Nanoscale Metal Oxide Coatings for Corrosion Protection of Component Materials used in Supercritical CO₂ Environments

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Statement of Purpose

Problem Statement: Generation IV power reactors use supercritical CO₂ (sCO₂) as the heat transfer fluid. New materials that can handle the harsh environment of sCO₂ are required to enable power generation and prevent issues with corrosion and erosion or efficiency degradation.

Project Overview: Funding provided by the DOE’s STR program is supporting the development of nanoscale ceramic barrier coatings to protect metal components from harsh sCO₂ environments.

Technical Objective: Our project team is developing a vapor phase deposition technology called Atomic Layer Deposition (ALD) to address material issues for metals and metal alloys in supercritical CO₂ power generators. Specifically our team is investigating if ALD coatings will allow use of lower cost materials (SS316).

Tasks:
1. Identify potential coatings
2. Deposit and characterize ALD coatings on SS316
3. Test in supercritical CO₂ environment
4. Investigate impact of thermal cycling
5. Investigate ALD application requirements

Technical Background

Introduction to ALD
- Sequential CVD process
- Temporal or spatial separation of reactants
- Half-reactions are self-limiting
- Controllable thickness at sub-nm scale
- Vapor phase reactive species
- Thickness determined by number of ALD cycles

Advantages of ALD
- Conformal coatings on hard to coat surfaces
- Precise growth control, sub-nanometer resolution
- Solvent free, Low process temperature (<150°C)
- Large selection of materials to deposit
- Metals, metal oxides, polymers

ALD in Manufacturing
- Cycle time seconds to minutes
- Many active ALD and related companies
- ALD used in electronics manufacturing
- Continuous – Spatial ALD methods
- Cost <$1.00 to coat 1m²

Example: Corrosion Protection of RF Sources and Components

Need: Isolate metals from coolant fluid (water, ethylene glycol)
Solution: Apply a thin (10-50 nm) ceramic coating over coolant surfaces
Key challenge: Protective coatings must be applied after final assembly – eliminates plating and sputtered coatings
Approach: Use ALD to coat interior surfaces following RF component assembly

Proof of Concept Demonstration: 6-Month Accelerated Life Test

Nanoscale Ceramic Barriers for Protection in sCO₂ Environments

Part 1: Deposit ALD coatings on SS316 and Inconel 625

Part 2: Test materials in supercritical CO₂ environments

Part 3: Test results from supercritical CO₂ test

Ceramic coatings were deposited by ALD onto SS316 and Inconel 625 coupons, the weight change was monitored after a 500 hour sCO₂ exposure

Part 4: Investigate ALD application requirements: Apply to Heat Exchanger Tubing

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