Solid Oxide Fuel Cell Manufacturing Overview

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The Solid Oxide Fuel Cell Electrochemistry
Stack Manufacturing Development

Component Development
- Cell
- Seal
- Interconnect
- Contacts
- Current Collection
- Flow Management
- Thermal Management
- Manufacturability
- Repeatability
- Tolerance

Technology Development

Stack Engineering Integration

Process Development and Piloting
Influencing Factors

- **Manufacturing**
  - Selection of fabrication process
  - Evolution of desired microstructure
  - Cell-to-cell variability as manufactured (high yields necessary)
  - Stack (cell-to-cell variation)

- **Design**
  - Cell architecture
  - Stack design
  - Material stability
    - Oxidation behavior of steels
    - Sintering at operating conditions
    - Interdiffusion of cations
    - Phase changes/phase separation
    - Creep → warpage

- **Operation**
  - Fuel composition (Uf, H/C ratio, contaminants, f(t))
  - Oxidant (Uo, contaminants, pO₂)
  - Temperature (max)
  - Temperature gradient (°C/cm)
  - Temperature variation: x, y, z
SOFC Elements: Independent of Construction

- Need to create and join the electrochemical elements (cells)
  - Anode, cathode, electrolyte
  - Ceramics

- Need to bring reactants to (and from) the cells and keep them where they belong
  - Flow fields, seals, manifolds
  - Ceramics or metallics

- Need to move electricity from cells
  - Interconnects, current collection
  - Ceramics or metallics

- Need to move heat from cells and stacks
  - Active and passive thermal management
SOFC Stack Elements

Fuel cell
- Electrolyte, cathode, anode

Interconnects
- Deliver gases, transfer electrons, mechanically support cell

Seals
- Keeps gases where they belong

Compression system
- Hold it all in place

Current collection
- Get the electrons out
Common Ceramic Manufacturing Steps

- Raw material preparation
  - Powder production
  - Powder preparation
  - Sizing

- Forming
  - Tape casting, slip casting, pressing, extrusion, calendaring, dispensing…
  - Printing, dip coating, spraying, vapor deposition…

- Conditioning
  - Drying, bisqueing, sintering
Ceramic Raw Material Preparation

- Generally, most powders will be procured from suppliers
  - May require in-house processing such as sizing or purification
  - Inbound quality control

- Further preparation prior to forming or deposition
  - Additional functional materials may be added as well as binders or slurry agents
  - Milling is commonly used to refine and mix materials
Ceramic Forming: Primary Layer

- Extrusion
  - Ceramic with a binder is forced through a mandrel forming the desired green shape (which can be closed at the leading end)

- Tape Casting
  - Ceramic tape is made by uniformly spreading slurry onto a smooth surface

- Drying
  - Both extrusions and tapes need to be dried to allow for handling and application of other functional elements prior to sintering

- Cutting
  - With extrusions, cutting may result in nearly no loss of material
  - In a planar cell, tape lost to cutting is a function of cell geometry and tape size
  - Recycling of tape lost to cutting is possible
Tape Casting

- Ceramic powder
- Binder and additives
- Solvent
- Mixing
- Slurry
- Homogenizing
- Pump
- Take-up reel
- Evaporated solvent
- Dry tape
- Doctor blade
- Flexible tape
- Support table
- Drying
- Slurry container
- Carrier film
- Peeling
- To additional processing

Anode Tape
Ceramic Forming: Additional Layers

- In either a planar or tubular configuration, additional layers are applied to the primary (usually support) layer
- Screen printing
  - Thickness can be limited, reasonable cycle times and cost, planar only
- Thermal spraying
  - Typically uses a flame or plasma, can provide thick coatings, higher depositions rates than vapor deposition
- Vapor deposition
  - Chemical processes use a fluid precursor which undergoes a chemical change at a solid surface, leaving a solid layer
  - Physical processes tend to require a low-pressure vapor environment to function properly
- Dip coating
  - Coating thickness a function of coated surface characteristics, ceramic paint properties, and number of applications
  - Equipment is inexpensive but cycle times can be relatively long
Screen Printing

Unfired Cell
Ceramic Conditioning

- **Drying**
  - Typically done at temperatures up to a few hundred °C
  - Yields a flexible green ceramic
- **Bisque firing**
  - 300 to 500 °C
  - Yields a stable but brittle shape
- **Sintering**
  - Ceramic powders are partially melted allowing particles to partially fuse
  - Time and temperature dependent
- **Co-firing** is possible but varying shrinkage rates make it challenging
- **Low volume production** tends to use batch furnaces, continuous furnaces are available for high volume firing
High Temperature Firing
Common Metallic Manufacturing Steps

- Metallic fabrication processes are well established and not unique to SOFC manufacturing
  - Stamping, punching, rolling, brazing, welding
  - Powder metallurgy, casting
- In some instances, coatings are applied to metallic stack components to improve oxidation characteristics
Assembly

- **Planar**
  - Layering of cells, flow fields, interconnects, seals, etc. bounded by end plates/manifolds and compressed
  - Leak check and initial conditioning

- **Tubular**
  - Tubes and interconnects assembled with manifolds and enclosed
  - Leak check and initial conditioning

- Automated assembly equipment can require significant volumes to justify its development and expense

- Conditioning and test equipment are nearly like full-featured development test stands
Quality Control

- Physical properties
  - Dimensions
  - Density or porosity
  - Flatness
  - Uniformity
  - Discontinuity

- Chemical properties
  - Compositions
  - Phases
  - Impurities

- Electrochemical properties

- Some QC activities are amenable to automation on non-operating parts, others are not to either or both
Cell Manufacturing Process Development

- Tape Casting
- Screen Printing
- Co-sintering
- Continuous Process
- Process on Green

Process Tracking Database

Total Process Capability Analysis for XY ave

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SECA Projected Stack Cost Reduction

The fuel cell stack cost has decreased substantially mainly due to the R&D activities in the SECA project.

Cost Reduction Focus Areas

1. Stack Performance Increase
   • Peak Power Increase
     🚩 Resolved thermal management issues

2. Material Reduction:
   • Thinner stack components
   • Interconnect material reduction
   • Reduced number of intermediate plates

3. Manufacturing Process Changes
   • Interconnect manufacturing development
   • Improved material utilization

4. Process Optimization
   • Automation
   • Elimination of process steps

SOFC Stack Block Cost Reduction

Phase I Factory Cost Est. (2002 USD)  $197  $210
2009 Interim (2002 USD)  $119  $153
Phase II Factory Cost Est. (2000 USD)  $85  $108

The fuel cell stack cost has decreased substantially mainly due to the R&D activities in the SECA project.
The majority of stack cost is driven by the cost of materials.

The relatively low labor cost is attributed partly to the fact that cells and seals are produced by VPS in-house.
Manufacturing Automation Strategies

▶ Manual operation
  – Production volumes from 5 MW to 25 MW
  – Use manual equipment with longer cycle times and smaller batch size

▶ Semi-automatic operation
  – Production volumes from 25 MW to ~100 MW
  – Use medium size equipment and has partial automation in key stations

▶ Automatic operation
  – High volume production from ~100 MW to 250 MW
  – Workstations and material handling system are automated
Cost and Manufacturing Initiatives

- Materials
  - Materials reduction in cell and stack
  - Low cost materials
  - Interconnect coating

- Fabrication and assembly
  - Cell co-sintering
  - Sealing technology

- Quality control and testing
  - On-line QA/QC with real time feedback
  - Stack conditioning
Questions?

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