A study on synthesis and characterization of Dy-doped La0.6Sr0.4Co0.2Fe0.8O3-δ via co precipitation method

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Abstract

The perovskite Lanthanum Strontium Cobalt Ferrite (LSCF) is investigated as the cathode material used in intermediate temperature solid oxide fuel cells (IT-SOFCs). In the present study, La0.6-xDy0.4Sr0.4Co0.2Fe0.8O3-δ (x= 0, 0.3, 0.6) was synthesized through co precipitation method. The obtained precipitate was calcined at 500, 700, 900 and 1000 °C. Phase characterization of synthesized LSCF and LDySCF powder before and after heat treatment at 700 °C was carried out by X-ray diffraction (XRD) analysis. XRD patterns revealed that the perovskite phase was obtained at 700 °C in all calcined samples. Chemical bond study to investigate synthesis process was done using the Fourier transform infrared spectroscopy technique. Thermal analysis of DTA and TG has been utilized to investigate how the calcination temperature affects the perovskite phase formation. According to the STA results, the perovskite phase formation started at 551 °C afterward it completed at 700 °C. The density values of synthesized powders were 6.10, 6.11 and 6.37 g.cm⁻³ for the undoped and doped samples calcined at 700 °C. Powder morphology was studied by Field emission scanning electron microscopy (FE-SEM) micrographs showed the spherical shaped particles with the average particle size of 24-131 nm.

Introduction:

The perovskite oxides with general formula of ABO₃ illustrate properties such as electronic conductivity, ionic conductivity and catalytic activity that are main reasons to use them for the different parts of a solid oxide fuel cell fabrication[1]. LaFeO₃ is a perovskite with orthorhombic crystal structure which has a potential to make the cathode in solid oxide fuel cells, especially when it is doped as La₁₋ₓSrₓCo₁₋yFeₙO₃₋δ (LSCF)[2], [3]. Among the various LSCF compounds La₀.₆Sr₀.₄Co₀.₂Fe₀.₈O₃₋δ (LSCF6428) is usually selected as a cathode material due to its high ionic and electronic conductivities[1], [4]. It has been shown that in LSCF based cathodes, defects of A site plays an important role in improving cell efficiency by increasing electrical conductivity hence doping strategy leads to reach on stoichiometry of LSCF by incorporating dopants in A site replaced Lacations [3]. Banerjee et al obtained the rombohedral structured LSCF powder through combustion synthesis method. They have reported that the maximum content of defects in the A sites resulted in the minimum amount of resistant (0.02Ω.cm) in the symmetric cells at the constant temperature of 800 °C[3]. Another prominent properties of LSCF as a cathode is the catalytic activity. Researchers investigated the effect of noble elements such as Pd on the catalytic activity of the LSCF powder[5]. It could be said that one important reaction in a solid oxide full cell is the oxygen reduction reaction (ORR), Lu Zhang et al investigated the effect of CaO additive on ORR reaction kinetics. They added CaO nanoparticles to the porous LSCF structure via the infiltration method. They observed that there was no reaction between CaO and LSCF indicating compatibility of LSCF and CaO within the moderate operating temperature range. Their impedance spectrum observations indicates that CaO nanoparticles can effectively reduce the polarization resistance for LSCF single phase and LSCF-SDC composite cathodes[6].
There are also several methods for synthesis of LSCF which can affect various aspects of the synthesized powders quality that eventually determined the efficiency of the cathode in the SOFCs. Therefore, the production process enhancement is a challenge that researchers focused on. For instance, compared to the citrate method, the more content of oxygen vacancy could be produced via hydrothermal method[7]. Sanzhao Song et al produced the LSCF porous structured powder via the molten salt technique. They have claimed that their way of synthesis is a suitable manual for the porous structured materials production in energy conversion field equipment[8]. In another research work LSCF powder obtained from the ultrasound assisted synthesis method, equiaxial LSCF phase was formed after calcination at temperature of 800°C[9]. In a comparative research work, researchers synthesized the genuine LSCF-CuO nano powder through the solid state reaction and sol-gel method in order to figure out how the synthesis method affected on quality of finally synthesized powders. The rombohedral perovskite structure formed at the calcination temperatures of 800°C and 600°C for solid state reaction and sol-gel methods respectively. According to their report, the lower calcination temperature for the obtained sol-gel powder can be attributed to the polymerization process that occurs during the sol-gel method. Also they have deduced that the CuO nanoparticles act as catalysts and reduce the activation energy of perovskite phase formation in both synthesis methods. It is worth mentioning that the low coverage of CuO particles on LSCF enhances the oxygen reduction reaction kinetics[10]. Another proposed idea is to combine different methods for the purpose of proper quality achievement such as Hamzah Fansuri et al work in which they have mixed solid state and mechanochemical routes to attain the fine structured powder with acceptable particle size in the optimum time[11]. Alireza babaei et al declared that the rigorous washing of the co precipitation yielded precipitates enhanced the purity of the calcined powder[12]. The aim of the present study is to acquire the fine and homogenous powder using the co-precipitation method and to investigate how dysprosium oxide influence the quality of the obtained powder.

**Experimental:**

In order to synthesis of \( \text{La}_{0.6}\text{Sr}_{0.4}\text{Co}_{0.2}\text{Fe}_{0.8}\text{O}_3 \) (LSCF), stoichiometric amounts of \( \text{Sr} (\text{NO}_3)_2 \), \( \text{FeCl}_3.6\text{H}_2\text{O} \) and \( \text{Co} (\text{CH}_3\text{CO}_2)_2.4\text{H}_2\text{O} \) were dissolved in distilled water separately, \( \text{La}_2\text{O}_3 \) (and \( \text{Dy}_2\text{O}_3 \) in the compositions containing Dy) was dissolved in diluted nitric acid. All materials are 99.99% pure and purchased from Merck. After that, all the above mentioned solutions were mixed together at 65°C under vigorous stirring for 30 minutes. Ammonium carbonate0.2M was poured to the solution until the pH reached the value of ~ 10 causing a light brown precipitate was emerged. After completing precipitation process, the obtained precipitate was washed several times until pH reduced to 7, then dried and heat treated in the furnace at temperature of 500–1000°C for 2 h. The phase identification was carried out by X-ray diffractometry using the Cu KαX-ray (λ = 1.54 Å) by means of the Siemens instrument model, and Fourier transform infrared spectroscopy with the PerkinElmer device model: spectrum 400 in the 4000 – 400 cm\(^{-1}\) wave number range, respectively. Thermo gravimetric analysis (TGA) and differential thermal analysis (DTA) were performed on a NETZSCH STA 409 PC / PG thermo analyzer in an air atmosphere, at a heating rate of 10°C / min. Study microstructure and morphology was carried out by MIRA3 TESCAN.
field emission scanning electron microscope (FE-SEM). Figure 1 implies the synthesis process schematically. Powder densities were measured using a helium pycnometer (Accupyc 1330, Micromeritics).

**Results And Discussion:**

The XRD patterns of the Co-precipitation yielded precipitate of supposedly LSCF before and after calcinations at different temperatures are shown in the Fig. 2.

According to the Fig. 2, XRD pattern of dried precipitate represents the formation of different metal hydroxides precipitated by increasing pH during synthesis process. Accordingly, after heat treatment of the dried Co-precipitation yielded powder at 500°C, LaFeO$_3$ perovskite phase (JCPDS card 82-1958), La$_2$O$_3$, SrCO$_3$, Fe$_3$O$_4$ and Co$_3$O$_4$ were emerged. The XRD pattern of the sample calcined at 700°C reveals that the perovskite LSCF (JCPDS card 82-1961)[13] was formed simultaneous with La$_2$O$_3$ and some SrCO$_3$ as secondary phases. Phase impurities of La$_2$O$_3$ and SrCO$_3$ have been reported in the synthesis process of LSCF powder from Co-precipitation[12],[14] and sol gel[15] methods too. Regarding to the preformation of the orthorhombic perovskite phase (500°C), orthorhombic structured LSCF has been presented as well. At the temperature 900°C, the LSCF characteristic peaks with rombohedral structure became stronger while the intensity of the La$_2$O$_3$ peaks decreased and the strontium carbonate peaks vanished since increasing temperature leads to enhance diffusion of lanthanum and strontium cations to the perovskite structure. As the calcination temperature reaches to 1000°C both the perovskite and La$_2$O$_3$ peaks became stronger because of the grain growth which is supported from the reported average crystallite size calculated from XRD pattern in the Table 1. Therefore, the best calcination temperature for precursor prepared by co-precipitation method is 900°C due to the minimum amount of remained secondary phase and increasing the crystallinity of perovskite phase.

The average crystallite size for those samples calcined at the temperatures of 700, 900 and 1000°C calculated by Scherer equation[16]:

\[
D = \frac{0.94 \lambda}{\beta \cos \theta}
\]

In which D is the average crystallite size, λ is the wave length, β is the peak width at the half maximum amount and θ is the diffraction angle.

| Calcination temperature | 700 | 900 | 1000 |
|-------------------------|-----|-----|------|
| average crystallite size (nm) | 9   | 11  | 13   |
The FT-IR results of the LSCF Co precipitation yielded precipitate and the LSCF sample calcined at 900°C are presented in Fig. 3.

According to the Fig. 3 the dried precipitate spectrum, a wide peak appeared at 3392.26 cm$^{-1}$ shows[17] the OH stretching band and therefore demonstrates the adsorbed water existence. The observed peaks in the 1471 – 1368 cm$^{-1}$ wave number range confirm the presence of the (OH) groups in the structural water and the metal hydroxides formation[18]. The absorption band in the 852.04 wave number illustrates the Co$^{2+}$ existence. Therefore considering the ammonium carbonate usage as the precipitant agent, may be a few amounts of carbonate compounds formed during precipitation too. There are two absorption bands in the 697.75 and 746.71 wave numbers, which referred to the La-O [19] bond and the Lepidocrocite[20]. The observed peak in the 451.08 cm$^{-1}$ indicates the Sr-O or H-Sr-OH bonds are present [21]. In the calcined sample, the MO$_6$ octahedral site absorption bands detection, indicates the perovskite phase formation[22]. The two absorption bands that come into sight in 439.99 and 857.65 cm$^{-1}$ which are related to lanthanum oxide[23] and C-O band[21] respectively confirm lanthanum oxide and strontium carbonate as secondary phases. The peaks in wave numbers of 1472.54 and 3367.56 cm$^{-1}$ are related to the environmental moisture absorbed by the sample[18].

The DTA and TG curves of Co precipitation yielded precipitate during heating are displayed in Fig. 4. According to the DTA results, the endothermic peak at 164°C is attributed to the released adsorbed moisture[16]. There are three other exothermic peaks in the temperature ranges of 290,462 and 551°C which correspond to the:

1) Metal hydroxides decomposition reaction according to the below equations[17], [24]–[26]:

\[
\begin{align*}
La(OH)_3 & \rightarrow LaOOH + H_2O \\
Sr(OH)_2 & \rightarrow SrO + H_2O \\
12CoO(OH) & \rightarrow 4Co_3O_4 + O_2 + 6H_2O \\
2Fe(OH)_3 & \rightarrow 2Fe_2O_3 + H_2O
\end{align*}
\]

2) The intermediate compounds formation[24], [26]–[29]:

\[
\begin{align*}
2LaOOH & \rightarrow La_2O_3 + H_2O \\
SrO + CO_2 & \rightarrow SrCO_3 \\
3La_2O_3 + 2Fe_3O_4 + \frac{1}{2}O_2 & \rightarrow 6LaFeO_3 \\
3 \rightarrow -Fe_3O_4 + H_2 & \rightarrow 2Fe_3O_4 + H_2O
\end{align*}
\]

3) and the beginning of the LSCF formation, respectively[16], [30], [31].

It seems that the formation of LSCF with rombohedral structure takes place through the pre formation of an orthorhombic structured phase (LaFeO$_3$)[32] simultaneous with the La$_2$O$_3$, SrCO$_3$, Co$_3$O$_4$ and Fe$_3$O$_4$ compounds. As - temperature increases, the perovskite with orthorhombic structure tends to change into rombohedral due to the distortion increasing which can be attributed to the above mentioned
compounds dissolving in LaFeO₃ unit cell. It should be noted that the LSCF with rombohedral structure forms at 700°C completely.

The proposed mechanism for the LSCF formation is as follows:

a) Ammonium carbonate dissolves in distilled water:

\[
\frac{52}{20} \text{(NH}_4\text{)}_2\text{CO}_3 + \frac{52}{20} \times 2\text{NH}_4^+ + \frac{52}{20} \text{CO}_3^{2-} \\
5.2\text{NH}_4^+ + 5.2\text{H}_2\text{O} \rightarrow 5.2\text{NH}_3 + 5.2\text{H}_2\text{O} \\
5.2\text{NH}_3 + 5.2\text{H}_2\text{O} \rightarrow 5.2\text{NH}_4\text{OH} \leftrightarrow 5.2\text{NH}_4^+ + 5.2\text{OH}^-
\]

b) Lanthanum oxide dissolves in diluted nitric acid:

\[0.3\text{La}_2\text{O}_3 + 1.8\text{HNO}_3 \rightarrow 0.6\text{La(NO}_3\text{)}_3 + 0.9\text{H}_2\text{O}\]

c) Metal salts dissolve in distilled water[22]:

\[
0.6\text{La(NO}_3\text{)}_3(aq) \rightarrow 0.6\text{La}^{3+}(aq) + 1.8\text{NO}_3^-(aq) \\
0.4\text{Sr(NO}_3\text{)}_2(aq) \rightarrow 0.4\text{Sr}^{2+}(aq) + 0.8\text{NO}_3^-(aq) \\
0.2(\text{CH}_3\text{COO})_2\text{Co.4H}_2\text{O}(aq) \rightarrow 0.2\text{CoO(s) + 0.4CH}_3\text{CO}_2\text{H + 0.6H}_2\text{O} \\
0.8\text{FeCl}_2.6\text{H}_2\text{O} \rightarrow 0.8\text{Fe}^{3+}(aq) + 1.2\text{Cl}_2(g) + 4.8\text{H}_2\text{O}
\]

d) The hydrated metal oxide and hydroxide complex formation at 65°C and the pH 8.5 as a result of the ammonium carbonate injection into the mixed metal solution reactor in the co precipitation process:

\[
0.6\text{La}^{3+}(aq) + 0.4\text{Sr}^{2+}(aq) + 0.2\text{CoO(s) + 0.8Fe}^{3+}(aq) + 5.2\text{OH}^{-1}(aq) \rightarrow \\
0.6\text{La(OH)}_2\text{XH}_2\text{O(s) + 0.4Sr(OH)}_2\text{.8H}_2\text{O(s) + 0.2CoO(OH).XH}_2\text{O(s) + 0.8FeO(OH).XH}_2\text{O(s) + 0.8Fe(OH)}_3\text{(s) + 0.2CoO(OH).XH}_2\text{O(s) + 0.8FeO(OH).XH}_2\text{O(s) + 0.8Fe(OH)}_3\text{(s)}}
\]

The washed and dried precipitate endures step by step transitions as follows:

1) Water evaporation in the 100–164°C temperature range:

\[
0.6\text{La(OH)}_2\text{XH}_2\text{O(s) + 0.4Sr(OH)}_2\text{.8H}_2\text{O(s) + 0.2CoO(OH).XH}_2\text{O(s) + 0.8Fe(OH)}_3\text{(s) + XH}_2\text{O(g) \xrightarrow{100-164°C} 0.6La(OH)}_2\text{XH}_2\text{O(s) + 0.4Sr(OH)}_2\text{.8H}_2\text{O(s) + 0.2CoO(OH).XH}_2\text{O(s) + 0.8Fe(OH)}_3\text{(s)}}
\]

2) Metal hydroxides decomposition reaction beginning in 290°C:

\[
0.6\text{La(OH)}_2\text{XH}_2\text{O(s) + 0.4Sr(OH)}_2\text{.8H}_2\text{O(s) + 0.2CoO(OH).XH}_2\text{O(s) + 0.8Fe(OH)}_3\text{(s) \xrightarrow{290°C} 0.6LaO}_2\text{O}_3\text{(s) + 0.4SrO(s) + + 0.2CoO(OH).XH}_2\text{O(s) + 0.8Fe(OH)}_3\text{(s) + + 1.9H}_2\text{O(g)}}
\]

3) Intermediate compound formation in the 462–551°C temperature range:
4) The lanthanum strontium cobalt ferrite formation beginning in the 551°C:

\[
0.6 \text{LaOOH(s)} + 0.4 \text{SrCO}_3(s) + \frac{1}{15} \text{Co}_2\text{O}_3(s) + 0.4 \text{Fe}_2\text{O}_3(s) + 0.4 \text{CO}_2(g) + \frac{2}{15} \text{H}_2\text{O(g)} \xrightarrow{550°C} \\
0.3 \text{La}_2\text{O}_3(s) + 0.4 \text{SrCO}_3(s) + \frac{1}{15} \text{Co}_2\text{O}_3(s) + \frac{4}{15} \text{Fe}_2\text{O}_3(s) + \frac{2}{15} \text{H}_2\text{O(g)} \rightarrow \\
(0.3 - 3x) \text{La}_2\text{O}_3(s) + 0.4 \text{SrCO}_3(s) + \frac{1}{15} \text{Co}_2\text{O}_3(s) + \frac{4}{15} \text{Fe}_2\text{O}_3(s) + \frac{2}{15} \text{H}_2\text{O(g)} + 6x \text{LaFeO}_3(s)
\]

The TG result (Fig. 4) shows the 40.48% weight lost during the heating process. This overall weight loss occurs approximately in - four steps with increasing temperature. First steps starts at temperature range of 164–330°C, the calculated weight loss is about 13.01 wt%, while the TG curve shows an approximate weight loss of 9 wt%. At the intermediate compounds formation stage (330–550°C) weight is expected to increase by 6.85% according to calculations based on chemical reactions, but the curve keeps its downward trend (12.5%). Incomplete and delayed reactions to the previous step and coinciding with their subsequent reactions could be the reason for these inconsistencies. For instance onset of formation lanthanum oxide - occurs at 600°C[24], therefore some of the LaOOH may remain unreacted during the peroveskite phase formation and be hydrolyzed at higher temperatures to La$_2$O$_3$.

At 550°C and higher temperatures, the samples lose weight accrues more slowly. This slow rate of weight loss is reasonable considering the formation of stable peroveskite phase.

The XRD patterns of the LSCF and the powders which contain 0.3molDyand 0.6molDyat 700°C are shown in the Fig. 6.

Phase characterization of the compounds containing 0.3molDyand 0.6molDyat 700°C are corresponded with LaFeO$_3$ (Jcpds no 01-082-1961) and DyFeO$_3$ (Jcpds no 00-046-0135) cards, respectively. As it could be seen from the XRD pattern of Dy-doped LSCF compounds, the peroveskite phase with rombohedral structure is formed and a few amount of strontium carbonate exists, too. The diffraction pattern peaks– have shifted to larger angles compared to the peak position of the un-doped LSCF pattern as a result of the diffusion of the Dy$^{3+}$ cations into the unit cell. Considering increasing density and the peak displacement to the larger diffraction angles implies the reduction of the distance between the crystalline plates led to reducing the volume of unit cell. Therefore it could concluded that the Dy$^{3+}$ cations are replaced by La$^{3+}$cations (A sites in peroveskite structure) regarding to the smaller cationic radius of the Dy$^{3+}$ (0.91Å) compared to the cationic radius of the La$^{3+}$ (1.03Å). It also shows that the dysprosium cations occupying the fewer space of the lattice and provide enough space for the La$^{3+}$ cations in A site and prevent the unreacted La$_2$O$_3$ remain[1] however according to table 5-the density of the sample which contains 0.3 mol Dy has not changed significantly. Based on the density relation ($\rho = \frac{M}{V}$), it was expected by replacing Dy into La ($M_{Dy}$= 162.5 g.mol$^{-1}$ and $M_{La}$=138.9 g.mol$^{-1}$). If the most amount of the
Dy$^{3+}$ cations located in the interstitial spaces whereas lanthanum cations are completely located in the position of the A sites in the perovskite structure and distortion caused by Dy$^{3+}$ inplacement in interstitial spaces makes some of the strontium cations unstable due to their relative large radius (cationic radius = 1.12 Å) and different oxidation state, so strontium cations move out of the network, therefore a few amount of strontium carbonate is detected in the XRD pattern of the sample containing 0.3 mol Dy. As evidenced by the XRD pattern and the increased density of the sample which contains 0.6 mol Dy, the crystalline structure change into orthorhombic and the volume of the unit cell reduces. In general, the substitution of lanthanide cations with higher atomic number and lower ionic radius than lanthanum, reduces the lattice parameter led to decrease the unit cell volume - and also causes a change in the structure of the rombohedral to the orthorhombic [33]. According to the pattern of the sample contains 0.6 mol Dy, the strontium carbonate peaks get stronger and the Dy$_2$O$_3$ peaks appear, too. It can be concluded - increasing distortion due to the significant radius difference of the Dy$^{3+}$ and Sr$^{2+}$ cations compared to the La$^{3+}$ and Sr$^{2+}$ radius difference besides the more reduced volume prevent Sr$^{2+}$ and some of the Dy$^{3+}$ from penetrating perovskite structure and intensifying strontium carbonate and Dy$_2$O$_3$ peaks. The calculated mean crystallite size for the compounds containing 0.3 and 0.6 mol Dy are 6 and 7 nm.

Table 2: the measured density for the samples which calcined at 700°C

| Sample | LSCF | LDSCF | DSCF |
|--------|------|-------|------|
| Density (g.cm$^{-3}$) | 6.10 | 6.11 | 6.37 |

The FE-SEM micrographs of the calcined powders are illustrated in Fig. 7. It can be observed that the porous agglomerated powder with spherical shape formed in all samples – the high calcination temperature which makes the weak primary chemical bonds stronger, is the agglomerated particles formation reason [16]. The small particle size is another factor facilitates the agglomerated particles formation as a result of the particle assembling that accruce to reduce the high surface energy. The particle size distribution is rather uniform and the average amounts of particle size determined by Dgmizer software for the LSCF samples which were calcined at 700, 900 and 1000°C are 44, 82 and 131 nm, respectively. Figure 7(a), (b) and (c) show the increase in agglomerates with increasing calcination temperature in the LSCF powder, so that the boundary between the particles in Fig. 7(a) is more separable compared to the Fig. 7(b) and (c). Figure 7(e) and (d) are for compounds containing 0.3 mol Dy and 0.6 mol Dy respectively. Although the calcination temperature for the (a), (d) and (e) is the same, there is a significant difference between the average particle sizes of the compounds containing the Dy and LSCF powder. The mean particle size of the sample - have decreased with increasing amount of Dy. Likewise, the calculated crystallite size decreased with increasing Dy content at the constant
calcination temperature. This confirms that incorporation of Dy$^{3+}$ in to the structure decreases the average particle size and crystallite size. It is likely that the presence of the Dy$^{3+}$ by distorting the structure make it difficult for other cations to penetrate into the primary nuclei [34]. Therefore, the growth of the nuclei is reduced, thus reducing the size of crystallites. The particle size distribution of the powders containing Dy is more uniform compared to the LSCF sample. The average particle size for the samples containing 0.3 mol and 0.6 mol Dy are 28 and 24 nm, respectively. Some reported average LSCF particle size from different references have been listed in the Table 3.

**Table 3: the average particle size for some different synthesis methods in the different temperatures**

| Synthesis method          | Calcination temperature(°C) | Average particle size (nm) | Reference |
|---------------------------|-----------------------------|----------------------------|-----------|
| Co precipitation          | 1000                        | 90                         | [12]      |
| Sol-gel                   | 700                         | 10-60                      | [31]      |
| Microwave assisted glycine ni | 800                        | 114                        | [35]      |
| Sol-gel                   | 900                         | 90                         | [36]      |

**Conclusion**

The LSCF light brown co precipitation yielded precipitate at 65°C at pH of 10. The synthesis of La$_{0.6}$Sr$_{0.4}$Co$_{0.2}$Fe$_{0.8}$O$_3$ compound in rombohedral crystal structure was completed after calcination at 700°C, during the heating process the orthorhombic phase performed at 551°C. In addition to LSCF phase, a very little amount of La$_2$O$_3$ and SrCO$_3$ have been detected in the x-ray diffraction pattern of the powder calcined at 700°C. Raising calcination temperature to 900°C led to vanish SrCO$_3$ then the most pure LSCF powder with the spherical shape and the average particle size of 82 nm obtained. Doping Dy replaced La sites reduced the average particle size to 28 and 24 nm in composition containing 0.3 and 0.6 mol Dy respectively. The dysprosium also eliminated the secondary phase of lanthanum oxide resulted pure LSCF phase in lower calcination temperature of 700°C.

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**Figures**

![Figure 1](image)

The co precipitation synthesis process flowchart
Figure 2

the XRD patterns of the synthesized powder before and after calcination at 500, 700, 900 and 1000°C

Figure 3

FTIR spectra of the synthesized powder before and after calcination at 900°C
Figure 4

STA results of the precursor before calcination
Figure 5

Graphical summary of LSCF formation steps

Figure 6

The XRD patterns of the LSCF and doped LSCF which contain 0.3 mol Dy and 0.6mol Dy after heat treatment at 700°C.
Figure 7

(a) the 700°C calcined LSCF powder, (b) the 900°C calcined LSCF powder, (c) the 1000°C calcined LSCF powder, (d) the sample containing 0.3molDy calcined at 700°C and (e) the sample containing 0.6molDy FE-SEM micrographs in 50Kx magnification