INDEC B.V. ON THE ROAD TOWARDS COMMERCIALIZATION

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ABSTRACT

InDEC (Innovative Dutch Electro Ceramics) is an HC Starck and ECN owned company that produces planar electrolyte-supported cells (ESC) and anode-supported cells (ASC). InDEC aims to offer cost-effective flat plate cutting edge SOFC technology. At present the planar SOFC component production takes place at the pilot manufacturing plant located in the Netherlands. Since acquiring the majority InDEC shares, HC Starck has built up a significant production technology activity in order to increase production capacity and to reduce manufacturing costs. A (semi)-automated quality controlled SOFC manufacturing plant is being set up in Selb, Germany. InDEC is also continuously improving the intrinsic product properties by R&D efforts focusing on improved cell performance for ESC and high mechanical strength for ASC. As a result, InDEC has introduced two new planar SOFC products, namely a newly formulated high performance ESC cell comprising a TZ3Y electrolyte having reduced thickness, and a new ASC cell having doubled mechanical strength.

INTRODUCTION

InDEC B.V. (Innovative Dutch Electro Ceramics) is an enterprise that produces planar SOFC components in a pilot manufacturing plant located in the Netherlands. InDEC was founded in 1999 as a 100% subsidiary of the Energy research Center of the Netherlands (ECN [1]. In April 2003, HC Starck (HCST) acquired the majority InDEC shares from ECN [2].

InDEC aims to offer cost-effective flat plate cutting edge SOFC technology. The InDEC products are produced on the basis of an exclusive license from ECN, which has been developing SOFC components since 1991 [3-5]. Since its foundation, InDEC has built up significant annual sales based on an extensive worldwide client base. In order to be prepared for further growth, InDEC needs to make the next step towards commercialization. HC Starck (HCST) is the ideal partner to help InDEC to 'move towards maturity', since HCST is a globally orientated industrial company with a background in ceramic and metallic powder production. In addition, HC Starck is developing powder materials for usage in SOFC since 1996 [6].
THE INDEC/HC STARCK SOFC ORGANIZATION

Within the HC Starck group, the SOFC activities are organized in the business unit, Ceramics and Surface Technologies (CST), as follows:

- InDEC B.V. is responsible for the commercialization and pilot scale production of SOFC components. For this purpose, InDEC is supported by HCS sales representatives in the US, Japan and Korea.

- The Research and Development department of HCST is responsible for the optimization of the intrinsic properties of the InDEC products based on customer specification. HCST uses the core competence and capacity of the SOFC R&D group at ECN to contribute to the component optimization and development. In addition, the HCST R&D division is responsible for the introduction of HCST SOFC powders into the InDEC products.

- The Production Technology group is responsible for setting up a prototype manufacturing line for low cost flat plate SOFC components.

InDEC plays a central role in defining the research and production technology topics that have to be addressed. Since InDEC communicates directly with its customers, they learn about the critical features of its cell technology. Based on the customers’ feedback, the research activities are defined. Furthermore, InDEC has built up significant experience in small scale manufacturing of SOFCs. Based on this experience, the critical aspects of SOFC manufacturing regarding costs and capacity can be defined, which is an essential starting point for the Production Technology group for further cost effective up-scaling of the manufacturing capacity.

**InDEC SOFC COMPONENTS**

InDEC produces electrolyte and anode supported cells, indicated as ESC and ASC (figure 1). The former comprises of a relatively thick (>90μm) zirconia type electrolyte giving the cell its mechanical integrity. Due to the thick electrolyte, the ESC cell has to be operated at temperatures > 850°C.

In case of the ASC, a porous NiO/8YSZ substrate determines the strength. Due to thin (<10 μm) electrolyte, also consisting of zirconia material, this type of cell can be operated at intermediate temperatures of 650°C and higher. For both ESC and ASC type cells, two kinds are offered, i.e. ESC1, ESC2, ASC1 and ASC2. Table 1 gives an overview of the different products and their operating temperatures.

*Figure 1. InDEC Electrolyte and Anode Supported Cell components having different configurations and sizes.*
Table 1. The InDEC planar SOFC products.

| Supportive Layer | Anode   | Cathode       | Operating Temperature |
|------------------|---------|---------------|-----------------------|
| ESC1 TZ3Y 130μm  | NiO/GCO | LSM-YSZ       | >900°C                |
| ESC2* TZ3Y 90μm  | NiO/GCO | LSM-YSZ       | >850°C                |
| ASC1 NiO/8YSZ 550μm | NiO/8YSZ | LSM-YSZ       | >750°C                |
| ASC2 NiO/8YSZ 550μm | NiO/8YSZ | YDC/LCSF     | >650°C                |

*Recently introduced ESC product, see chapter "InDEC product optimization", section "ESC development".

InDEC PLANAR SOFC MANUFACTURING

The ESC and ASC components are produced in a pilot manufacturing line in Petten, the Netherlands. InDEC is concentrating on manufacturing techniques, which are known from commodity ceramic and electronics industry, i.e. tape casting for the supporting ceramic substrates and screen printing for the thin active components. These commonly used manufacturing technologies enable InDEC to 'easily' upscale the capacity to bulk manufacturing of cells.

Currently the InDEC products are produced in a batch process, requiring significant manpower. The total InDEC production area is approximately 350 m², consisting of two batch-wise tape casting rooms (of which the electrolyte tape cast room is a climatized clean room), a screen print and sintering facility (comprising of eight electrically heated chamber furnaces, see figure 2). In addition InDEC owns a cutting facility (for mechanically cutting of substrates) and a packing/characterization room. For the final QC, InDEC cell components are validated by ECN on electrochemical characteristics. Figure 3 shows some of the ECN test infra-structure.

In order to meet the cost-price targets of < 500 EUR/ m² and to be prepared for future cell demands, at the HC Starck Ceramics site in Selb, Germany, preparations are underway to set up a semi-automated production line for SOFC components. This prototype scale manufacturing facility will be built up of a climatized clean room in which a continuous tape-caster, an automated screen print line and industrial scale sintering furnaces will be installed. This facility should have an annual production capacity of >100,000 cell components having 100 cm² active area. In addition, at InDEC/HC Starck, activities have...
commenced to set up a Quality Management System (QMS) by using tools like FMEA's (Failure Mode Effect Analyses), SPC (Statistical Process Control), and DoE (Design of Experiments).

InDEC is continuously improving the intrinsic product properties by R&D efforts focusing on improved cell performance for ESC and high mechanical strength for ASC aiming to offer cutting edge cell technology.

ESC Development

The ESC research activities primarily focus on increasing the cell performance and reducing the operating temperature. In addition, the cell has to be able to obey typical stack requirements like showing a proper mechanical stability, withstand redox and temperature cycles, reduced sensitivity towards sulphur contamination in the fuel and chromium poisoning of the Cathode.

As a result of the research activities, the ESC2 type cell has been introduced. This type of electrolyte supported cell consists of a TZ3Y electrolyte having a reduced thickness (90 μm). The cathode is produced by use of HCST LSM material. In addition, the manufacturing procedure of the ESC2 type cell is slightly simplified compared to the ESC1 cell. The thinner electrolyte enables reduced temperature operation (i.e. > 850°C for the ESC2 vs. > 900°C for the ESC1). The ESC2 type cell shows similar properties with respect to mechanical strength, duration behavior and redox stability. Figure 4 shows the ESC2 cell performance including four oxidation-reduction cycles, as operated in an ideal alumina single cell housing. During each oxidation-reduction cycle, the cell is put in OCV mode and the fuel flow is switched off allowing oxygen to enter the anode compartment. After each cycle, fuel is again applied to the anode and the cell is switched back to its previous testing condition. Figure 4 shows that the ESC2 cell fully recovered after each of the four cycles.
Figure 4. Cell voltage of a 100 cm² ESC2 type cell tested under ideal conditions in ceramic housing. Fuel 350 ml.min⁻¹ humidified hydrogen; oxidant 2000 l.min⁻¹ air. The four ox/red cycles were carried out after 80 hrs, 165 hrs, 195 hrs and 340 hrs of operation.

ASC Development

The main R&D effort for the anode supported cell is aiming at improving the mechanical integrity. The strength of the ASC cell is predominantly determined by the NiO/8YSZ porous substrate. The substrate microstructure of the previous type ASC showed some inhomogeneities like varying sizes of the solid particles and flake like pores (figure 5). ECN and HC Starck researchers have successfully increased the ASC strength by a factor of 2 (ring on ring test). By improving the NiO and 8YSZ powder dispersion in the slurry, an optimized particle size distribution has been obtained resulting in increased substrate homogeneity. An alternative pore former is responsible for an additional substrate improvement with respect to the pore structure, in which the flake like pores are minimized. This high strength ASC has been introduced within the InDEC manufacturing line at the end of 2004 and is considered to be the new state of the art. Figure 5 shows the comparison between the anode support structures of the previous and the current, more homogeneous, ASC cell.

Figure 5. Comparison of the previous (left) and improved (right), homogeneous high strength type porous ASC substrates. Magnifications 200x and 2000x.
CONCLUSIONS

InDEC is an HC Starck and ECN owned company that produces planar electrolyte-supported cells (ESC) and anode-supported cells (ASC). At present, the planar SOFC component production takes place at the pilot manufacturing plant located in the Netherlands. Since acquiring the majority InDEC shares, HC Starck has built up a significant production technology. Preparations are under way to build a (semi)-automated quality controlled SOFC manufacturing plant in Germany. As a result of the R&D efforts, InDEC has introduced two optimized planar SOFC products, namely a newly formulated high performance ESC cell and a new ASC cell having doubled the mechanical strength.

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