in its ionic conductivity, rendering GDC a viable electrolyte substance for ITSOFCs that function at intermediate temperatures. Oxygen-ion transport is enhanced in ceria-based electrolytes by the presence of gadolinium; thus, solid oxide fuel cells' overall performance and functionality are improved.

3.3 Compare the ionic conductivity of GDC with other potential ITSOFC electrolyte materials

Gadolinium-doped Ceria (GDC) exhibits a notable degree of ionic conductivity, with values spanning from 0.034 to 0.37 S·cm^−1 across a temperature range of 500 to 550°C. As stated by Chen et al. (2019). Due to its elevated ionic conductivity at intermediate temperatures, GDC is deemed an appropriate substance to serve as the electrolyte in Intermediate-Temperature Solid Oxide Fuel Cells (ITSOFCs).

On the contrary, alternative potential electrolyte materials such as Ce0.8Sm0.2O2-ծ–SrTiO3 demonstrate notable enhancements in ionic conductivities (0.05–0.14 S·cm^−1) at temperatures ranging from 450 to 550°C when compared to unmodified Samarium-doped ceria (SDC) (Cai et al., 2021). Moreover, research has demonstrated that the utilization of lithium compounds as anodes can substantially enhance the ionic conductivity of GDC electrolytes; at 550°C, values have risen to 0.045 S·cm^−1. Doping mechanisms and composite structures may be utilized to further improve the ionic conductivity of GDC and other electrolyte materials utilized in ITSOFCs, according to these results.

In general, the high ionic conductivity of GDC at intermediate temperatures distinguishes it as a highly promising material for ITSOFC electrolytes. Further investigations into doping mechanisms and composite structures have the potential to enhance the ionic conductivity of diverse electrolyte materials, thereby broadening the range of viable alternatives for ITSOFC technology that is both efficient and dependable.

3.4 Recent research findings on GDC electrolyte performance in ITSOFCs, including power density, efficiency, and stability

Hong et al. (2019) conducted recent research with the objective of improving the efficiency of Gadolinia-Doped Ceria (GDC) electrolytes utilized in Intermediate-Temperature Solid Oxide Fuel Cells. The research examined the effects of grain control on GDC functional layers in order to optimize interface reactions and increase the productivity of SOFCs operating at low temperatures. The study underscored the significance of surface grain boundary density (SGBDE) in thin-film electrolytes, placing particular emphasis on its correlation with the rate of surface oxygen incorporation. This correlation is of utmost importance in order to optimize the functionality of GDC electrolytes in ITSOFCs.

Furthermore, Nandasiri and Thevuthasan (2015) investigated cutting-edge thin-film electrolytes, such as GDC/YSZ bi-layer electrolytes, for Solid Oxide Fuel Cells (SOFCs). As shown in Figure 4, this research has contributed to the comprehension of the enhanced performance of SOFCs and the prospective advantages of combining GDC and YSZ for fuel cell applications to achieve greater stability and efficiency.

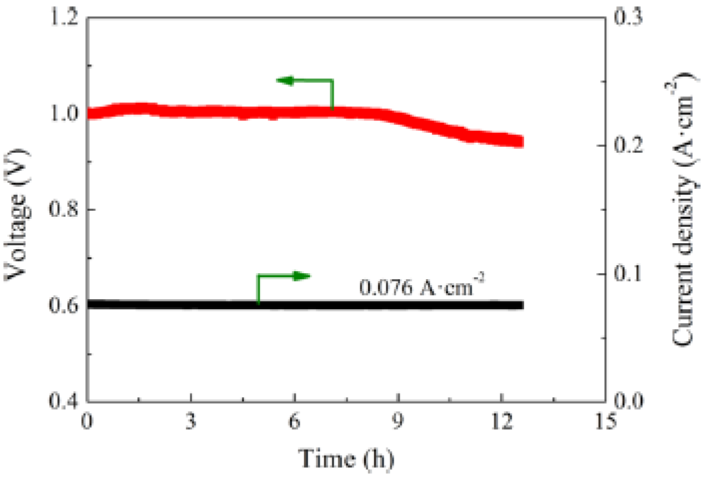

Figure 4. Short-term stability test performed at 550 °C for the cell with the nanocrystalline structure GDC electrolyte (Chen et al., 2019).

In brief, recent research has underscored the importance of optimizing GDC electrolytes in ITSOFCs in order to attain increased power density, stability, and efficiency. Through the examination of particle control and surface properties of GDC electrolytes, scholars endeavor to optimize the operational capabilities of ITSOFCs and propel the progression of dependable and effective solid oxide fuel cell technology.

4. CONCLUSION

At temperatures between 300 and 700°C, Gadolinia-Doped Ceria (GDC) is regarded as a promising electrolyte material for Intermediate-Temperature Solid Oxide Fuel Cells (ITSOFCs) owing to its high ionic conductivity. (2016). Poozhikunnath et al. Compatible with other cell components and possessing favorable chemical stability, GDC is a viable candidate for ITSOFC applications (Akbar et al., 2022). Nevertheless, mixed ionic and electronic conduction (MIEC), which results in increased electronic conductivity and decreased theoretical voltage, particularly when exposed to reducing atmospheres, is a drawback of GDC (Yang & Choi, 2014). This may have an effect on the fuel cell's overall efficacy and efficiency.

Previous studies have demonstrated that increasing ionic conductivity by decreasing the thickness of the electrolyte in order to minimize ohmic resistance is possible; however, resistance does not continue to decrease beyond a certain threshold thickness (Rafique et al., 2015). Moreover, GDC could potentially experience thermodynamic instability, whereby Ce4+ is converted to Ce3+ in reducing atmospheres, thereby compromising its functionality in SOFCs (Liu et al., 2023). In addition, it has been documented that, under specific circumstances, GDC electrolytes demonstrate a reduced ionic conductivity in comparison to materials such as Yttria-Stabilized Zirconia (YSZ) (Matsui et al., 2019).

In summary, although GDC exhibits commendable stability and high ionic conductivity, it is imperative to confront its inherent drawbacks, including thermodynamic instability, MIEC behavior, and comparatively lower conductivity in relation to alternative materials, in order to achieve peak performance in ITSOFCs. Additional investigation and progress are imperative in order to surmount these constraints and completely exploit the capabilities of GDC as a viable electrolyte material for ITSOFC applications.

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