Preparation of Sm$_{0.2}$Ce$_{0.8}$O$_{1.9}$ electrolytes via the chitosan templating method and investigation of the sintering behavior

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**ABSTRACT**

Sm$_{0.2}$Ce$_{0.8}$O$_{1.9}$ electrolytes were prepared using a novel chitosan templating method. To examine the sintering kinetics of the materials, 5 minutes, 1 hour, and 6 hours of sintering processes were carried out at 1200, 1300, and 1400 °C. The phase structure of the sintered samples was clarified by XRD analysis. The morphological structure was examined by SEM and the average grain sizes were calculated with the Linear Intercept Method. The dominant diffusion mechanism and grain growth activation energies during sintering were calculated for the SDC20 electrolytes synthesized by the chitosan templating method for the first time. In addition to the sintering study, the ionic conductivities of the samples were determined by electrochemical impedance spectroscopy. The maximum $\Omega^{-1}$ conductivity value for the 1300–6 sample was found to be 0.052 S.cm$^{-1}$. The study showed that the chitosan templating method is an effective way of synthesizing SDC20 materials.

**1. Introduction**

Fuel cells have numerous benefits over conventional combustion-based technologies currently used in power plants. A wide variety of fuel cell types are currently available. Among these, solid oxide fuel cells (SOFCs) stand out due to their capacity to convert chemical energy into electrical energy with high efficiency. The most critical parameter affecting the efficiency of solid oxide fuel cells is the ionic conductivity of the electrolyte. The electrolyte is the main organ that performs ion transport within the cell and thus ensures electrochemical reactions. Various chemical materials can be used as an electrolyte. Besides, doped ceria compounds are showing remarkable performance due to their high efficiencies and low activation energies in the intermediate temperature SOFCs (500–800 °C). The ionic conductivity of an electrolyte strongly depends on the concentration and the ionic radius of the dopant cations [1]. The most effective dopant materials are Sm$^{3+}$ and Gd$^{3+}$ cations since their ionic radii are very similar to the ionic radius of the Ce$^{3+}$ cation.

The doped ceria compounds can be synthesized by auto-combustion methods using fuels such as ethylene glycol [2], urea [3], and glycine [4], or by co-precipitation methods using precipitation agents such as ammonium hydroxide [5] and oxalic acid [6]. Apart from these, it is possible to synthesize extremely pure and fine particle-sized ceramic powders by using templating methods. Studies show that polymeric materials such as cellulose, polyvinyl alcohol, and chitosan can be used as a template in the production of porous materials [7,8]. Previously, chitosan was used as a template for the synthesis of the nanospheres from Ti, Al, and Si oxides [9]. Apart from that, it is known that the chitosan templating method is used in pure CeO$_2$ synthesis [10]; however, this method has not been used before for SDC20 materials.

Aside from the dopant cation and the synthesis method, another important parameter affecting the performance of the electrolyte is sintering process. The sintering temperature and duration directly changes the density and ionic conductivity of the electrolyte. Sintering process can be considered as the densification stage of the material [11]. Sintering aims to obtain fully dense and non-porous electrolytes. The insufficient information in previous studies prevented the determination of suitable sintering conditions for SDC20 electrolytes.

In this study, 20% mol samarium doped cerium oxide (SDC20) compounds were synthesized using the chitosan templating method for the first time. Synthesized powders were pressed into pellets and sintered at different temperatures for different durations, and a comprehensive and novel sintering study was carried out for the first time to the best of our knowledge.

**2. Experimental procedure**

Samarium doped ceria compounds (Sm$_{0.2}$Ce$_{0.8}$O$_{1.9}$, SDC20) were synthesized by using chitosan as
template by the following method [10]. 1.7 g chitosan was dissolved in a (3%, v/v) acetic acid solution. 0.1 M cation solution was prepared using stoichiometric amounts of cerium nitrate hexahydrate (CeN₃O₉.6H₂O, 99.5%, Alfa Aesar) and samarium nitrate hexahydrate (Sm(NO₃)₃.6H₂O, 99.9%, Alfa Aesar) salts. Then, the chitosan solution and the cation solution were mixed until they became homogeneous. The obtained solution was dropped into NH₄OH (30%, v/v) solution under stirring. Hybrid spheres formed as a result of dropping were washed using distilled water and ethyl alcohol. The spheres were then left to dry overnight in the oven at 70 °C. The dried spheres were calcined at

Figure 1. Hybrid spheres formed after dropping into NH₄OH solution (left), spheres after dried at 70 °C (right).

Figure 2. Flow diagram for the SDC20 electrolyte synthesis.
600 °C for 6 h. Figure 1 shows as-formed and dried hybrid spheres.

After the calcination, pure SDC20 powders were obtained and were ground in an agate mortar. Then, they were pressed into cylindrical pellets using a 10 mm diameter stainless steel pellet die. The cold isostatic press was applied to the pellets in order to increase their strength. Afterward, pellets were sintered at 1200, 1300, and 1400 °C for 5 min, 1 h, and 6 h. All sintering processes were carried out isothermally with a heating rate of 5 °C/min. Figure 2 shows a flow diagram for the preparation route of SDC20 electrolytes.

The thermal behavior of the powders was studied with Seiko SII Exstar 6000 thermogravimetric/differential thermal analysis (TG/DTA, SII Nano Technology Inc., Chiba, Japan) between 30 °C–800 °C with a constant heating rate of 10 °C/min under air.

Phase structures, crystallite sizes, and lattice parameters were investigated by applying X-ray diffraction analysis (XRD; Rigaku D/Max 2200 Ultima, Austin, TX) with CuKα radiation (0.15418 nm) in an angular region of 2θ = 20° – 80° on samples after calcination and sintering. The average crystallite sizes of the samples were calculated from the X-ray line broadening of the reflections of (111) using the Scherrer equation.

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

(1)

The lattice parameters of the samples were calculated by using the equations;

\[ a = \sqrt{h^2 + k^2 + l^2} \]  

(2)

\[ d = \frac{\lambda}{2\sin\theta} \]  

(3)

where \( d \) is the planar spacing, \( \lambda \) is the wavelength of the radiation, \( \theta \) is the diffraction angle, and \( a \) is the lattice parameter.

Sample densities after sintering were determined using the Archimedes method. The theoretical density was calculated via equation (4), and relative density was calculated by dividing the measured density by the theoretical density:

\[ \rho = \frac{4\pi xM_d + (1-x)M_{Ce} + (2-x)M_O}{N_A (a^3)} \]  

(4)

where \( \rho \) is the theoretical density (g.cm\(^{-3}\)), \( x \) is the dopant concentration, \( M_d \) is the molecular weight of the dopant, \( M_{Ce} \) is the molecular weight of the cerium, \( M_O \) is the molecular weight of the oxygen, \( a \) is the lattice parameter and \( N_A \) is the Avogadro number.

Scanning electron microscopy (SEM-EDX, FEI Quanta FEG-450) was used to identify the morphology and microstructure of the sintered samples. The mean grain sizes of sintered pellets were estimated from the SEM micrographs, using the linear intercept method from three different micrographs. The linear intercept method is one of the simplest techniques to estimate an average grain size. A random straight line is drawn through the micrograph. The number of grain boundaries intersecting the line is counted and, then the average grain size is found by dividing the number of intersections by the actual line length. The process of estimating the mean grain size of the 1400–1 sample is given in Figure 3.

The total conductivity of the samples measured by using a GAMRY Instruments PCI4750/46,070 Potentiostat in the temperature range of 250 °C to 800 °C in air. A complex plane plot of real impedance (Z') vs imaginary impedance (Z") was prepared for each set of data. By curve fitting a circle to semicircles on these plots, sample resistances (R) were obtained. The total conductivity values were then calculated from the following equation:

\[ \sigma_{\text{total}} = \frac{l}{A R_{\text{total}}} \]  

(5)

where \( \sigma_{\text{total}} \) is the total ionic conductivity, \( R_{\text{total}} \) is the total resistance, \( A \) is the cross-sectional area of the sample, and \( l \) is the sample thickness.

3. Results and discussions

3.1. Characterization of the powders

The thermal behavior of hybrid spheres was examined with TG/DTA and the results are given in Figure 4. The first weight loss resulted from the removal of the moisture remaining in the spheres. Then, around 30% of sudden weight loss occurred and this may be attributed to the decomposition of the hybrid structure. Decomposition of the chitosan occurs at 292 °C [12]. On the other hand, the decomposition of the hybrid structure took place at approximately 210 °C. No weight loss has been observed after 210 °C, and the remaining mass can be ascribed as SDC20.

XRD patterns of the calcined and sintered samples are given in Figure 5. XRD patterns show it is clear that calcined powders have reached the CeO2 cubic structure (JCPDS Card No: 34–394) and no peak of any other phase was found. Dopant Sm\(^{3+}\) cation is fully immersed into the CeO2 phase. In order to understand the effects of sintering conditions on phase structure, XRD analysis was applied to sintered pellets, which they were crushed and ground. After sintering, the peaks became sharper and narrower. That indicates there is an increase in the crystallite sizes of the samples.

Calculated values for crystallite sizes and lattice parameters of samples are given in Table 1. It was observed that as the sintering temperature increased, the lattice parameters and the crystallite sizes increased. The samples are named to express the sintering conditions.
applied. For example, 1200–6 refers to the sample sintered at 1200 °C for 6 hours. As a result of sintering, the crystallite sizes increased from 14 nm to 37.5, 38.7 and 45 nm for 1200, 1300 and 1400 °C, respectively. Similarly, although there is an expansion in the lattice parameter with increasing temperature, there was no change at 1300 and 1400 °C. (Table 1 near here)

Figure 6A shows the SEM image of hybrid sphere formed after dropping the cation-chitosan solution into NH₄OH and dried in air at 70 °C. Chitosan is soluble in dilute acidic solutions such as 1% (v/v) aqueous acetic acid due to protonation of the free amine groups [13]. After the solution is neutralized chitosan precipitates by forming spherical beads. During
precipitation, the solvent surrounding the polymer molecules is in liquid phase and the solidification of chitosan is due to neutralization that takes place while the polymer chains are in solution [10]. Drying the hybrid spheres causes shrinkage due to interactions between polymer chains, especially due to the formation of strong hydrogen bonding from hydroxyl and amino groups as liquid water evaporates [13].

After calcination at 600 °C (Figure 6B), a structure with open and closed pores was obtained in foam-like morphology. These pores were formed due to CO2 and water released by decomposition of the polymer.

### 3.2. Sintering and microstructure

The sintering process has serious effects on the characteristics of solid oxide electrolytes. For a long time, the sintering temperature and time have been important parameters for synthesizing electrolytes with high conductivity. To examine the sintering process, temperatures of 1200, 1300, and 1400 °C, which are frequently preferred for many studies [14–16] were chosen. To reveal the effects of the time of sintering on the characteristics of the material, a short sintering time of 5 minutes, a relatively long sintering time of 1 hour, and a very long sintering time of 6 hours were preferred. Density measurements were carried out by using Archimedes method. Measured, theoretical and relative densities are given in Table 2.

As expected, increasing sintering temperature and time caused an increase in the sample densities. However, it is possible to reach the density value obtained by performing 6 hours of sintering at 1200 °C by 5 minutes at 1300 °C. At the same time, it was seen that increasing the sintering time from 1 hour to 6 hours had little effect on density values. Generally, in all sintering conditions, relative densities of more than 87% were achieved for the samples. Although the highest density value was achieved in the 1400–6 sample, it is possible to reach similar results at 1300 °C. This situation reveals that sintering at high temperatures such as 1400 °C and for long periods such as 6 hours will be disadvantageous for SDC20 samples in terms of time and energy consumption.

![Figure 4. TG/DTA graph of the hybrid spheres.](image)

![Figure 5. XRD patterns of all samples after calcination and sintering.](image)

**Table 1.** Crystallite sizes and lattice parameters of the samples.

| Sample          | Lattice Parameter (Å) | Crystallite Size (nm) |
|-----------------|-----------------------|-----------------------|
| Calcined (600 °C, 6 h) | 5.425                  | 14.380                |
| 1200–6          | 5.432                  | 37.550                |
| 1300–6          | 5.436                  | 38.730                |
| 1400–6          | 5.436                  | 45.060                |

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Table 2. Density measurements.

| Sample | Measured Density (g.cm⁻³) | Theoretical Density (g.cm⁻³) | Relative Density (%) |
|--------|---------------------------|------------------------------|---------------------|
| 1200–5 | 6.261                     | 7.136                        | 87.739              |
| 1200–1 | 6.300                     | 7.120                        | 88.484              |
| 1200–6 | 6.357                     | 7.151                        | 88.887              |
| 1300–5 | 6.317                     | 7.104                        | 89.920              |
| 1300–1 | 6.400                     | 7.104                        | 90.087              |
| 1300–6 | 6.500                     | 7.136                        | 91.092              |
| 1400–5 | 6.423                     | 7.077                        | 90.760              |
| 1400–1 | 6.540                     | 7.089                        | 92.265              |
| 1400–6 | 6.628                     | 7.136                        | 92.882              |

Figure 7 shows the SEM micrographs of sintered pellets at different conditions. Samples named 1200–5, 1200–1 and, 1200–6 are sintered at 1200 °C for 5 min, 1 h, and 6 h, respectively. At 1200 °C, a large number of microcracks and pores were found in the samples. Also, the grain boundaries could not be clearly determined, and the grains do not have a certain shape. Samples named 1300–5, 1300–1, and 1300–6 are sintered at 1300 °C. The 100 °C increase in sintering temperature significantly improved the microstructure of the sample. The porosity of the sample decreased, grain sizes increased, and the grain boundaries became clear. Likewise, increasing the sintering time at the same temperature provided improvement in the structural properties. Samples named 1400–5, 1400–1, and 1400–6 are sintered at 1400 °C. As expected, grain growth continued at this temperature and, no significant porosity was found in the structure. Besides, the increase in sintering time also provided an improvement in the microstructure at this temperature. Generally, after 1-hour sintering at 1300 and 1400 °C, no observable porosity was found and, a relative density of >90% has been achieved under these sintering conditions.

Normal grain growth in polycrystalline structures could be explained most clearly for pure, single phase solids. But even in this case, as the energies of the grain boundaries change, the growth kinetics also change from boundary to boundary. For this reason, detailed analysis of grain growth is difficult even for the simplest systems. To simplify the kinetics, constant grain boundary energy is assumed. Accordingly, the classical grain growth kinetics are given by the following equations:

$$D^n - D_0^n = K t$$ \hspace{1cm} (6)

$$K = K_0 e^{-\frac{Q}{RT}}$$ \hspace{1cm} (7)

where $D$ is the mean grain size, $D_0$ is the grain size of the starting polycrystalline powders at time $t = 0$, $t$ is the time, $K_0$ is a rate constant, $Q$ is the activation energy of grain growth, and $n$ is an exponent, which is an integer ranging from 1 to 4 depending on various kinetic aspects involved in the growth process [17].

The grain growth exponent ($n$) changes according to the dominant diffusion mechanism during sintering. It was stated that, if volume diffusion is dominant, $n = 3$; the grain boundary diffusion is dominant $n = 4$ [18]. Since the initial grain size ($D_0$) of the ceramic powder will be very small compared to the final grain size ($D$), the term ($D_0^n$) can be omitted. In this case, equation (6) can be simplified as follows:

$$\frac{D^n}{t} = K_0 e^{-\frac{Q}{RT}}$$ \hspace{1cm} (8)

When the same equation is written in logarithmic scale;

$$\ln \left( \frac{D^n}{t} \right) = \ln K_0 - \frac{Q}{RT}$$ \hspace{1cm} (9)

Assuming that the activation energy is constant in a suitable temperature range, the value of $n$ can be calculated using the slope of the $\ln(D) - \ln(t)$ plot. Then it is possible to calculate the activation energy using equation (9) [17].

The mean grain sizes of all samples are given in Table 3. As expected, the highest grain size value (1029.0 ± 9.5 nm) was reached after 6 hours of sintering at 1400 °C. Similarly, the lowest grain size value (95.3 ± 1.5 nm) has achieved sintering at 1200 °C for
5 minutes. As the temperature increased, the grain sizes of the samples increased monotonically in the same sintering time. In terms of density, although there is no significant difference between 6 hours sintering at 1300 °C and 5 minutes at 1400 °C, it is different for grain sizes. For example, while the mean grain size of the sample sintered at 1400 °C for 5 minutes (1400–5) is 340.0 ± 4.7 nm, the mean grain size of the sample sintered at 1300 °C for 6 hours (1300–6) is 497.2 ± 7.0 nm. At this point, it can be concluded that extending the sintering time has a positive effect on increasing the grain size of the sample. However, the increase in grain size with time is not linear. Figure 8 shows the dependence of mean grain sizes on the sintering temperature and time. When the graph is examined, it has been seen that the grain sizes of the samples sintered at 1300 and 1400 °C reached 1.5–2 times when the sintering time increased from 5 minutes to 1 hour. However, when the sintering time was extended up to 6 hours, the increase in grain sizes did not occur at the same rate. This situation shows that grain growth is limited at a certain point. Contrary, as a result of sintering for 6 hours at 1400 °C, the grains show excessive growth, and an almost linear increase was encountered.

Sintering occurs through different diffusion mechanisms. The “n” exponent in the kinetic equation (equation 6) gives which mechanism is dominant during sintering. The slope of the ln(D) – ln(t) plot in Figure 9 gives the value of 1/n. It has been seen that the value of n is around 4 for all samples. That indicates grain growth is dominated by grain boundary diffusion. The

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**Table 3. Mean grain sizes of all the samples.**

| Sample          | 1200 °C |            |            | 1300 °C |            |            | 1400 °C |            |            |
|-----------------|---------|------------|------------|---------|------------|------------|---------|------------|------------|
|                 | 5 min   | 1 h        | 6 h        | 5 min   | 1 h        | 6 h        | 5 min   | 1 h        | 6 h        |
| **Mean Grain Size (D, nm)** | 95.3 ± 1.5 | 150.8 ± 4.0 | 240.1 ± 4.7 | 186.9 ± 3.9 | 352.0 ± 7.2 | 497.2 ± 7.0 | 340.0 ± 4.7 | 475.3 ± 8.4 | 1029.0 ± 9.5 |

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*Figure 7. SEM micrographs of the sintered samples.*
highly defective nature of the grain boundaries provides the driving force for sintering. Grain boundary diffusion occurs faster than lattice diffusion, and it contributes to the densification of the material rather than grain growth [19].

The calculated n = 4 value was used to determine the sintering activation energies of the samples in Figure 10 by using equation (6). Sintering activation energies of the samples sintered for 5 minutes, 1 hour, and 6 hours are 521.0, 474.4, 595.6 kJ/mol, respectively. This value was given as 254 kJ/mol after 4 hours of sintering for SDC20 prepared by carbonate precipitation method in previous studies [20]. Differences in the production method and sintering conditions lead to different values for sintering activation energy. There is no reported value of sintering activation energy of SDC20 prepared by the chitosan templating method in the literature. However, similar values have been reported for other solid oxide electrolytes (i.e. 669 kJ/mol for LSGM [21], 697 kJ/mol for CeO2 [22], 580 kJ/mol for 3YSZ [23]).

3.3. Conductivity measurements

In this study, to examine the effect of sintering temperature on ionic conductivity, EIS analysis was applied only to samples sintered for 6 hours. The ionic conductivity measurement was performed in air atmosphere in the temperature range of 250 to 800 °C.

Electrochemical Impedance Spectroscopy (EIS) was used to determine the electrical properties of the samples. EIS uses electronically conductive electrodes to characterize the electrical properties of materials. The evaluation of the electrochemical behavior of the electrolyte or electrode materials is performed by applying a voltage to the electrodes and observing their response [24]. SOFC electrolytes are oxygen ion conductors; Therefore, they can be studied using this technique. Impedance spectroscopy is an important technique for investigating mobile charges in ionic, semiconductor, or insulating solids. Additionally, this characterization method can be used to measure the grain boundary, grain interior, and electrode resistance or impedance of a sample [25].

Figure 11 shows the impedance spectra of samples measured at 300, and 800 °C. As could be seen in Figure 11, the 1200–6 and the 1300–6 samples show almost the same and the lowest grain interior resistivity (Rgi) at 300 °C. On the other hand, the 1400–6 sample shows the highest grain interior resistivity at 300 °C considering that it has sintered at the highest temperature. However, at 800 °C, the 1400–6 sample has the highest total resistance value possibly a result of increased grain boundary resistance (Rgib) due to excessive growth of grains by sintering at 1400 °C. Rgib/Rgi value was found 1.7% and 11% for the samples 1200–6 and 1300–6, respectively. Also, for the 1400–6 sample this value was calculated as 30%. The total conductivity values of the samples measured at 800 °C and low and high-temperature activation energies

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1.6 × 10⁻² S.cm⁻¹ at 600 °C. Mori et al. [27] found the ionic conductivity of the SDC20 prepared by carbonate precipitation method and sintered at 1500 °C as 1.2 × 10⁻² S.cm⁻¹ at 600 °C, and Peng et al. [28] calculated the ionic conductivity of the SDC20 electrolyte prepared by oxalate precipitation method and sintered at 1350 °C as 2.0 × 10⁻² S.cm⁻¹ at 600 °C. This study has shown that chitosan templating method is more successful than many methods in the literature for synthesizing superior SDC20 electrolytes.

The ionic conductivity of ceramics generally increases with increasing density and decreases with increasing activation energy. The difference in conductivity between the 1200–6 and the 1300–6 samples may be due to the improvement in density with increasing sintering temperature. In the 1400–6 sample, although the sintering temperature increased, a significant decrease in ionic conductivity was observed. Studies show that there is a decrease in ionic conductivity in SDC20 samples at sintering temperatures above 1300 °C as a result of the merging of high concentration oxygen vacancies due to the reduction of cerium ions. Apart from this, the excessive growth of grains at high temperatures has a negative effect on ionic conductivity. It can be said that the deepening of the grain boundaries plays a preventive role in ion transport [29].

Figure 12 shows the Arrhenius plots of the samples according to the equation: ln σT = ln σ₀ − Ea/kT (k = Bolzmann constant, 8.617 × 10⁻⁵ eV K⁻¹). Plots contain two parts called as LT (low-temperature regime) and HT (high-temperature regime) where the linearity of the plots change and thus the activation energy of the bulk, grain and overall conductivity change with increasing temperature. The change of the activation energy begins around 500 °C. At lower temperatures, oxygen vacancies condense into clusters of ordered vacancies, and at above this temperature all oxygen vacancies appear to be mobile. Thus, in the low-temperature range, the required activation

| Sample  | Ionic Conductivity (S.cm⁻¹) | Eₐ (HT, eV) | Eₐ (LT, eV) | ΔE (eV) |
|---------|----------------------------|-------------|-------------|---------|
| 1200-6  | 0.047                      | 0.678       | 0.778       | 0.100   |
| 1300-6  | 0.052                      | 0.685       | 0.786       | 0.101   |
| 1400-6  | 0.028                      | 0.710       | 0.834       | 0.124   |

are given in Table 4. The highest conductivity value was achieved at the 1300–6 sample (0.052 S.cm⁻¹). This value is almost twice the conductivity value of the 1400–6 sample (0.028 S.cm⁻¹). Ionic conductivity decreased significantly after sintering to 1400 °C. It even went below to the conductivity of 1200–6 sample (0.047 S.cm⁻¹). 1300 °C has been determined as the optimum sintering temperature.

Ma et al. [8] reported the ionic conductivity of the SDC20 electrolyte prepared by the PVA templating method and sintered at 1300 °C as 3.3 × 10⁻² S.cm⁻¹ at 700 °C. Kosinski et al. [1] stated that the ionic conductivity of the SDC20 sintered at 1400 °C is 3.08 × 10⁻² S.cm⁻¹ at 700 °C by using the citrate-nitrate combustion method. Peng et al. [26] calculated ionic conductivity of the SDC20 electrolyte sintered at 1350 °C and synthesized by glycine-nitrate combustion method as

Figure 11. Impedance spectra of the samples measured at 300 °C, and 800 °C.

Figure 12. Arrhenius plots of the samples.
energy for ion conduction equals the sum of the migration enthalpy of oxygen ions (ΔH_m) and association enthalpy of charged defect associations (ΔH_a). In the high-temperature range, free dopant cations and oxygen vacancies occur as a result of dopant cation-oxygen vacancy complex dissociation. Since all the defects are dissociated, the activation energy for conduction (E) equals the migration (ΔH_m) activation energy [30]. It has been shown that oxygen ionic conductivity in doped ceria can be represented by the following equations [31]:

At low temperatures: \[ \sigma = \sigma_0 \exp \left( \frac{\Delta H_m}{R T} \right) \] (9)
At high temperatures: \[ \sigma = \sigma_0 \exp \left( \frac{-\Delta H_a}{R T} \right) \] (10)

The activation energies of the samples sintered at 1200 and 1300 °C are almost same for both high and low-temperature regions. But when the sintering temperature was increased to 1400 °C, a significant increase occurred in the activation energies. Therefore, the decrease in the ionic conductivity of the 1400–6 sample might be explained by the increase in activation energy due to excessive grain growth.

4. Conclusion

Sm_{0.2}Ce_{0.8}O_{1.9} materials were synthesized by a fast and facile chitosan templating method for the first time. Powders were obtained with a single fluorate phase through a calcination step. Prepared pellets sintered at 1200 °C, 1300 °C, and 1400 °C for 5 min, 1 h, and 6 h each. Relative densities of the samples were found to be 93% at 1400 °C for 6 h. Mean grain sizes calculated by using Linear Intercept Method. The grain growth exponent (n) calculated as 4 and grain boundary diffusion was found to be the dominant diffusion mechanism during sintering. Grain growth activation energy was calculated for the first time for this method and was found to be 595.6 kJ/mol for 6 h. 1300–6 sample gave the highest conductivity value of 0.052 S.cm⁻¹ at 800 °C. The chitosan templating method could be used as an effective method to prepare ceria-based structures since the performances of the samples are higher than the samples which were prepared by more complex methods. To understand the ionic conductivity behavior of the SDC20 more clearly, studies will continue under different sintering conditions in the upcoming work.

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