



# Compositional optimization of gadolinia-doped ceria treatment for enhanced oxygen reduction kinetics in low-temperature solid oxide fuel cells

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## ABSTRACT

We report the optimization of the dopant concentration of gadolinia-doped ceria (GDC) to enhance the oxygen reduction reaction (ORR) kinetics for low-temperature solid oxide fuel cells (LTSOFCs). Crystalline GDC layers with uniform nano-granular structures were prepared by aerosol-assisted chemical vapor deposition (AACVD) on the cathode side of a GDC electrolyte. The current-voltage (*I*–*V*) characteristics and power performances of the AACVD GDC-treated cells were measured and their cathodic reactions were analyzed by electrochemical impedance spectroscopy (EIS) to investigate the effect of GDC treatments with various dopant compositions. The cell treated with Gd<sub>0.14</sub>Ce<sub>0.86</sub>O<sub>2-δ</sub> was found to show an optimized power performance with the best ORR kinetics, due to its nano-granular structure and high concentration of oxygen vacancies.

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## 1. Introduction

Solid oxide fuel cells (SOFCs) are a type of fuel cell made of ceramic components that operate at high temperatures of over 800 °C [1–3]. SOFCs are regarded as promising power-generation devices because they have high conversion efficiencies, allow usage of various types of fuels, and produce high-quality waste heat [4–7]. However, their high operating temperatures can cause critical thermal degradation of cell components, so much research has been done to try to achieve a cell with the high performance that can operate at a lower temperature [8–11]. In low-temperature solid oxide fuel cells (LTSOFCs), gadolinia-doped ceria (GDC) has been widely utilized as an electrolyte. This is because its oxygen ion conductivity is much higher in an intermediate temperature range, and its activation energy (~0.60 eV) is lower than that of yttria-stabilized zirconia (YSZ), which is the most conventional electrolyte used in SOFCs. This high ionic conductivity stems from the high mobility of oxygen ions and the high concentration of oxygen vacancies in GDC, which is created when trivalent gadolinium ions

(Gd<sup>3+</sup>) are introduced into the lattice of fluorite-structured ceria [12–15]. GDC is also used as an electrolyte buffer layer [16–18], inhibiting the reaction between the YSZ electrolyte and perovskite cathode materials (e.g., La<sub>1-x</sub>Sr<sub>x</sub>MnO<sub>3-δ</sub> [19], La<sub>1-x</sub>Sr<sub>x</sub>CoO<sub>3-δ</sub> [20], and La<sub>1-x</sub>Sr<sub>x</sub>Co<sub>1-y</sub>Fe<sub>y</sub>O<sub>3-δ</sub> [21]), because the interfacial reaction creates a highly resistive SrZrO<sub>3</sub> and La<sub>2</sub>ZrO<sub>7</sub> insulating layer that blocks oxygen ion transport through the electrolyte and reduces the electrochemical performance of devices [22,23].

Not only does the GDC electrolyte have a fast ionic conduction performance, but the catalytic activity on the GDC surface and related surface exchange properties are also significant for the practical use of GDC in SOFCs. The surface oxygen vacancies are considered attractive properties for enhancing the surface kinetics of the oxygen reduction reaction (ORR), which is the slowest reaction step in SOFCs, especially in the low temperature region [24,25]. The generation of oxygen vacancies and the ORR on GDC can be summarized by the following chemical reaction equations, which use Kröger–Vink notation: [15,26,27]



in which  $\text{Gd}'_{\text{Ce}}$ ,  $V_{\text{O}(\text{GDC})}^{\bullet\bullet}$ , and  $\text{O}_{\text{O}(\text{GDC})}^{\times}$  represent an introduced Gd<sup>3+</sup> cation, a generated oxygen vacancy, and a lattice oxygen in GDC, respectively.

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