Characterisation of single step fabricated Intermediate Temperature Solid Oxide Fuel Cells (IT-SOFC)

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Abstract:

In this study facile tape casting process has been successfully carried out to fabricate unit Solid Oxide Fuel cells (SOFC) with four different layers. A composite cathode which is a mix of $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_3$ and $G_{0.1}C_{0.9}O_{1.9}$ -HP (GDC), GDC as a thin layer of electrolyte, NiO-GDC without pore former as thin anode functional layer (AFL), and anode support layer of NiO-GDC with carbon pore former. The multi layer was Co - sintered to have an OCV 0.943 V is obtained at 500°C, and power density of 363mW.cm^{-2} at 650°C indicating negligible leakage of fuel through electrolyte. Furthermore scanning electron microscope (SEM) revealed crack free dense electrolyte. These results prove that our single step co-sintering process to fabricate a unit planar cell, exhibits good performance without use of sintering aids, Co-pressing, and lamination of green tape.

1. Introduction:

Solid Oxide fuel cells are an electrochemical conversion device which directly convert chemical energy into electrical energy. This system has gained attention in the last few decades due to its high efficiency and variety of fuels used [1]. For effective commercialization of SOFC, research are focused on reduction of operating temperature down to 500-700°C from conventional 800-1000°C, and reduce the fabrications costs. Anode supported planar type design with thin dense electrolyte film is widely preferred than tubular design in regard to high power density, low fabrication cost, and low anode polarization [2], [3].

There are various thin film deposition techniques have been practiced such as Chemical Vapor Deposition CVD[4], dip coating [5], spin coating [6], sputtering [7], spray pyrolysis[8] Electrochemical Vapour deposition EVD[9], Screen printing [10], Electro phoretic deposition [11], Tape casting[12]. Each method has its own advantage and disadvantages, among which tape casting has been widely considered as cost effective, more suitable for anode supported planar cells and mass production of large size cells [13]. Conventional process of fabrication involves two steps, first sintering of anode support half cell followed by cathode preparation and sintering which involves more time and production cost.

In this paper, anode supported planar unit cell is fabricated by tape casting and single step Co-sintering process without use of sintering aid, laminating and dry pressing. The electrochemical performance of unit cell was performed in Fiaxell device. SEM measurement was carried on SU1510 and JOEL for studying microstructure of the cell.

2. Experiment:

Commercial Nickel Oxide (NiO) sigma Aldrich (99.99%) purity and $Gd_{0.1}Ce_{0.9}O_{1.95}$ (GDC) Neyco were used as raw materials in making of anode substrate layer with carbon as pore former Sigma Aldrich. Concerning the anode functional layer the active materials are (NiO-GDC) composite. GDC were used as electrolyte, where as a mix of $La_{0.6}Sr_{0.4}Co_{0.2}Fe_{0.8}O_3$ synthesised in the lab and commercial GDC were used as cathode layer.

The raw material are first mixed and ball milled with 8 balls of diameter 10mm which is of high wear resistant zirconia grinding media in a turbula for 24 hours with solvents like Ethanol (Sigma Aldrich) and Ethyl Methyl Ketone (Sigma Aldrich) and dispersant Tri Ethanol Amine (Sigma Aldrich). The binder Poly Vinyl Butyral Butvar B-98 (Sigma Aldrich), plasticizers Poly ethylene glycol (Sigma Aldrich) and Benzyl butyl Phthalate (Sigma Aldrich) are added and ball milled for another 24 hours. Tape casting was performed on a glass plate using a tape caster (Elcometer) with a casting rate of $1cms^{-1}$. The tape was dried in air at room temperature for 3 hours and then co-sintered at 1215°C for 5 hours with heating and cooling ramp of $1°C.m^{-1}°C$.[14]. Fig 1 describes the schema of the described procedure.

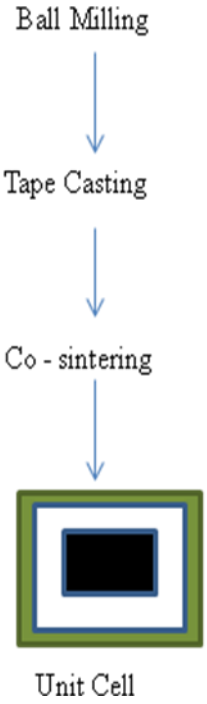

Fig1.Schema of Single Step sintering procedure

To evaluate electrochemical performance, the single cell was characterized in Fiaxell set up with anode size of 6*6cm and active area of cathode was $10cm^2$. NiO foam coated with NiO powders were used as anode current collector and gold grids were used as cathode current collector. Heating of the cell was started with both air on both sides. The electrochemical performance was measured starting with N_2/H_2 (92/8) gas mixture, during the experiments N_2H_2 gas mixture was slowly replaced using humidified Hydrogen as fuel and air as oxidant. Hydrogen and air flow rates were kept constant at $210ml.min^{-1}$ and $600ml.min^{-1}$. NiO in the anode layers were reduced to Ni during flow of hydrogen. The I-V curves were plotted accordingly. The morphology of single cell was also performed using scanning electron microscope.

3. Results and discussion:

The fig.2 shows cross section of the cell, the back scattered image shows the final unit cell. Total thickness of cell measured was 320 µm, with cathode thickness of 20µm and electrolyte thickness of 10µm, and afl and anode thickness comes to 290 µm. The cathode was on the bottom side of the SEM picture.

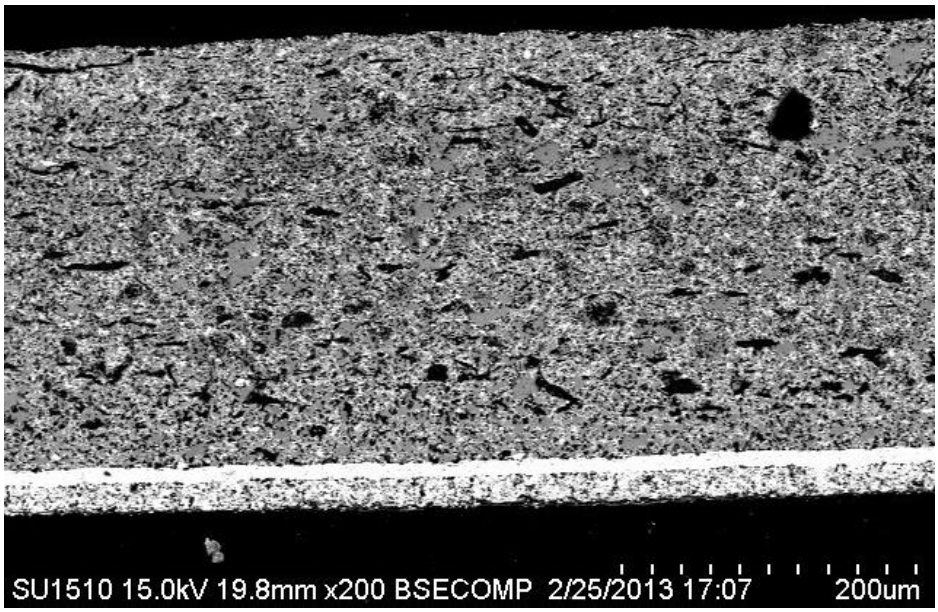

Fig.2 Cross Section of unit cell.

From the SEM image, it can be clearly understood that thin, dense electrolyte layer can be obtained by tape casting. Fig 3 describes current density in $mA.cm^{-2}$ versus Voltage and power density obtained from unit planar cell of 10 cm^2 obtained by tape casting and single step sintering. The OCV values obtained are 0.943V, 0.911V, 0.868V and 0.805 V at 500°C, 550°C, 600°C, and 650°C respectively. These OCV at 500°C and 600 °C value can be compared to [15]; there is small deviation of 0.017mV, and 0.042mV. Though the difference in OCV can be attributed to fact that we have used a lower sintering temperature of 1215°C corresponding to conventional sintering temperature of 1300°C for nano particles. With increasing sintering temperature the density of GDC increases and leads to increase in OCV. Obtained OCV were similar to values obtained [16]. With sintering temperature of 1500°C and two step sintering of cell. This can be related to the fact that the GDC layer obtained by our process is dense and free of crack at very low temperature of 1215°C compared to 1500°C for micro sized particles of GDC and 1300°C for nano particles of GDC.

The maximum power density obtained at 500°C, 550°C, 600°C, and 650°C are 139 $mW.cm^{-2}$,227$mW.cm^{-2}$, 306$mW.cm^{-2}$ and 363$mW.cm^{-2}$. The difference in power density can be related to fact that this study of cell Fiaxell Set up were done with no sealing. When once these cells are expected to studied with expensive gold sealing rings, these are supposed to have higher values of power density. Still obtained OCV values were far higher when compared to [17], the maximum power density obtained were also higher at lower temperature of 500°C and 550°C, though BSCF used as cathode expected to provide higher performance compared to LSCF used in this study.

So the preliminary results obtained prove that our process of fabrication of unit cell by tape casting and single step Co-sintering at low temperature was successful and can be extrapolated to large area cells. The large area cells obtained by this process are about to be stacked and studied for long term performance.

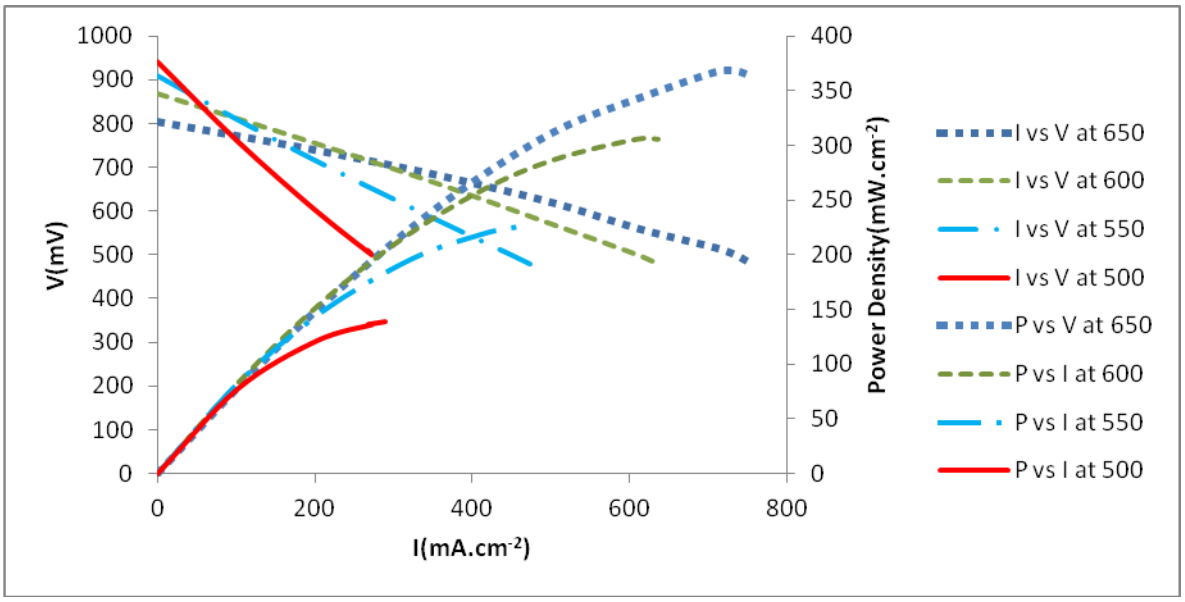

Fig 3. I-V and I-P curve at different temperatures.

4. Conclusions:

Planar anode supported SOFC single cell were prepared by simple tape casting, and Co sintering process. The dense electrolyte GDC layer of 10 µm was well adhered to anode support and no delamination and cracks were observed. While using humidified hydrogen as fuel and air as oxidant OCV at 500° C were 0.943 V and the maximum power density obtained was 363 $mW.cm^{-2}$. These results lead us to conclude that this process is cost effective and much suitable for mass production.

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