Processing and Characterization of Structural and Functional Materials for Heavy Vehicle Applications

Project (PM_9140)

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Co-investigators: Sergey Yarmolenko, Zhigang Xu

Center for Advanced Materials and Smart Structures

North Carolina A&T State University

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Processing and Characterization of Structural and Functional Materials for Heavy Vehicle Applications

21CTP Technical Goal: Develop and demonstrate an emissions compliant engine system for Class 7-8 highway trucks that improves the engine system efficiency from ~42% today to ~50% by 2010.

Project Objectives

- Establish CCVD facility for SOFC materials processing
- Study and optimize deposition parameters for YSZ electrolyte, nucleation and microstructural evolution of the films
- Integrate anode, cathode and electrolyte development into single SOFCs and study their performance

FY 2005 Focus

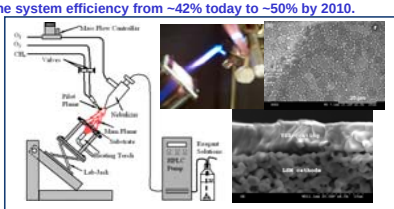
Study electrophoretic deposition of YSZ electrolyte and the effect of the processing parameters on the porosity of the NiO/YSZ anode

Planned Duration

October 2001 to September 2007

DOE Funding/Industry Cost Share

FY04: $75K; FY05: $50K



CCVD deposition setup and SEM images of YSZ coating on porous LSM cathode

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Accomplishments

- CCVD facility for SOFC was established (2001-2002)
- Electrolyte deposition technique with CCVD was optimized (2002-2004)
- Parametric study of electrophoretic deposition of YSZ provided basis for low-cost fabrication of thin dense coatings on SOFC electrode (3/05).
- Manufacturing method based on materials factorial design has been optimized for the development of SOFC anode with desired level of porosities (8/05)

Significant Future Milestones

- Continue to develop fundamental understanding of ceramic materials and processing techniques for potential energy sources in heavy vehicle applications

Project ID/Agreement ID	Program Structure	Sub-Program Element	R&D Phase	Date
PM_9140	Materials Technology	HV Propulsion Materials	Exploratory R&D	8-15-05

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Objectives

- Basic research on thin film electrolyte processing for solid oxide fuel cells (SOFCs)
- Develop and establish innovative techniques to produce SOFC electrolyte coatings for heavy vehicle applications
- Study the effect of the processing parameters of combustion chemical vapor deposition (CCVD), electrolytic deposition (ELD) and electrophoretic deposition (EPD) techniques on the growth rate and quality of the films
- Investigate the material formulation and processing parameters of slurry casting and die-pressing methods for fabrication of porous anodes and cathodes
- Integrate anode, electrolyte and cathode to develop single SOFCs
- Study the cell performance and continue development towards new materials

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Relevance to 21CT Goals

- Development of innovative techniques and materials for solid oxide fuel cells for 21st Century trucks to reduce fuel use and emissions

21CT Partner involvement

- Oak Ridge National Lab

Technology Transfer

Current collaborators

- Global Engineering and Materials, Inc., Anteon Corporation
- Drexel University
- Connecticut Global Fuel Cell Center

Potential commercialization pathway

- We are in the process of working out the details related to patenting our technical developments on SOFC fuel cell materials carried out under the auspicious of CAMSS and exploring SBIR/STTR activities.

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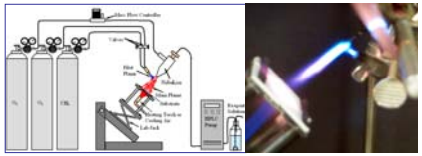
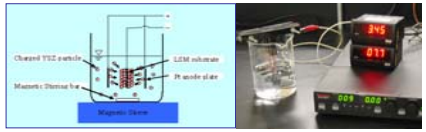
Approach

- Develop combustion chemical vapor deposition (CCVD), electrolytic and electrophoretic deposition (ELD and EPD) techniques to process thin film coatings of electrolyte layers, such as, YSZ, doped strontium cerates, for SOFCs
- Conduct parametric studies to correlate processing parameters, coating productivity and quality
- Develop slurry casting and die-press/sintering techniques for fabrication of the anode and cathode.
- Study the fabrication parameters to produce large area anode/cathodes without cracks. Optimize the ingredient formulation to obtain the desired porosity and pore structure

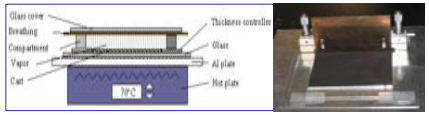
Tech	Investigated Parameters
CCVD	Fuel : oxidant ratio, substrate temperature, substrate-to-nebulizer distance, total-metal-concentration, thermophoresis, processing time
ELD	Precursor, ion concentration, solvent, processing mode, i.e., constant voltage or constant current, current (*I*) or voltage (*V*) levels, processing time
EPD	Powder selection, Selection of charging methods (solvents, additives), processing mode, processing *I*, *V*, and time
Slurry Casting	Material formulation, powder pre-treatment, casting method, drying technique, sintering cycle
Die Pressing	Batch formulation, pressing pressure, sintering cycle



Combustion Chemical Vapor Deposition



Electrophoretic Deposition



Slurry Casting

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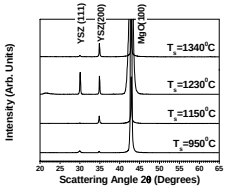
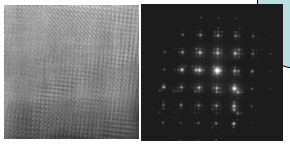
Technical Accomplishments/ Progress/Results

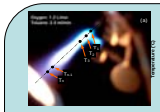
CCVD operational parameters optimization for deposition of dense YSZ films on both dense and porous substrates

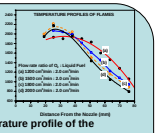
XRD spectra show the pure cubic structure of the YSZ films



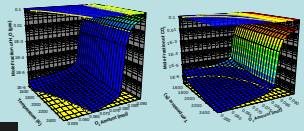


TEM image (left) and electron diffraction pattern (right) show superlattice structure of YSZ coating.



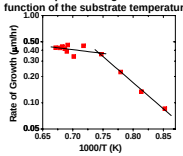


Measurement the temperature profile of the flame at different fuel : oxidant ratios

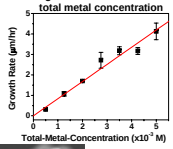


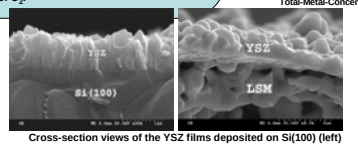
Simulation of the mole fractions of H_2O (vapor) and CO_2 in the flame as functions of flame T and amount of O_2.

Arrhenius plot of film growth rate as a function of the substrate temperature



Film growth rate as a function of total metal concentration





Cross-section views of the YSZ films deposited on Si(100) (left) and porous LSM cathode (right) using CCVD

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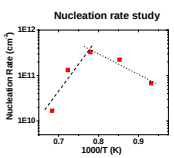
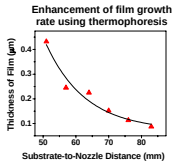
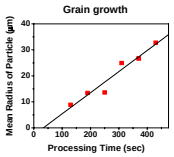
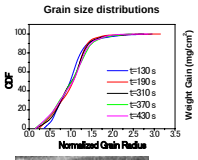
Technical Accomplishments/ Progress/Results

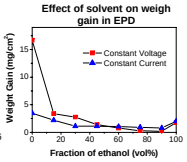
- Nucleation and microstructure evolution in CCVD were studied
- Film growth enhancement was achieved by using thermophoresis mechanism and higher metal concentration in the solution
- YSZ coatings were understood and produced using both electrolytic and electrophoretic liquid phase depositions (EPD)
- Large area sheets of anode and cathode without cracks were produced by slurry casting and high-humidity drying technique
- Materials formulation to make desired anode/cathode pore properties was optimized by statistical experimental design
- 2 PhD produced during last 4 years
- 2 MS students (African American) graduated from A&T (2004) and conducting PhD research in Georgia Tech

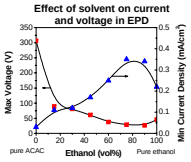


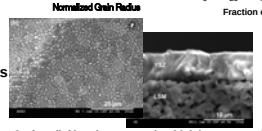




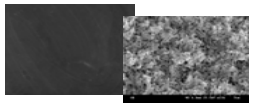








Surface (left) and cross-section (right) micrographs of YSZ deposited by EPD on porous LSM cathode.



5"x6" dried green form (left) and microstructure after sintering (right) of NiO/YSZ anode produced by slurry casting.

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Future Work

- Modify the CCVD facility for lower cost coatings of YSZ electrolyte on porous electrode.
- Continue on the property characterizations for the fuel cell components.
- Processing of proton conductive thin films for solid oxide fuel cells.
- Integrate the components into single SOFCs and study their performance
- Continue development towards new materials