Integrated TBC/EBC for SiC Fiber Reinforced SiC Matrix Composites for Next Generation Gas Turbines

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Advanced Ceramic Research

Abstract

- Design an integrated and graded bond coat/ environmental barrier coating/thermal barrier coating (BC/EBC/TBC) system that can effectively protect and lead to use of SiCf/SiC matrix CMCs in next generation gas turbine.
- This Project: develop a novel integrated and graded EBC/BC that can significantly reduce thermal stress caused by CTE mismatch, as well as severely slow down the oxygen transport and oxide volatilization of EBC under high velocity steam, oxidizing conditions.
- Future Program: collaborate with GE Power to develop and demonstrate the performance of a TBC system that is compatible with the integrated EBC/BC for next generation gas turbines.

Goals and Objective

Overall Goal:

- Develop an integrated and graded EBC/BC that has: (a) Good bonding with CMC; (b) Graded compositions without sharp interfaces; (c) Low oxidation rate and low volatility in high temperature, high velocity steam environment; (d) Tolerant to certain degree of oxidation; (e) Chemically stable and compatible with CMC and TBC
- Create a strong collaborative team with complementary expertise and state-of-the-art facilities: (a) The Clemson University team of PIs Bordia and Peng and (b) The GE team, led by John Delvaux

Objectives:

- Investigate the effect of composite stoichiometry (*i.e.* Si/B/C/N ratio in the precursor and the ratio of the Si-based precursor to yttrium oxide (Y_2O_3) (or ytterbium oxide (Yb_2O_3)) particle filler and processing conditions on the resultant phases and nanostructure of the composite ceramics.
- Investigate the effect of the composition and nanostructure on the thermal properties and oxidation and volatilization behavior in oxidizing and high velocity steam environments.
- Process the graded Y_2O_3 (or Yb_2O_3) particulate /silicon boron carbon nitride (SiBCN) matrix composite coating and investigate the phase and microstructure stability during high velocity steam exposure at temperatures up to 1500ºC.
- Develop a method to create Y_2O_3 (or Yb_2O_3) and SiBCN powders suitable for atmospheric plasma spraying (APS). The powders will be provided to *GE Power* for the fabrication of integrated environmental barrier coating/bond coating (EBC/BC) using APS.
- Evaluate the performance of integrated BC/EBCs from APS under high velocity steam environments at temperatures up to 1500ºC.

Introduction and Background

- Engine efficiency increases as turbine gas temperature increases. The gas temperature in 65 % combined cycle efficiency turbines is expected to reach ~1700ºC.
- This will require SiC/SiC CMC as the turbine material with coatings However, SiC/SiC CMCs can have catastrophic recession under high velocity steam as shown in the following reactions.

SiC can be oxidized to SiO_2 to form a protective scale

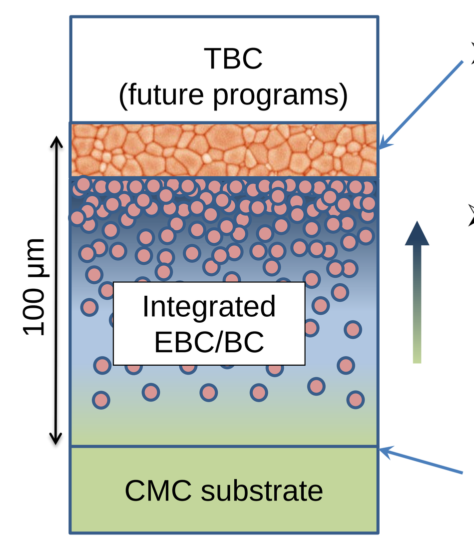
$$SiC + \frac{3}{2}O_2\,(g) \rightarrow SiO_2 + CO\,(g)$$

Silica reacts with water vapor to form volatile hydroxide species[1]

$$SiO_2 + 2H_2O\,(g) \rightarrow Si(OH)_4\,(g)$$

Proposed Research

The concept of integrated TBC/EBC/BC



- Dense Y_2O_3 or Yb_2O_3 top layer ensures low oxygen diffusion and volatilization rates under high temperature high velocity steam environment.
- Graded composition allows smooth transition from SiC to SiBCNO with increasing amount of embedded Y_2O_3 particles.
  - Graded structure avoids sharp CTE mismatch
  - Tolerant to oxidation; further increases TBC lifetime
- PDC SiC bond coat provides excellent adhesion to SiC-fiber reinforced SiC ceramic matrix composite (CMC).

Advantages

- Good bonding with CMC;
  Si-based PDC precursors can yield ceramics with the same composition as the composite
- Graded compositions without sharp interfaces to mitigate thermal stresses from CTE mismatch;
  Flexibly adjustable ratios between the SiBCN/Y_2O_3 (or Yb_2O_3), the C:N ratio and the Si:B ratio in Si-B-C-N makes PDC precursors useful in fabricating our graded coating.
- Low oxygen transport rate, low oxidation rate and low volatility in high temperature, high velocity steam environment;
  Y_2O_3 has very good resistance to volatilization under the steam environment[2]; In addition, Y_2O_3 has an extremely low oxygen diffusion coefficient that is at least two orders of magnitude lower than that of HfO_2 or ZrO_2.[3]
- Tolerant to certain degree of oxidation thereby preventing catastrophic failure;
  Even if SiO_2 forms within integrated EBC/BC due to oxidation, Y_2O_3 reacts with SiO_2 and forms a mixture of Y_2SiO_5 and $Y_2Si_2O_7$ at 1400ºC. The yttrium silicates themselves have been found to have very low oxygen diffusion coefficient and volatilization rate[4].
- Chemically stable and compatible with CMC and TBC (TBC to be developed in future projects)

Research Tasks

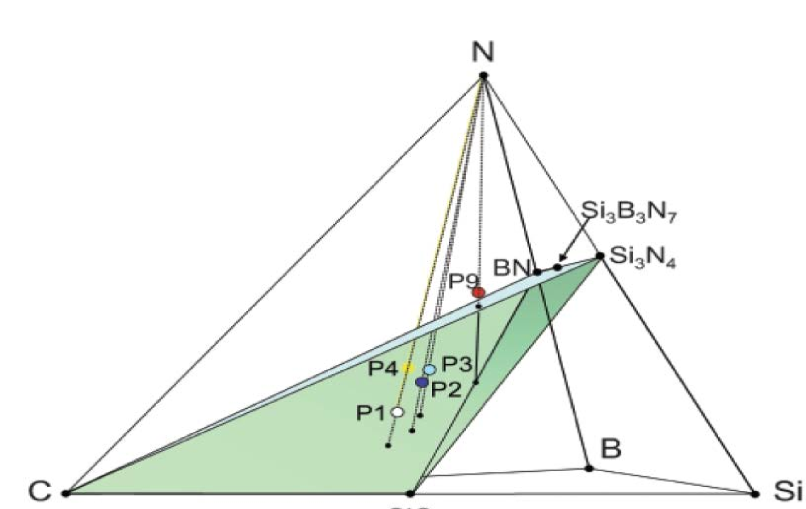
Task 1: Project management and planning

- Collaborative effort between Bordia and Peng at Clemson University who have complementary expertise and our colleagues at GE Power Systems.
- As PI, Bordia will serve as the primary contact with DoE and will be responsible for project management, with the assistance of Co-PI Peng
- The PIs will meet regularly with project personnel to discuss results and plans for meeting the milestones.
- The scientific/technical decisions will be made by Drs. Bordia and Peng with regular input from our collaborators at GE Power team members (Mr. Delvaux will serve as the lead of the GE team).

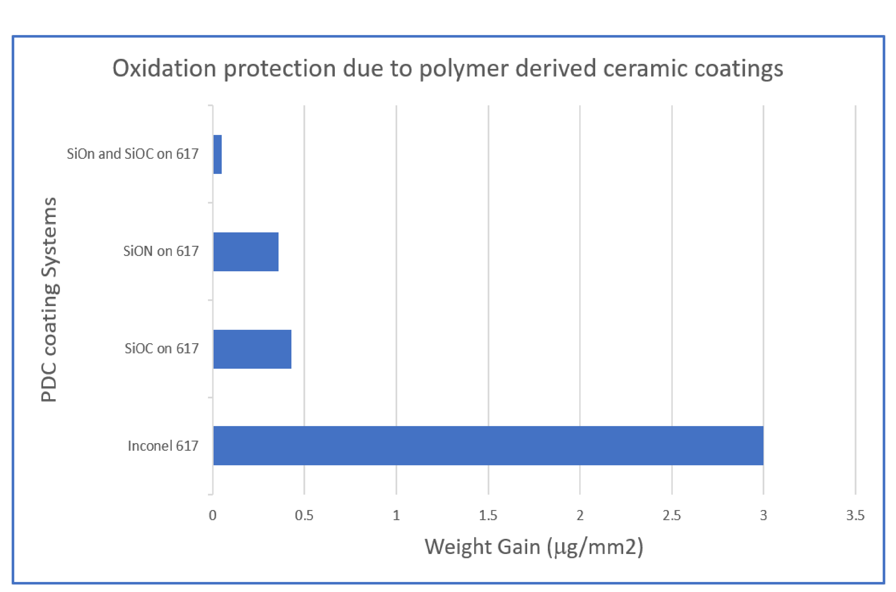
Task 2: Processing and stability of Y_2O_3-Si-B-C-N and Yb_2O_3-Si-B-C-N composites

Goal: to develop a rational approach to process composites with the desired phases and microstructure.

- Subtask 1: Determine the effect of composition and processing temperature on the phase and microstructure of composites
- Subtask 2: Investigate the effect of temperatures on the phase-stability phase and microstructure of composites during oxidation at temperatures up to 1500ºC



PDC is very flexible in controlling the final compositions

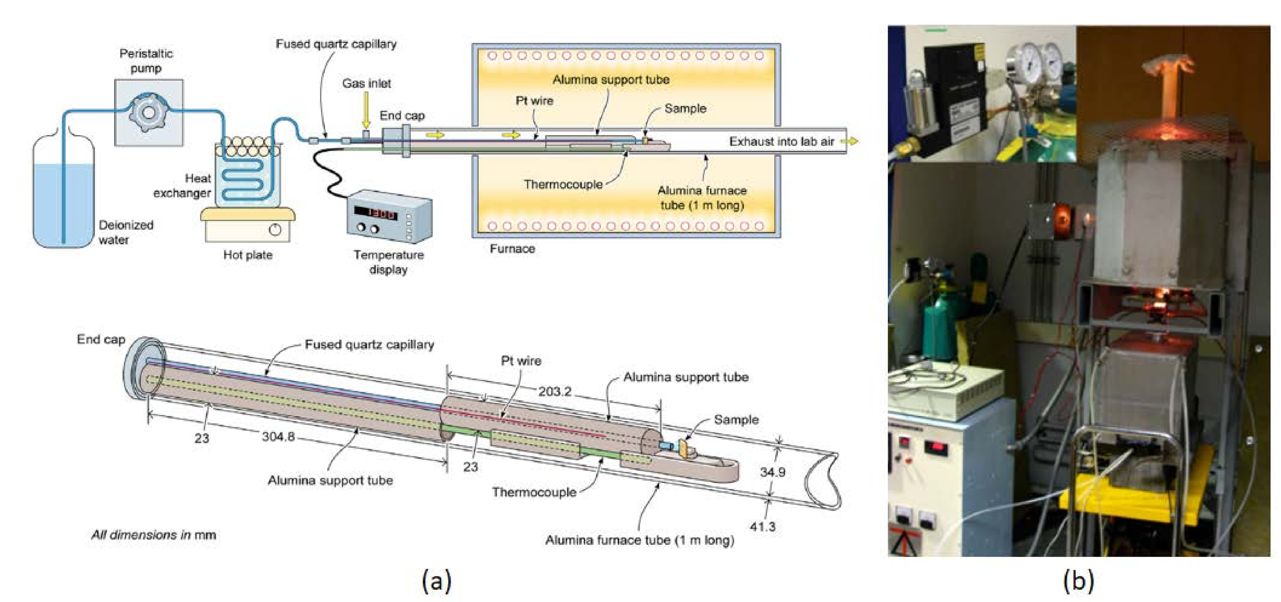


We have abundant experience in fabricating and characterizing PDC ceramic coatings (example above is for oxidation resistant coatings for metals)[4]

Task 3: Thermal and oxidation response of Y_2O_3-Si-B-C-N and Yb_2O_3-Si-B-C-N composites

Goal: to develop the needed database for the rational design of graded coatings.

- Subtask 1: Effect of composition and microstructure of composites on thermal expansion coefficient, elastic modulus and thermal conductivity
- Subtask 2: Effect of composition and microstructure of composites on oxidation and volatilization during exposure to high velocity steam at temperatures up to 1500ºC.



(a). Illustration of the high velocity testing apparatus that will be built to characterize volatilization under high velocity steam[2].
(b) Our home-build TGA unit to characterize oxidation behavior up to 2000 ºC.

Task 4: Processing and performance of graded coatings processed using cold spray and pyrolysis

Goal: to demonstrate a graded BC/EBC system for effective oxidation protection of SiC based CMC

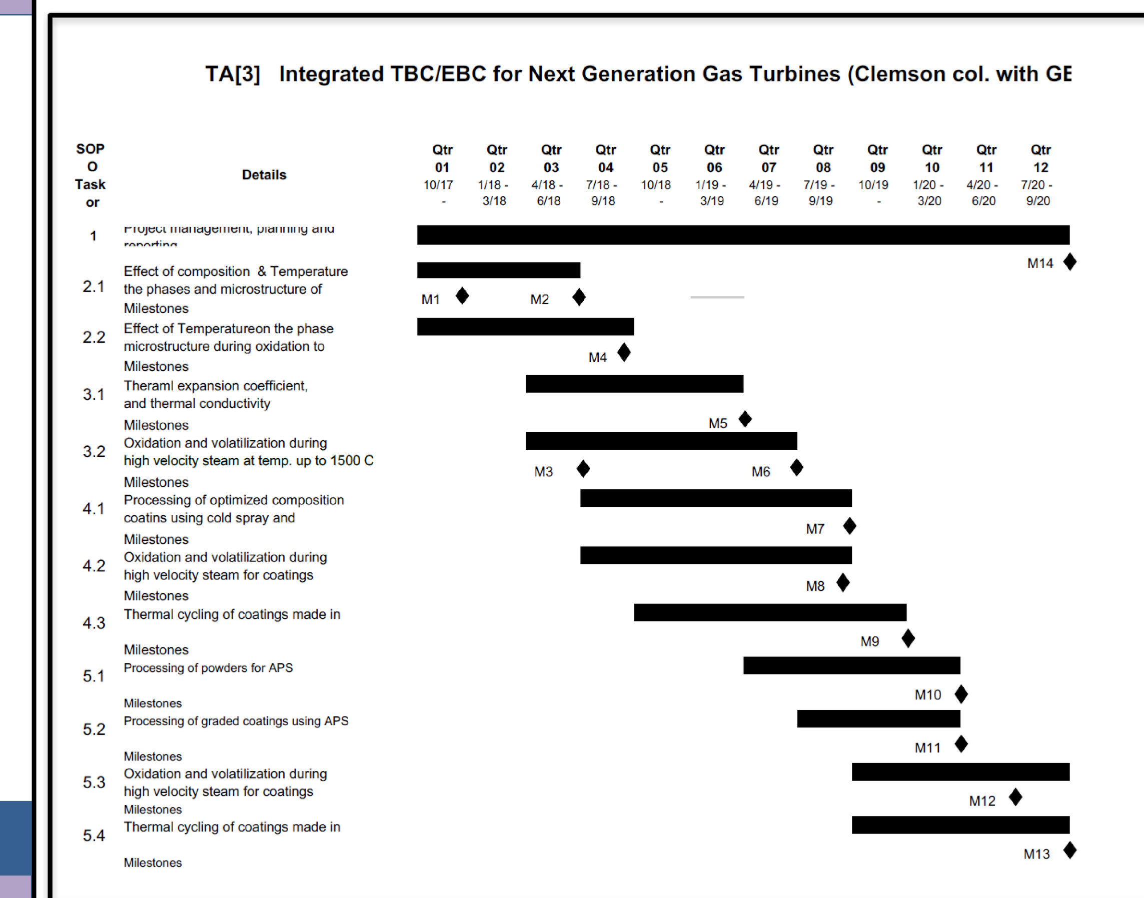
- Subtask 1: Processing of optimized composition graded coatings (based on results of Tasks 1 and 2)
- Subtask 2: Characterization of the oxidation and volatilization of coatings during exposure to high velocity steam at temperatures up to 1500ºC and performance in burner rig and under thermal cycling

Task 5: Graded composition coatings using atmospheric plasma spraying (APS)

Goal: to demonstrate the feasibility of using APS to make graded coatings and their properties.

- Subtask 1: Processing of powders suitable for APS
- Subtask 2: Processing of graded coatings using APS
- Subtask 3: Characterization of the oxidation and volatilization of APS coatings during exposure to high velocity steam at temperatures up to 1500ºC and performance in burner rig.

Schedule



Outcomes

Development of high performing coating systems for SiC based composites for use in high efficiency gas turbines. We will deliver:

- The understanding of the effect of composite stoichiometry and processing conditions on the resultant phases and nanostructure of the composite ceramics.
- The understanding of the effect of the composition and nanostructure on the thermal properties and oxidation and volatilization behavior in oxidizing and high velocity steam environments.
- The processing of the graded Y_2O_3 (or Yb_2O_3) /SiBCN composite coating and the understanding of the phase and microstructure stability during high velocity steam exposure at temperatures up to 1500ºC.
- The demonstration of using atmospheric plasma spraying (APS) to make graded coatings and the investigation of their performance in high velocity steam environment up to 1500ºC.

Training and education of a next generation work force in this important area. The proposal will support one post-doc and several UG students who will work on the scientific issues outlined in the research and will also be exposed to the broader context of research in the area of energy efficiency.

The collaborative research program between the two PIs, together with our industrial partners, GE Power, will provide a unique and complementary expertise and state-of-the-art facilities.

Acknolegement

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