

## High Temperature Environment Barrier Coating for SiC based Substrates

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# High Temperature Environmental Barrier Coating (EBC) for Silicon Carbide Composites

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Technical Objective

**Increase temperature capability of environmental barrier coatings**

- Si-based ceramic components are of interest to reduce weight and increase operating temperatures in gas turbine engines
- EBCs are applied to the component surface to protect against moisture-assisted, oxidation-induced ceramic recession
- Advanced EBC systems are desired for use temperatures up to 1650°C (currently limited to ~1300°C)

Key Challenges

**For high temperature ( up to 1650°C) EBC development several key issues must be overcome. These include:**

- Coating volatilization in high velocity combustion environments
- Current Si bond coats limited to temperatures below 1350°C due to low Si melting point
- EBC materials must be able to withstand erosion, impact and high temperature corrosion (CMAS).

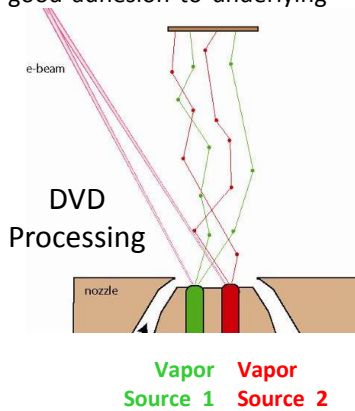
Technical Approach

**Advanced coating compositions and structures enabled through the use of a novel Directed Vapor Deposition processing technique are envisioned to improve high temperature performance**

- EBC materials having enhanced high temperature phase and chemical stability in combustion atmospheres have been identified
- Chosen materials will be deposited using DVD approach with a dense microstructure and enhanced substrate adhesion (resulting from vapor phase processing approach) to eliminate the need for temperature limited bond coats
- A strain tolerant, thermal protection layer is added to limit temperature exposure of the EBC layer and protecting it from erosion, impact and corrosion damage.

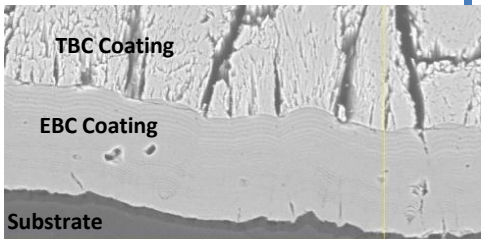
## How it Works:

- DVD-applied coatings with advanced chemistries are applied to ceramic substrates for temperature stability above 1300°C
- Coating forms a barrier between the substrate and water vapor from the environment at elevated temperature
- Novel multi-source deposition technique enables required compositional and microstructure control with good adhesion to underlying substrate



## Results to Date:

- T/EBC layers having the desired phase and microstructure have been deposited using a multi-source DVD approach.
- Coating architectures having good thermochemical capability have been developed
- Coatings survived testing at 1482°C in simulated engine environment (high temperature water vapor/oxidizing environment)



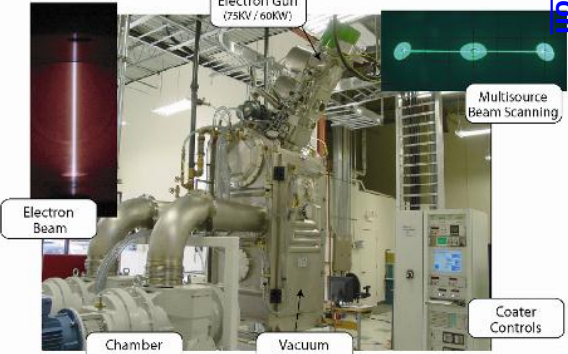
T/EBC system after survival of 100 1h cycles in 90% H<sub>2</sub>O-O<sub>2</sub> at 1316 °C

## Next Steps / Research Goals :

- Optimize T/EBC composition and microstructure for desired performance
- Perform additional engine qualification testing (such as: laser testing with thermal gradients, and high pressure burner rig testing)
- Apply advanced T/EBC system onto ceramic engine components

## Transition Plan

- DVTI is working with engine OEM's to qualify EBCs for use on ceramic matrix composites
- Follow-on work will apply coatings to Si-based ceramic components for ground-based engine testing
- DVTI's production scale DVD coater will be used to coat engine test components



## Planned Impact

- Increase the temperature stability of Si-based ceramics to 1650°C in water vapor environments to enable increased thrust and fuel efficiency in advanced gas turbine engines

**Presentation** UCSB – MS&T 2012(Poerschke)

Technology Transition

Impact

# Company Overview

## Core Competencies / Expertise:

- Development and application of advanced coatings
- Technology transition to a production environment
- Directed Vapor Deposition (DVD) – an improved Electron Beam Physical Vapor Deposition process



## Coating Capabilities:

- 3000 sq. ft. coating facility
- Production capable coater
  - Designed, built, and installed by DVTI (March 2007)
  - Currently used to qualify DVD process for OEM production
  - Capable of moderate volume production
- Access to two research coaters





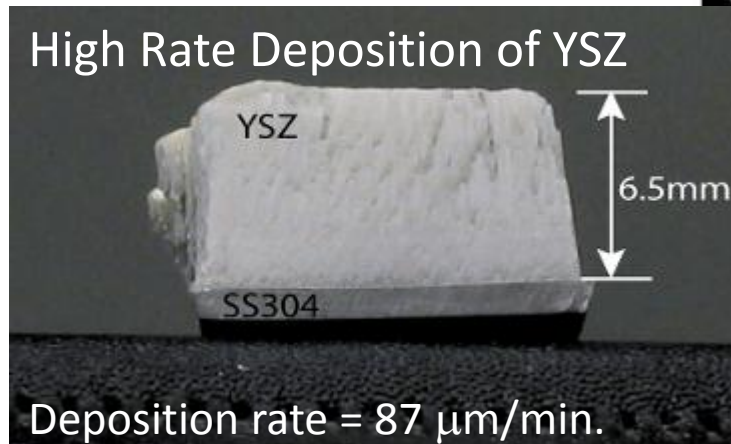
# Directed Vapor Deposition

## Concept

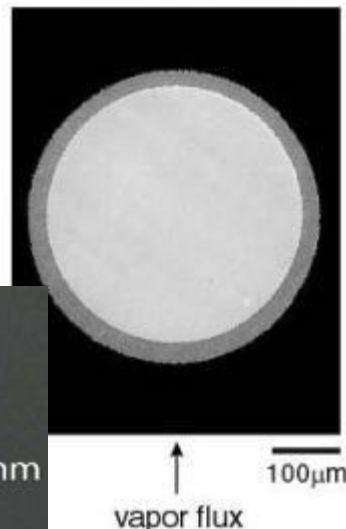
gas phase scattering of an evaporated vapor flux (by collisions with supersonic gas) enables the flux trajectory to be controlled

## Rationale for DVD:

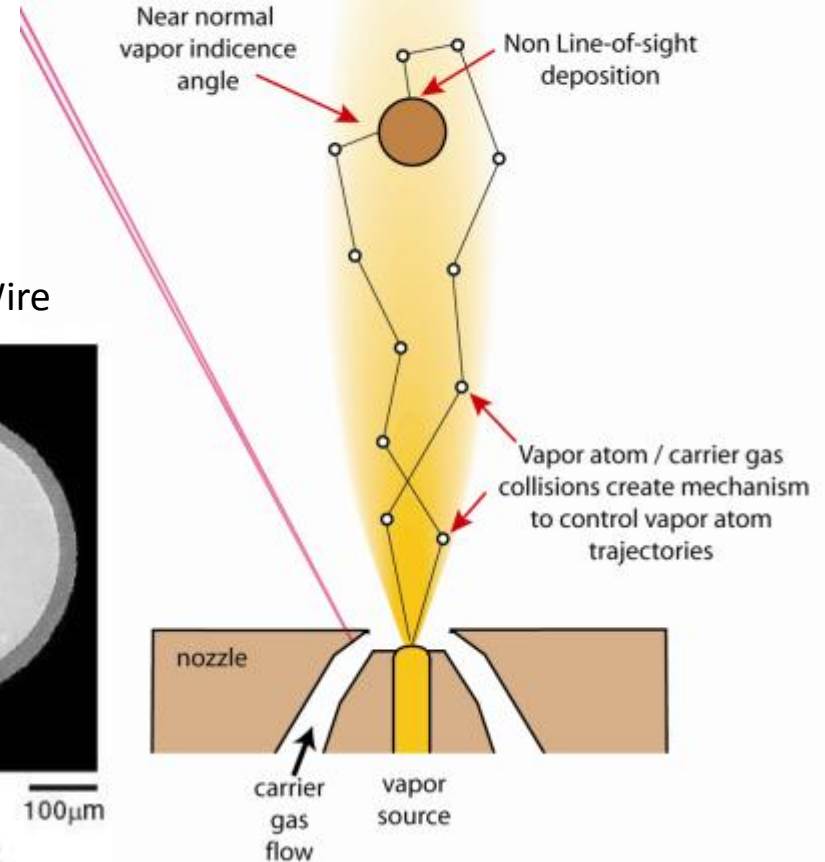
- increase deposition efficiency of EB-PVD process
- increase deposition rate
- non-line-of-sight coating
- composition and morphology control
- soft vacuum – ease of use



DVD Coated Wire



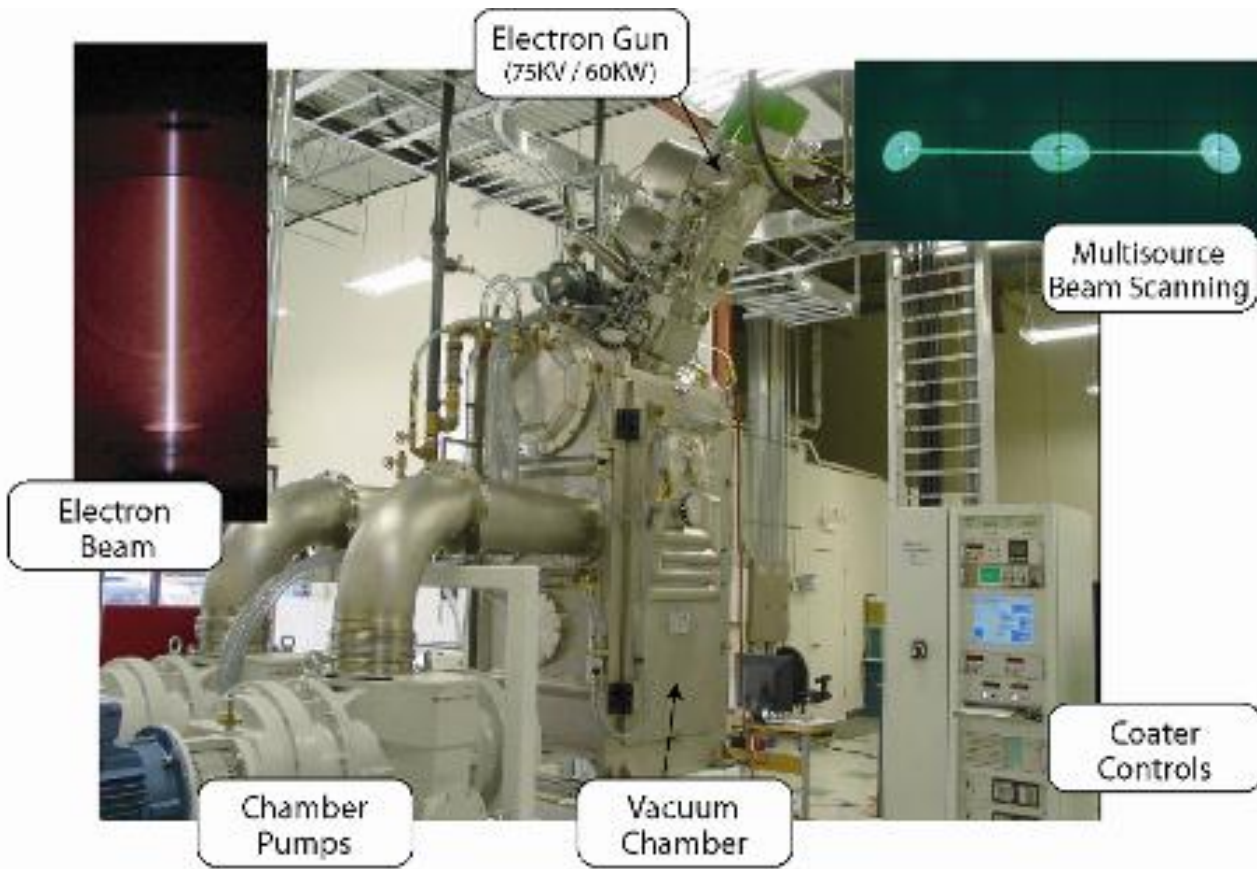
Moderate vacuum (5 to 50 Pa)  
DVD



## **DVD Advantages:**

- Non Line-of-sight capability
- High deposition efficiency

# Scaled DVD Coater



# Environmental Barrier Coatings

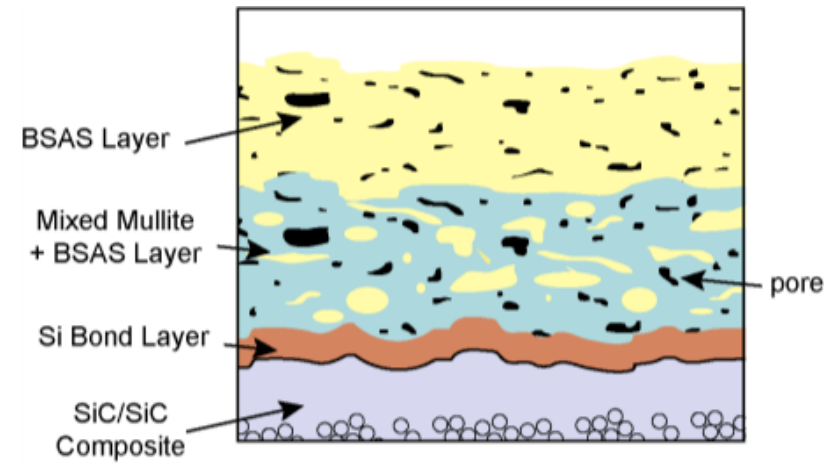
**Silicon-based ceramic materials** (both monolithic and composites) are the leading candidates to replace nickel-based turbine components in next generation gas turbine engines

## Due to:

- high melting points,
- relatively low density,
- high toughness relative to other ceramic materials and
- excellent oxidation resistance in clean oxidizing environments due to the formation of a protective, slow-growing silica scale.

**Key Issue:** Exposures to water vapor containing combustion environments alter the effectiveness of the silica scale. Such conditions result in the formation of hydrated silica species ( $\text{Si(OH)}_x$ ) and volatilization of the protective scale. This results in decreased oxidation protection and rapid ceramic recession during service.

One approach to limit the environmental drawback is through the incorporation of environmental barrier coatings (EBCs) that protect the substrate from environmental attack.



# *EBCs for Enhanced Temp. Capability*

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Future military applications may require EBCs to survive temperature exposures of up to 3000°F (1650°C) while retaining a 2700°F~1482°C ceramic substrate temperature.

2<sup>nd</sup> Generation EBC system are anticipated to be limited in these environments by:

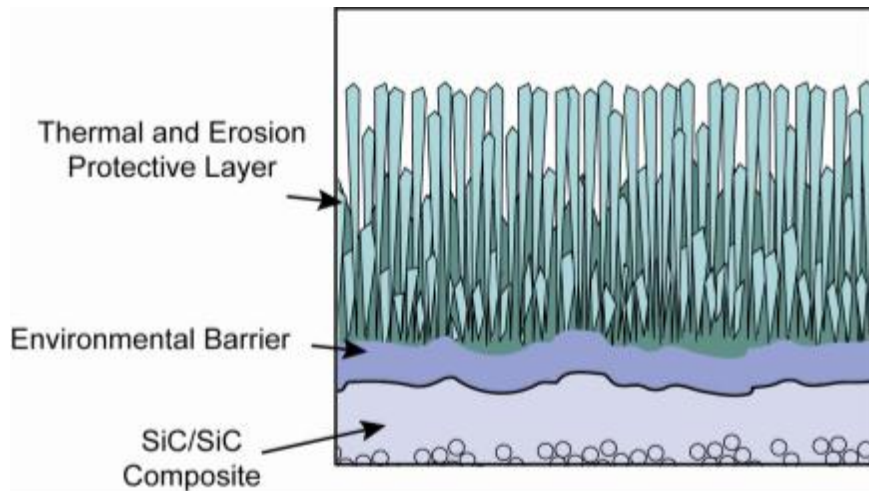
- BSAS volatilization
- EBC bond coat reactions
- Si bond coat melting temperature

Thus, the use of such coatings are the future desired temperatures may require several items:

- i) An additional thermal barrier to be applied to limit the temperature exposure of the underlying EBC and substrate.
- ii) Removal of any low melting point / high volatilization materials
- iii) Identification of high temperature replacement materials for BSAS.
- iv) Advanced processing techniques

# Program Objective

The objective of this project is to develop high temperature protective coating system that will provide enhanced environmental, thermal and erosion protection for Si-based ceramics.



- Coatings will be designed to operate in combustion gas environments that include high heat flux (temperatures up to 1650°C), particle and foreign object erosion and water vapor.
- To achieve these goals DVTI will develop advanced T/EBC coatings having **low oxygen permeability** to provide environmental protection and an electron beam deposited thermal and erosion barrier having **a columnar microstructure, a substrate-compatible CTE and a low thermal conductivity**.
- **The use of a novel vapor deposition based processing approach is employed to potentially enhanced coating adhesion to the substrate** due to the chemical bonding intrinsic to PVD processing approaches and to aid the creation of advanced coating microstructures and architectures.



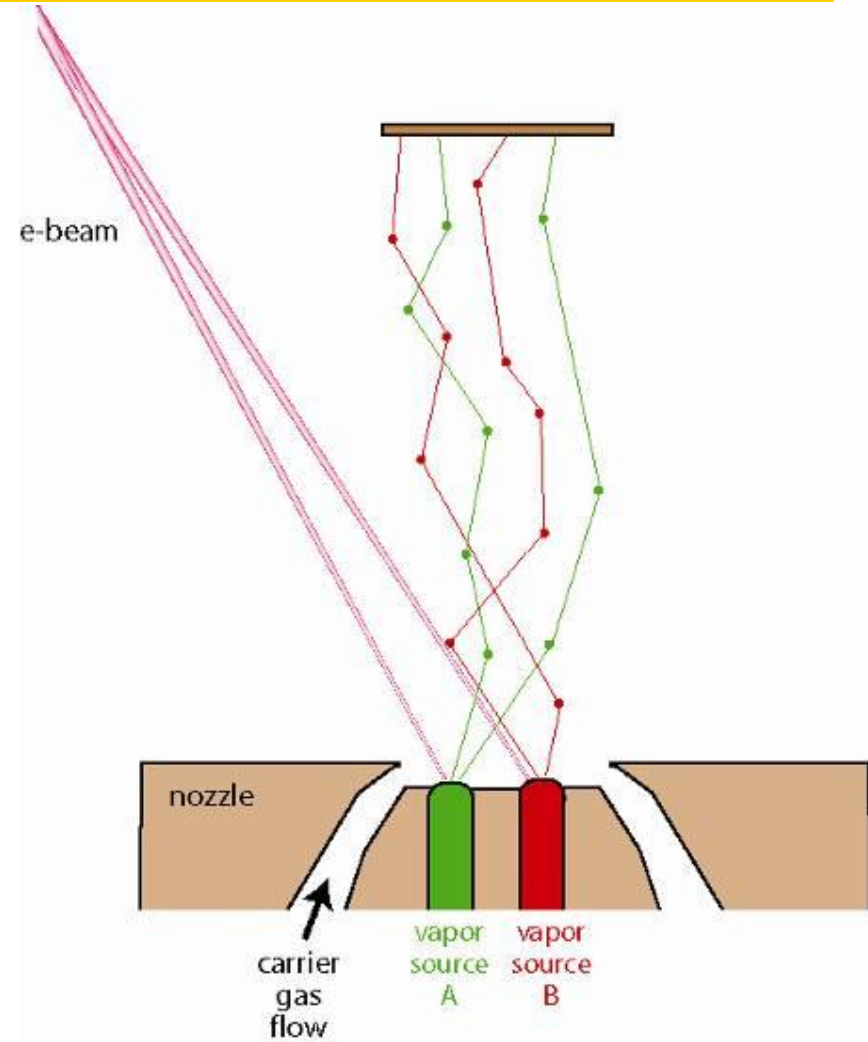
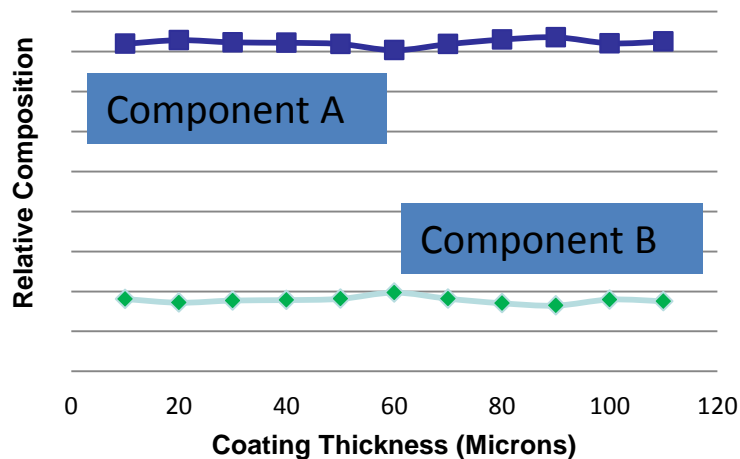
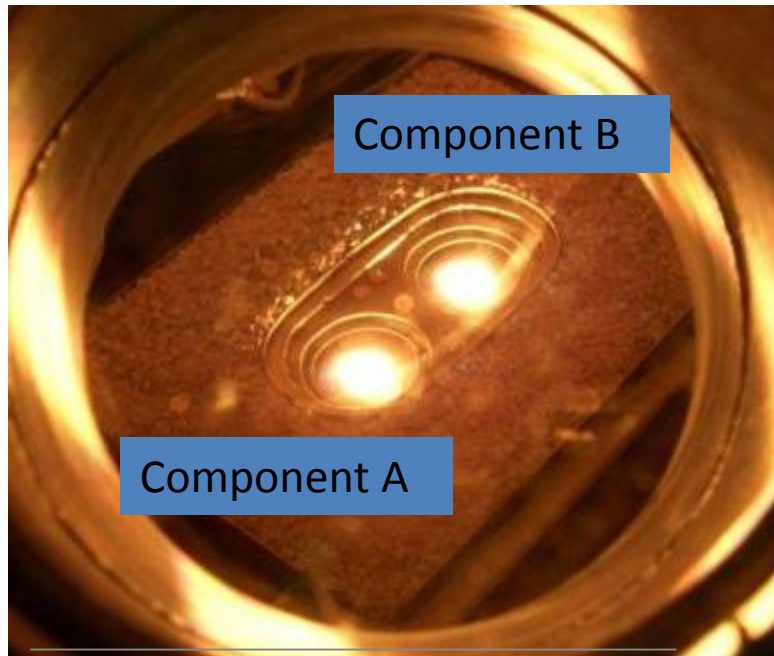
# Phase II Approach

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- DVD technology assessment, test plan development and kick-off meeting: Key aspects of this objective are to assess the current status of DVTI's EBC processing capabilities and to refine, the testing protocol to assure the proper suite of testing is performed in the Phase II effort.
- Optimize EBC layer deposition from the vapor phase.
- High temperature T/EBC system development and processing capable of achieving 1650°C maximum operation temperature.
- Coupon level T/EBC testing.
- DVD process development for multi-source EBC deposition.
- Simulated engine environment testing of T/EBC system to temperatures of 1650°C: Successful testing in the simulated engine environment will lead to qualification engine testing and the potential for DVTI to provide or license coating application technology on a commercial basis.
- Identification of qualification testing opportunities.

# T/EBC Processing

## 2 x 1" Dual source evaporation



Excellent compositional uniformity obtainable for materials systems having large vapor pressure differences between components