International Research Journal of Innovations in Engineering and Technology (IRJIET)

ISSN (online): 2581-3048

Volume 9, Issue 1, pp 170-174, January-2025

https://doi.org/10.47001/IRJIET/2025.901021

Preparation of Electrolyte Based on YSZ Material at the Green Boundary of NiO-YSZ

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Abstract **- The development of alternative energy technologies, particularly based on fuel cells, has become a primary focus in material research for energy applications. Solid Oxide Fuel Cells (SOFCs) are promising due to their high efficiency, fuel flexibility, and relatively low environmental impact. In SOFC systems, the electrolyte plays a key role in the oxygen ion conduction from the cathode to the anode. Yttria-Stabilized Zirconia (YSZ) is a widely researched electrolyte material due to its superior ionic conductivity at high temperatures, chemical stability, and thermal compatibility with other materials in SOFCs. However, optimizing the performance of YSZ-based electrolytes at intermediate-to-low operating temperatures remains a challenge. This research explores a new approach for fabricating YSZ electrolytes with an emphasis on optimizing the green boundary between NiO-YSZ composites, which significantly affects ionic conductivity and electrochemical performance. A spin coating method was employed to create YSZ layers with controlled thickness and homogeneity. The addition of polyethylene glycol (PEG) as a binder enhanced slurry viscosity and layer uniformity. Scanning Electron Microscopy (SEM) analysis revealed dense, crack-free, and uniform YSZ layers with submicron crystalline grains, contributing to improved ionic conductivity and mechanical stability. The findings suggest that optimizing green boundary structures can enhance the overall performance of SOFCs, particularly in medium-temperature applications, making significant contributions to more efficient fuel cell technology development.**

Keywords: Spin Coating, Electrolyte, SOFC, Yttria Stabilized Zirconia, SEM.

I. INTRODUCTION

In the field of materials research within the energy sector, the advancement of fuel-cell-based alternative energy technologies has become a key area of focus. Among the various fuel cell types, Solid Oxide Fuel Cells (SOFC) are a particularly promising option, primarily because of their high efficiency, ability to use diverse fuels, and minimal environmental impact[1]. Electrolytes play a vital role in SOFC systems by enabling the movement of oxygen ions from the cathode to the anode. Yttria-Stabilized Zirconia (YSZ) has gained significant attention as an electrolyte material because of its exceptional ionic conductivity at high temperatures, stability in chemical reactions, and thermal compatibility with other SOFC components[2]. Nevertheless, enhancing SOFC performance faces obstacles in the production and analysis of YSZ-based electrolyte materials that demonstrate high efficiency and effectiveness at moderate-to-low operating temperatures[3].

The incorporation of yttria (Y_2O_3) into zirconia (ZrO_2) results in yttria-stabilized zirconia (YSZ) that maintains a stable cubic crystal structure. YSZ's ionic conductivity of YSZ is enhanced by the creation of oxygen vacancies owing to yttria ion addition, making it the material of choice for electrolytes[4]. However, the performance and properties of YSZ electrolytes are significantly influenced by their interactions with electrode materials, particularly NiO-YSZ, which is frequently used as an anode in solid oxide fuel cell (SOFC) systems. The ionic conductivity and stability of the electrolyte are largely determined by the manufacturing and processing methods employed at the microstructural level, including the control of the green boundaries or grain interfaces during presintering[5]. Consequently, this study focuses on a novel approach to YSZ-based electrolyte production, specifically examining how the green boundary between NiO and YSZ affects electrolyte performance.

During SOFC development, the green boundary denotes the microstructural arrangement that forms during the early stages before complete sintering occurs. The properties of green boundaries play a vital role in determining the density, mechanical robustness, and ionic conductivity of electrolyte materials[6]. For composite materials such as NiO-YSZ, the interplay between the anode component (NiO) and the electrolyte component (YSZ) greatly affects the movement of ions and electrons. This research seeks to investigate YSZ-based electrolyte manufacturing methods capable of enhancing the green boundary in NiO-YSZ composites, thus yielding improved electrolyte performance[7]. Using an

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appropriate strategy, the green boundary can be engineered to reduce the ionic resistance and enhance the oxygen ion transfer efficiency, ultimately boosting the overall SOFC performance.

Exploring the effects of green boundaries on YSZ-based electrolyte properties at the nanoscale level could lead to broader technological advancements. This study focuses on creating YSZ electrolytes using spin-coating techniques. These findings are expected to play a crucial role in enhancing SOFC efficiency, especially at mid-range operating temperatures.

II. MATERIALS AND RESEARCH METHODS

This study employed various materials, including Yttria-Stabilized Zirconia (YSZ) powder, a coating substance with a 25 mm green edge, polyethylene glycol (PEG), and a liquid for spin coating. The electrolyte was produced using YSZ and PEG, both of which were selected for their high purity levels to ensure reliable research results. These ingredients were carefully selected to fulfill the standards of the experimental protocol.

2.1 Mixing Slurry Yttria Stabilized Zirconia

The YSZ solution was prepared by combining YSZ powder with polyethylene glycol (PEG), which served as a binder to ensure mixture consistency. This procedure involved weighing 15 g of YSZ powder and adding 12 ml of PEG to achieve the desired viscosity[8]. The resulting blend was then subjected to ultrasonic agitation for 2 h to promote the particle distribution[9]. Ultrasonic cleaning is essential for breaking down YSZ particle clusters and improving solution uniformity, thus yielding a material with consistent characteristics suitable for subsequent electrolyte production phases. This approach also ensures proper dispersion of YSZ particles within the medium, thereby improving the microstructural quality of the final product[10].

Figure 1: Slurry Mixing with Ultrasonic Cleaner

2.2 Spin Coating Slurry YSZ pada Substrat Green Boundary

A spin coating was employed to apply a Yttria-Stabilized Zirconia (YSZ) slurry solution onto the substrates. The process involved the use of a spin coater device, which was initially operated at 800 rpm. To ensure even distribution, the substrate was first rotated at a low speed and then accelerated to 3000 rpm, resulting in the creation of a uniform thin film[11]. This step was repeated three times to achieve the target layer thickness. Subsequently, the coated substrate underwent drying and heat treatment phases to improve the durability and overall quality of the layer[12].

Figure 2: Spin Coating Tool

III. RESULT AND DISCUSSIONS

The spin-coating technique has proven effective in creating dense crack-free YSZ layers, which are essential for electrolyte use in solid oxide fuel cells (SOFCs) and IT-SOFCs. The use of PEG as an organic binder in the preparation of coating slurries offers significant benefits, such as the ability to control the solution viscosity, resulting in more uniform layers that adhere easily to substrates[13]. Moreover, PEG helps maintain the structural integrity of the layer during the drying and heat treatment processes, while also influencing the final layer morphology.

Spin coating is a technique that provides excellent management of the coating layer thickness and consistency by adjusting factors such as rotation speed and solution density[14]. This flexibility renders it a crucial method for generating layers with precisely controlled thicknesses, which is vital for applications that require specific film dimensions[15]. The effective use of spin coating to produce uniform YSZ layers with exact thicknesses demonstrates its ability to meet the requirements of technical applications that require thin electrolyte films with particular characteristics.

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Figure 3: Yttria-Stabilized Zirconia Electrolyte

The lack of cracks demonstrates that the coating method effectively addresses the common challenges associated with thin films, such as extreme temperature changes or mechanical strain[16]. This unbroken layer serves as a sturdy base for electrochemical and filtration applications, guaranteeing a consistent performance throughout its lifespan.

The produced YSZ coating layer exhibited a thickness range of 0.2-0.8 mm, which is consistent with the suggested specifications for electrolyte and membrane filtration applications[17]. This range of thicknesses maximizes ionic conductivity and mechanical strength. Deviations outside these limits can substantially impact the effectiveness of the coating layers that are too thin may jeopardize the structural stability and conductivity, whereas excessively thick coatings could result in problems related to porosity and flexibility[18]. Consequently, it is essential to maintain the coating thickness within this defined range to ensure ideal performance of the YSZ layer in applications requiring high durability and conductivity.

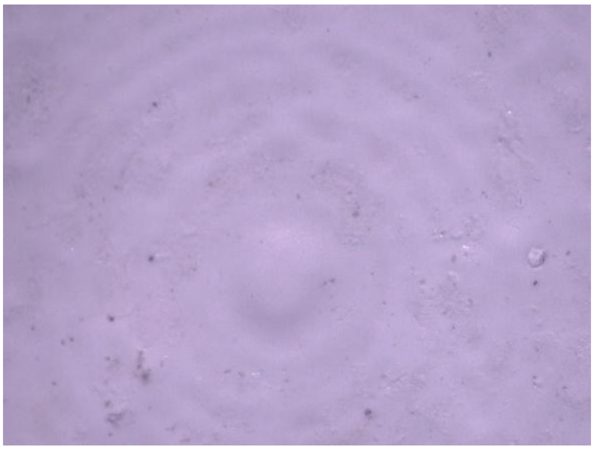

Figure 4: Yttria Stabilized Zirconia Layer Surface

The surface morphology of the YSZ layer, produced via spin coating methods, was thoroughly analyzed using a scanning electron microscope (SEM) image at 20,000 × magnification, featuring a 1 µm scale bar. The micrograph reveals a tightly packed grain structure throughout the YSZ layer with a fairly uniform distribution across the entire surface[19]. The observed grain sizes were in the submicron range, indicating the formation of a nanocrystalline layer, which is essential for high-performance electrolyte materials. This nanocrystalline structure suggests an effective control during the synthesis process, resulting in a surface with excellent structural quality, making it ideal for electrochemical applications[20].

The formation of the electrolyte layer is characterized by high density and low surface porosity. These features suggest strong mechanical durability and the ability to effectively conduct oxygen ions, which are essential for fuel-cell applications. The absence of significant cracks or gaps between the grains indicates superior coating quality[21]. This lack of structural defects is vital, as surface cracks or voids can potentially cause gas leakage, thereby reducing the effectiveness of electrochemical processes, particularly in solid oxide fuel cell (SOFC) systems[22].

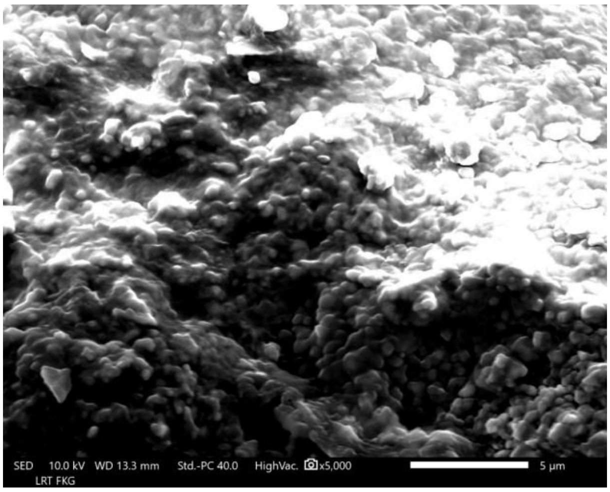

Figure 5: Morphology of Yttria Stabilized Zirconia Electrolyte

IV. CONCLUSION

The results highlight the efficacy of spin coating in creating Yttria-Stabilized Zirconia (YSZ)-based electrolytes for solid oxide fuel cell (SOFC) applications. This technique

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yields dense, uniform, crack-free electrolyte layers, which are essential for optimal SOFC functionality. Incorporating polyethylene glycol (PEG) as a binding agent in YSZ slurry preparation enhances viscosity control, leading to improved layer uniformity and structural integrity during the drying and heat treatment processes. Moreover, spin coating enables precise regulation of the layer thickness, which is a critical factor in achieving the required ionic conductivity and mechanical strength for applications demanding specific layer dimensions.

The synthesized YSZ layer displays a nanocrystalline composition with evenly distributed particles, enhancing both ionic conductivity and structural durability. Optimal performance in terms of ion transport and long-term durability was achieved with layer thicknesses between 0.2 and 0.8 mm. This study advances the development of more efficient SOFCs, particularly for low to intermediate operating temperatures, by fine-tuning the green boundary in NiO-YSZ composites to enhance electrolyte functionality and oxygen ion transfer efficiency.

ACKNOWLEDGMENTS

The author would like to express sincere gratitude to Universitas Diponegoro, especially to the Department of Mechanical Engineering and the Faculty of Engineering, for the support and facilities provided throughout the course of this research. The author also would like to thank his family and loved ones who always support him in writing this scientific journal so that the manuscript can be completed on time.

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Citation of this Article:

Muhammad Faesal Febriandyono, Sulistyo, Mohammad Tauviqirrahman, Rayhan Calista, Tatagraha Rahmanda, & Fachrizal Radya Mahendra. (2025). Preparation of Electrolyte Based on YSZ Material at the Green Boundary of NiO-YSZ. *International Research Journal of Innovations in Engineering and Technology - IRJIET*, 9(1), 170-174. Article DOI https://doi.org/10.47001/IRJIET/2025.901021

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