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# Various synthesis methods of aliovalent-doped ceria and their electrical properties for intermediate temperature solid oxide electrolytes

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ARTICLE INFO

*Article history:*
Received 16 August 2012
Received in revised form
6 November 2012
Accepted 8 November 2012
Available online 14 December 2012

*Keywords:*
Intermediate temperature-solid oxide electrolytes
Ceria-based materials
Composite electrolytes
Conductivity
Ceramic processing

ABSTRACT

This article investigates the relationship between ionic conductivity and various processing methods for aliovalent-doped, ceria solid solution particles, as an intermediate temperature-solid oxide electrolyte to explain the wide range of conductivity values that have been reported. The effects of doping material and content on the ionic conductivity are investigated comprehensively in the intermediate temperature range. The chemical routes such as coprecipitation, combustion, and hydrothermal methods are chosen for the synthesis of ceria-based nanopowders, including the conventional solid-state method. The ionic conductivity for the ceria-based electrolytes depends strongly on the lattice parameter (by dopant type and content), processing parameters (particle size, sintering temperature and microstructure), and operating temperature (defect formation and transport). Among other doped-ceria systems, the $Nd_{0.2}Ce_{0.8}O_{2-d}$ electrolyte synthesized by the combustion method exhibits the highest ionic conductivity at 600 °C. Further, a novel composite $Nd_{0.2}Ce_{0.8}O_{2-d}$ electrolyte consisting of a combination of powders (50:50) synthesized by coprecipitation and combustion is designed. This electrolyte demonstrates an ionic conductivity two to four times higher than that of any singly processed electrolytes.



## 1. Introduction

Solid oxide fuel cells (SOFCs) are increasingly recognized as a next generation clean technology for electrical energy conversion due to their high energy conversion efficiency and various fuel capabilities. SOFCs can convert hydrocarbon-based resources including fossil fuels, potentially, biomass and municipal solid waste to electricity and the electrical efficiency of SOFCs is 45–60% based on the lower heating value of the fuel [1,2]. Over the past decade, many studies have attempted to reduce the operational temperatures of SOFCs in order to increase the durability and electrical efficiency, and to reduce the fabrication cost through wider choices of constituent materials for the interconnector and sealant. In

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http://dx.doi.org/10.1016/j.ijhydene.2012.11.044

particular, aliovalent-doped ceria (such as $Y_2O_3$, $Gd_2O_3$, $Sm_2O_3$ and $Nd_2O_3$) has received great attention as an intermediate temperature-solid oxide electrolyte (IT-SOE) due to its superior ionic conductivity at lower temperatures (500–800 °C) compared to conventional yttria-stabilized zirconia (YSZ) SOEs under air atmosphere [3–5].

Yahiro et al. [6] examined the total ionic conductivity of the series $(CeO_2)_{0.8}(LnO_{1.5})_{0.2}$ (Ln = La, Nd, Sm, Eu, Gd, Y, Ho, Tm and Yb) at 800 °C. The samaria-doped samples had the highest conductivity (0.0945 S $cm^{-1}$) and lanthania the lowest (0.0416 S $cm^{-1}$). Steele [7] demonstrated that $Gd_{0.1}Ce_{0.9}O_{2-\delta}$ (GDC) exhibited the highest ionic conductivity among the other doped-ceria systems in the IT range, with an ionic conductivity of 0.0253 S $cm^{-1}$ at 600 °C in air, in contradiction with the above results. This low conductivity is related to the deleterious effects of $SiO_2$ impurities, which are responsible for the high grain boundary resistivities that obscure the intrinsic lattice ionic conductivities for large dopant concentrations [8–10]. Mogenson et al. [11] also attributed the apparent disagreement to the differences in the methods of sample fabrication, which is in turn dependent on the grain boundary resistivity.

Eguchi et al. [12] showed that the lattice constant of ceria-based materials is linearly changed with increasing dopant content until its solubility limit and that the ionic conductivity of $(CeO_2)_{0.8}(SmO_{1.5})_{0.2}$ is higher than with other rare-earth

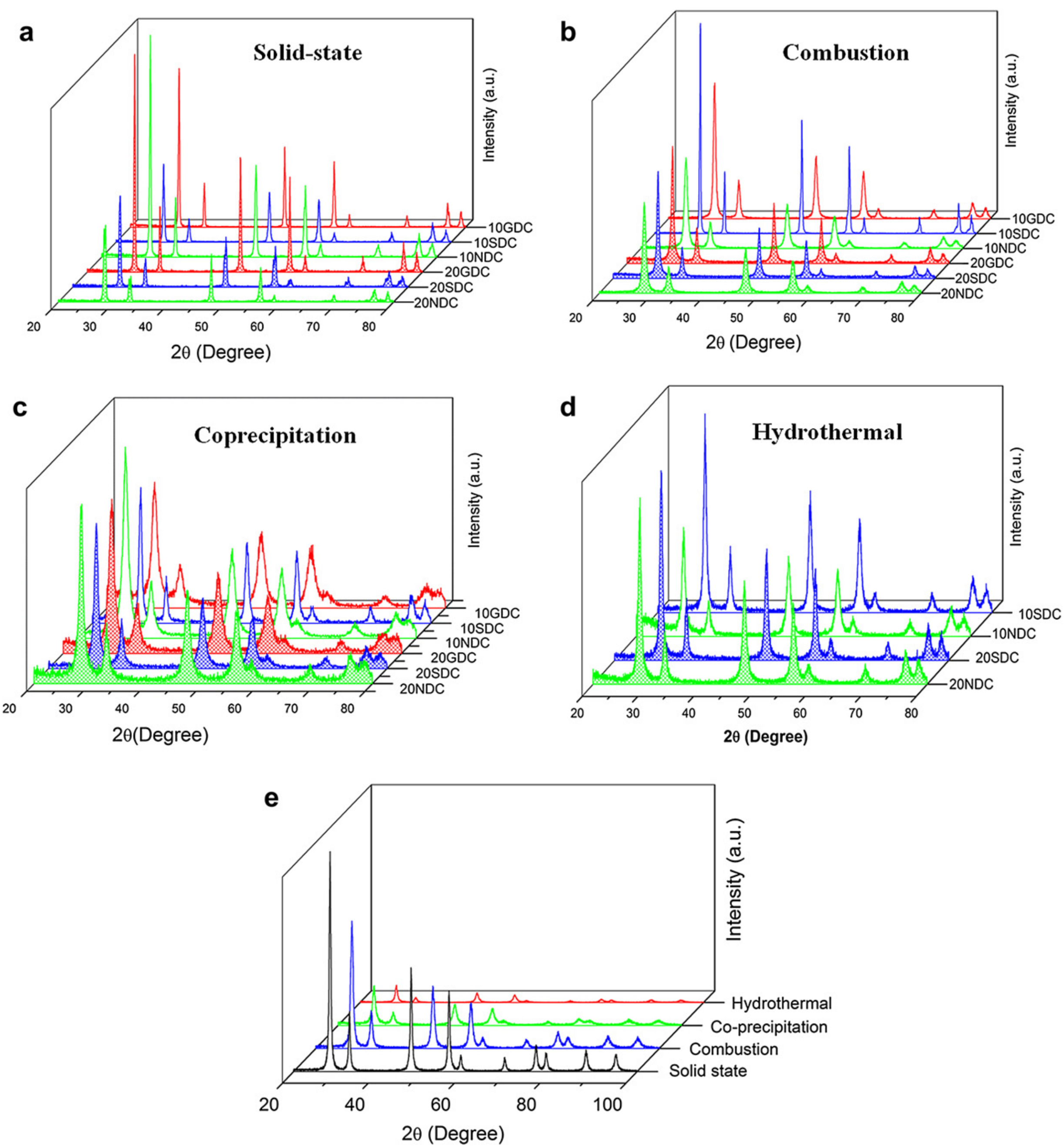


**Fig. 1 – XRD patterns of aliovalent-doped ceria powders synthesized by (a) solid-state, (b) combustion, (c) coprecipitation, and (d) hydrothermal methods and (e) comparisons of all synthesis methods of $Nd_{0.2}Ce_{0.8}C_{2-\delta}$ powders.**