

Synthesis and performance of $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_3$ cathode for solid oxide fuel cells

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Abstract

In the present work, different synthesis methods i.e., sol-gel method, glycine-nitrate method and solid state route have been used to synthesize lanthanum strontium cobaltite (LSCO), which is utilized as cathode in low and intermediate temperature solid oxide fuel cell (SOFC). Calcination temperature for LSCO has been determined by TGA. XRD, SEM, EDX and TEM have been used to assess the phase purity, crystallite size, morphology, distribution of constituent elements and particle size of synthesized LSCO material. Two-probe AC conductivity method has been used to calculate the ionic conductivity of LSCO in air environment between 400-800 °C. LSCO synthesized by sol-gel method provided highest ionic conductivity of 0.42 S/cm at 700 °C and lowest activation energy of 31.60 kJ/mol between 500 to 700 °C among all the methods. LSCO synthesized by sol-gel method gives lowest area specific resistance (ASR) of 3.52 $\Omega \text{ cm}^2$ at 800 °C for half-cell (LSCO/YDC). High ionic conductivity and low polarization resistance established LSCO synthesized by sol-gel method, as the potential cathode material. Copyright © 2017 VBRI Press.

Keywords: SOFC, LSCO, cathode material, method of preparation, area specific resistance.

Introduction

The electrochemical reduction of oxygen takes place at cathode in solid oxide fuel cell (SOFC) [1]. Cathode must have high electrochemical activity and electrical conductivity and should be stable under oxidizing conditions and maintain sufficient porosity at the operating temperature. It must have a comparable thermal expansion coefficient and chemical compatibility with the electrolyte and interconnect materials [1-3]. Oxygen reduction reaction (ORR) takes place at the cathode close to triple phase boundaries (TPBs), where oxygen ion conductor, electronic conductor, and gas phase come in contact [1,4].

Lanthanum strontium manganite (LSM) has been used as cathode material in conventional SOFC. LSM shows poor ionic conductivity at ambient oxygen partial pressure. During high temperature sintering LSM react with yttria stabilized zirconia (YSZ) and forms insulating lanthanum zirconate ($\text{La}_2\text{Zr}_2\text{O}_7$) and strontium zirconate (SrZrO_3) at the electrode and electrolyte interface. The insulating phases between LSM and YSZ induce high ohmic loss and polarization loss. The losses have large impact on performance of SOFCs and should be as minimum as possible. Formation of lanthanum zirconate will be high when (La+Sr) content at the A-site is greater than Mn^{3+} ions at the B-site and when Sr/La ratio is less than 0.43. High Sr content leads to Sr depletion from the lattice and eventual SrZrO_3 formation [5-7].

To increase the efficiency of SOFCs at low and intermediate temperature, mixed ionic and electronic

conductors (MIECs) are used as cathode material. MIECs shows both properties of ionic and electronic conductivities. MIECs are ABO_3 -type perovskite, where A belongs to rare earth ions (e.g., La) and B belongs to the transition metal ions (e.g., Co) and A-site is doped with other earth metal. MIEC, strontium doped lanthanum cobaltite ($\text{La}_{1-x}\text{Sr}_x\text{CoO}_{3-\delta}$ - LSCO) reduces the losses and enhances the performance of cells. Here strontium is doped on lanthanum. At low current density LSCO shows linear i-V characteristics and at high current density, it follows Tafel kinetics [8-11]. High chemical diffusion coefficient of oxygen in LSCO helps in bulk transport of oxygen, which leaves larger region of the electrode for ORR that enhance the performance of SOFC [12]. Due to octahedral symmetry around the transition metal at high temperature metallic or semiconducting band structure provide high electronic conduction [13]. At operating conditions, MIECs support large number of oxygen ion vacancies which enhance significantly bulk ionic oxygen transport [4, 14].

Sr-doped lanthanum cobaltites are p-type conductors due its high electrical conductivity. Conductivity increases with increase in temperature, increase in oxygen partial pressure and decrease in Sr-content [15, 16]. Cobalt content ensures good electronic conductivity and a slight oxygen over-stoichiometry favours the oxygen transport and also enhances electrochemical properties. Metal-oxygen distance shortening with increase in Sr-content increases the surface area [17, 18]. Surface area is an important factor for reaction rate on LSCO electrode. High performance electrodes can be obtained by using MIEC electrode with a

large surface area. For the MIEC cathodes, the role of surface area in improving their performance lies in the fact that a higher surface area leads to more active sites for the oxygen reduction reaction. LSCO electrode synthesized by tape casting and laser ablation method provides high surface area for reaction [19, 20]. It is reported that $\text{La}_{0.6}\text{Sr}_{0.4}\text{CoO}_{3-\delta}$ cathode material synthesized using citric acid (CA) and ethylenediaminetetraacetic acid (EDTA) complexing method and calcined at 1000 °C shows cubic perovskite structure [21]. Polarization resistance reduced in air for symmetric LSCO cathode on a GDC electrolyte substrate [22]. Egger et al. synthesized $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_{3-\delta}$ and $\text{La}_{0.6}\text{Sr}_{0.4}\text{CoO}_{3-\delta}$ cathode materials for IT-SOFCs by modified Pechini process and characterized by the conductivity relaxation technique between 525 °C-725 °C at oxygen partial pressures of 0.1, 0.01 and 0.001 bar. They reported ionic conductivity of 1×10^{-2} S/cm with an activation energy of 118 kJ/mol for $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_{3-\delta}$ at 725 °C [15]. Hu et al. synthesized $\text{La}_{2-x}\text{Sr}_x\text{CoO}_{4-\delta}$ ($x=0.9, 1.0$ and 1.1) using a microwave assisted citrate-nitrate combustion method [16]. Electrochemical performance is improved by varying LSCO and cerium gadolinium oxide (CGO) ratio (50 wt% LSCO-50 wt% CGO) [17].

There is scarcity of literature to provide comparative studies of LSCO cathode synthesis by different methods. It is seen that the different synthesis methods of LSCO provide different conductivities and ASR values. In the present work, $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_3$ (LSCO) has been synthesized by three different synthesis routes i.e., sol-gel method, glycine-nitrate method and solid state route. Comparative study has been done for ionic conductivity and performance of SOFC half-cell. Two-probe AC conductivity method (Electrochemical Impedance Spectra, EIS) has been used to evaluate ionic conductivity of LSCO. To study the cathode polarization resistance, $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_3/\text{Ytria doped ceria}$ (YDC) half-cells are measured.

Experimental

Materials details

For the synthesis of LSCO powder, $\text{La}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ (99.9% Alfa Aesar, USA), $\text{Sr}(\text{NO}_3)_2$ (99.9% Alfa Aesar, USA) and $\text{Co}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ (97.7% Alfa Aesar, USA) were used as precursors in all the synthesis methods.

Material synthesis

In sol-gel method, precursors in stoichiometric ratio were dissolved in distilled water. Citric acid ($\text{C}_6\text{H}_8\text{O}_7$) (anhydrous pure, Merck, India) was dissolved in distilled water in a separate container. Both the solutions were mixed in a 1 litre glass beaker, under constant stirring condition on a hot plate to evaporate the excess water. The temperature of hot plate was kept at 80 °C for 3 h. The gel was obtained after heat treatment at 100 °C for 1 h and at 120 °C for 2 h. Further it was calcined at 800 °C for 2 h and at 850 °C for 10 h to get perovskite LSCO powder.

In glycine-nitrate method, precursors in stoichiometric ratio were dissolved in distilled water. The solution was mixed in a 1 litre glass beaker, under constant stirring condition on a hot plate to evaporate the excess water. The

temperature of the hot plate was kept at 100 °C for 1 h. After significant reduction of the solution volume, the glycine ($\text{C}_2\text{H}_5\text{NO}_2$) (purified, Merck, India) dissolved in distilled water was added to it. The amount of glycine used was calculated in order to obtain a glycine-nitrate molar ratio of 2:1. The self-combustion of glycine/nitrate starts at 200 °C. The obtained powder was calcined at 800 °C for 2 h and at 850 °C for 10 h to get perovskite LSCO powder. Effect of fuel on crystallite size was analyzed using glycine nitrate method by varying glycine to nitrate ratio (g/n ratio) and keeping other parameters, calcination temperature and time constant. Glycine and nitrate were taken in three different ratios, i.e. g/n=0.5:1, 1:1 and 2:1.

In solid state reaction, precursors in stoichiometric ratio were mixed thoroughly in an automatic agate mortar and pestle for 4 h. This powder was sintered at 1250 °C to get perovskite LSCO powder. Fig. 1 (a-c) compares flowchart of synthesis process for sol-gel, glycine nitrate and solid state route to obtain perovskite, LSCO powder and sintered pellets.

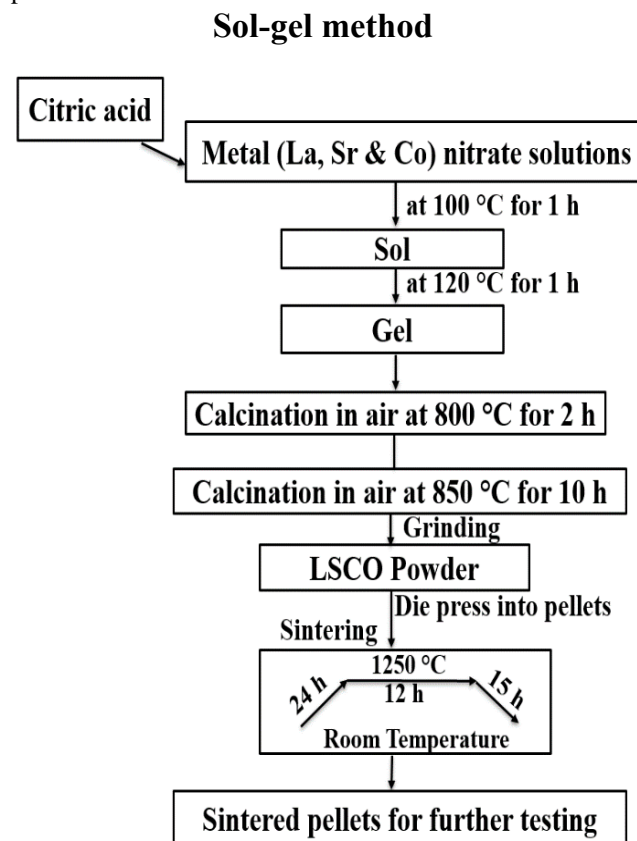


Fig. 1. (a) Flowchart of the sol-gel method for LSCO perovskite synthesis.

Physical and electrochemical characterization

Thermal analysis of samples was analyzed using NETZSCH TG 209 F3 Tarsus between temperature range 28-900 °C with heating rate of 10 °C/min, which provide information about calcination temperature. X-ray diffraction (XRD) was carried out to assess phase purity and crystallite size of cathode powder and cathode pellet. Rigaku MiniFlex X-ray diffractometer with $\text{Cu K}\alpha$ radiation (wavelength, $\lambda=1.54$ Å) was used for this purpose. The 2θ range was set from 20-80° with a step size of 4°/min.

Glycine-nitrate method

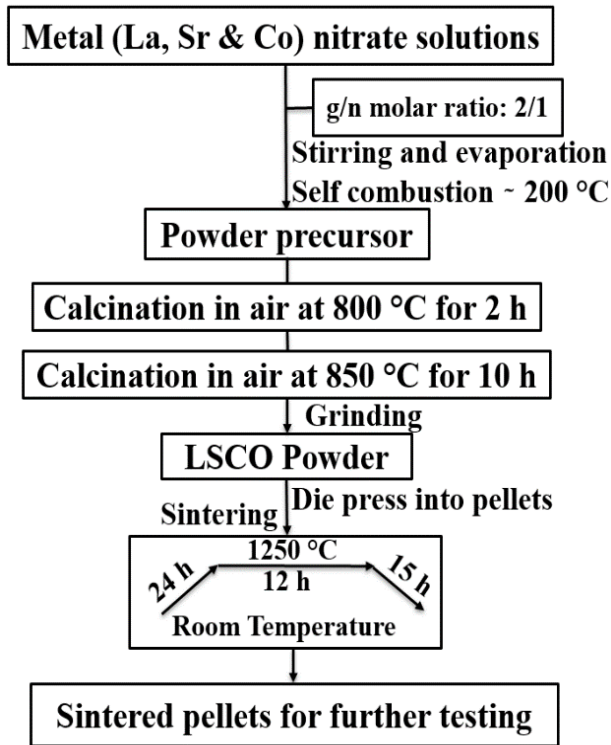


Fig. 1. (b) Flowchart of the glycine-nitrate method for LSCO perovskite synthesis.

Solid state route

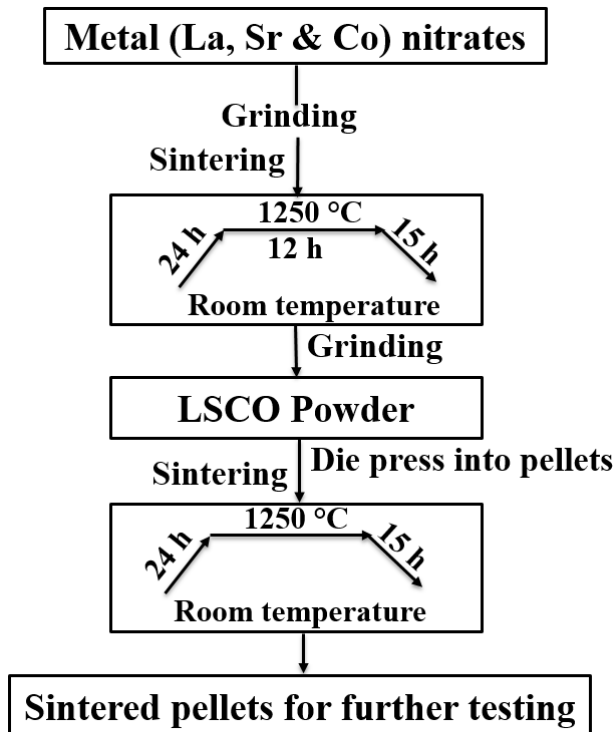


Fig. 1. (c) Flowchart of the solid-state route for LSCO perovskite synthesis.

Average crystallite size of synthesized LSCO cathode was calculated using Scherrer's equation:

$$d = \frac{K\lambda}{\beta \cos \theta}$$

where, d is the crystallite size, K is Scherrer constant (0.94), λ is the wavelength of radiation (1.54), β is the full width at half maximum (FWHM) in radians and θ is the Bragg angle. Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) for LSCO powder, LSCO pellet and composite half-cell were carried out for microstructure and elemental analysis using JEOL JSM 6010 LA JAPAN. The microstructure analysis was carried out before and after cell testing to ascertain the changes occurring during the operation. The particle size analyses of the cathodes were carried out by transmission electron microscope (TEM CM 12, Phillips).

To fabricate cathode pellet, the weighed amount of LSCO powder was placed in a clean die and the uniaxially pressed into pellets of 15 mm diameter by applying 150 kg/cm² pressure. Pellets were sintered at 1250 °C for 12 h. Cathode pellets of LSCO powder were used to evaluate the electrochemical performance between temperature range 400-800 °C in a split furnace. Potentiostat/ Galvanostat (PGSTAT 302N Autolab) was used to carry out electrochemical impedance spectra between frequency range 1 MHz to 0.1 Hz. To calculate the ionic conductivity, the following formula is being used:

$$\sigma = \frac{L}{RA}$$

where, σ is the conductivity, L is the thickness of pellet, R is the resistance and A is active area. For half-cell fabrication, yttria doped ceria (YDC) powder (99.9% American Elements, USA) was used as electrolyte. A 5 wt% solution of polyvinyl alcohol (PVA) (Fisher Scientific, India) was used as binder and starch (Merck, India) as pore former. To fabricate composite cathode, LSCO (70 wt%), electrolyte YDC (30 wt%) and starch (30 wt% of total LSCO and YDC) were mixed thoroughly in an automatic agate mortar and few drops of PVA solution were added and mixed thoroughly to make slurry. The slurry was dried in an oven at 100 °C. The solid mixture was crushed to very fine powder using an automatic agate mortar for 4-5 h. Composite cathode (LSCO: YDC=70:30) and electrolyte (YDC) were co-pressed into half cells of 15 mm diameter by applying 150 kg/cm² pressure. The silver wires were attached to both sides of the cathode pellets and half-cells using silver conductive ink and analyzed between 400-800 °C in a split furnace. Potentiostat/Galvanostat (PGSTAT 302N Autolab) was used to carry out electrochemical impedance spectra for half-cell between frequency 1 MHz - 0.1 Hz. The real part of the impedance was plotted on the x-axis and the negative of the imaginary part of the impedance was plotted on the y-axis (Nyquist plot). The high frequency intercept on the x-axis gives the ohmic resistance of the cell which is due to the electrolyte. The diameters of the semicircles are the measure of the polarization resistances of the electrodes.

Results and discussion

Thermogravimetric analysis (TGA) has been done to determine calcination temperature of synthesized LSCO

powder to obtain phase pure perovskite structure. **Fig. 2 (a)** shows the TGA curve between temperature 28-900 °C for LSCO cathode synthesized by sol-gel method and glycine-nitrate method.

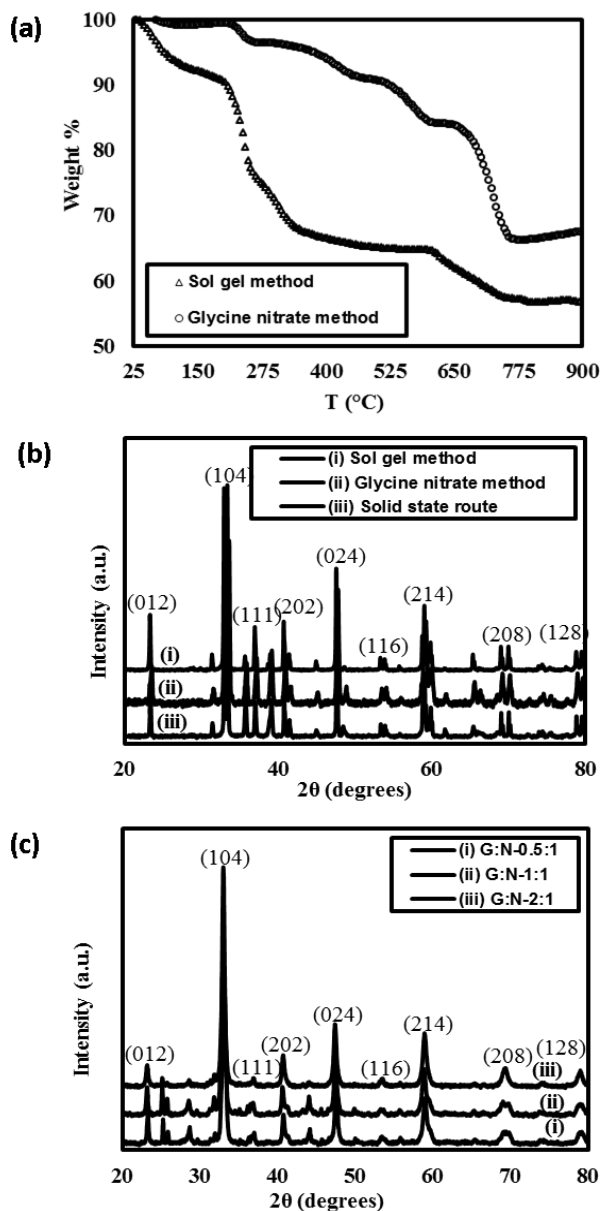


Fig. 2 (a) TGA curve of LSCO cathode material as synthesized by sol-gel method, and glycine-nitrate method. **(b)** XRD patterns for $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_3$ cathode powder as synthesized by different methods. **(c)** XRD patterns for $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_3$ cathode powder of different glycine and nitrate ratio as synthesized by glycine nitrate method.

It has been observed from TGA curve of sol-gel method that decrease in weight loss starts at temperature 28 °C, which may be due to formation of some gaseous product escaping from the sample. Evaporation of remaining water, low boiling temperature organic species and decomposition of nitrates occurs between temperature range 28-215 °C. Boiling point of citric acid and glycine is 175 °C and 205 °C, respectively. Volatilization of organic species and decomposition of residual nitrates occurs between 215 to 608 °C. It has been reported that oxygen vacancies also contributed in weight loss around 350 °C.

The weight loss observed between 608 to 760 °C might be initiated from the removal of residual or trapped carbon which is formed as intermediate products [21]. There is no weight loss after 760 °C in case of LSCO cathode synthesized by sol-gel method, whereas small weight gain is observed around 780 °C in TGA curve of LSCO synthesized by glycine nitrate method. From the above observation, the calcination temperature required to get LSCO perovskite phase is fixed between 800-850 °C. For the cathode synthesized by solid state route, all the precursors have been mixed and kept at 1250 °C to form solid solution of LSCO. In this case, it is not required to determine the calcination temperature using TGA.

The nanoparticles of LSCO cathode powder are investigated to assess phase purity using XRD analysis. Data from Joint Committee on Powder Diffraction Standards-International Centre for Diffraction Data (JCPDS) has been used for phase identification. **Fig. 2 (b)** shows the XRD patterns of LSCO powder as synthesized by different methods. The observed major peaks of cathode powder are matched with JCPDS card no. 48-0122 and confirms the formation of perovskite phase of LSCO powder. Some small peaks correspond to strontium oxide (JCPDS card no. 49-0692) at 48° and cobalt oxide (JCPDS Card No. 43-1004) at 61° have been also detected. Effect of fuel on crystallite size has been analyzed using glycine nitrate method by varying glycine to nitrate ratio (g/n ratio) and keeping other parameters like calcination temperature and time constant. XRD patterns shown in **Fig. 2 (c)** confirms the perovskite phase of LSCO powder correspond to different g/n ratios. Average crystallite size of synthesized LSCO powder for different g/n ratios is calculated using Scherrer's equation. Average crystallite size is decreased as glycine amount increased. It is observed that g/n = 2:1 provides smallest crystallite size (21.9 nm). Average crystallite size have been presented in **Table 1**.

Table 1. Crystallite size of LSCO as synthesized by different methods.

Method	Crystallite Size (nm)
Sol gel method	32.2
Glycine nitrate method	29.6
Solid state route	37.1
Glycine nitrate method	
S. No	Glycine:Nitrate Crystallite Size (nm)
1.	0.5:1 30.4
2.	1:1 23.2
3.	2:1 21.9

Some extra peaks with very less intensity are detected for g/n=0.5:1 and 1:1 at 25°, 29° and 43° but there is no extra peak observed for g/n=2:1. It can be inferred from the observed XRD patterns that fuel rich environment provides phase pure LSCO perovskite.

Fig. 3 (a-c) shows morphology and EDX analyses of the LSCO powder as synthesized by different methods. The

particle sizes are in micron range (approx. 0.5 μm) and well connected. From **Fig. 3 (a)** it is observed that particles of LSCO synthesized by so-gel method are agglomerated. It has been reported that substitution of Sr in LaCoO_3 structure increases the agglomeration [23]. The average particle size for LSCO powder synthesized by glycine-nitrate method and solid state route are between 0.5-1 μm and they are well connected to each other as shown in **Fig. 3 (b) and (c)**. Slightly larger particle size has been observed for LSCO powder synthesized by solid state route due to high temperature sintering at 1250 $^\circ\text{C}$. Presence of constituent elements La, Sr and Co in LSCO cathode is confirmed by EDX analysis.

Fig. 3 (d-f) shows TEM micrographs of LSCO powder synthesized by different methods. It can be observed from TEM that the particle size (264 nm) of LSCO synthesized by glycine nitrate method is lesser than the particle size of cathode synthesized by sol-gel method (412 nm) and solid state route (797 nm). Large particle size and agglomeration in case of LSCO synthesized by solid state route is due to high temperature treatment (1250 $^\circ\text{C}$) in order to get perovskite phase. The LSCO pellets sintered at 1250 $^\circ\text{C}$ are investigated to assess phase purity and crystallite size of the samples using XRD analysis.

cobalt oxide (JCPDS Card No. 43-1004) at 61 $^\circ$ have been also detected. Average crystallite size for LSCO cathode synthesized by different methods have been presented in **Table 1**. The smallest crystallite size (29.6 nm) has been observed for LSCO cathode synthesized by glycine nitrate method.

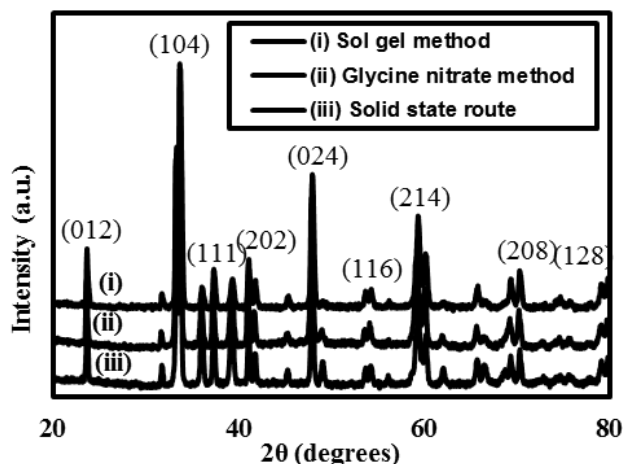


Fig. 4 XRD patterns for sintered $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_3$ cathode pellets.

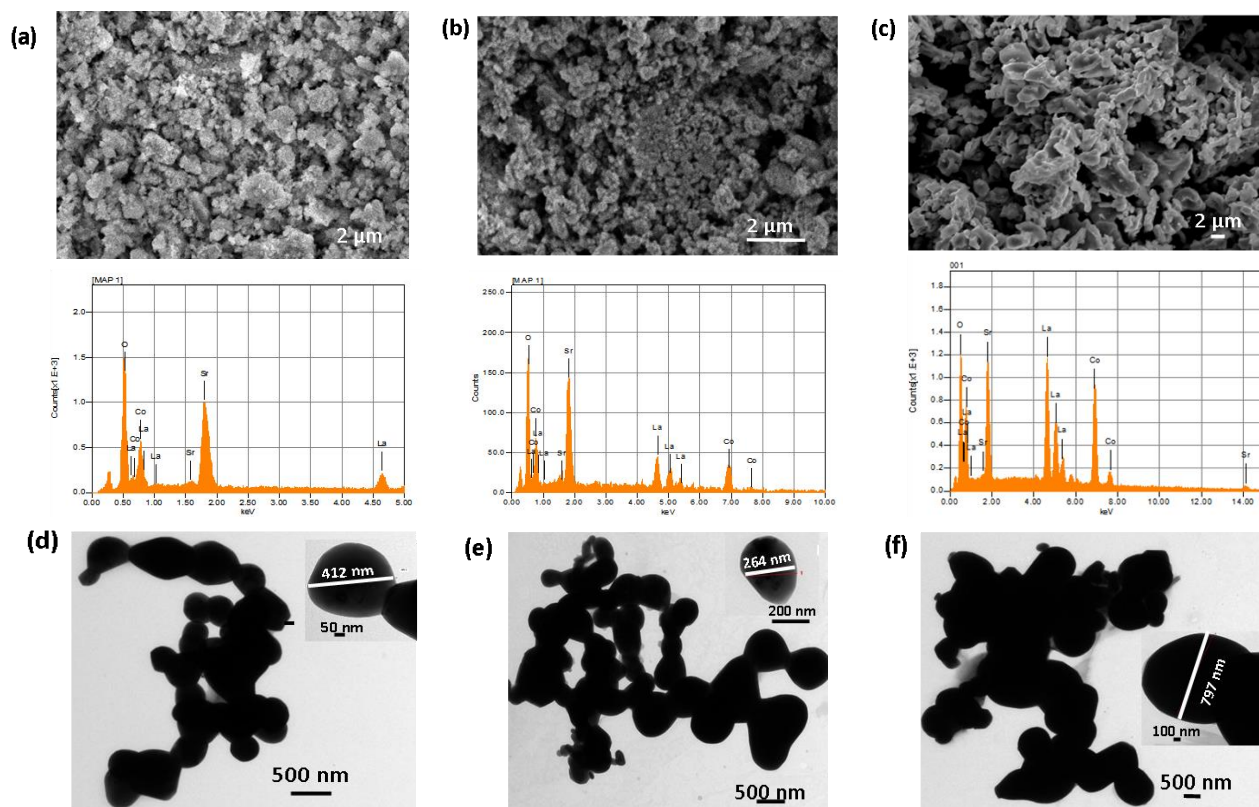


Fig. 3. (a) SEM image and EDX analysis of LSCO powder synthesized by sol-gel method after calcination at 850 $^\circ\text{C}$ for 10 h. (b) SEM image and EDX analysis of LSCO powder synthesized by glycine nitrate method after calcination at 850 $^\circ\text{C}$ for 10 h. (c) SEM image and EDX analysis of LSCO powder prepared by solid state route after sintering at 1250 $^\circ\text{C}$ for 12 h. TEM images of LSCO cathode material as synthesized by (d) sol-gel method, (e) glycine-nitrate method, and (f) solid state route.

Fig. 4 shows the XRD patterns of LSCO cathode pellets. The observed major peaks of LSCO are matched with JCPDS card no 48-0122 and confirms the formation of perovskite phase. Some small peaks correspond to strontium oxide (JCPDS card no. 49-0692) at 48 $^\circ$ and

Fig. 5(a-c) show morphology, EDX analysis and elemental mapping of sintered LSCO cathode pellet synthesized by sol-gel method. It can be observed from SEM (**Fig. 5 (a)**) that sufficient porosity is present such that high triple phase boundary is achieved. Particles are well

connected and have stable structure. The presence of constituent elements is confirmed by EDX (Fig. 5 (b)). The homogenous distribution of constituent element can be seen in elemental mapping presented in Fig. 5 (c).

Fast oxygen ion transportation is essential for cathode materials hence ionic conductivity measurements has been done between 400-800 °C for the performance assessment of the LSCO cathode pellets in air atmosphere. Fig. 6 (a) shows Arrhenius plot for LSCO cathode material as synthesized by sol-gel, glycine-nitrate and solid state routes. The ionic conductivity for LSCO by sol-gel method initially increases with increase in temperature up to 700 °C then it remains constant till 800 °C. The highest ionic conductivity 0.42 S/cm at 700 °C is observed for LSCO synthesized by sol-gel method.

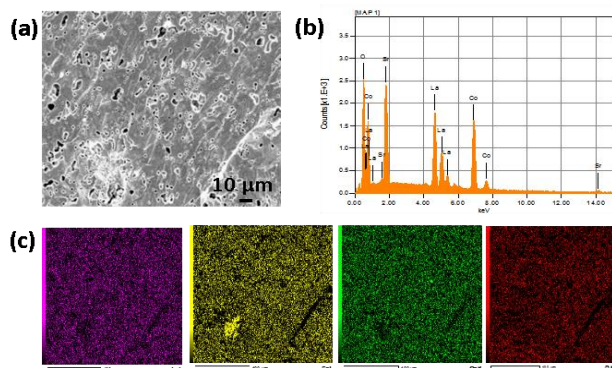


Fig. 5. (a) SEM image, (b) EDX analysis, and (c) Elemental mapping analysis of LSCO pellet by sol-gel method after sintering at 1250 °C for 12 h.

The ionic conductivity of LSCO synthesized by glycine-nitrate method and solid state route is found to be 0.20 S/cm and 0.22 S/cm at 700 °C, respectively. Endo *et al.* (2000) observed ionic conductivity of 0.1 S/cm for $\text{La}_{0.6}\text{Sr}_{0.4}\text{CoO}_3$ synthesized by Laser ablation method [20]. Ullmann *et al.* (2000) reported ionic conductivity of 0.22 S/cm at 800 °C for $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_{3-x}$ synthesized by spray drying [24], which is comparable to the ionic conductivity reported here even at lower temperature (700 °C). Lowest activation energy of 31.60 kJ/mol for LSCO synthesized by sol gel method has been observed between temperature range 500 to 700 °C. Activation energy for LSCO synthesized by glycine-nitrate method and solid state route is observed to be 52.48 kJ/mol and 51.28 kJ/mol, respectively. Egger *et al.* (2012) reported activation energy of 118 kJ/mol at 725 °C for $\text{La}_{0.5}\text{Sr}_{0.5}\text{CoO}_{3-\delta}$ by modified Pechini process [14], which is much higher than what we observed. It is inferred that LSCO cathode synthesized by sol-gel method has great potential for low/intermediate temperature solid oxide fuel cells as it has low activation energy.

To assess the performance of LSCO cathode, half-cell (LSCO-YDC/YDC) testing has been carried out between temperature 400-800 °C. Area specific resistance (ASR) for the half cells has been calculated by impedance spectra at different temperatures. ASR provides the polarization losses corresponding to LSCO cathode. Fig. 6(b) shows variation of ASR with temperature for half-cell having LSCO cathode as synthesized by different methods. As

temperature increases ASR decreases which signifies lower polarization losses at higher temperature. Half-cell consists LSCO cathode synthesized by sol-gel method shows reduction in ASR from 6.44 $\Omega \text{ cm}^2$ at 700 °C to 3.52 $\Omega \text{ cm}^2$ at 800 °C.

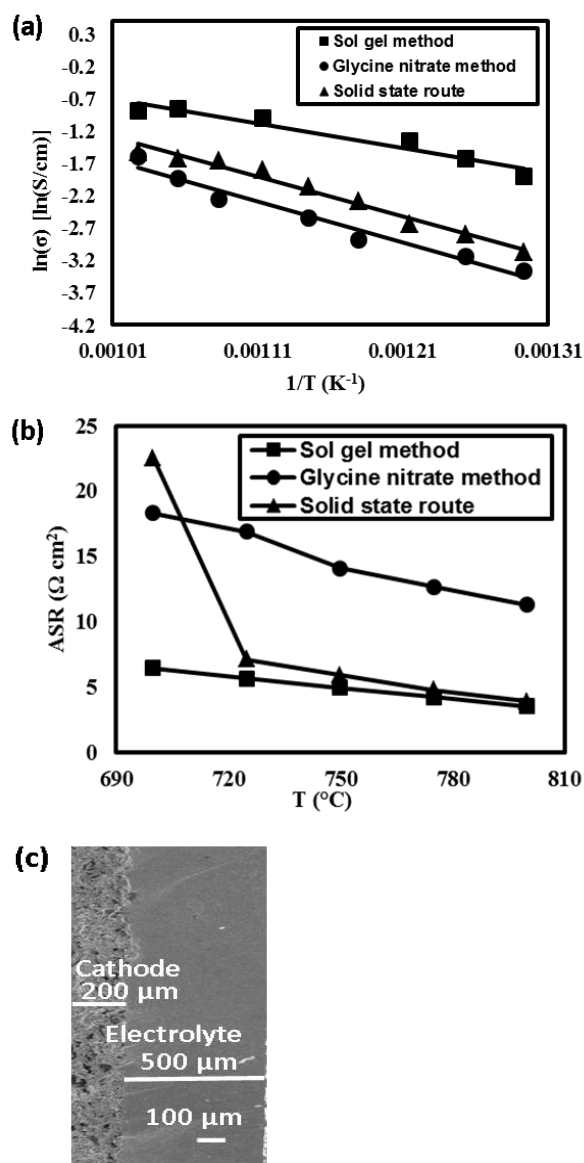


Fig. 6. (a) Arrhenius plot for LSCO cathode material synthesized by different methods. (b) ASR variation with temperature for half-cell, and (c) SEM images of fracture surface of half-cell.

Half-cell consists of LSCO cathode synthesized by glycine-nitrate method shows reduction in ASR from 18.30 $\Omega \text{ cm}^2$ at 700 °C to 11.26 $\Omega \text{ cm}^2$ at 800 °C but it is much higher than the half-cell having LSCO synthesized by sol-gel method.

Half-cell with LSCO cathode synthesized by solid state route shows reduction in ASR from 22.53 $\Omega \text{ cm}^2$ at 700 °C to 3.90 $\Omega \text{ cm}^2$ at 800 °C but higher than the half-cell with LSCO synthesized by sol-gel method. Fracture surface of half-cell in Fig. 6(c) shows 500 and 200 μm thick electrolyte and cathode respectively. YDC electrolyte is perfectly dense and shows proper adherence with cathode. There is no delamination or crack observed even after cell

operation. Fig. 7(a-c) shows SEM images of different cathode pellets after operation. It is observed that cathode pellets synthesized by glycine nitrate method have lesser porosity than the other two methods. It can be infer that higher ASR value for half-cell having cathode synthesized by glycine nitrate is due to less porosity which hinder the oxygen movement into bulk.

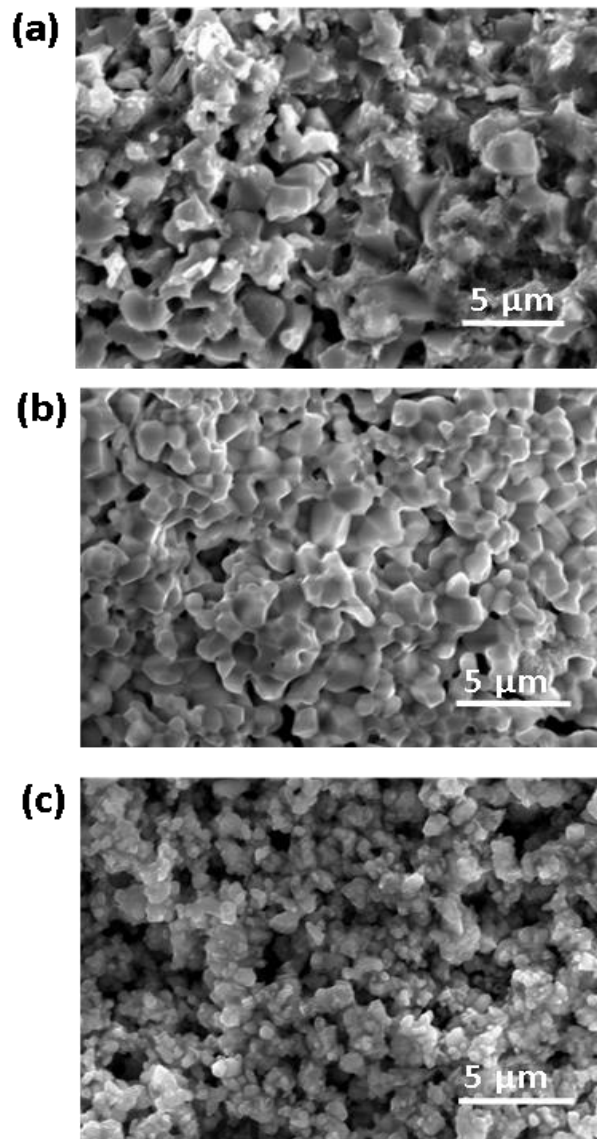


Fig. 7 SEM images of sintered LSCO pellet after operation, synthesized by (a) sol-gel method, (b) glycine nitrate method, and (c) solid state route.

Conclusion

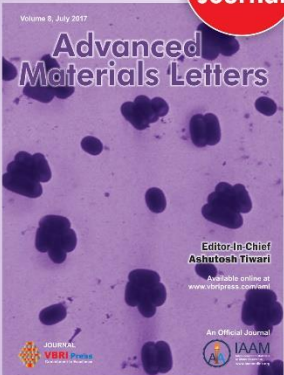
LSCO cathode material has been synthesized by three different methods i.e., sol-gel method, glycine-nitrate method and solid state route. Physical and electrical characteristics of LSCO has been compared in the present work. XRD confirms the formation of perovskite phase corresponds to LSCO. Smallest crystallite size of 21.9 nm has been observed for LSCO synthesized by glycine nitrate method (g/n=2:1). SEM and TEM of as synthesized cathode powder show well dispersed particles. Highest ionic conductivity, 0.42 S/cm at 700 °C and activation

energy, 31.60 kJ/mol between 500 to 700 °C is exhibited by LSCO synthesized using sol-gel method. Sufficient porosity and uniform distribution of constituents has been observed in LSCO cathode matrix. The compatibility between YDC and LSCO even after co-sintering at 1250 °C shows their potential application for SOFC components at elevated temperature. Half-cell having LSCO cathode synthesized by sol-gel method shows lowest ASR, 3.52 Ω cm² at 800 °C.

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