Advanced Ceramic Materials for Future Aerospace Applications

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Widespread Use of Ceramics in Multiple Aerospace Systems
Ceramic Materials in Gas Turbine Engines

CMC Combustor

Ni-base disk

Thermal Barrier Coatings

CMC Turbine Blade

CMC Turbine Vane
Future challenges:
- Increased temperature capability
- Low thermal conductivity
- Erosion resistance
- Resistance to molten sand/glass deposit
CMCs for Gas Turbine Engine Hot Section

SiC/SiC CMC preferred

Environmental Barrier Coatings Required for CMCs
Challenges for Increasing Temperature Capability of SiC/SiC CMCs for Gas Turbine Engines

2400°F Today  2700°F + Future

Advanced SiC Fiber

Dense, Si-free Matrix

Durable Environmental Barrier Coatings with 2700°F+ Capability

Recession Rate, mg/cm²-hr

- BSAS
- HPBR
- Yb silicate
- HfResilicate

Three-layer coating
Hf-RE oxide w/dopant variation (Directed EB-PVD)
HfO₂-Si bond coat (Directed EB-PVD)
Increasing Use of CMCs in Aircraft

Boeing – CMC Exhaust Nozzle

NASA Environmentally Responsible Aviation Project – CMC Nozzle Demonstration

GE Passport Engine Exhaust Nozzle
Ceramic Matrix Composites for Hypersonic Vehicles

3000 F + temperature capability required

Benefit: Reduced weight

In-test photo at 2600°F

Acreage TPS

Actively Cooled CMC Combustor

Control Surfaces

Leading Edges

Reentry TPS

Hypersonic Control Surfaces

Leading Edges

Exhaust-Washed Structure
Cooled Ceramic Matrix Composite Structures in Hypersonic and Rocket Propulsion

NASA GRC

AFRL

EADS - Astrium

NASA GRC - Teledyne
High Temperature Materials for Planetary Entry, Descent, and landing (EDL)

- Thermal Barrier Seals
- Woven SiC Fiber
- Outer Fabric
- Aerogel Insulation
- Gas Barrier
- High Temperature Ceramic Aerogel
High Temperature Thin Film Ceramic Sensors

SiC Pressure Sensor

Cr-doped GdAlO$_3$ Coating for Temperature Measurement

Multifunctional TaN-Based Sensors

Ceramic Sheath for 2400$^\circ$C – Capable Temperature Probe
Ion and Hall Thrusters for In-Space Propulsion

- Provides higher exhaust velocity than chemical rockets – reduces propellant mass and reduction in launch mass

**Erosion and depletion of cathode material**

**Life Limiting Mechanisms:**
- Ion sputter erosion of electrodes and ceramics
- Erosion and depletion of cathode materials

**Material Needs:**
- High temperature sputter resistant electrodes and ceramics
- Long-life, low work function cathode (LaB$_6$ – ZrB$_2$ eutectic promising)

**BN ceramic discharge chamber – sputter erosion limits life**
Superconducting Ceramics in Electric Propulsion

Variable Specific Impulse Magnetoplasma Rocket (VASIMR)

- MgB$_2$ round wire
  - Small diameter to reduce ac loss
- BSCCO or YBCO tape

Turboelectric Propulsion for Aircraft

High Power Density Superconducting Motor

Rotor Coils
- Can be planar

Stator Coils
- Must be non-planar to clear rotor

Superconducting magnet for VASIMR
Mars Oxygen ISRU Experiment (MOXIE)

- Extract oxygen from the horrible Martian atmosphere by breaking down carbon dioxide.
- Enable a manned Mars mission to have oxygen ready and waiting when they arrived by sending remote oxygen generators to the surface ahead of time.
Glass Windows in Space Systems

Rendezvous / Docking Windows (2) Silica/Silica/Acrylic
Side Windows (2) Silica/Silica/Acrylic
Docking Hatch Window Silica/Silica/Silica
Hatch Window Silica/Silica/Acrylic

Crew Vehicles

Ascent vehicles
Habitats
Rovers
ISS

Laboratories
Visors
Advanced Window Glass Materials for Space Systems

Damage of Glass Windows due to Micrometeoroid Impact

Damaged Space Shuttle window

Damaged ISS window

![Graph showing window life and mass for different materials and sizes.](image)
Application of Piezoceramic Materials

**AIRFRAME**
Piezoresistive Devices
- Embedded pressure sensors
- Embedded strain sensors

Piezoelectric Devices
- Energy harvesting
- Cabin noise suppression
- Active flow control
- Variable control surfaces

**ENGINES**
Piezoelectric Devices
- Energy harvesting
- Power amplification
- Vibration suppression
- Noise suppression

Challenges:
- High temperature capability ($>> 300^\circ C$)
- Large displacement
- Integration with structure and durability of integrated structure
- Multifunctionality
Piezoceramic Patches for Controlling Vibration of PMC Fan Blades

**GE Blade Vibration Control**

- **No Control**
- **Control**

### Blade Response vs. Excitation Frequency

- Blade Response (microstrain/excitation G)
- Excitation Frequency (Hz)

**Fan Blade with Piezo patches**

**Fan Blade with Piezo Patch in Test Rig**
Demonstration of Smart Rotor for Helicopters Using Piezoceramic Materials

- Smart rotor incorporates cutting edge changes to MD900 baseline rotor
  - Trailing edge control flap
  - Piezo-electric “smart” material actuators
- Effectiveness of flap for noise and vibration control demonstrated
- Closed-loop feedback control applied for first time to full-scale active rotor
- Initial demonstration of blade displacement technique
Power Conversion and Energy Storage System

High Power Density Solid Oxide Fuel Cell

- Need 2 – 4X increase in energy density of batteries
- Need > 5X increase in power density of fuel cell for electric aircraft

Multifunctional systems with structural load bearing capability ??

SiC Power Electronics for High Power Density and Radiation Tolerant Power Processing System
Ceramics in Satellite Communication

- Ceramic dielectric materials with engineered properties for microwave, millimeter wave communication system
- Dielectric ceramics as resonators, filters, oscillators
- Miniaturization continuing trend

Piezoceramic materials
- Change in shape of reflector to improve signal quality
- Vibration control
- Positioning control
Use of Ceramics in Space Telescope Mirror

- Hubble Space Telescope: Glass mirror
- Herschel Space Telescope: SiC mirror
- James Webb Telescope: Electrostrictive ceramic actuator to control the shape of mirrors

Future requirements: Lower cost and increase in aerial density
Concluding Remarks

• Will see increasing use of CMCs in aircraft – challenge to increase temperature capability to > 2700°F; cost reduction required

• Goal of Durable 3000°F CMC system for hypersonics and rocket propulsion still remains a major challenge

• Increasing use of piezoceramic and dielectric type of materials
  – Multifunctional structures will be future
  – Integration with components without adversely impacting component performance is challenging
  – Miniaturization will be the trend

• For high power density and high energy density systems, engineered porous materials through advanced manufacturing processes will be required
  – Additive manufacturing likely to play a role
  – Increasing use of nanomaterials

• Significant potential for improving ceramic materials for in-space propulsion