NEXTECH MATERIALS

Protective Coatings for Metallic SOFC Components

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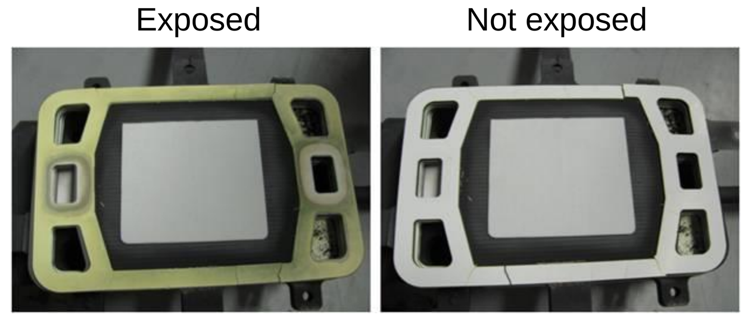
Problem Statement

Cost is a key barrier to widespread commercialization of SOFCs. To make SOFC systems more manufacturable and reduce system costs, system developers, wherever possible, have substituted lower cost stainless steel into the stack design. However, for successful implementation of these steels, protective coatings are necessary to protect the air-facing metal surfaces from high temperature oxidation and to minimize chromium volatilization from the metal, because chromium volatiles poison the cathode and degrade cell performance.

For metallic interconnects the active area needs to be electrically conductive to minimize ohmic losses through the cell, whereas the primary functions of the non-active, sealant area of the interconnect are to provide a sealing surface and to be chemically inert. Unfortunately chromia-forming steels interact with alkaline aluminosilicate sealant glasses, forming $SrCrO_4$ and $BaCrO_4$. These low TEC chromates lead to rapid failure during stack thermal cycling.

Exposed | Not exposed

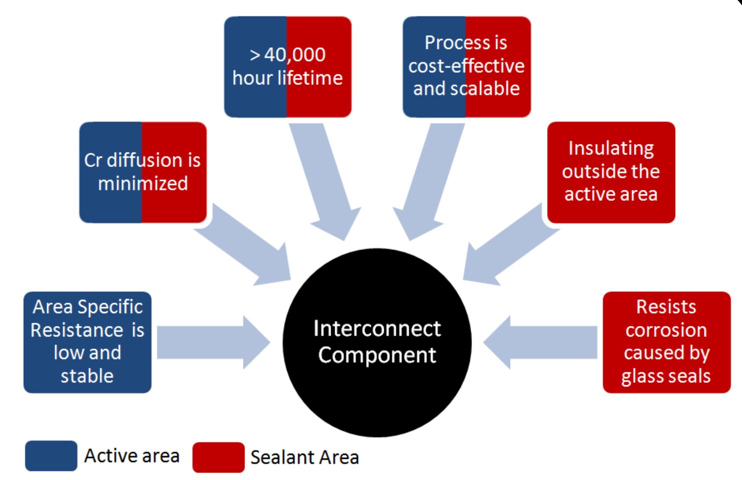


Post-test inspection of seals with and without exposure to chromia-forming steels.

Interconnect Coating Solution

NexTech has developed multiple coating approaches to target the different functionalities associated with different areas of the interconnect.

To fully exploit the cost advantages offered by metallic interconnect designs, coating approaches must be size-scalable and allow high volume throughput at low capital cost. NexTech has identified and developed an aerosol-spray deposition coating (ASD) process for depositing protective oxide coatings on a range of substrates. The process is amenable to high-volume production and capable of providing low cost coatings.



Interconnnect functionalities

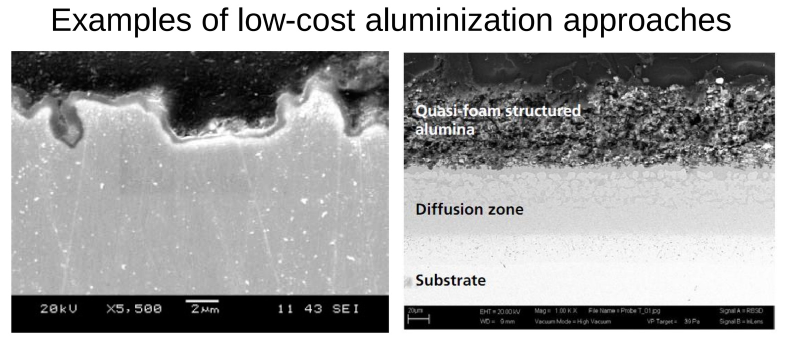
Cost-Effective Aluminization Coatings

Aluminide coatings oxidize to form self-repairing alumina scales that enhance alloy corrosion resistance in high temperature applications. Conventionally, aluminide coatings are produced by vapor deposition or pack-cementation approaches, batch processes that require controlled atmospheres. [1] Unfortunately the high cost of these processes has resulted in limited applicability of aluminization processes in SOFC applications.

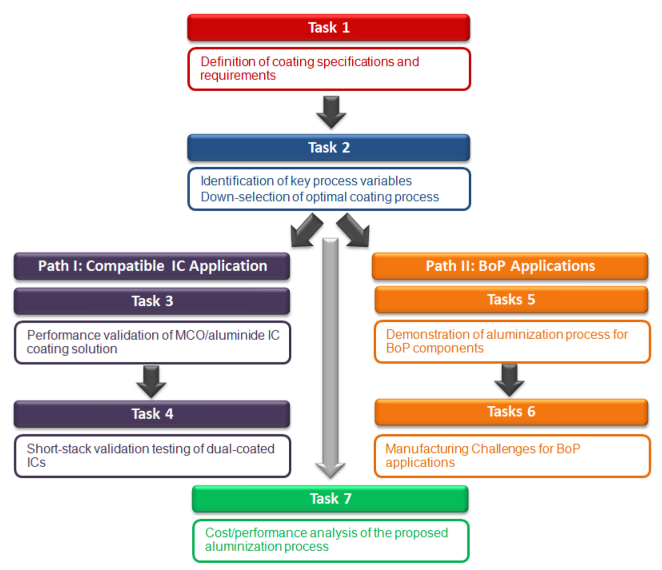
For aluminide diffusion coatings to be commercially viable for SOFC applications, lower cost coating processes are required. Researchers at Pacific Northwest National Laboratory (PNNL) have recently demonstrated a reactive air aluminization (RAA) process which does not require a controlled atmosphere heat treatment [2,3].

Outside SOFCs, similar air-fired spray/slurry aluminization processes have been reported by the PARTICOAT consortium in Europe to deposit complete thermal barrier coatings (TBC) systems on nickel-based superalloys [4,5].

Examples of low-cost aluminization approaches



PNNL Reactive-Air Aluminization (RAA) [3] | *PARTICOAT multifunctional aluminide based TBC [5]*



Structure of Aluminization Based Coating Development

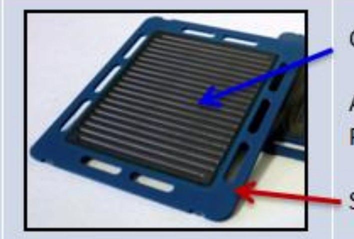
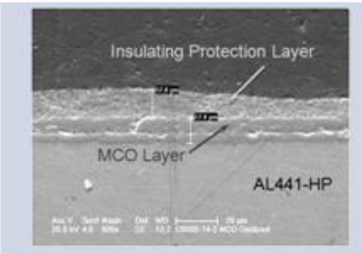
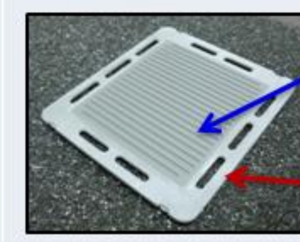
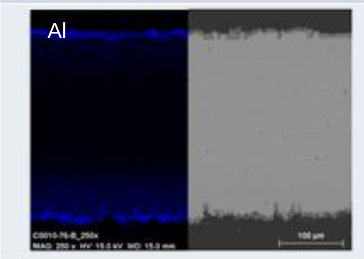
The approaches discussed above illustrate the potential of a low-cost aluminization process. Work is in progress to develop a commercially viable aerosol-spray deposition (ASD) based aluminization process that is amenable to high volume SOFC manufacturing.

This work will leverage NexTech's commercial process technology for applying conductive oxide protective coatings to ferritic steels. The ASD process has been translated from the laboratory to pilot scale manufacturing at NexTech. It is anticipated that this experience will expedite commercialization of the aluminization process.

Aluminization Based SOFC Protective Coatings

Compatible non-active seal area coatings for interconnects

NexTech has developed two complementary coating products for protecting the non-active seal area. The first is based on insulating oxide overlay coatings, the second on an aluminide diffusion coating. NexTech has evaluated interconnect seal-face overlay coatings in SOFC stacks and has demonstrated a significant improvement in both fuel utilization and stack power density. A cost analysis for the two coating scenarios indicates a significant cost-reduction is possible if the aluminized process can be substituted for the current overlay coating process.

Approach	Appearance	Coating	Cross-Section
Overlay Coating		Cathode Active Area: MCO Anode Active Area (back): Proprietary Oxide Coating Seal Area: Overlay Coating	
Aluminide Diffusion coating		Cathode Active Area: MCO Anode Active Area (back): None Seal Area: Aluminide Coating	

Two approaches for multiple-coated IC components.

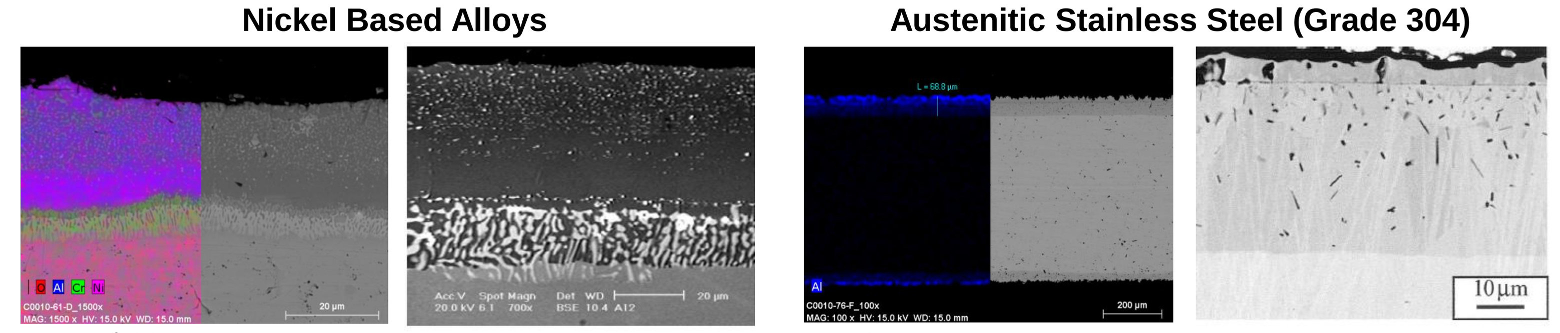
Extension of the Coating Process to BoP applications

To increase the value proposition of the coating technology the process has been successfully applied to other alloy systems of commercial interest for high-temperature balance of plant (BoP) including:

- Austenitic stainless steels: Grades 304, and 316.
- Nickel-based alloys: Inconel 600, 617, 625, and Incoloy 800HT.

Comparison to microstructures formed by traditional pack-cementation/vapor deposition techniques.

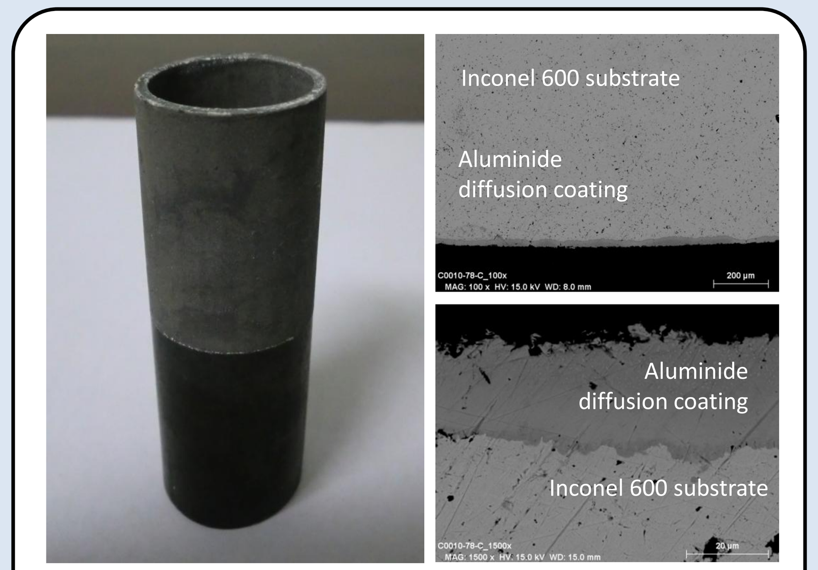
Nickel Based Alloys | **Austenitic Stainless Steel (Grade 304)**



Inconel 617 ASD-based Aluminization | *Ni-based alloy IN738LC Pack Cementation [6]* | *Grade 304 ASD-based Aluminization* | *Grade 304 CVD process [7]*

Non-planar Components

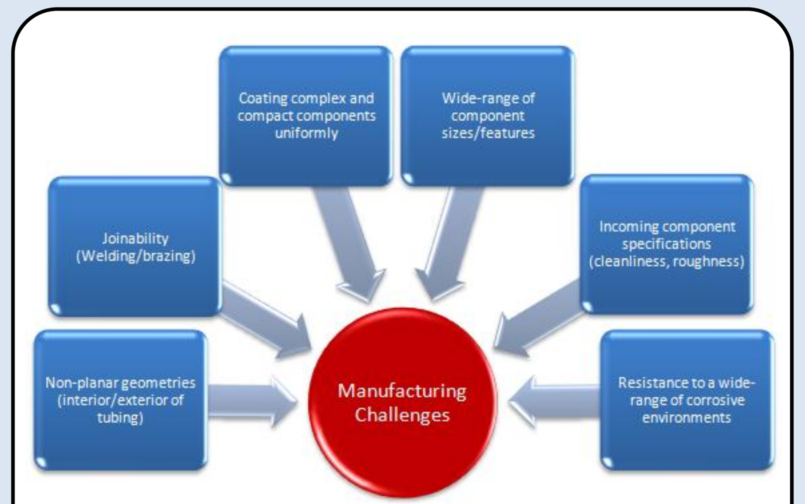
A modified dip-coating process has been developed to allow for both overlay and diffusion-based coatings to be uniformly applied to non-planar components. The images below show a one inch outer diameter Inconel 600 tube that has been successfully aluminized by a dip-coating process.



Demonstration of modified dip-coating process

Manufacturing Challenges

Manufacturing challenges that may limit the adoption of the coating technology are being identified and ranked and coating strategies to address them defined. Many of the challenges are associated with the wide-range of possible applications and environments the coating could be subjected to.

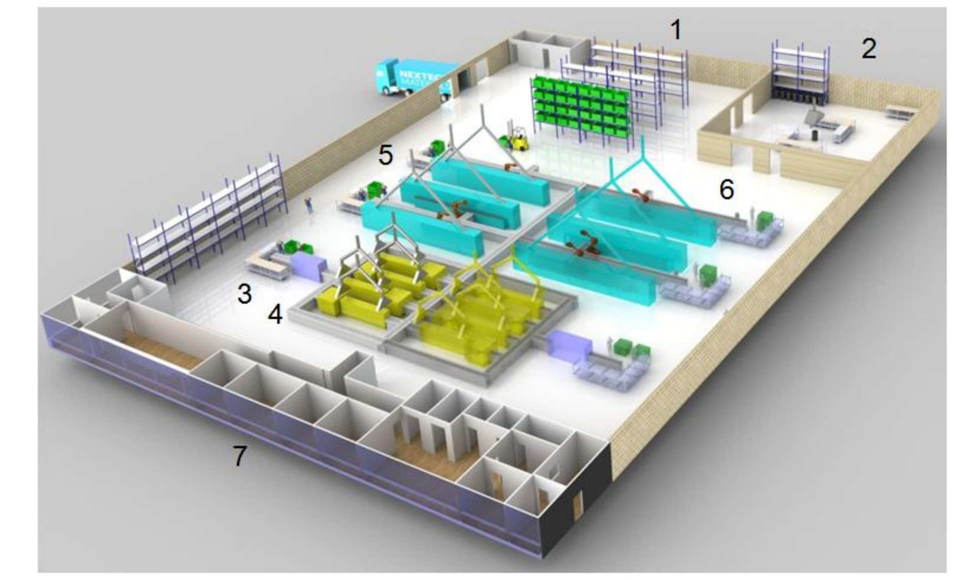


Examples of Manufacturing Challenges for BoP applications

Cost and Manufacturing Analysis

Translation of Pilot Scale Processing to High-Volume Production

Today, NexTech has the ability to coat approximately 10,000 interconnects per year. However, through collaboration with equipment manufacturers and industrial process integrators, we are designing a plant that will move our production capabilities from small run prototype to scale up to high-volume manufacturing where the coating operation can coat up to 12 million interconnects per year.



Schematic of proposed high-volume manufacturing plant for NexTech's interconnect coating products.

Key Features

Plant is 45,000 sq. ft

1. Storage racks for receiving and storage of interconnects.
2. Suspension Preparation Area
3. Inline cleaning station
4. Integrated spray-coating/drying operation
5. Continuous, controlled atmosphere furnaces
6. Mirrored process line demonstrating space for expansion (multiple lines for additional capacity)
7. Support Offices

Multiple Coatings Cost-Analysis

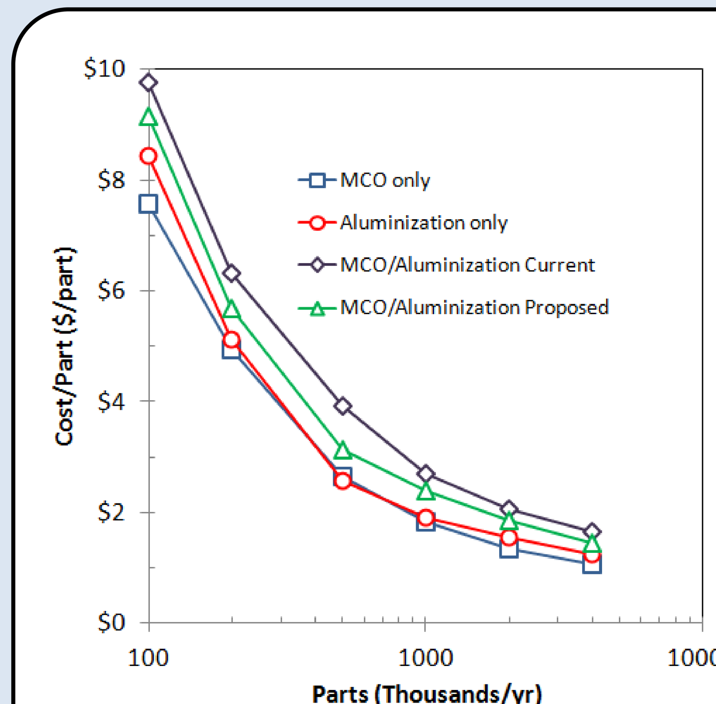
A detailed cost-model has been developed for a range of interconnect coatings:

- MCO cathode active area coatings.
- Aluminization based, non-active seal area coatings.
- Dual MCO/aluminization based coatings.

Cost curves for annual volume production from 100,000 to 4 M parts/year are shown. Parts are assumed to be: 15 cm by 15 cm with a 10 cm by 10 cm active layer. 20 μm thick MCO and aluminization based coatings are assumed.

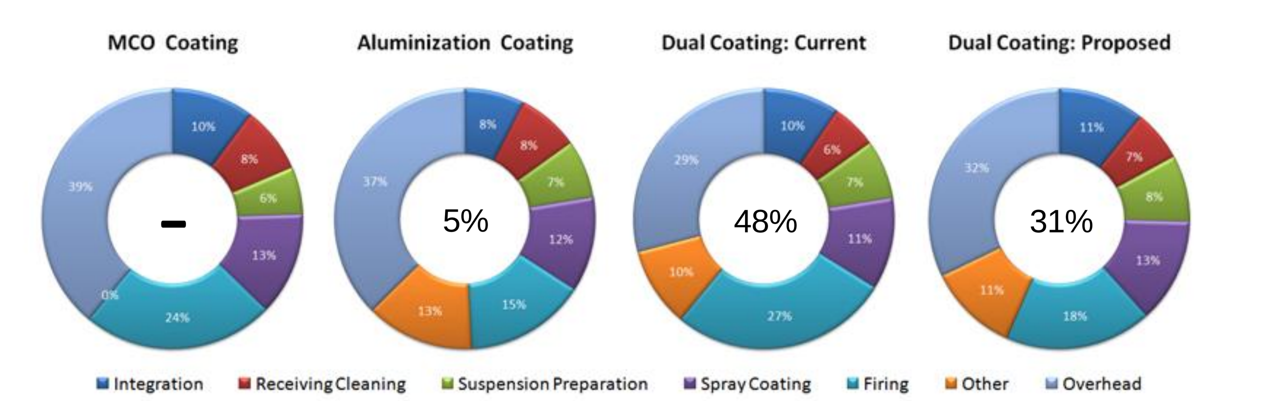
Various manufacturing decisions are built into the model including:

- Batch versus continuous furnaces
- Incorporation of automated part handling/transfer and integration as production volume increases
- Integrated spray coating/drying system.



Cost model for various coating scenarios of NexTech's ASD-based interconnect coating process.

The contribution of the different process steps to the overall coating cost for the different coating scenarios to shown below. The significant savings in combining the two coating processes (MCO and aluminization) is driven by a reduction in overhead expenses. In addition, work is in progress to optimize the compatibility of the MCO and aluminization processes for further cost reduction.



Cost breakdown at annual volume production of 1 M parts/yr for NexTech's ASD-based interconnect coating process.es Value in the center is percent increase in cost of the process vs. standard MCO coating process.

1. V. Rohr, PhD thesis, Institut National Polytechnique de Toulouse (2005).
2. J. P. Choi, K. S. Weil, *Aluminization of metal substrate surfaces*, US Patent Application, US2010/097341 A1
3. J. P. Choi et al., *Reactive Air Aluminization*, PNNL Report 20859 (2011)
4. X. Montero et al., *A Single Step Process to Form In-Situ an Alumina/Aluminide TBC System for Alloys in Extreme Environments at High Temperatures*, Surf. Coat. Technol. 206 (2011) 1586.
5. M. Juez-Lorenzo et al., *Diffusion Aluminide Coatings using Spherical Micro-Sized Aluminium Particles*, Defect and Diffusion Forum, 289-292 (2009) 261
6. H. Arabi et al., *Formation Mechanism of Silicon Modified Aluminide Coating on Ni-Base Superalloy*, Int. J. Eng. Sci. 19(5-1) (2008) 39.
7. B. A. Pint et al., Performance of Al-Rich Oxidation Resistant Coatings for Fe-Base Alloys, Mat. Sci. Corr. 62(6) (2011) 549