1. Introduction

Y-Doped BaZrO₃ (BZY) is an attractive material due to its high protonic conductivity in a humid atmosphere.¹⁻³ Incorporation of BZY into fuel cells as an electrolyte therefore seems to be quite promising, since the operation temperature can thereby be decreased to an intermediate temperature range (450–700 °C), lower than that of conventional solid oxide fuel cells (SOFCs) using oxide ion conductive electrolytes (around 750–1000 °C).⁴⁻⁵ Great efforts have been devoted to the development of BZY electrolyte-based fuel cells.⁶⁻¹³ However, a lot of challenges still remain. Referring to the anode, it is regarded to be a good choice to use a composite one (generally, a mixture of nickel oxide (NiO) and the corresponding electrolyte material) which has already been widely applied in the SOFC community.³ The same strategy has also been introduced into the BZY electrolyte-based fuel cells with prospective applicability.¹⁴⁻¹⁶

However, during the co-sintering process for fuel cell fabrication, a second phase of BaY₂NiO₅ formed due to the reaction between BZY and NiO.¹⁴⁻¹⁵ Although a positive role of BaY₂NiO₅ was demonstrated in improving sinterability of BZY was suggested by Tong et al.,¹⁷ a recent work by Fang et al. reported that such second phase decomposed in reducing or humid environment at 900 °C.¹⁸ Since H₂ will be fed to the anode, existence of BaY₂NiO₅ is rather unfavorable, whose decomposition introduces electrochemical insulator phase (Y₂O₃), and also potentially results in cracks or delamination in the anode.¹⁷ However, although BaY₂NiO₅ formed after heating BZY–NiO mixture at 1400 °C, its existence was not confirmed by elevating the temperature to 1600 °C.¹⁷ Such information suggests the possibility to suppress the formation of BaY₂NiO₅. But first of all, it is necessary to perform a detailed investigation on the behavior of BaY₂NiO₅ at high temperature, and also the reaction between BZY and NiO. We therefore conducted this work.

2. Experimental

2.1 Material preparation

Samples of BaZr₀.₈Y₀.₂O₃₋₅ (BZY20) and BaY₂NiO₅ were prepared by a conventional solid state reaction method. Starting materials (BaCO₃, ZrO₂ and Y₂O₃ for BaZr₀.₈Y₀.₂O₃₋₅ and BaCO₃, Y₂O₃ and NiO for BaY₂NiO₅) were mixed at the desired ratios, and ball-milled for 24 h. Mixtures were then pressed into pellets under 9.8 MPa and heat-treated at 1000 °C in ambient atmosphere for 10 h. After ball-milling for 10 h, the samples were pressed into pellets under 9.8 MPa again, and kept at 1300 °C in ambient atmosphere for 10 h for synthesisizing. The as-synthesized samples were ball-milled for 100 h and 24 h for BZY20 and BaY₂NiO₅.
respectively. The BaY$_2$NiO$_5$ powder was pressed at 392 MPa to prepare pellet-like samples. For all the heat-treatments in this work, the heating rates from room temperature to 1000 °C, and 1000 °C to higher temperature (1300, 1400, 1500 and 1600 °C) were 4.17 and 3.33 °C min$^{-1}$, respectively.

The as-synthesized BZY20 powder was pressed into pellets at 392 MPa. After being embedded in sacrificial powder with the composition of the as-synthesized BZY20, these BZY20 pellets were heated at 1600 °C for 24 h in oxygen atmosphere for sintering. The as-sintered BZY20 was pulverized by ball-milling for 50 h. For the sake of clarity, BZY20 with the final heating temperature of 1300 and 1600 °C are named as BZY20 (1300 °C) and BZY20 (1600 °C), respectively, in this work. Then, both BZY20 (1300 °C) and BZY20 (1600 °C) were mixed with 70 wt% NiO, and ball-milled for 10 h for mixing. The mixture was then pressed at 392 MPa to form pellet-like samples.

2.2 Sintering strategy

With the purpose to create environment containing different BaO activity during the sintering process, as shown in Fig. 1, different strategies were attempted for sample setting. To evaluate the stability of BaY$_2$NiO$_5$ at 1500 and 1600 °C, a method as shown in Fig. 1(a) with the name of open-sintering was used. Magnesia (MgO) containers were inserted between the BZY20 plate-like samples and alumina (Al$_2$O$_3$) plate-like crucibles to prevent their direct touch and unfavorable reaction. In addition to the open-sintering, two other methods named as cover-sintering (Fig. 1(b)) and embed-sintering (Fig. 1(c)) were also applied to evaluate the reactivity between BZY20 and NiO by heat-treating the BZY20–70 wt% NiO pellet-like samples. In the cover-sintering method, the BZY20–70 wt% NiO pellet-like samples were covered with Al$_2$O$_3$ caps. Sacrificial powder (BZY20 (1300 °C)–10 wt% BaCO$_3$) was added to prevent a direct touch of the samples from the Al$_2$O$_3$ plate-like crucibles, and also seal the space between the Al$_2$O$_3$ caps and the plate-like crucibles in certain degree. In the embed-sintering, the samples were embedded in sacrificial powder (only BZY20) in the MgO containers. After heat-treatment, the BaY$_2$NiO$_5$ and BZY20–70 wt% NiO pellet-like samples were all quenched in the ambient atmosphere.

2.3 Characterization

X-ray diffraction (XRD) measurements were performed using Cu K$_\alpha$ radiation with X’Pert-ProMPD (PANalytical, Almelo, Netherlands). Rietveld refinement was carried out utilizing a commercial software X’Pert HighScore Plus to simulate the XRD patterns. Microstructures were observed by scanning electron microscopy (SEM) with VE-7800 (Keyence Co., Osaka, Japan) and scanning transmission electron microscopy (STEM) with JEM-2100F (JEOL, Tokyo, Japan). Energy dispersion X-ray spectroscopy with Genesis-XM2 (SEM-EDS, EDAX, Mahwah, NJ) and also JED-2300 (STEM-EDS, JEOL, Tokyo, Japan) were used for composition measurement.

3. Results

3.1 Stability of BaY$_2$NiO$_5$ in H$_2$ and O$_2$ atmospheres

As shown in Fig. 2(a), the as-synthesized BaY$_2$NiO$_5$ sample was a single phase after the heat-treatment at 1300 °C. The single
phase was also confirmed after keeping the sample powder at 600 °C in dry O₂ atmosphere for 72 h (Fig. 2(b)). However, when the atmosphere was changed to dry H₂, as shown in Fig. 2(c), BaY₂NiO₅ decomposed completely (eqn (1)). Since the sample was later exposed to the ambient atmosphere containing H₂O and CO₂ for the XRD measurements, Ba(OH)₂ H₂O, BaCO₃ were identified. Such result agrees with that reported by Fang et al. by heating BaY₂NiO₅ at 900 °C in dry H₂.¹⁵

\[
\text{BaY}_2\text{NiO}_5 + \text{H}_2(\text{g}) \xrightarrow{600 \degree \text{C}} \text{Ba(OH)}_2 + \text{Y}_2\text{O}_3 + \text{Ni}
\]

### 3.2 Stability of BaY₂NiO₅ at 1500 and 1600 °C

In order to evaluate the behaviour at 1500 and 1600 °C, BaY₂NiO₅ pellet-like samples were heat-treated at these temperatures in ambient atmosphere for desired time, and finally quenched. It is worth noting here that at first, we placed the samples directly on Al₂O₃ plate-like crucibles, but found that BaY₂NiO₅ reacted with Al₂O₃ to form BaAl₂O₄ and Ba₂Y₆Al₆O₂₃ at 1500 and 1600 °C (detailed information is given in Fig. S1 to S3f). In order to prevent such reaction, we then used MgO containers to accommodate the BaY₂NiO₅ samples (a schematic as shown in Fig. 1(a)). As shown in Fig. 3, when heating at 1500 °C, the samples kept the round pellet-shape, and no obvious change in their appearance was confirmed. However, when heating at 1600 °C, although the shape of the pellets can still be identified, it is obvious that black liquid-like product formed, which further spread over the entire surface of the MgO containers with the heating time increased to 2 h. After the sample was heated for 24 h, such black liquid-like product disappeared, and the MgO crucibles showed green appearance possibly due to the diffusion of Ni inward.

These residues of BaY₂NiO₅ pellet-like samples were pulverized and analysed by powder XRD. As shown in Fig. 4, when heating at 1500 °C for 0 h (quenched immediately after heating up to 1500 °C) and 1 h, only the diffraction peaks belonging to the BaY₂NiO₅ single phase were observed. When the sample was kept at 1500 °C for 2 h, diffraction peaks of Y₂O₃ appeared. And the intensity of Y₂O₃ peaks further increased with the heating time extended to 5 and 24 h. These results suggest that at 1500 °C, BaY₂NiO₅ is still a solid phase. However, theoretical calculation based on reported thermodynamic data¹⁹⁻²¹ reflects the fact that Ba and Ni oxides and hydroxides have relatively high partial pressure at high temperature, as shown in Fig. 5. For example, the partial pressure of Ba(OH)₂ was calculated to be as high as 7.32 × 10⁻⁵ atm at 1500 °C, if the reaction among BaO(s), H₂O(g) (partial pressure assumed as 0.01 atm), and Ba(OH)(g) reached equilibrium. Such volatile property of Ba and Ni oxides and hydroxides results in a gradual decomposition of BaY₂NiO₅, with Y₂O₃ remained (eqn (2)).

\[
\text{BaY}_2\text{NiO}_5(\text{s}) \xrightarrow{1500 \degree \text{C}} \text{Y}_2\text{O}_3(\text{s}) + \text{BaO}(\text{g}) + \text{NiO}(\text{g})
\]

The case for heating at 1600 °C is different. As shown in Fig. 6(a), even the sample was just heated up to 1600 °C, in addition to BaY₂NiO₅, diffraction peaks belonging to Y₂O₃ and BaNiO₂ appeared. When the sample was heated for 24 h, the BaNiO₂ peaks disappeared. Such results suggest a totally different phase relationship at 1600 °C, compared with the case at 1500 °C. SEM-EDS analysis was then performed on the sample heated at 1600 °C for 0 h (quenched immediately after heating up to 1600 °C). As shown in Fig. 7(a), the area marked with number 1 and 2 has the composition close to BaY₂NiO₅ (detailed SEM-EDS point analysis results are given in Table S1†), whereas some adjacent areas (point 6) is compositionally Y-rich, indicating possible existence of Y₂O₃. The areas with the composition close to BaNiO₂ (points 4 and 5) showed a clear liquid-like appearance with some small precipitates embedded (a SEM image with large magnification is given in Fig. 7(b)). However, we did not succeed in determining the composition of these precipitates by SEM-EDS, because they are too small. Since the shape of the round pellets can still be identified even after heating for 24 h (Fig. 3(f)-(j)), it is reasonable to believe that at 1600 °C, BaY₂NiO₅ do not melt, but peritectically decomposed to Y₂O₃ and a liquid phase, as given in eqn (3). But during
the quenching from 1600 °C, the liquid phase decomposed to BaNiO2 and the small precipitates (eqn (4)). Based on previous reports on relevant systems,22–25 we here propose a schematic pseudoternary phase diagram of BaO–YO1.5–NiO at 1600 °C (Fig. 8), in which a qualitative indication of the phase relationship was given. Anyhow, quantitative determination of the phase boundary might be an interesting topic in the future.

$$\text{BaO} + \text{NiO} \rightarrow \text{BaNiO}_2$$

$$\text{Ba} + \text{Y}_2\text{O}_3 \rightarrow \text{BaY}_2\text{NiO}_5$$

$$\text{BaY}_2\text{NiO}_5 \rightarrow \text{BaNiO}_2 + \text{Y}_2\text{O}_3$$

$$\text{BaY}_2\text{NiO}_5 \rightarrow \text{BaNiO}_2 + \text{small precipitates}$$
Y2O3 peaks disappeared, whereas those of BaY2NiO5 appeared. The existence of BaY2NiO5 was con... 1200–1300 °C, and also reduced the BaY2NiO5 amount (1.1 and 1.7 wt% at 1200 and 1300 °C, respectively). In addition, in both the two cases, Y2O3 appeared at 1400 °C, with its amount increased with the elevating temperature.

Variation of lattice constants of the perovskite phase (BZY20) in the BZY20–70 wt% NiO mixture is shown in Fig. 11. It is clear that without adding NiO, the lattice constant of BZY20 finally heat-treated at 1300 °C is smaller than that heat-treated at 1600 °C. The lattice constant of the perovskite phase in BZY20 (1600 °C)–70 wt% NiO decreased with the increasing heating temperature, due to diffusion of Ni cations into the BZY20 lattice, accompanied by an intra-grain Ba-loss.3 But the lattice constant of the perovskite phase in BZY20 (1300 °C)–70 wt% NiO increased slightly with the increasing temperature, which is regarded to be a combined effect from the Ni diffusion (shrinking the lattice) and improvement in compositional homogeneity (expanding the lattice). The status of the perovskite phase in these two samples seems to get approached after heating at 1500 °C for 10 h, since the lattice constants was very close. However, after heating at 1600 °C, the lattice constant of the perovskite phase in BZY20 (1600 °C)–70 wt% NiO is relatively small, compared with that in BZY20 (1300 °C)–70 wt% NiO. It is attributed to a more severe Ba-loss in the open-sintering mode at such high temperature (1600 °C), and also a more significant segregation of Y2O3 (as shown in Fig. 10).

### 3.3 Dependence of BZY20–NiO reactivity on final heating temperature of BZY20

It is thereby an interesting and also important topic that under what kind of conditions would BaY2NiO5 form in the anode. Pellet-like samples with the composition of BZY20 : NiO = 30 : 70 wt% were heated in ambient atmosphere at the temperature range of 800 to 1600 °C for 10 h with the open-sintering method (Fig. 1(a)). Both the BZY20 powders finally heat-treated at 1300 and 1600 °C were used. As shown in Fig. 9(a), for the BZY20 (1300 °C)–70 wt% NiO mixture, peaks belonging to Y2O3 appeared even after heating at 800 and 900 °C, possibly due to the improvement of crystallinity of the Y2O3 residue. When the temperature was elevated to 1000 °C, the Y2O3 peaks disappeared, whereas those of BaY2NiO5 appeared. The existence of BaY2NiO5 was confirmed from 1000 to 1400 °C. In addition, at 1400 °C, the peaks of Y2O3 rose again to co-exist with those of BaY2NiO5. When the temperature was further increased to 1500 and 1600 °C, BaY2NiO5 disappeared. Only the Y2O3 peaks were observed.

However, the mixture added with the BZY20 powder finally heated at 1600 °C behaved in a different way. As shown in Fig. 9(b), no second phase was confirmed when the sample was heat-treated from 800 to 1100 °C. The peaks belonging to BaY2NiO5 appeared only with the temperature elevated to 1200 and 1300 °C. Further heating at 1400–1600 °C results in the formation of Y2O3, but BaY2NiO5 disappeared.

The XRD patterns were simulated by Rietveld refinement to estimate weight amounts of the second phases. As shown in Fig. 10, when BZY20 (1300 °C) was added, the weight amount of BaY2NiO5 was larger than 3 wt% after heating at 1000–1200 °C, and decreased with the increasing temperature higher than 1200 °C. However, using BZY20 (1600 °C) powder did not only lead to a relatively narrow temperature range for BaY2NiO5 confirmation (1200–1300 °C), and also reduced the BaY2NiO5 amount (1.1 and 1.7 wt% at 1200 and 1300 °C, respectively). In addition, in both the two cases, Y2O3 appeared at 1400 °C, with its amount increased with the elevating temperature.

### 3.4 STEM-EDS analysis on BZY20 finally heat-treated at 1300 and 1600 °C

In our previous works, we supposed that the status of BZY20 is different after finally heating at 1300 and 1600 °C due to an obvious difference in lattice constant.18,26 Moreover, it is a very common method to fabricate the anode by mixing NiO with as-synthesized BZY20.4–14 And 1300 °C is a typical synthesizing temperature for using solid state reaction method to synthesize BZY20.26–32 So, a detailed analysis of the as-synthesized BZY20 after heating at 1300 °C is highly necessary.

Fang et al.34 suggested that by mechanical mixing (such as ball-mill in this work), it was difficult to achieve a homogeneous mixing of the raw materials of BaCO3, ZrO2 and Y2O3. It seems to be true, since we confirmed the residue of these raw materials in BZY20 heat-treated at 1300 °C by STEM observation, as shown in Fig. 12 (although these residues were not observed from XRD patterns (Fig. S4†)). However, such raw material residue was not observed in the sample heat-treated at 1600 °C. Elevating the final heating temperature from 1300 to 1600 °C decreased effectively the residue of raw materials, raising a great difference between BZY20 (1300 °C) and BZY20 (1600 °C).

Fig. 13(a) shows a bright field STEM (BF-STEM) image of the perovskite phase area in BZY20 (1300 °C), which exhibits a different morphology from that containing residue of raw materials (Fig. 12). Then, STEM-EDS point analysis of several different areas was performed to determine the local composition of such perovskite phase (examples for the STEM-EDS analysis are given in the ESI†). As shown in Fig. 13(c) (BaCO3,
Fig. 9 Powder XRD patterns between 27 and 33 degree of the BZY20 – 70 wt% NiO mixtures. The BZY20 powder added was finally heat-treated at (a) 1300 °C in ambient atmosphere for 10 h, and (b) 1600 °C in O2 for 24 h, respectively. These samples were kept in ambient atmosphere at the desired temperature between 800 and 1600 °C for 10 h using the open-sintering method (Fig. 1(a)). The heating rates in the temperature ranges of room temperature to 1000 °C, and 1000 °C to 1600 °C were 4.17 and 3.33 °C min⁻¹, respectively. All the samples were finally quenched in ambient atmosphere.

Fig. 10 Weight amount (wt%) of the second phases (BaY2NiO5 and Y2O3) generated after heat-treatment at various temperature. The weight amount was estimated by Rietveld refinement to simulate the powder XRD patterns shown in Fig. 9.

Fig. 11 Lattice constants of the perovskite phase in the mixture of BZY20 and NiO after heat-treated at the desired temperature between 800 and 1600 °C in ambient atmosphere for 10 h, using the open-sintering method (Fig. 1(a)). All the samples were finally quenched in the ambient atmosphere after the heat-treatment.
Y$_2$O$_3$ and ZrO$_2$ residues were excluded), a very obvious compositional scattering, especially in the Y content, can be seen. A quite significant amount of the analyzing points locate in the area where the Y content is lower than the nominal value, and existence of highly Y-rich grains was also detected. Such result clearly indicates that the cation distribution in the as-synthesized BZY20 is not so homogeneous, possibly due to the insufficient diffusion of cations to achieve a uniform distribution under the current synthesizing condition (1300 °C for 10 h) or different phase relationship at 1300 °C. And we consider that such compositional inhomogeneity should be the reason why the peak shape of BZY20 (1300 °C) is broad and asymmetric, and its lattice constant is smaller than that of BZY20 (1600 °C).

In contrary, for BZY20 finally heat-treated at 1600 °C (a BF-STEM image is shown in Fig. 13(b) for the powder sample after ball-milling), significantly improved homogeneity in composition was confirmed by STEM-EDS. As shown in Fig. 13(d), most of the grains analyzed were...
determined to have the composition close to the nominal one. Although some grains are detected to be compositionally deviated from the nominal value, but the amount is very small. Such improvement in compositional homogeneity agrees well with our previous work. The difference in compositional homogeneity is a quite interesting and important factor.

It is thereby definite that the final heating temperature of BZY20 (1300 or 1600 °C), which greatly influence the status of BZY20 (compositional homogeneity, residue of the starting materials, etc.), makes BZY20 to show different reactivity with NiO.

3.5 Dependence of BZY20–NiO reactivity on BaO activity

With the aim to control the BaO activity during sintering, different sintering strategies, namely the open-sintering (Fig. 1(a)), cover-sintering (Fig. 1(b)), and embed-sintering (Fig. 1(c)), were attempted. The open-sintering and the embed-sintering methods are considered to maintain the lowest and highest BaO activity, respectively. The BZY20–70 wt% NiO pellet-like samples were heated at 1500 °C for desired time (0, 2, 5, and 10 h) with a subsequent quench in the ambient atmosphere.

Both the mixtures containing BZY20 finally heating at 1300 and 1600 °C were examined here, but in general, these two samples behaved in a similar way, because the heat treatment temperature is 1500 °C. With the open-sintering method, as shown in Fig. 14(a) and (b), BaY2NiO5 existed even the samples were just heated up to 1500 °C (0 h), but the peak intensity of BaY2NiO5 decreased with the increasing heating time. Meanwhile, the peaks belonging to Y2O3 appeared when the sample was kept at 1500 °C for 2 h with its intensity increased with the time. Such phenomenon indicates that BaY2NiO5 formed during the elevating of temperature, but gradually decomposed during the static heating at 1500 °C. A quite similar result was obtained by using the cover-sintering method, as shown in Fig. 14(c) and (d). But it is worth noting here that a delayed rising of Y2O3 peak occurred with the cover-sintering method (2 h for the open-sintering method, but 5 h for the cover-sintering method).

When the embed-sintering method was applied, as shown in Fig. 14(e) and (f), peaks belonging to BaY2NiO5 were observed...
after just heating up to 1500 °C, but became weakened and finally disappeared after keeping at 1500 °C for 2 and 5 h, respectively (see a peak around 32.5°). It is especially interesting to see that $Y_2O_3$ was not observed, regardless of the heating time. No second phase appeared when the sample was kept at 1500 °C for 5 and 10 h. The results imply that relatively high BaO vapor assists incorporation of $Y_2O_3$ into the perovskite phase. These results indicate that controlling BaO activity is important.

4. Discussion

Tong et al. suggested that the melting point of BaY$_2$NiO$_5$ was between 1450 and 1500 °C.$^{37}$ However, in this work, we confirmed that BaY$_2$NiO$_5$ to be a solid phase at 1500 °C. But it is unstable due to the evaporation of oxides and hydroxides of barium and nickel at such high temperature. Furthermore, at 1600 °C, Ba$_3$Y$_2$NiO$_8$ peritectically decomposed to $Y_2O_3$ and a liquid phase. Anyhow, remaining of BaY$_2$NiO$_5$ in the fuel cells seems to be rather problematic, since it decomposes in the hydrogen atmosphere at 600 °C, which is an expected temperature for the BZY20 electrolyte-based fuel cell to operate.

In the anode, BaY$_2$NiO$_5$ formed due to the reaction between NiO and BZY20, which is revealed in this work to be a rather sophisticated process depending on a couple of parameters. Especially, the status of BZY20 after synthesizing is a very important factor. BZY20 which is relatively poor in homogeneity, and contains residue of raw materials (BaCO$_3$, $Y_2O_3$) exhibited high reactivity with NiO to maintain a wide temperature range for BaY$_2$NiO$_5$ to exist. However, a positive effect on suppressing the BaY$_2$NiO$_5$ formation was achieved by improving the compositional homogeneity of BZY20. Such improvement can be simply realized by just elevating the final heating temperature of BZY20 (namely, from 1300 °C to 1600 °C, in this study).

The sintering strategy, or the BaO activity during sintering in another word, also impacts greatly the phase appearance in the BZY20–NiO mixture. With the open-sintering (Fig. 1(a)) and cover-sintering (Fig. 1(b)) methods, which have relatively low BaO activity, $Y_2O_3$ was identified to be the only second phase after keeping at 1500 °C for 10 h. Such $Y_2O_3$ is considered to be generated from the decomposition of BaY$_2$NiO$_5$ residue formed at the low temperature range during the heating up process, because as shown in Fig. 14, Ba$_3$Y$_2$NiO$_8$ already existed in the sample just heated up to 1500 °C. We then increased the BaO activity during sintering by using the embed-sintering method (Fig. 1(c)), and was excited to see that the segregation of $Y_2O_3$ did not occur. Furthermore, there is even no second phase identified from XRD measurements after heating at 1500 °C for 5 and 10 h. It seems that Y, and possibly also Ni, return to the crystal lattice of barium zirconate, if a properly sufficient BaO activity can be supplied during the sintering.

5. Conclusions

The results in this work revealed that BaY$_2$NiO$_5$ was unstable at high temperature (1500 and 1600 °C) in a different way, and also in a reducing atmosphere at 600 °C. Remaining of BaY$_2$NiO$_5$ as a second phase in BZY20-based fuel cells seems quite problematic. A systematic work was therefore performed to provide fundamental insight into the reactivity between BZY20 and NiO. It was found that improving the compositional homogeneity of BZY20 powder, which was used in composing the electrolyte and anode layers, reduced or even suppressed effectively the formation of BaY$_2$NiO$_5$. It is rather interesting that such improvement in the compositional homogeneity can be yielded simply by just elevating the final heating temperature for BZY20, such as from 1300 to 1600 °C. Furthermore, a proper BaO activity in the environment during the sintering is another key factor, which can be adjusted by choosing appropriate sintering method. Improving the compositional homogeneity of BZY20, and controlling precisely the BaO activity, therefore provide a potential strategy to prepare a BZY20 electrolyte-based fuel cell without second phases.

Acknowledgements

The authors want to thank Mr Kenji Kazumi for STEM-EDS analysis.

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