Electronic Supplementary Material (ESI) for Materials Advances.

Supplementary information

for

Dual-phase Yb-doped $La_2Ce_2O_7$ Materials for Fuel Flexible SOFCs

Bishnu Choudhary[1, 2, *], Shahid Anwar[1, 2, *]

[1] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, India

[2] CSIR-Institute of Minerals and Materials Technology (IMMT), Bhubaneswar-751013, India

Corresponding authors

*(shahidanwr@gmail.com; shahid@immt.res.in) Shahid Anwar

*(bishnumailg@gmail.com) Bishnu Choudhary

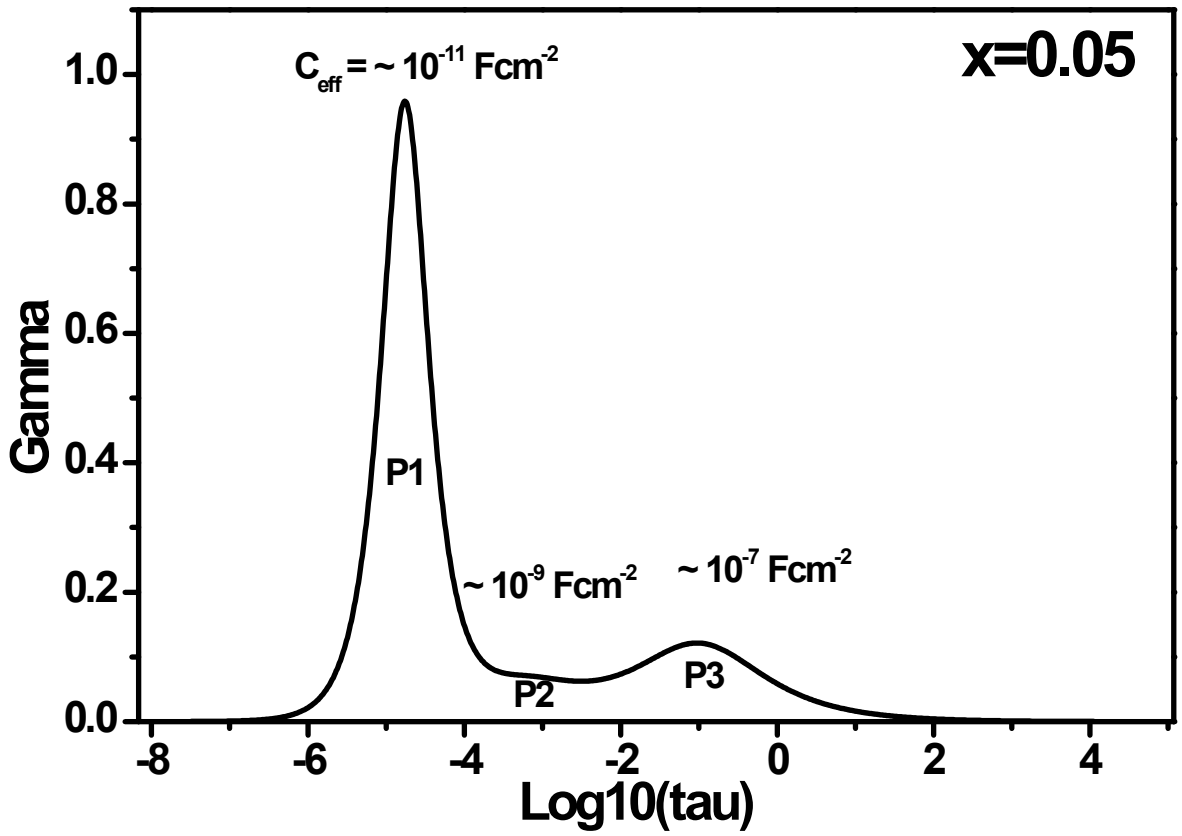

Fig. S1: ISGP spectra of $La_{1.95}Yb_{0.05}Ce_2O_7$ at 300°C

EPD Suspension preparation, characterizations and deposition optimization:

To prepare the suspension of $La_{1.95}Yb_{0.05}Ce_2O_7$, a 2 wt.% of $La_{1.95}Yb_{0.05}Ce_2O_7$ powder was subjected to ball milling in a solvent for a period of 24 hrs. Subsequently, the milled powder was subjected to probe sonication for a duration of 15 minutes, after which the resulting suspensions were promptly transferred into test tubes. The examination of the suspensions in the test tubes was conducted with continuous observation in order to discern the settling behavior of $La_{1.85}Y_{0.15}Ce_2O_7$ powders in different time. The assessment of the suspension stability of was executed in various media such as acetylacetone, ethanol, isopropanol, butanol, and acetone. These same suspensions were designated as 1, 2, 3, 4, and 5, respectively, as illustrated in Fig. 2S.

Fig. 2S a illustrate the $La_{1.95}Yb_{0.05}Ce_2O_7$ suspension which were immediately poured into the test tube after the 15 min of probe sonication. Amongst all the suspensions, the suspension based on acetone exhibited the lowest degree of stability after a span of 24 hrs. (as depicted in Fig. 2S b). Furthermore, the medium involving acetylacetone was the second least stable after 24 hrs. (Fig. 2S b). After time span of 69 hrs., the order of stability was observed to be as follows: isopropanol exhibited the highest stability followed by butanol, ethanol, acetylacetone, and finally acetone (Fig. 2S d). The dash line indicates the powder suspended level after different time of span. To commence the deposition process of $La_{1.95}Yb_{0.05}Ce_2O_7$ onto the fuel electrode via EPD, a quantity of 2 g of nano powder $La_{1.95}Yb_{0.05}Ce_2O_7$ was compacted utilizing a uniaxial hydraulic press. Subsequently, the compacted powder was sintered in atmospheric air at a temperature of 1100°C for a period of 5 hrs. Following this, the resultant pellet was subjected to grinding for a duration of 24 hours using a roll mill in isopropanol as the solvent in a volume of 100 ml. In order to achieve enough mechanical strength during the EPD process, the anode powder composition, consisting of 60% Nickel Oxide (NiO), 40% $La_{1.95}Yb_{0.05}Ce_2O_7$, and 20% starch, was pre-sintered at 600°C for 5 hours.

Our previously published paper describes the EPD setup and sample preparation [1–3]. The EPD of $La_{1.95}Yb_{0.05}Ce_2O_7$ was performed in Isopropanol by varying the deposition parameters (electrode distance: ~1.5 cm, time: 45 sec to 6 min; and voltage:40 to 60V). It was found that 50V for 4 mins of deposition were the ideal deposition condition followed by 5 hrs. of sintering at 1450°C.

The suspension chemistry of isopropanol-based suspension of $La_{1.95}Yb_{0.05}Ce_2O_7$ is tabulated in the Table S1.

The distribution of particle sizes (in terms of volume, number, and intensity) for $La_{1.95}Yb_{0.05}Ce_2O_7$ dispersed in isopropanol is depicted in Fig. S2. It is noted that the distribution of $La_{1.95}Yb_{0.05}Ce_2O_7$ in isopropanol showed the bimodal peaks in all aspects (i.e., in terms of volume, number, and intensity). The distribution based on intensity percentage revealed the existence of bimodal peaks, which were observed at an approximate size of 220.8 and 1245 nm. Conversely, the distribution based on volume percentage, the peaks were detected at approximately 200.70 and 1390.8 nm. Finally, the distribution based on number percentage also displayed at an estimated size of 175.2 and 1003.4 nm.

Table S1: Properties of $La_{1.95}Yb_{0.05}Ce_2O_7$ suspension:

Hydrodynamic diameter	1003.8 nm
Mean zeta potential	+41.7 mV
Conductivity	0.0056 mS/cm
Electrophoretic mobility	0.59 μm*cm/Vs
pH	~7.5

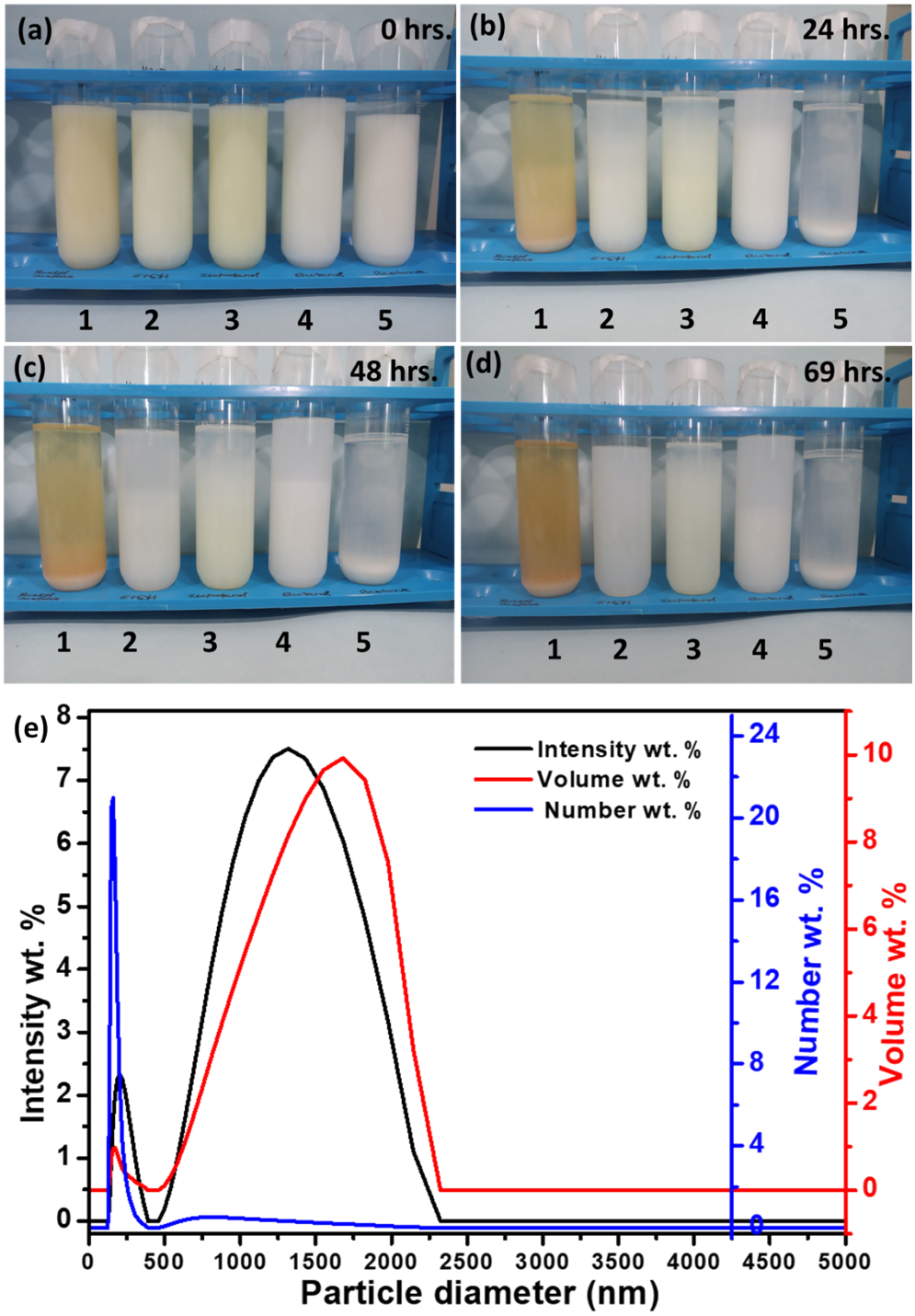

Fig. S2: (a-d) Suspension stability test of $La_{1.95}Yb_{0.05}Ce_2O_7$ powder in different media at different time of intervals and (e) particle size distribution curve of $La_{1.95}Yb_{0.05}Ce_2O_7$ powder in isopropanol media.

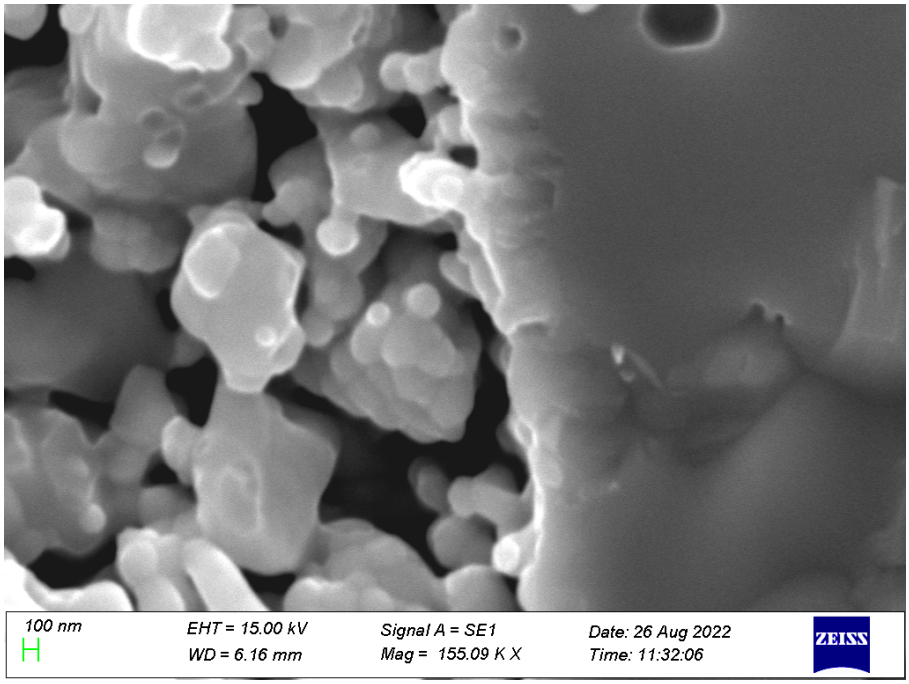

Fig. S3. Cross-sectional SEM image focused on interface between cathode and electrolyte

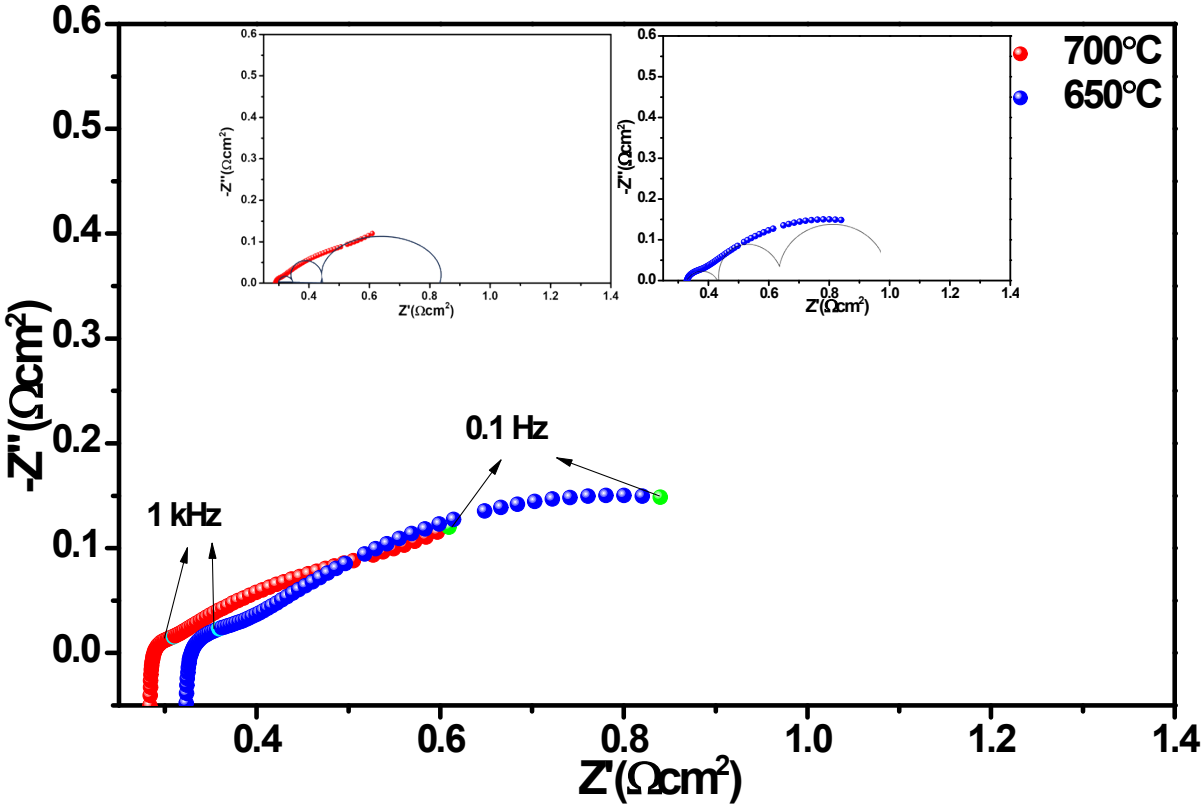

Fig. S4: Impedance spectra plot under OCV condition at 650ºC and 700ºC. (Left inset: 650ºC and right inset: 700ºC)

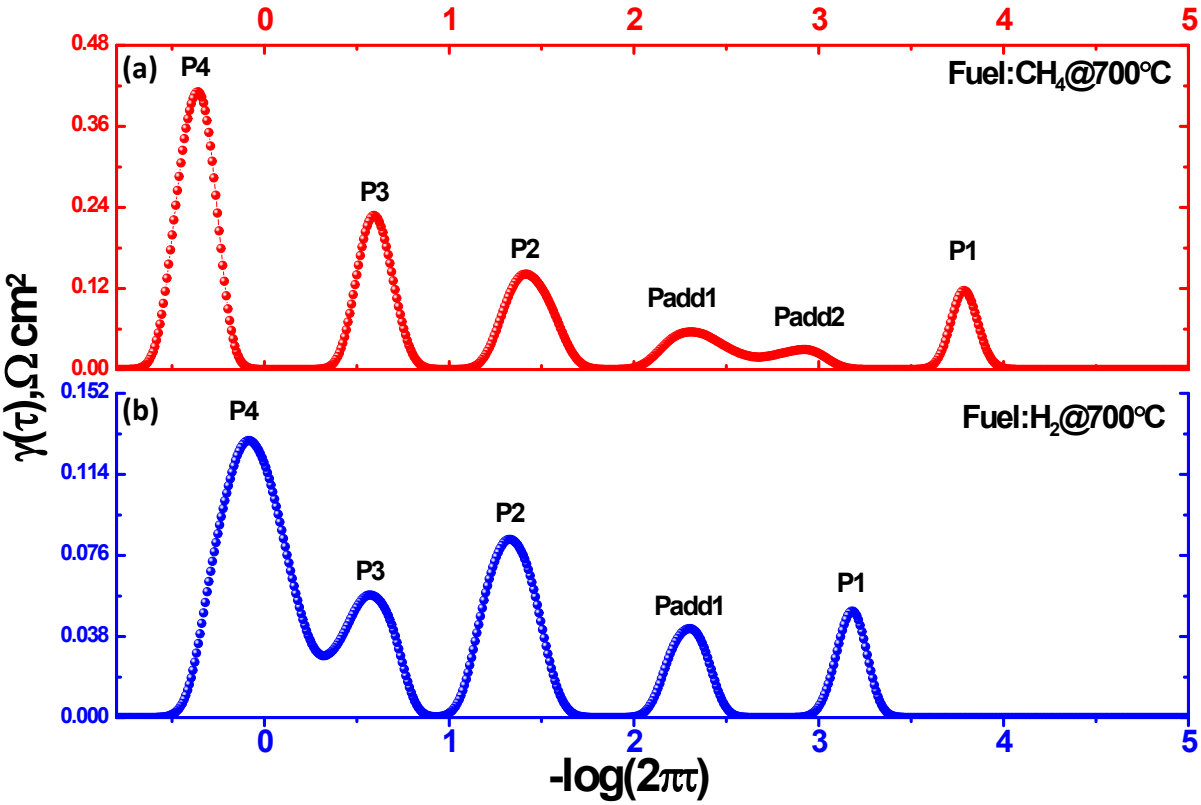

Fig. S5: DRT plot comparison at 700ºC in (a) moist CH_4 fuel, (b) moist H_2

References

1 B. Choudhary and S. Anwar, *Solid State Ionics*, 2023, **401**, 116356.

2 B. Choudhary, K. S. Dash, S. Anwar, L. Besra and S. Anwar, *Journal of Power Sources*, 2023, **583**, 233543.

3 B. Choudhary and S. Anwar, *ACS Appl. Energy Mater.*, 2023, **6**, 11817–11827.