

**RESEARCH ARTICLE**

## Enhanced Anodes for Pollution-Free Intermediate Temperature Solid Oxide Fuel Cells

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### ABSTRACT:

Fuel cells have emerged as a promising technology in the modern era for the efficient conversion of chemical energy into electrical energy, offering high performance and scalability for sustainable power generation. Among various types, solid oxide fuel cells (SOFCs) stand out as one of the most promising candidates for green energy applications due to their all-ceramic composition and high operating temperatures in the range of 500–1000°C. In this study, copper-based cermet (Cu–CGO) was investigated as a potential anode material for SOFCs. To enhance the electrical conductivity, copper (Cu) was introduced as a dopant. Conventional synthesis methods for Cu–CGO anode materials often present certain limitations; however, the urea-combustion method was found to offer several advantages over the glycine-combustion approach. The X-ray diffraction analysis of the synthesized samples confirmed that the experimental diffraction peaks closely matched the standard JCPDS data corresponding to the  $Cu_x [Ce_{0.9}Gd_{0.1}]_{1-x}O_{2-\delta}$  phase. All observed reflections were indexed to a tetragonal unit cell, indicating the formation of a homogeneous single-phase compound. The absence of additional peaks suggested that no intermediate phases were formed, confirming the phase purity of the synthesized material. Furthermore, the electrical conductivity of  $Cu_x [Ce_{0.9}Gd_{0.1}]_{1-x}O_{2-\delta}$  increased with higher copper content, which correlated with a decrease in activation energy. However, the hardness of the anode material decreased slightly with increasing Cu concentration, attributed to the rise in porosity within the crystal structure. Overall, these findings demonstrate that Cu-doped CGO synthesized via the urea-combustion route exhibits favorable structural and electrical properties suitable for use as an efficient SOFC anode material.

**KEYWORDS:** Fuel Cell, SOFC, Anode, Cermet, Urea-Combustion Method.

### INTRODUCTION:

The fuel cell is a one of the electrochemical appliances that directly converts the chemical energy by governing a reaction between the suitable fuel and a reformed oxidant into an electrical energy. The fuel cell provides a clean pollution free (green) technology to produce electricity electrochemically at desirable efficiencies.

The necessary elements of a classical fuel cell consist of an electrolyte having porous anode (negative charge) and a porous cathode (positive charge)<sup>1-5</sup>. The fuel necessary for the initiation of the reaction and oxidant gases flow along the sides of the whole surface of the anode and cathode respectively and then they react electrochemically in the three-phase periphery region formed at the gas-electrolyte-electrode boundary. A fuel cell can theoretically produce electrical energy for as long as the fuel and sufficient oxidant are feed to the porous electrodes. But in some cases, the degradation or malfunction of some of its components confines the practical life span of entire fuel cell. A variety of fuels have been used in fuel cell such as hydrogen, ethanol, methanol, gaseous fossil fuels like natural gases. The solid or liquid fossil fuels used in need to be gasified

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first prior to they can be used as fuel. The oxygen or air can be used as an oxidant during the reaction. SOFCs are superior to other fuel cells because they have higher efficiency, can use various fuels (like hydrogen, natural gas, or biofuels), don't need expensive catalysts such as platinum, and offer long-term stability due to their solid ceramic structure. They also operate at high temperatures, allowing waste heat recovery for combined heat and power (CHP) applications.

Fuel cell electrochemically combines the molecules of the fuel and oxidizer avoiding the burning and pollution of additional combustion so its acts as a green energy production technology<sup>6</sup>. Solid oxide fuel cells (SOFCs) are considered environmentally friendly because they convert chemical energy directly into electrical energy with very high efficiency, which minimizes fuel consumption and reduces greenhouse gas emissions. Unlike conventional combustion-based power generation, SOFCs produce mainly water and a small amount of carbon dioxide when hydrocarbon fuels are used, resulting in significantly lower air pollution. They can also operate on renewable fuels such as hydrogen or biofuels, further supporting sustainable energy systems. Additionally, SOFCs have no moving parts, making them quiet and reliable while reducing mechanical losses. When integrated with renewable hydrogen production, they offer a pathway toward carbon-neutral electricity generation, making them an excellent option for clean and sustainable energy applications. The solid oxide fuel cells (SOFC) composed of thin layer of zirconium oxide ( $ZrO_2$ ) as a ceramic electrolyte, lanthanum magnate ( $LaMnO_3$ ) cathode and a nickel-zirconium anode<sup>7-11</sup>. The conducting ion of the solid oxide fuel cell (SOFC) is made up of  $O^{2-}$  ions and nickel or some perovskites have been used as conduction ion and electro catalyst respectively. The reformed hydrogen ( $H_2$ ) and carbon monoxide (CO) as well as methane ( $CH_4$ ) have been used as fuels. The solid oxide fuel cells (SOFCs) have a power density of the order of 240 mW/cm<sup>3</sup>. These characteristics will expertise the solid oxide fuel cells (SOFCs) useful in towering pollution free power applications like industrial power supplies and electrical generators<sup>12-17</sup>, as it can attain an efficiency of 45%. The solid oxide fuel cells (SOFCs) would not be well appropriate for the vehicles and other smaller uses because they necessitate an operating temperature of at least 800°C. The component layers of SOFCs have been found to be some short of expensive for fabrication and require different electrolytes for the lower temperature operation requirements. The intermediate temperature (IT) solid oxide fuel cell (SOFC) have many advantages over the usual energy conversion system including high efficiency, reliability, modularity, fuel adaptability, and very low levels of  $NO_x$

and  $SO_x$  gases emission. Besides these because of their comparable high temperature of operation, natural gases can be improved within the cell stack and there is no need of extra efforts. Several solid oxide fuel cell (SOFC) designs have been developed in these recent years to carry out the fuel cell and reformers into the stacks and eventually the whole fuel cell system<sup>18-21</sup>.

## MATERIALS AND METHODS:

### Materials:

In our study, Cu-CGO based anode materials were prepared by the combustion route. The initial ingredients such as  $Cu(NO_3)_3 \cdot 3H_2O$ ,  $Ce(NO_3)_3 \cdot 6H_2O$  and  $Gd(NO_3)_3 \cdot 6H_2O$  were procured from Sigma Aldrich.

### METHODS:

The stoichiometric proportions of the corresponding metal nitrates were weighed and then it dissolved in 100 ml deionized (distilled) water for different proportions 40/60, 50/50 and 60/40 of Cu-CGO. Appropriate amount of fuel (urea) was added into the solution while stirring, so as to achieve homogeneity in the solution. The aqueous redox solution prepared by metal nitrates and urea as a fuel element was later on put in a muffle furnace, which is preheated at 400°C. The solution boils, ignites and catches fire as soon as temperature of mixture reaches to 400°C. Concurrently, the metal nitrates decomposed to metal oxides, and oxides of nitrogen that acts as oxidizer for auxiliary combustion process to complete. The residual solid product, after the fire extinguished, was obtained within 5 minutes. A white residue powder collected was crushed in the agate mortar and calcined at 850 °C for continue 3 hrs in the furnace. The calcined powder was then pelletized with the help of Specac Hydraulic Press at a pressure of 4 tons /cm<sup>2</sup> (9mm) and sintered at 1000°C for 1 hour<sup>22</sup>.

In recent years there is a high demand of engineering materials and its applications are also increased. The knowledge of a structure of a materials and its correlation with properties are advancing. In this point of view the samples prepared during the present study was characterized using X-ray powder diffraction, four probes D.C. conductivity.

## RESULTS AND DISCUSSION:

### X-ray powder diffraction:

The X-ray powder diffraction patterns of  $Cu_x [Ce_{0.9}Gd_{0.1}]_{1-x}O_{2-\delta}$  prepared by combustion method using urea as a fuel for  $x=0.4, 0.5, 0.6$  (from bottom to top), where  $x$  is the composition of copper are shown in figure1. The very sharp characteristic potential diffracted lines in the XRD pattern indicate good crystallinity<sup>23</sup>.

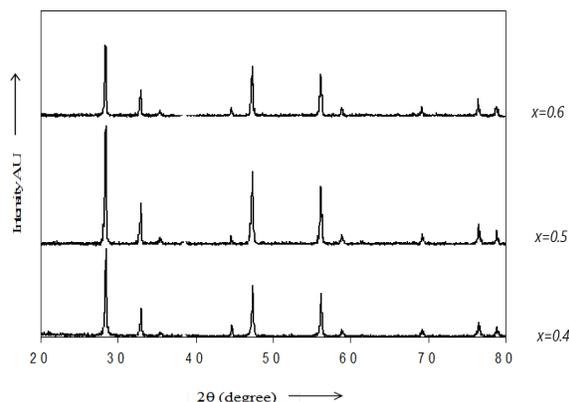


Figure 1. XRD of  $\text{Cu}_x [\text{Ce}_{0.9}\text{Gd}_{0.1}]_{1-x}\text{O}_{2-\delta}$  prepared by urea combustion for  $x = 0.4, 0.5$  and  $0.6$  resp. matched with JCPDS file no. 00-047-0431

#### Four Probe DC Conductivity:

The Arrhenius plot for  $\text{Cu}_x [\text{Ce}_{0.9}\text{Gd}_{0.1}]_{1-x}\text{O}_{2-\delta}$  for  $x = 0.4, 0.5$  and  $0.6$ , where  $x$  is the composition of copper are depicted in the figure 2. Further the conductivity of samples  $\text{Cu}_x [\text{Ce}_{0.9}\text{Gd}_{0.1}]_{1-x}\text{O}_{2-\delta}$  reveals that it increases with increasing the percentage of copper which is in close conformity with the reported records in the literatures<sup>24</sup>. The activation energy of the prepared sample  $\text{Cu}_x [\text{Ce}_{0.9}\text{Gd}_{0.1}]_{1-x}\text{O}_{2-\delta}$  decreases with increase in the percentage of copper.

Therefore, the bulk conductivity for all samples under study obeys the Arrhenius law, as shown in the following figure 2.

$$\text{Log}(\sigma T) = \text{Log}[(\sigma T_0)e^{-E_a/kT}]$$

Where, 'Ea' and 'k' are activation energy and Boltzmann constant respectively. 'T' is the temperature in Kelvin

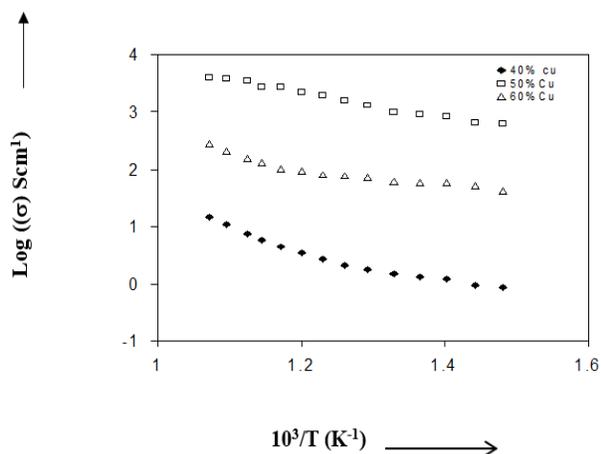


Figure 2. DC conductivity measurements for  $\text{Cu}_x [\text{Ce}_{0.9}\text{Gd}_{0.1}]_{1-x}\text{O}_{2-\delta}$  prepared by urea combustion for  $x = 0.4, 0.5$  and  $0.6$  resp.

#### Density and Porosity Measurements:

AS shown in table 1, practically the radius of the pellet was determined using micrometer screw gauge with the accuracy of 0.01mm in different directions and average of all is considered to obtain surface area. Similarly, the thickness of pellet was also determined. The volume of pellet was obtained using formula<sup>25</sup>:

$\pi R^2 t$ . Finally, the sintered density of the sample was determined using the formula given below:

$$\text{Density} = \text{Weight/Volume (gm/cm}^3\text{)}$$

The porosity of the sample was estimated by comparing sintered density with theoretical density using equation as mentioned below<sup>26</sup>:

$$\% \text{ Porosity} = \left\{ \frac{\text{Theoretical density} - \text{Sintered density}}{\text{Theoretical density}} \right\} \times 100$$

Table: 1. Values of Sintered density, % Porosity and Activation energy for different composition of copper (x)

Composition of copper	Density (gm/cm <sup>3</sup> )	Porosity %	Ea (eV)
x= 0.4	4.61041	43.081	0.5799
x= 0.5	4.11387	49.211	0.4339
x= 0.6	3.95406	51.844	0.3445

#### CONCLUSION:

The combustion synthesis route proved to be a simple, cost-effective, and highly efficient method for preparing  $\text{Cu}_x (\text{Ce}_{0.9}\text{Gd}_{0.1})_{1-x}\text{O}_{2-\delta}$  samples with varying copper compositions. This method offers a significant advantage over conventional ceramic techniques by producing fine, homogeneous powders suitable for intermediate-temperature solid oxide fuel cell (IT-SOFC) anodes. The electrical conductivity of the synthesized materials was found to increase with higher copper content, primarily due to the reduction in activation energy. Conversely, the hardness and density of the samples decreased with increasing copper concentration, which can be attributed to enhanced porosity within the crystal structure. Overall, the  $\text{Cu}_x (\text{Ce}_{0.9}\text{Gd}_{0.1})_{1-x}\text{O}_{2-\delta}$  anode materials synthesized via the combustion route exhibit several desirable characteristics, including adequate porosity, improved p-type electronic conductivity, and compatibility with intermediate operating temperatures. These features make them promising candidates for efficient and durable SOFC anodes, contributing to the advancement of clean and sustainable energy technologies.

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