Refractory Foam Materials and SiC Matrix Composites by Melt Infiltration

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Outline

- Ultramet Introduction

- Refractory Tungsten Foam First Wall Armor for Inertial Fusion Energy Reactors

- SiC_f/SiC CMC Development for Gen IV Structural Applications

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Ultramet

- Founded in 1970 still privately owned
- Advanced high temperature materials development and manufacturing
- Worldwide leader in chemical vapor deposition/infiltration (CVD/CVI) materials application
- 33 years of profitable operation

Ultramet

- 2003 Sales $13MM
- Product Line
  - 35% Government R&D
  - 35% Advanced Materials Products
  - 30% Medical/Biomedical, Incl. Licensed Products
- 65 Employees, Ph.D., M.S., B.S.

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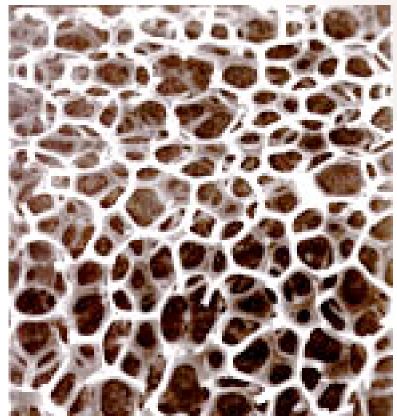
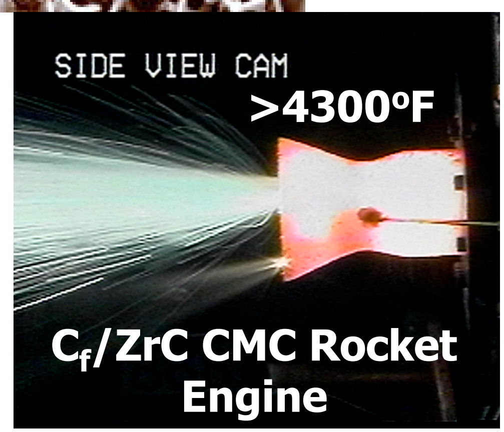
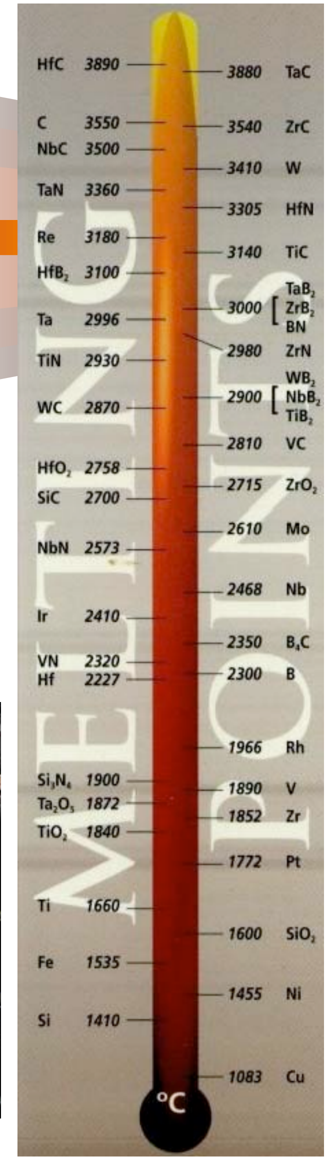
Technology Base

- CVD/CVI
- Refractory Metals
- Engineered Ceramics
- Coatings
- Catalysts
- Ceramic and Metal Foams
- CMCs







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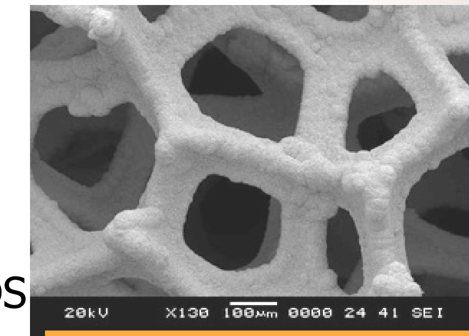
W First Wall Armor for IFE Reactors

***DoE** (7/21/03– present)*

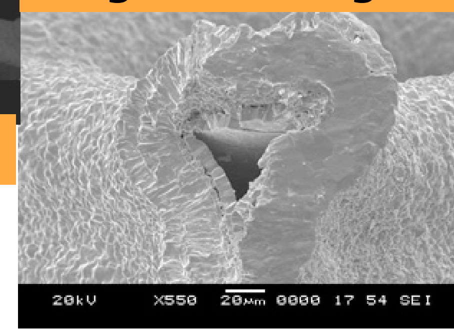
Contract#DE-FG02-03ER8310

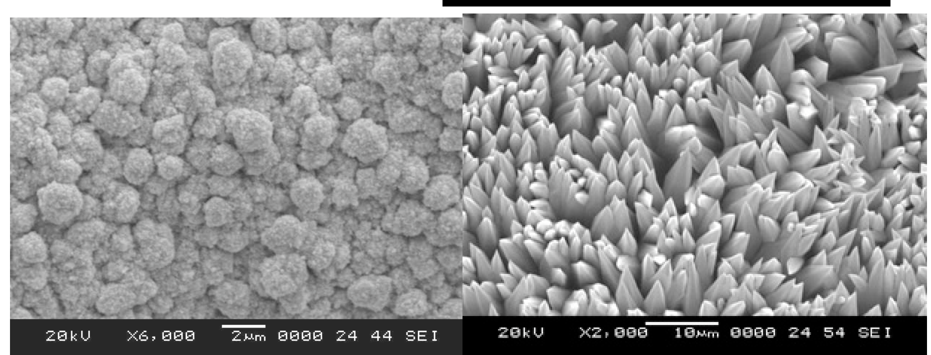
- Primary objective: Establish the feasibility of microengineered open-cell W foam for application to dry first wall concepts in the High Average Power Laser (HAPL) program
- Target: Micro-engineered porous tungsten foam armor, applied to an ODS steel first wall. Benefits:
  - Ability to withstand surface layer temperature increases of up to 2800°C
  - Exhibit substantially improved thermal shock and ablation resistance over solid tungsten
- Textured, porous ligamental structure benefits:
  - More volumetrically distribute incident radiation
  - Reduce ablation and thermally induced stress
  - Facilitate He release



W Foam Structure

Single Foam Ligament





Possible Surface Textures

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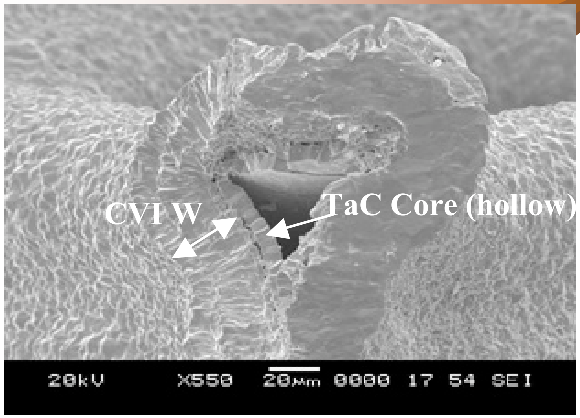
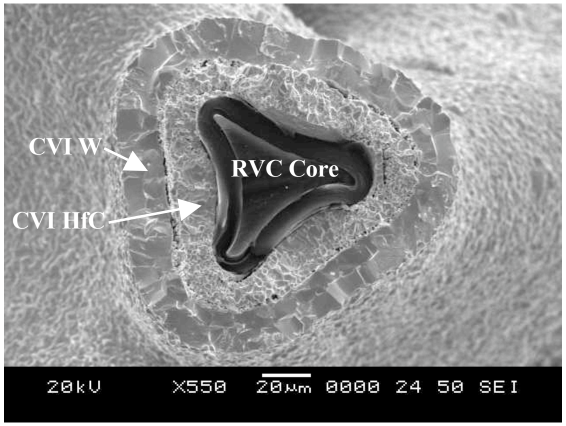
Phase I Results

- Modeling by Digital Materials Solutions (DMS):
  - W foam structures can be tailored to survive the extremely demanding first wall thermal environment
  - W coated on RVC core will convert partially to WC which has a lower melting temperature
  - A stable carbide coating (TaC, HfC) was applied to separate W and C materials.
- CVI W foam benefits:
  - High purity, strength, and thermal shock resistance
  - Will not sinter at high temperature
  - Variable foam ligament size and surface texture possible
  - Variable ppi and densities
- Several variations of W foam evaluated:
  - High specific strengths were measured
  - No change following 2500°C exposure
  - Different, high surface area textures were demonstrated for optimization of heat transfer and He removal



W foam ligament with hollow TaC core.



W foam ligament with HfC-coated RVC core

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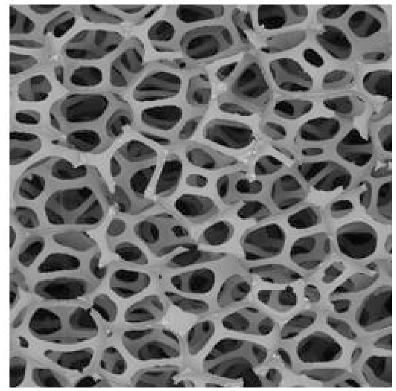
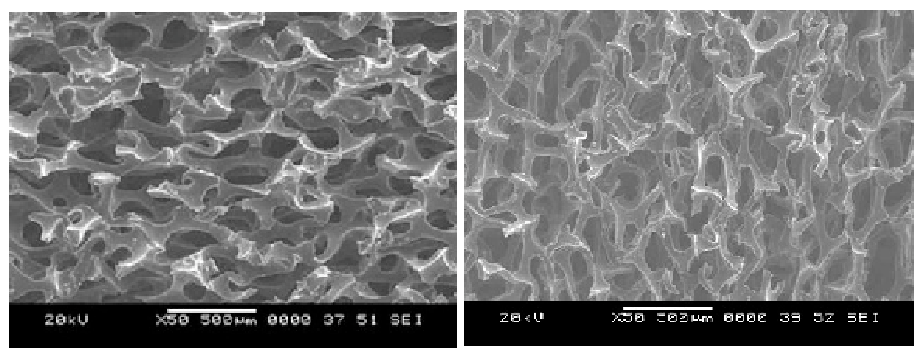
Phase I Results

- Testing of W foam in Sandia's RHEPP-1 ion beam:
  - Surface damage less severe than that found in PM W
  - No surface texture optimization has been performed thus far for the foam materials
  - Pore structure refinement has not been performed, but remains an option for further study
- Similar refractory metal and ceramic foam materials have been successfully used as structural heat exchangers in high heat flux rocket engine combustion chambers.



Uncompressed 100-ppi RVC Foam .



500-ppi Compressed RVC Foam.

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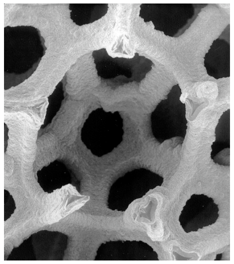
Phase II Plans (proposal pending)

- Establish inertial fusion energy (IFE) armor requirements in coordination with the High Average Power Laser (HAPL) program dry-wall concept.
- Armor Design and Modeling at DMS: modeling and simulation, experimental design and verification, and material and component performance evaluation.
- Perform foam materials and process optimization at Ultramet:
  - pore density and skeletal structure; deposition of W and W-Re coatings; surface texture
- Establish foam armor/first wall bonding technique at Ultramet: CVD bonding, brazing for foam/ODS steel and foam/SiC-SiC composite
- Evaluate W armor performance through testing at Sandia National Lab (ions, X-rays), Lawrence Livermore National Lab (X-rays), Oak Ridge National Lab (ions), University of Wisconsin (ions), University of San Diego (laser)



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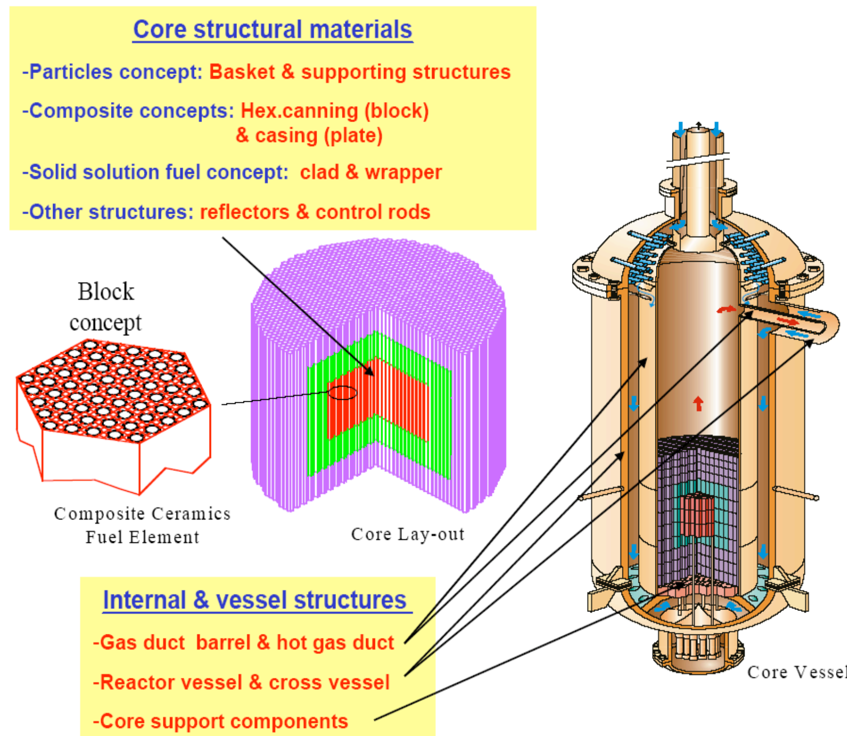
Low-Porosity SiC/SiC Composite Materials for Nuclear Energy System Components

***DoE** (7/21/03– present)*

Contract#DE-FG02-03ER83811

- Primary objective: establish CMC processing for SiC_f/SiC
- Target: Stuctural components for Gen IV gas-cooled fast reactor
- Expected operating environment
  - 850°C (1560°F) normal outlet temperature
  - 1600°C (2910°F) accident outlet temperature
  - 7 MPa (1 ksi) outlet pressure
  - 320 kg/s He flow
- Obstacles and Research Objectives
  - Establish CMC processing capable of providing adequate mechanical properties
  - Produce hermetic CMC to contain gas flow
  - Demonstrate radiation stability
  - Establish means for joining to metal base structures
  - Reasonable production cost



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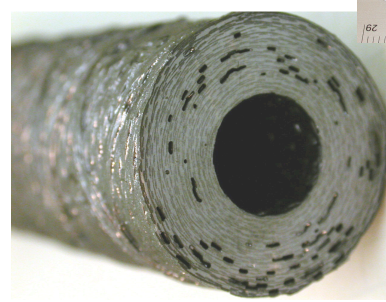
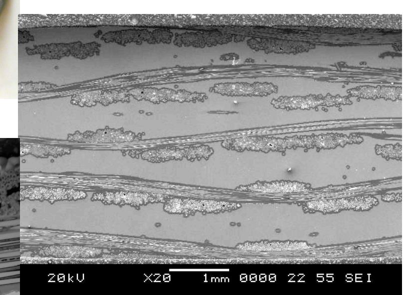
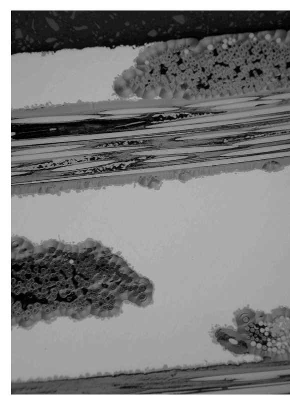
Phase I Results

- SiC_f/SiC CMC flats and tubes fabricated and evaluated
- Low porosity, good initial flexure strengths achieved—160 MPa (23.3 ksi)
- _” ϕ x _” wall x 5.4” long tube was He-impermeable to 3.4 MPa (500 psi)
  - Will test to 6 MPa—sealing issues
- Evaluation of helium flow heat transfer characteristics at the Plasma Materials Test Facility (PMTF) at Sandia is pending
  - Test conditions: 22 g/s He mass flow at 4 MPa and 300°C
- FEM analyses by DMS:
  - Elastic modulus between 3 and 4 GPa
  - Estimated stress limits and temperatures expected for 0.5 MW/m^2 fall within tested limits of Ultramet CMCs





20x SEM



100x optical

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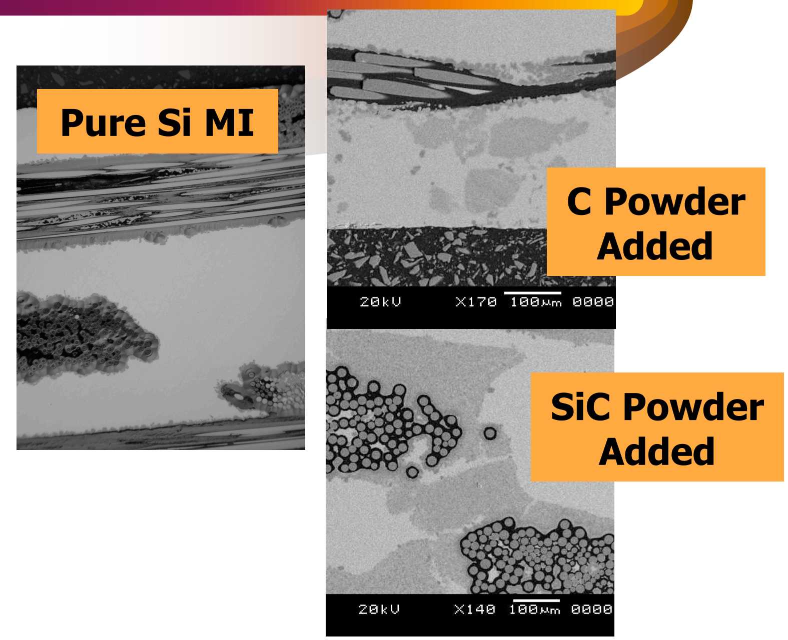
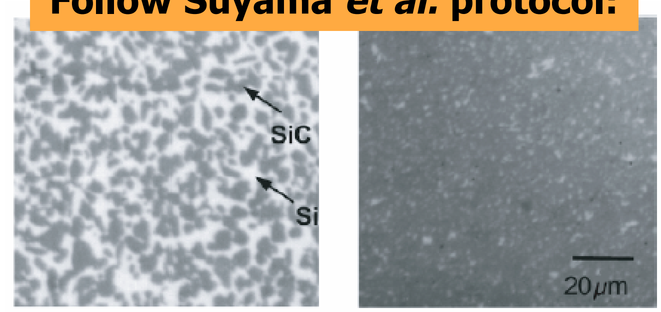
Phase II Plans (proposal pending)

- Primary objectives for process improvment:
  - Minimize porosity, amount of elemental silicon in the CMC matrix
  - "Break up" free metal into uniform nano-size network
  - Maximize fracture toughness of matrix material
- Residual Si reduction via powder incorporation prior to MI
- Evaluate other refractory carbides (ZrC)—resistance to neutron effects?
- Investigate CMC-metal joining
- Use of modeling to assist in materials selection, study fiber-matrix interface, evaluation of CMC properties and behavior in neutron irradiation
- Evaluate CMCs before and after exposure to neutron irradiation at the HFIR at ORNL



Follow Suyama *et al.* protocol:



(a) (b)

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Summary

- Ultramet overview
- DoE SBIR work for W foam development focusing on material modeling and optimization for advanced first wall materials
- DoE SBIR activity for SiC_f/SiC CMC development focusing on increasing carbide content in MI matrix