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Electrical and mechanical properties of proton conducting $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$

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Abstract

Yb^{3+} -doped ceramic strontium cerate of exactly the composition $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ was prepared, having a relative density of 99.0 ($\pm 0.3\%$). Great care was taken to obtain homogeneous, carbonate free material. Analysis are made of the X-ray powder diffraction pattern of the as-prepared dense ceramic, resulting in the orthorhombic unit cell parameters $a = 6.997(2)$ Å, $b = 12.296(3)$ Å, $c = 8.588(2)$ Å, $Z = 8$ and $d_x = 5.806(2)$ g cm⁻³. Bending strength values of the ceramic in non-proton and proton conducting state are found to be 177 and 194 MPa respectively. The ceramic kept under proton conducting conditions for 500 h at 300°C to 800°C in a N₂ flow containing 155 mbar water vapour and 245 mbar H₂, have shown to remain chemically and structurally stable. Impedance spectroscopy measurements of the bulk conductivity of the proton conducting ceramic revealed an activation energy of 53.2 kJ mol⁻¹ and a preexponential factor of 359.1 (Ω cm)⁻¹ K. In the non-proton conducting state the ceramic is mainly oxygen ion vacancy conducting, which indicates that charge compensation on substituting Yb^{3+} in SrCeO_3 takes place by oxygen ion vacancies.

Keywords: Wet-chemical synthesis; $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$; HTPC; Chemical and structural stability; Powder X-ray diffraction; Bending strength; Bulk proton conductivity

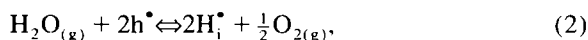
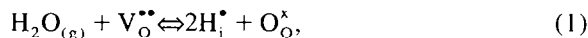
1. Introduction

Alkaline earth cerate perovskites, such as BaCeO_3 and SrCeO_3 , are known to exhibit protonic conductivity, in the presence of water vapour at elevated temperatures ($\leq 500^\circ\text{C}$) [1]. Iwahara and co-workers have demonstrated that rare earth oxide-doped BaCeO_3 and SrCeO_3 have the highest protonic conductivity of any material in this temperature range [1–12]. For this reason proton conducting rare earth oxide-doped barium and strontium cerate are

considered to be possible electrolyte materials for use in electrochemical devices like high-temperature solid oxide fuel cells, steam electrolyzers, hydrogen sensors in gas atmospheres and in molten metals, hydrogen supply or extraction to or from hydrogenation or dehydrogenation reactions with organic gases, etc. [1–14]. However, a precondition for applications, which is hardly checked in literature, is that the ceramic material remains chemically and structurally stable and sufficiently strong when submitted to various conditions during application. Unique for these high temperature protonic conducting materials is that they contain intrinsically no

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protons. The protons have to be introduced into the host matrix at elevated temperatures, either by dissolution of and reaction with water vapour [see Eqs. (1) and (2)], or with hydrogen [see Eq. (3)], depending on the dominant conducting species in the intrinsically non-proton conducting state. These species are the oxygen ion vacancies or the electron-holes respectively:



A proton dissolved in an oxide may be regarded simply as an interstitial proton, H_i^+ . However, the proton is an infinitesimally small particle. It is incapable of occupying a regular interstitial position in the lattice. An interstitial proton is attracted to the electron cloud of a neighbouring oxygen ion and associates strongly with this ion, resulting in a hydroxide ion, with defect notation $(\text{OH})_\text{O}^{\bullet}$, [12]. These two defect expressions for an interstitial proton however, are equivalent for defect structure evaluations. For simplicity we shall therefore use, H_i^+ . The transport of protons is accepted [12] to be completely dominated at elevated temperatures by the free migration mechanism, i.e. the protons move by jumping between stationary host oxygen ions. Transport related properties of ceramic rare earth oxide doped barium and strontium cerates have been extensively studied in literature, e.g. [1–25]. However, it is open to question if the materials subjected to these studies have been chemical homogeneous, were carbonate free, had a sufficiently high relative density, were strong enough in the as prepared and proton conducting state, or had the composition that they were supposed to have. The reason for this doubt is that in literature, in all cases the synthesis was started by a solid state reaction of a mixture of the metal oxides and nitrates, or by a wet-chemical synthesis of weighed amounts of the latter powders. Presentation of the results of a characterization of e.g. the composition, chemical homogeneity, purity, density or fracture strength of the resulting ceramics is in general very scarce or not given at all. The aim of the present study is the preparation of carbonate

free, dense and chemically homogeneous ceramic material of exactly the composition $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$. Results are given of characterizations of the ceramic material by: X-ray powder diffraction pattern analysis, measurement of the (relative) density, chemical and structural stability, fracture strength and the electrical transport properties of the ceramic as proton conductor and as non-proton conductor.

2. Experimental

2.1. Synthesis and density of carbonate free, ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$

Stock solutions of the nitrates of strontium, cerium and ytterbium were made and acidified to prevent hydroxide formation. The metal ion concentrations in each of these acidified solutions were determined by chemical analysis. For sample preparation calculated amounts of each stock solution were taken and mixed with EDTA (ethylenediaminetetraacetic acid), while the pH was increased simultaneously to about pH 10 by adding concentrated ammonia. In this way, a clear yellow-coloured solution was obtained of the metal-EDTA complex. This solution was heated in a porcelain pan, to evaporate the liquid. In the last part of the liquid evaporation very strong swelling of the EDTA-complex solution took place, which was followed by pyrolysis. The resulting powder was very voluminous. To reduce the volume, the powder was dry-milled for 3 h with nylon balls in a polyethylene (PE) bottle in a Turbula-3D apparatus. Then the powder was heated in air first to 400°C and next to 650°C, altogether in 10 h, in order to remove the ammonium nitrate by decomposition. The remaining powder showed a broadened X-ray diffraction pattern, already containing reflections characteristic for the orthorhombic structure of ceramic ytterbium-doped strontium cerate. This powder was then wet-milled in a PE-bottle with nylon balls and propanol-2 in a Turbula-3D apparatus for 5 h, to reduce the mean agglomerate size. After drying under nitrogen at 70°C–120°C, the powder was calcined for 16 h at 1195°C, in a nitrogen stream to promote decomposition of metal carbonates [26], if present. Next the powder was dry-milled for 6 h

under nitrogen with nylon balls in a PE-bottle in the Turbula-3D apparatus. Analysis of the particle size distributions was made by means of the Microtrack X100 particle analyzer of the dry-milled, calcined powder. For comparison the latter powder was also analysed, after being dispersed ultrasonically in water, during 10 min. The untreated powder had a mean particle size of 3.26 μm , whereas the ultrasonically treated powder had a mean particle size value of 2.28 μm . This shift in mean agglomerate size was significant. On the other hand the effect of ultrasonic dispersion on the mean agglomerate size was considered to be too small for including ultrasonic dispersion in the ceramic preparation route. To determine if carbonates might be present in the calcined powder, thermogravimetric/differential scanning calorimetry (TG/DSC) runs were made of samples of powder not heated higher than 650°C and of powder calcined at 1195°C, in high purity helium gas on a PL Thermal Sciences System (STA-625) equipment. Only the former powder showed a weight loss, that occurred between about 870°C and 970°C and was ascribed to loss of CO_2 [26]. From these results it was concluded that the calcined powders were carbonate-free.

For preparing sintering of pellets, about 10 grams of the calcined, dry-milled powder was taken to press hydrostatically a cylindrical pellet, by applying 120 MPa during 5 min. Subsequently, this pellet was pressed isostatically at 400 MPa during 5 min. The green-density of the pellets after the latter treatments was very reproducibly $3.65 \pm 0.04 \text{ g cm}^{-3}$, which corresponds to a relative density of $62.9 \pm 0.7\%$ as determined on the basis of X-ray powder diffraction data, obtained in this study [27]. Densities were measured according to the Archimedes method by immersing the pressed pellets in mercury. Prior to sintering the green pellets were placed on Pt foil and covered with powder of the same composition to provide an atmosphere composition during sintering. Sintering took place in a nitrogen flow at $1295 \pm 5^\circ\text{C}$ for 12 h. During sintering no weight loss was observed. The density after sintering was very reproducibly $5.75 \pm 0.02 \text{ g cm}^{-3}$, which corresponds to a relative density value of $99.0 \pm 0.3\%$ [27]. Sintered samples had a mean grain diameter of $7 \pm 1 \mu\text{m}$, as measured by scanning electron microscopy (SEM) analysis.

Two methods were applied to determine if metal carbonates were present in the dense sintered $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ samples. The first method was carried out by subjecting about 20 mg of the powdered ceramic in a Pt pan, to TG/DSC runs. A PL Thermal Sciences System (STA-625), was used for the experiments, which were performed under a constant flow of high purity helium gas (PRAXAIR Helium 5.0), between room temperature and 1300°C, applying a heating and cooling rate of 2°C min^{-1} . The detection limit of weight changes was about 0.01 mg. No significant weight change or DSC signal was observed. Hence no carbonates were found in the ceramics [26]. The second method was a chemical analysis which was performed by adding a strong acid to about 200 mg of the powdered ceramic material. This treatment should decompose carbonates if present. In the case that CO_2 was developed, this should be carried by a flow of high purity helium gas to a titration vessel. The detection limit of the latter analysis technique was $3.3 \times 10^{-4} \text{ mol CO}_2$. Hence, by this second method also no carbonate was detected.

3. Results and discussion

3.1. X-ray powder diffraction pattern and phase composition analysis

X-ray diffraction runs were made of powdered ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ without and with LaB_6 as a standard to determine the corrections for the d -spacing of $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$. Results are collected in Table 1. No reflections could be related to other phases than of $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$. Details of this X-ray powder diffraction pattern analysis and comparison of the results with literature values are given elsewhere [27].

Table 1
Refined unit cell parameters for $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ [27]

Orthorhombic setting			
a (Å)	6.997(2)	Z	8
b (Å)	12.296(3)	d_x (g cm^{-3})	5.806(2)
c (Å)	8.588(2)		

3.2. Three-point bending strength

Bending strength experiments were made of non-proton and of proton conducting bars. To be able to compare the bending strength values of both types of bars, these were prepared from the same ceramic pellet. This preparation was as follows. From one dense ceramic pellet of $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$, 20 bars of $20 \times 3 \times 1$ mm were cut by a diamond saw. All the bars were ultrasonically cleaned for 15 min in propanol-2 and after drying, heated in a nitrogen flow, up to 800°C during 30 min for relaxation of mechanical stresses. Heating and cooling rates were both 1°C min^{-1} . After cooling, 10 bars were ready as non-proton conducting bars. The other 10 bars were converted to proton conducting material by exposing them during two days at 700°C to a nitrogen flow containing 155 mbar water vapour and 245 mbar hydrogen gas. Then the temperature was decreased fast to room temperature, while keeping the flow composition unchanged until about 20 h later when both the series of 10 bars each, were subjected to the three point bending test procedure to determine their fracture strength in air and at room temperature. The measurements of the three-point bending strength (σ_{F}) values were performed with Overdyn S220 equipment provided with a load cell for 5 kN. The bending strength, σ_{F} , is calculated from Eq. (4):

$$\sigma_{\text{F}} = 3 \cdot F \cdot s / 2 \cdot b \cdot w^2. \quad (4)$$

Here, F (N) is the measured force at which fracture took place, s , b , w , are the length (20 mm), the height (1 mm) and the width (3 mm) of the bar, respectively. The mean three-point bending strength values of the parallel prepared series of non-proton and of proton conducting bars, are presented in Table 2. Also given in Table 2 is the mean three-point bending strength value of a series of bars of non-

Table 2
Three-point bending strength values of ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$

Non-proton conducting	Proton conducting
177 ± 7 MPa ^a	194 ± 6 MPa ^a
175 ± 6 MPa	

^a These values are for sample series made of the same ceramic pellet.

proton conducting material, prepared from a fresh powder batch. The strength values of the series of non-proton conducting ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ bars, made from different powder batches, are reproducible and high. In literature [30], four-point bending strength values of about 45 MPa are reported for solid state reaction prepared ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ samples that were exposed for 100 h, at 900°C to a coal gas atmosphere. The difference between 45 MPa and 177 MPa is significant, hence we conclude that the preparation route of ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ that is followed, gives much stronger ceramics, than when preparation takes place by a solid state reaction of the metal oxides and carbonates.

The increase in bending strength found for proton conducting samples compared to the bending strength for the non-proton conducting ones, is significant, when the inaccuracy limits are considered. There are no investigations made to study the mechanism of this increase in strength. A suggestion why the bending strength value is increased, may be that the hardness of the ceramic material is increased, because of a decrease in the presence of macrocracks, as a consequence of localised stresses that are generated by filling of oxygen ion vacancies with oxygen ions, coming from the dissolved water.

3.3. Chemical and crystal phase stability of dense, ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$

Chemical instability was reported [28] of undoped and of rare earth oxide doped ceramic BaCeO_3 that was exposed to water vapour at temperatures between 500°C and 900°C , during a few days. The chemical instability of both doped SrCeO_3 and doped BaCeO_3 was discussed by [34]. The conclusion of [34] was that chemical instability of the cerate electrolytes does not present a significant problem for the operation in hydrogen–air fuel cells in spite of presence of CO_2 in the anodic atmosphere. We have investigated by powder X-ray diffraction analysis, if the dense ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ samples may have suffered chemically and/or structurally by the exposition during 500 h to temperatures between 300°C and 800°C at atmospheric pressure to a nitrogen flow, containing 155 mbar water vapour and 245 mbar H_2 .

The reflection data of the exposed ceramic were compared with those belonging to as-prepared ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ [27], but also with the d -spacings and relative intensities obtained from the ICDD system of the following materials: CeO_2 , Ce_2O_3 , SrO , SrCO_3 and Yb_2O_3 of which one or more may be expected to be formed on chemical disintegration of $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$. Comparison of the d -spacings and the relative intensities of the latter materials, with those observed for the exposed ceramic, showed that none of the possible decomposition materials reflections were coinciding with reflections of the exposed ceramic. However, comparison of the reflection data of the exposed ceramic with the X-ray diffraction (XRD) data of as-prepared ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ [27], presented in Table 3, show a perfect agreement. Hence, it can be concluded that the ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ material exposed to the conditions mentioned above, to make it proton conducting for longer times, is not suffering from chemical or structural instability.

3.4. Impedance spectroscopy

Dense sintered ceramic pellets of $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ were cut by a diamond saw into discs with a diameter of 15 mm and a thickness of 1 mm. Subsequently these discs were cleaned ultrasonically in propanol-2 during 10 min and after drying, heated in a N_2 flow, up to 800°C for 30 min for relaxation of the mechanical stresses. Heating

and cooling rates were both 1°C min^{-1} . The discs were provided with thin Au films, as electrodes, by DC-magnetron sputtering of an Au target in an Ar plasma (20 min, 35 mA) and subsequent annealing during 1 h at 900°C , in a flow of N_2 , to make the films porous. Impedance spectroscopy measurements have been performed with a 20 mV AC signal, using a Solartron model 1250 Frequency Analyser in a two-terminal set-up, between 350°C and 800°C . The spectra were recorded in a frequency range from 0.1 Hz to 65.5 kHz. The impedance spectra have been analysed to yield the bulk conductivity values by using the curve-fit computer programme EQUIVALENT CIRCUIT [31–33]. The two Arrhenius parameters, i.e. the activation energy E_{act} and the pre-exponential factor A , are taken from plots of $\ln(\sigma T)$ against $1/T$. The impedance measurements were made of ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ discs in the non-proton conducting state as well as in the proton conducting state. The as-prepared ceramic is non-proton conducting material.

Impedance spectroscopic measurements were performed of non-proton conducting ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ discs, in two flowing ambients, containing different oxygen concentrations, at atmospheric pressure. The ambients were dry, pure N_2 (containing $P_{\text{O}_2} \leq 10^{-2}$ Pa) and dry 100% O_2 . The aim of these measurements was to determine if 5 mol% Yb^{3+} substituted SrCeO_3 is mainly an electron-hole or an oxygen ion vacancy conductor. In case the highest bulk conductivity is observed for

Table 3

X-ray diffraction pattern of ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ samples pretreated during 500 h, at 300°C to 800°C in a N_2 flow containing 15.5% $\text{H}_2\text{O}_{(\text{g})}$ and 24.5% $\text{H}_{2(\text{g})}$, compared with X-ray powder reflections of $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ taken from [27]

$2\theta_{\text{obs}}$	$I(\text{rel})_{\text{obs}}$	$d\text{-space}_{\text{obs}}$	2θ [27]	$I(\text{rel})$ [27]	$d\text{-space}$ [27]
20.656	12	4.2966	20.66	12	4.2968
29.020	29	3.0745	29.02	29	3.0744
29.384	100	3.0372	29.37	100	3.0390
29.728	26	3.0028	29.71	29	3.0046
42.061	47	2.1465	42.03	48	2.1479
43.478	8	2.0798	43.39	4	2.0838
47.306	9	1.9200	47.30	9	1.9204
51.700	24	1.7667	51.68	27	1.7672
51.923	16	1.7596	51.91	20	1.7600
52.388	19	1.7451	52.34	20	1.7466
52.591	29	1.7388	52.57	30	1.7394
60.995	15	1.5178	60.98	17	1.5182
69.155	16	1.3573	69.12	18	1.3578

samples in the ambient of pure N_2 , it can be concluded that the electrical conductivity in the bulk of $SrCe_{0.95}Yb_{0.05}O_{3-\alpha}$ ceramics is dominated by oxygen ion vacancies. If the conductivity of the bulk is higher in the oxygen ambient, electron-holes dominate the bulk conductivity. The Arrhenius parameters of the bulk conductivity in the latter measurements, presented in Table 4, show that the bulk conductivity of ceramic $SrCe_{0.95}Yb_{0.05}O_{3-\alpha}$ is lower when the oxygen partial pressure is higher. This leads to the conclusion that the bulk conductivity of ceramic $SrCe_{0.95}Yb_{0.05}O_{3-\alpha}$ is dominated by migration of oxygen ion vacancies. This result supports the model that oxygen ion vacancies are formed by charge compensation on substituting the aliovalent cation Yb^{3+} for Ce^{4+} in $SrCeO_3$ and that protons can be introduced in ceramic $SrCe_{0.95}Yb_{0.05}O_{3-\alpha}$ according to Eq. (1), by dissolving H_2O vapour in the ceramic, at elevated tempera-

tures. In Table 4 also Arrhenius parameter values are presented which are obtained from literature. The magnitude of these values do agree with ours and hence they support our conclusions.

To prepare proton conducting ceramic $SrCe_{0.95}Yb_{0.05}O_{3-\alpha}$ material, discs were exposed to flowing ambients at atmospheric pressure, of either 15.5% water vapour, 24.5% hydrogen gas and 60.0% nitrogen gas, or 15.5% water vapour, 5.4% hydrogen gas and 79.1% nitrogen gas. Impedance measurements were made after reaching equilibrium. The Arrhenius parameters of the bulk conductivity of the latter experiments are presented in Table 5. These results show that in spite of a difference of almost 20% in hydrogen gas concentration between the two ambients to which the discs were equilibrated, the Arrhenius parameters are almost equal. That may lead to the conclusion that the presence of a relatively high water vapour concentration of 15.5% in the ambients is of more importance for having protonic conductivity in ceramic $SrCe_{0.95}Yb_{0.05}O_{3-\alpha}$, than the extent of the simultaneously present hydrogen gas concentration. Comparing our E_{act} values with those from literature [15,29,37,38], also mentioned in Table 5, show that our values are significant lower. The latter observation may be due to a higher chemical homogeneity of the material that we have prepared. The literature values of E_{act} are mutually almost equal in magnitude, although the compositions of their ambients seem to differ considerable and do contain only water vapour or hydrogen gas. This apparent insensitivity for the composition of the ambients, may be

Table 4
Parameters of the bulk conductivity of $SrCe_{0.95}Yb_{0.05}O_{3-\alpha}$ in dry N_2 and in dry O_2

E_{act} (kJ mol ⁻¹)	A (Ω cm) ⁻¹ K	Treatment	Ref.
64 ^b	160.1 ^b	Dry, pure N_2	This work
91 ^c	7.84×10^3 ^b	Dry, 100% O_2	This work
79 ^{a,c}		N_2	[1]
92.6 ^{a,c}		O_2	[1]
64.7 ^b		100% O_2	[15]
60.8 ^b		1% O_2 + 99% Ar	[15]

^a Values are calculated from Fig. 3 in [1].

^b Estimated from the Arrhenius plot of $\ln(\sigma T)$ against $1/T$.

^c Estimated from the Arrhenius plot of $\ln(\sigma)$ against $1/T$.

Table 5
Parameters of the total bulk conductivity of $SrCe_{0.95}Yb_{0.05}O_{3-\alpha}$ in various ambients at atmospheric pressures

E_{act} (kJ mol ⁻¹)	A	Treatment	Ref.
53.2 ^a	359.1^a (Ω cm) ⁻¹ K	15.5% $H_2O_{(g)}$, 24.5% $H_{2(g)}$, 60% $N_{2(g)}$	This work
53.6 ^a	345.4^a (Ω cm) ⁻¹ K	15.5% $H_2O_{(g)}$, 5.4% $H_{2(g)}$, 79.1% $N_{2(g)}$	This work
60.8 ^a	3000^a (Ω cm) ⁻¹ K	H_2O saturated Ar	[29]
56.9 ^b		5% H_2 + 95% N_2	[36]
60.8 ^a	3.3×10^3 (Ω cm) ⁻¹ K	$H_2O_{(g)}$	[15]
61.8 ^a		$N_2 - H_2$ mixtures	[35,37]
60.8 ^a		$H_2O_{(g)}$	[38]

^a Estimated from the Arrhenius plot of $\ln(\sigma T)$ against $1/T$.

^b Estimated from the Arrhenius plot of $\ln(\sigma)$ against $1/T$.

a consequence of the solid state reaction route applied for the synthesis of the ceramic material, investigated in the literature mentioned.

4. Conclusions

1. Ceramics of exactly the composition $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ could be prepared by starting the synthesis from stock solutions of the metal nitrates. Prior to the synthesis the metal concentrations of these stock solutions were determined by chemical analysis.
2. The wet-chemical synthesis route applied, have shown to be advantageous for obtaining carbonate-free, chemical homogeneous material, with a high relative density ($99.0 \pm 0.3\%$) and a high bending strength of 177 MPa and 194 MPa for non-proton and proton conducting material respectively.
3. The high temperature proton conductivity of the bulk of ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ in equilibrium with a flowing ambient, containing 15.5% water vapour, at least 60% pure N_2 and between 5.4% and 24.5% hydrogen gas, have shown to be independent of the exact amount of hydrogen gas present.
4. Ceramic $\text{SrCe}_{0.95}\text{Yb}_{0.05}\text{O}_{3-\alpha}$ exposed during 500 h to temperatures between 300°C and 800°C in a flowing ambient of 15.5% water vapour, 24.5% hydrogen gas and 60.0% nitrogen gas, do not suffer from chemical or structural instability.

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