Advanced Ceramic Materials for Future Aerospace Applications

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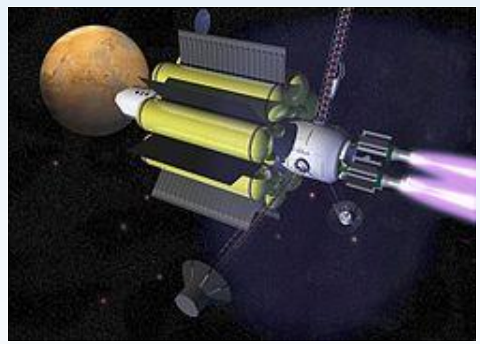
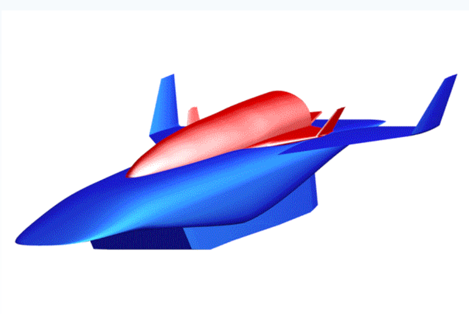
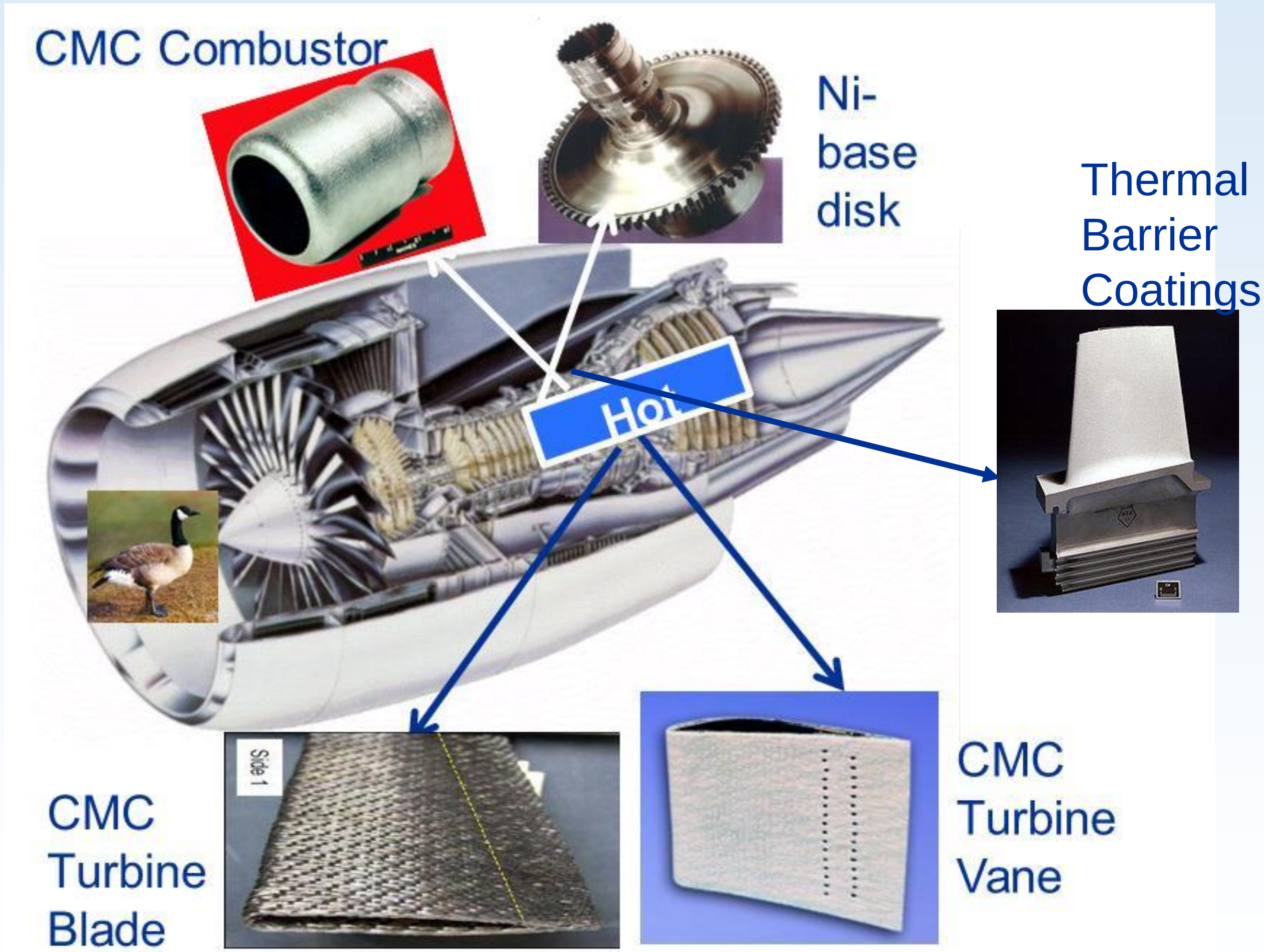
Widespread Use of Ceramics in Multiple Aerospace Systems

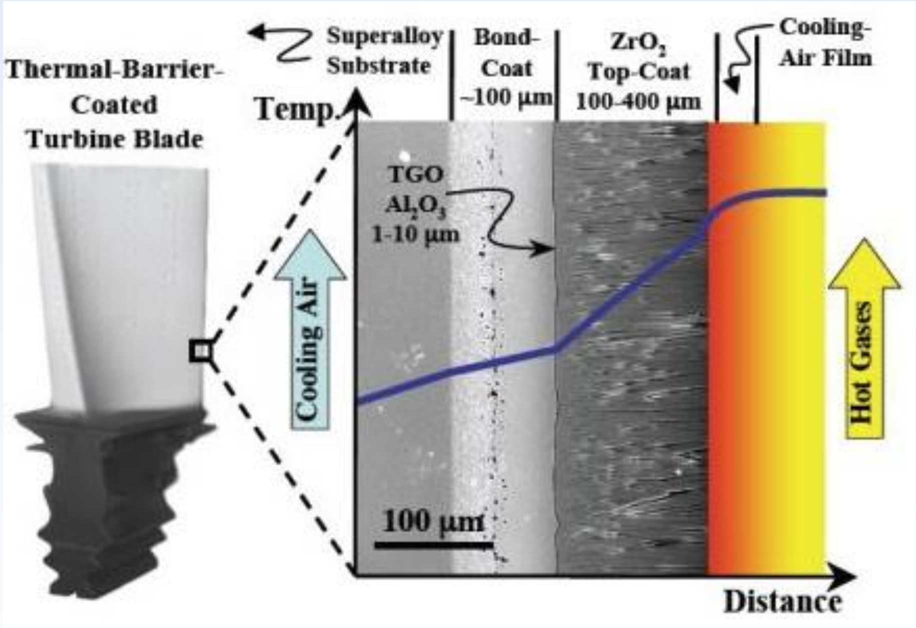




Ceramic Materials in Gas Turbine Engines



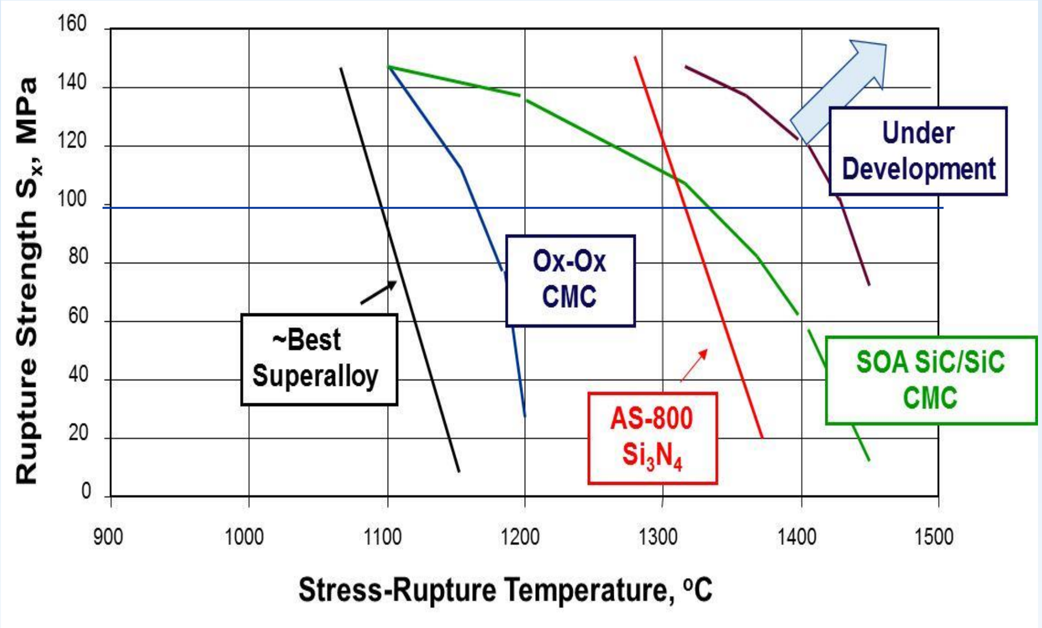
Thermal Barrier Coatings



Future challenges:

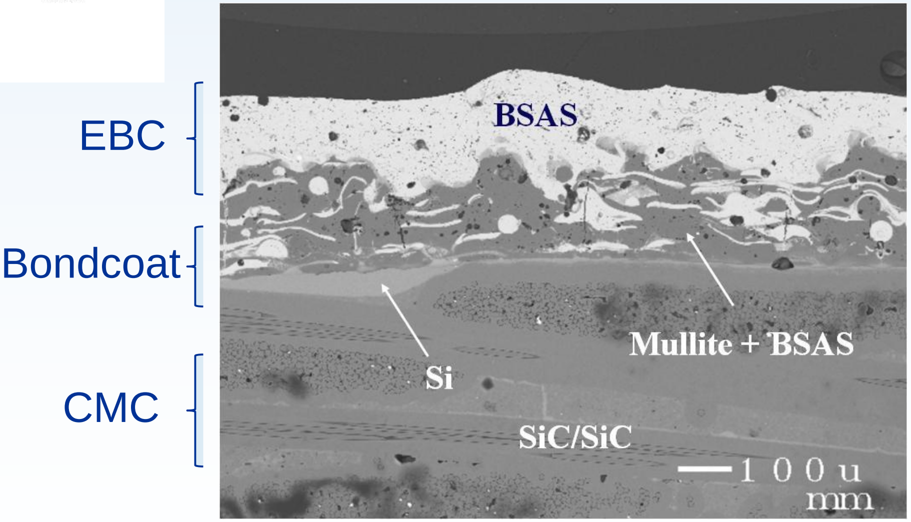
- Increased temperature capability
- Low thermal conductivity
- Erosion resistance
- Resistance to molten sand/glass deposit

CMCs for Gas Turbine Engine Hot Section



SiC/SiC CMC preferred

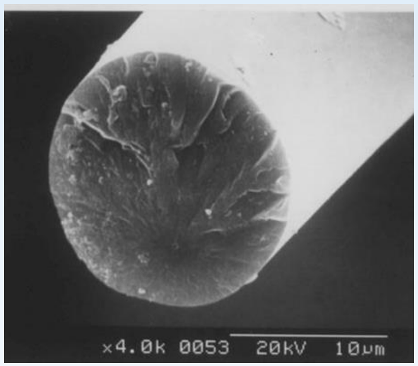
Environmental Barrier Coatings Required for CMCs



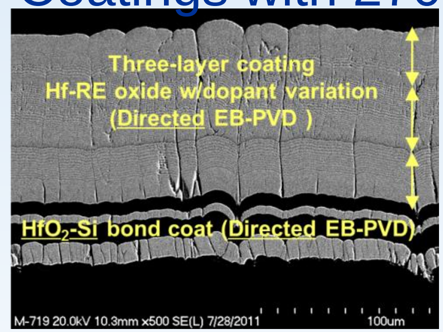
Challenges for Increasing Temperature Capability of SiC/SiC CMCs for Gas Turbine Engines

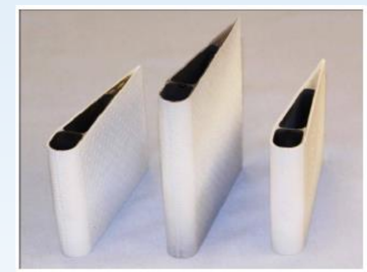
2400ºF Today → 2700ºF + Future

Advanced SiC Fiber

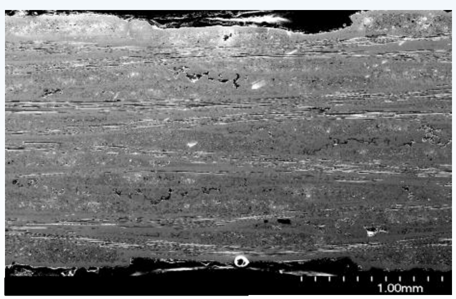


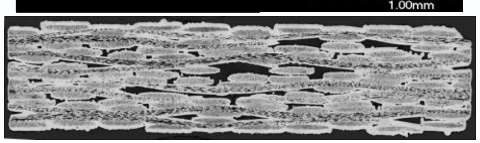
Durable Environmental Barrier Coatings with 2700ºF+ Capability

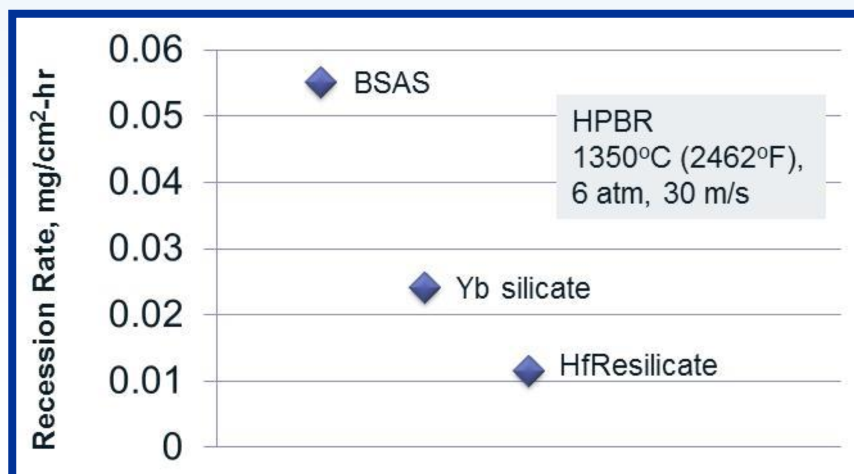




Dense, Si-free Matrix



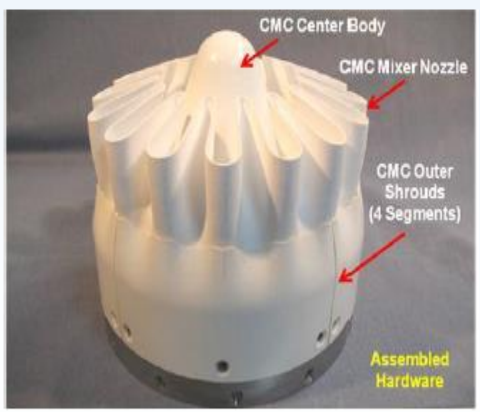




Increasing Use of CMCs in Aircraft

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

Ceramic Matrix Composites

Leading Edges

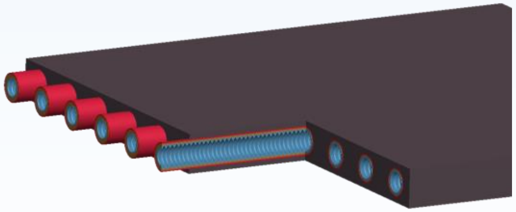
Reentry TPS

Hypersonic Control Surfaces

Leading Edges

Exhaust-Washed Structure

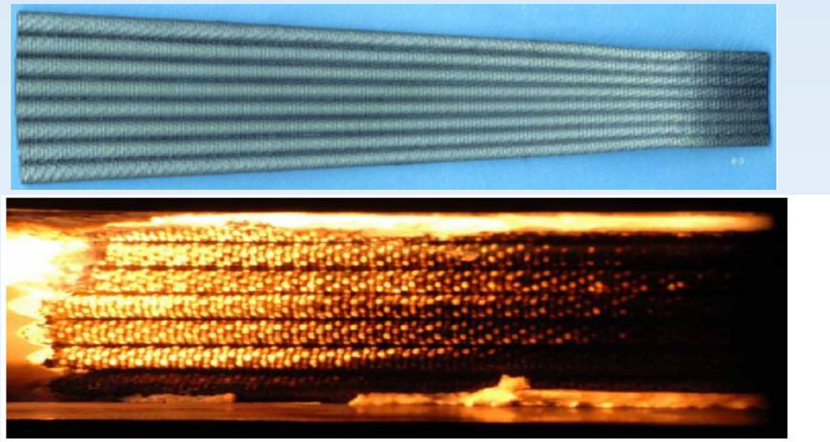
Acreage TPS



Actively Cooled CMC Combustor

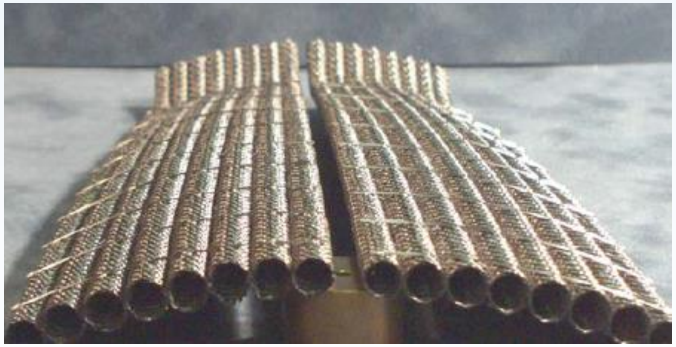
Control Surfaces

Cooled Ceramic Matrix Composite Structures in Hypersonic and Rocket Propulsion

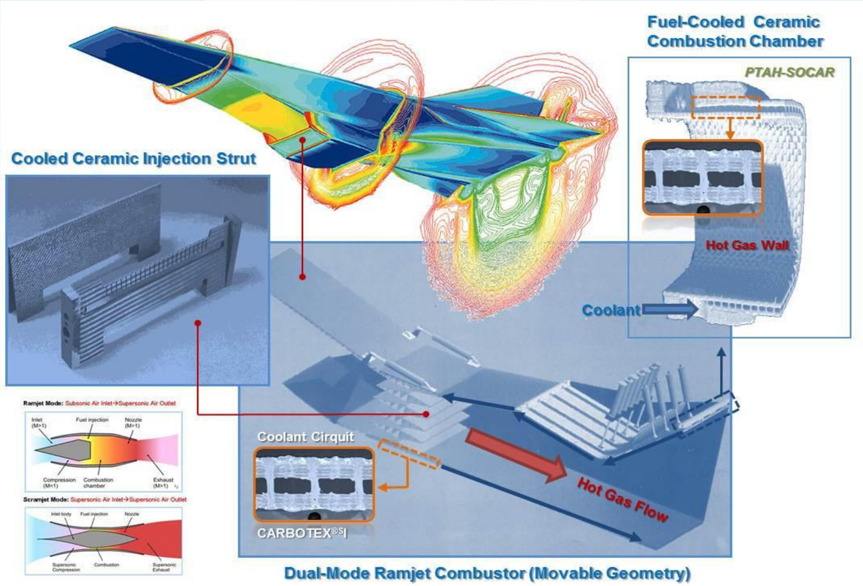


NASA GRC - Teledyne

NASA GRC

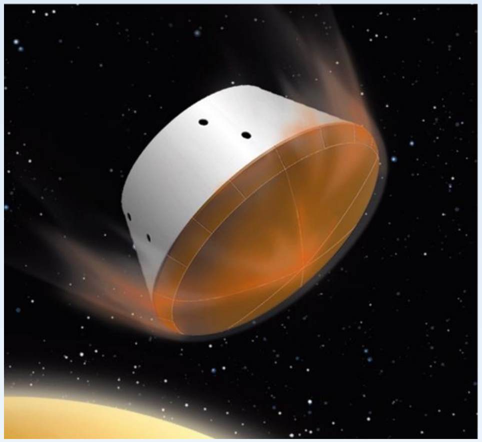


AFRL

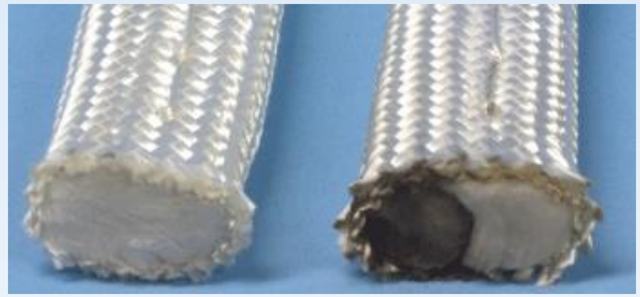


EADS - Astrium

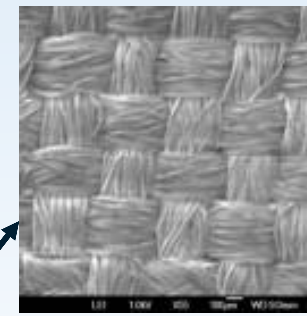
High Temperature Materials for Planetary Entry, Descent, and landing (EDL)



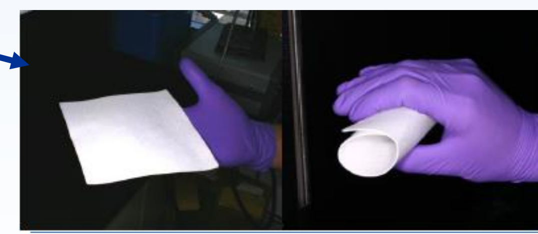
Thermal Barrier Seals



Woven SiC Fiber



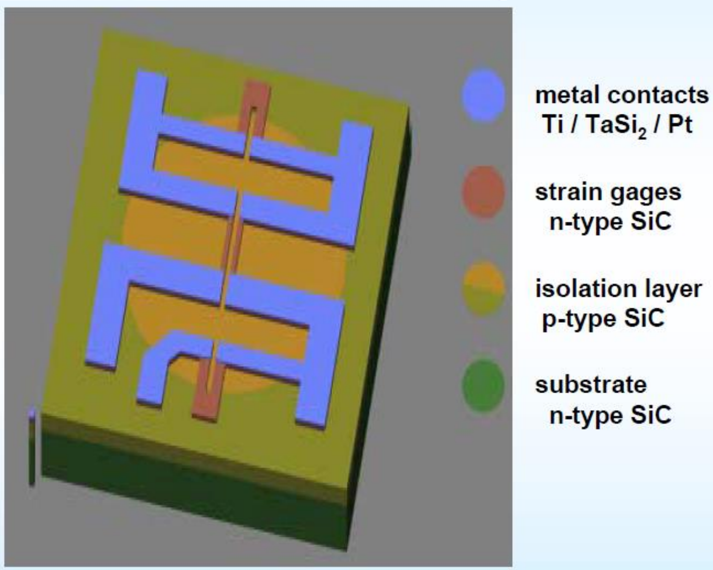
Outer Fabric
Aerogel Insulation
Gas Barrier



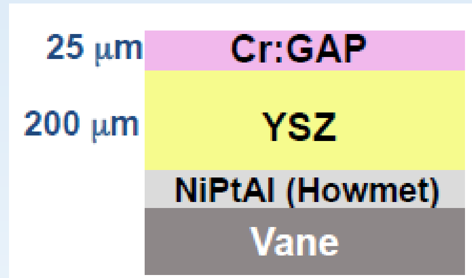
High Temperature Ceramic Aerogel

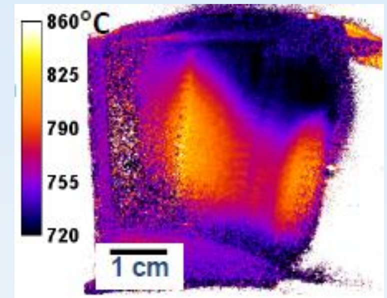
High Temperature Thin Film Ceramic Sensors

SiC Pressure Sensor



Cr-doped $GdAlO_3$ Coating for Temperature Measurement

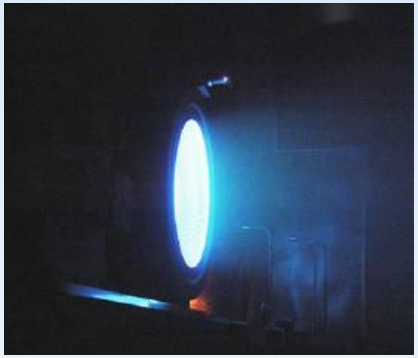




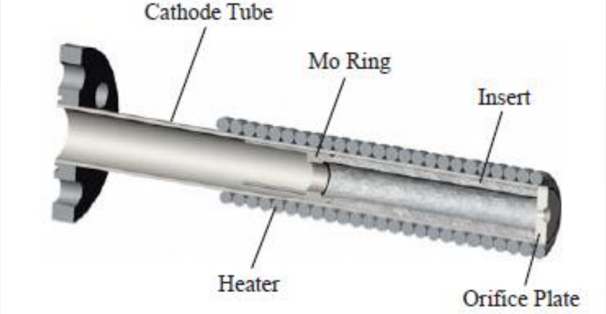
Multifunctional TaN-Based Sensors

Ceramic Sheath for 2400ºC – Capable Temperature Probe

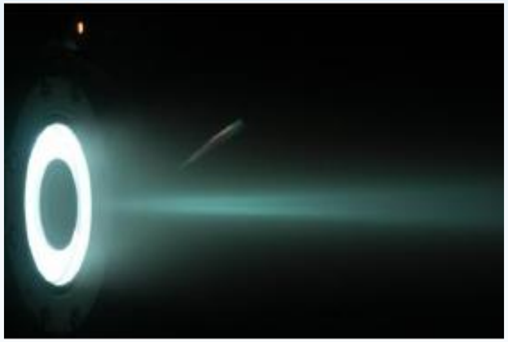
Ion and Hall Thrusters for In-Space Propulsion



Erosion and depletion of cathode material



BN ceramic discharge chamber – sputter erosion limits life



Life Limiting Mechanisms:

- Ion sputter erosion of electrodes and ceramics
- Erosion and depletion of cathode materials

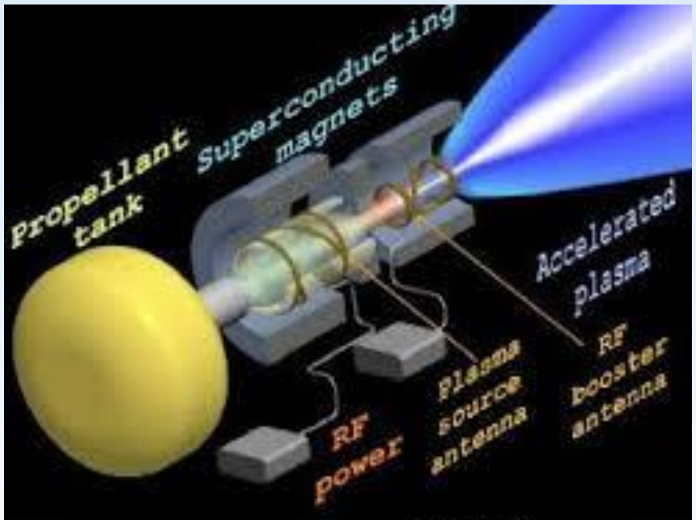
- Provides higher exhaust velocity than chemical rockets – reduces propellant mass and reduction in launch mass

Material Needs:

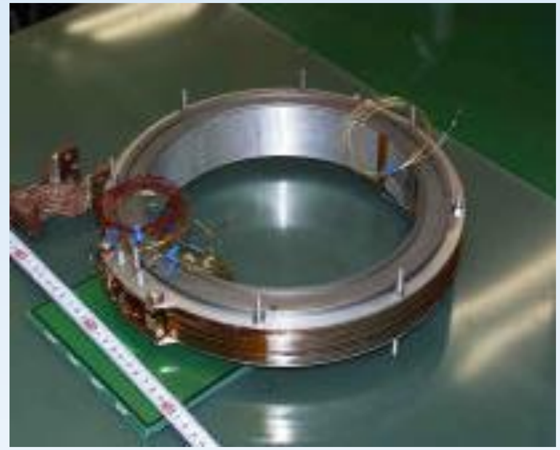
- High temperature sputter resistant electrodes and ceramics
- Long-life, low work function cathode (LaB_6 – ZrB_2 eutectic promising)

Superconducting Ceramics in Electric Propulsion

Variable Specific Impulse Magnetoplasma Rocket (VASIMR)

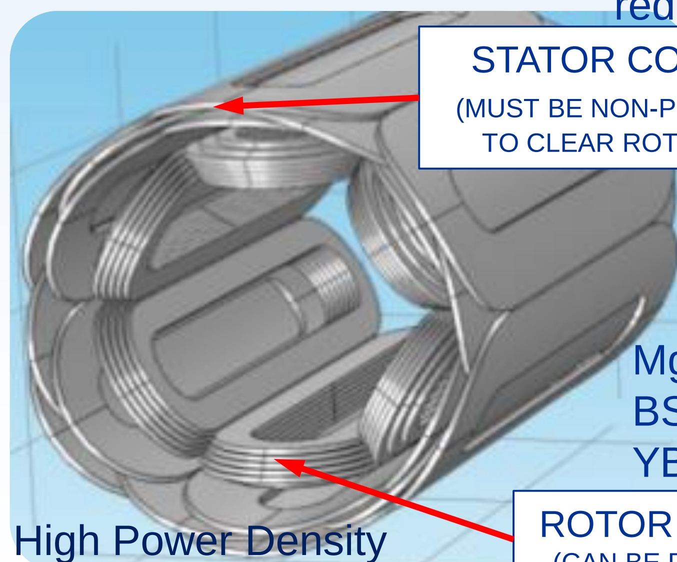


Schematic overview of the VASIMR® system



Superconducting magnet for VASIMR

MgB_2 round wire
- Small diameter to reduce ac loss

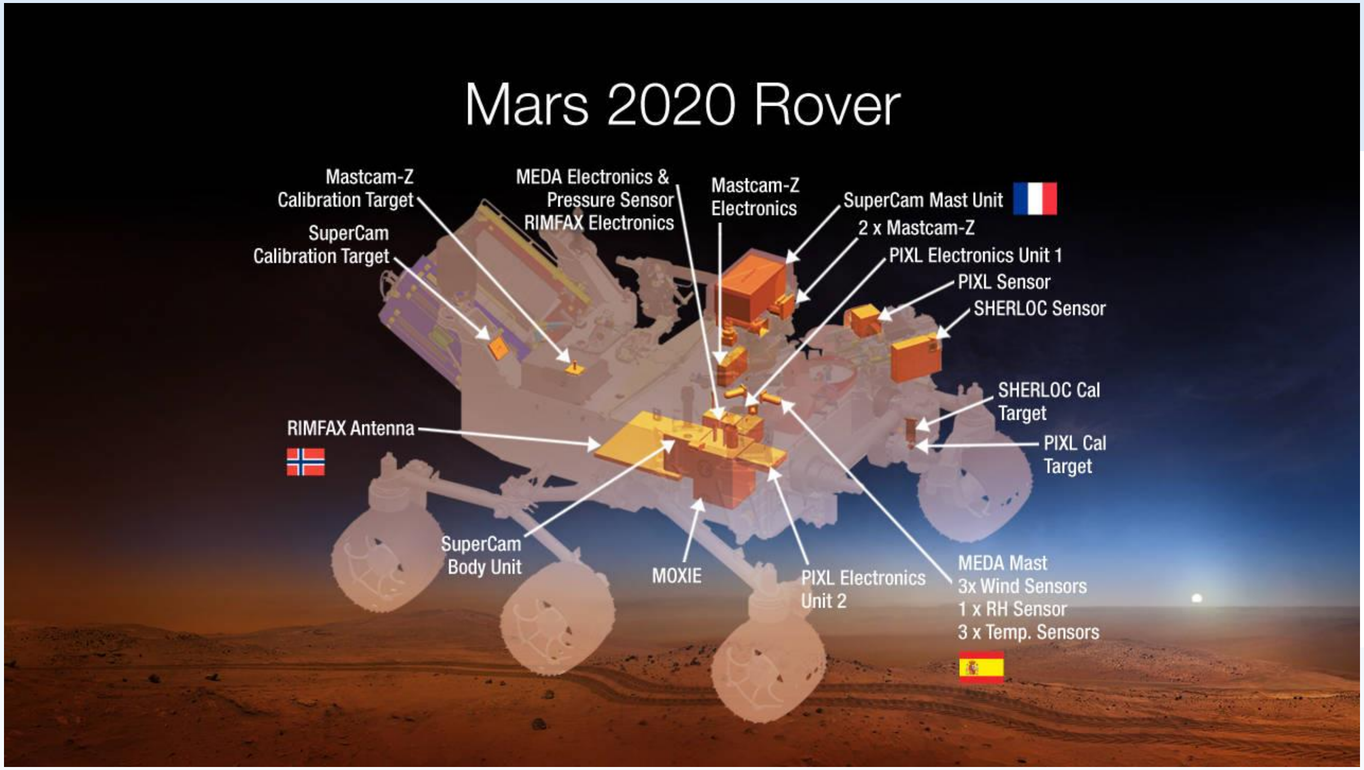


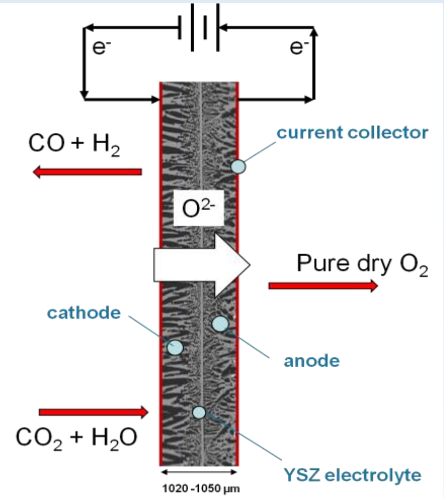
MgB_2 round wire
BSCCO or
YBCO tape

High Power Density Superconducting Motor

Turboelectric Propulsion for Aircraft

Solid Oxide Electrolyzer for Oxygen Generation on Mars





Mars Oxygen ISRU Experiment (MOXIE)

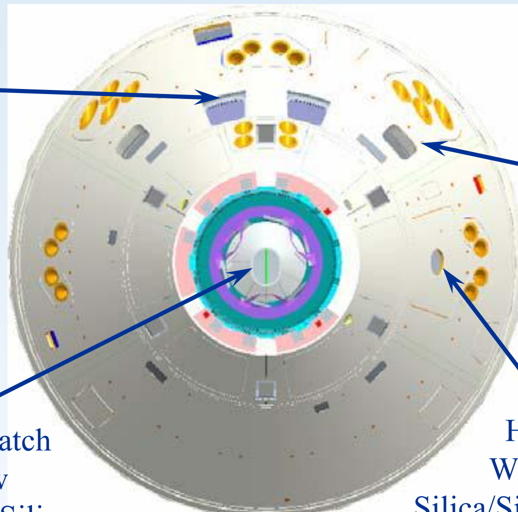
- Extract oxygen from the horrible Martian atmosphere by breaking down carbon dioxide.
- Enable a manned Mars mission to have oxygen ready and waiting when they arrived by sending remote oxygen generators to the surface ahead of time.

Glass Windows in Space Systems

Rendezvous / Docking Windows (2)
Silica/Silica/Acrylic

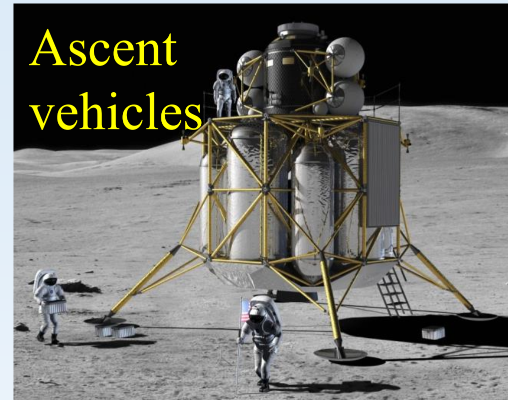
Side Windows (2)
Silica/Silica/Acrylic

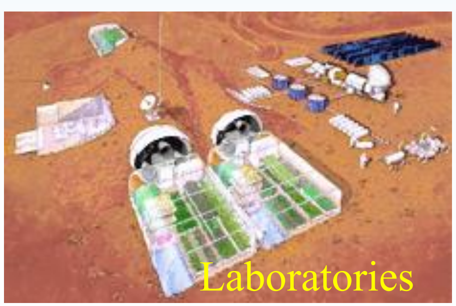
Crew Vehicles



Docking Hatch Window
Silica/Silica/Silica

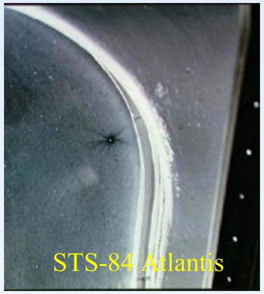
Hatch Window
Silica/Silica/Acrylic



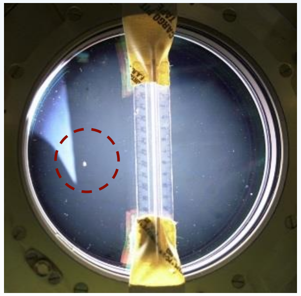


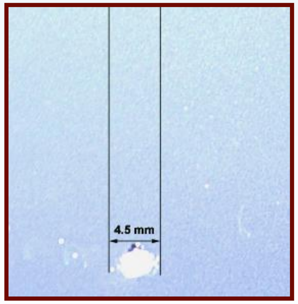
Advanced Window Glass Materials for Space Systems

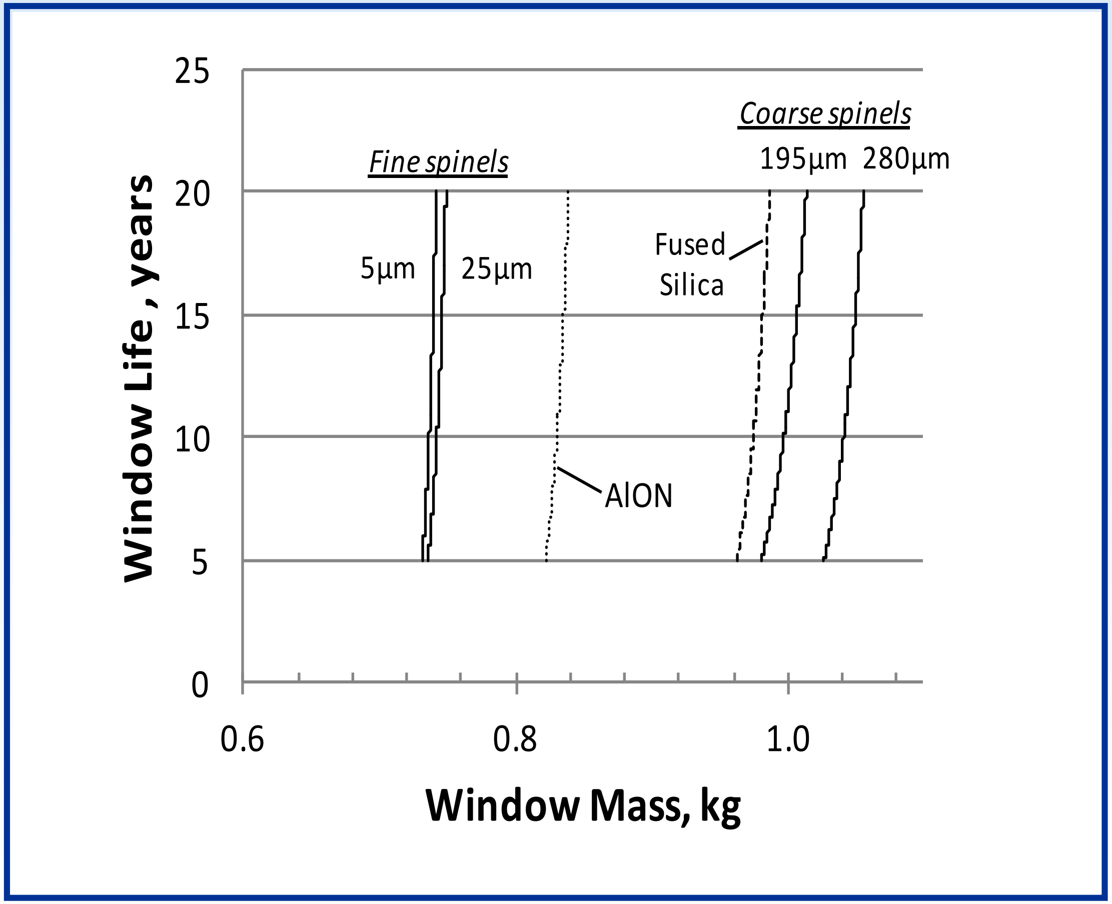
Damage of Glass Windows due to Micrometeroid Impact



Damaged Space Shuttle window

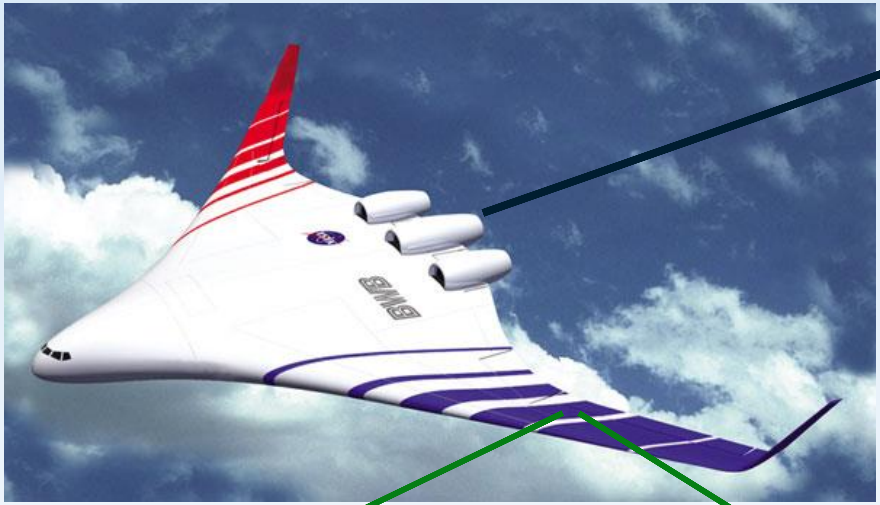






Damaged ISS window

Application of Piezoceramic Materials



ENGINES

Piezoeletric Devices

- Energy harvesting
- Power amplification
- Vibration suppression
- Noise suppression

AIRFRAME

Piezoresistive Devices

- Embedded pressure sensors
- Embedded strain sensors

Piezoelectric Devices

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

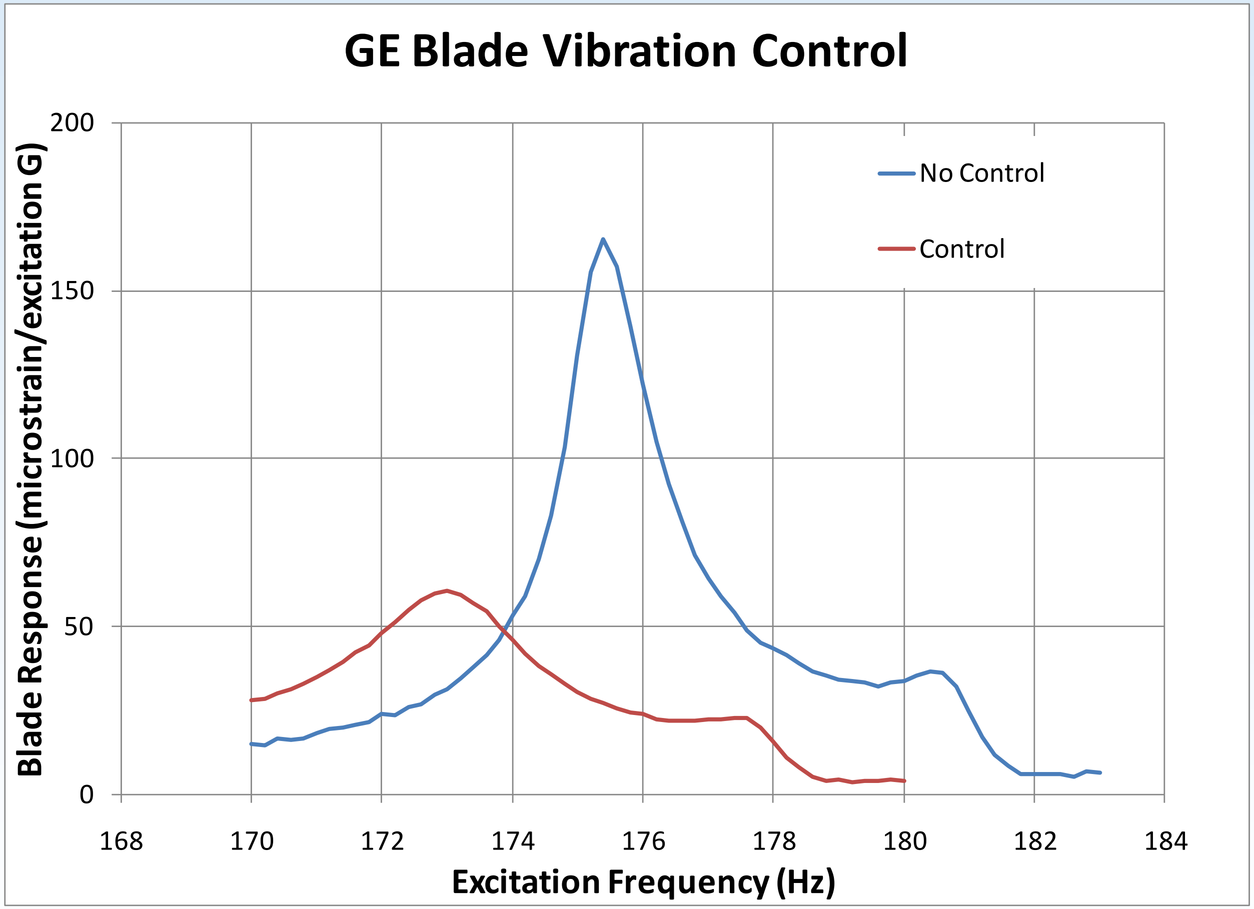
Challenges:

- High temperature capability (>> 300ºC)
- Large displacement
- Integration with structure and durability of integrated structure
- Multifunctionality

Piezoceramic Patches for Controlling Vibration of PMC Fan Blades

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

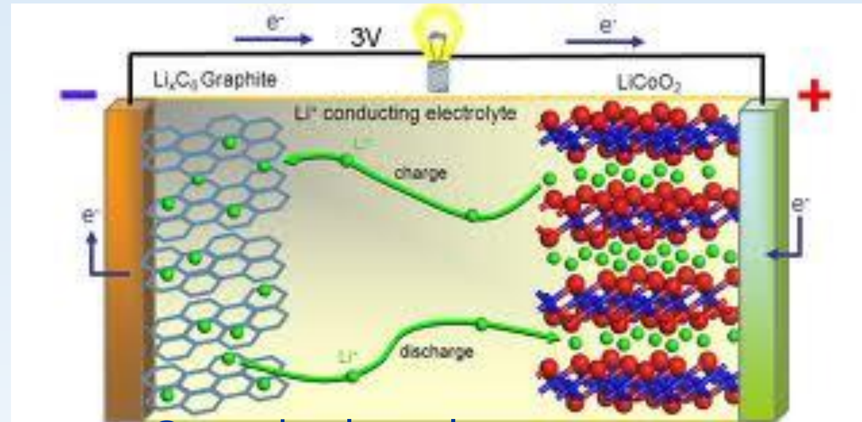
Hybrid Electric Aircraft

Long-Duration EVA

Landers, Rovers, Habitats

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

High Energy Density Batteries

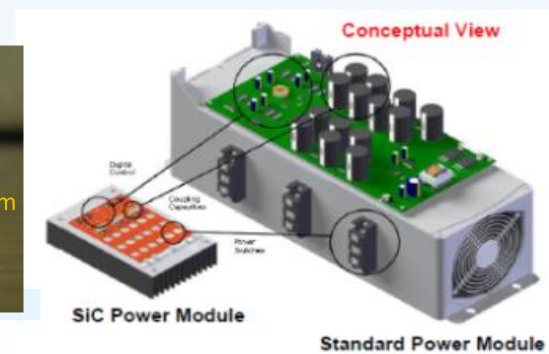


Ceramic electrolyte for solid state batteries

Ceramic cathode

High Power Density Solid Oxide Fuel Cell

All oxide ceramic components



SiC Power Electronics for High Power Density and Radiation Tolerant Power Processing System

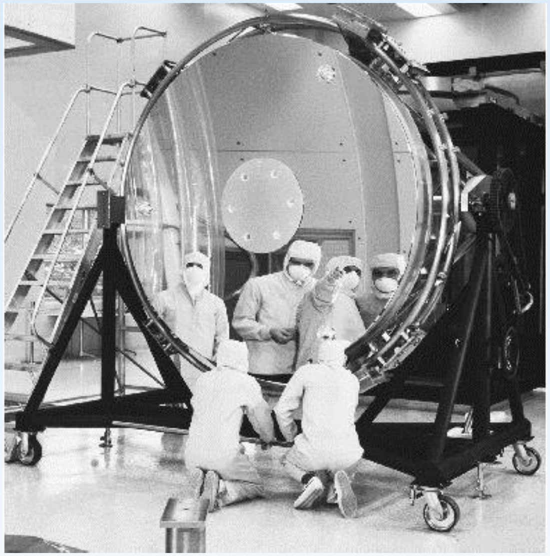
Multifunctional systems with structural load bearing capability ??

Ceramics in Satellite Communication

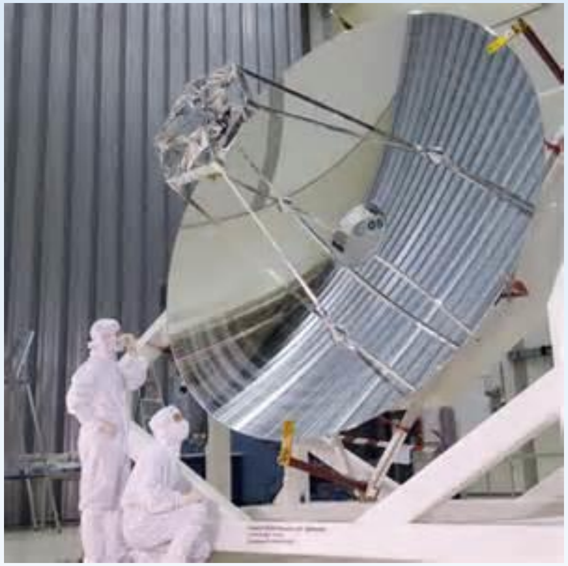
- Ceramic dielectric materials with engineered properties for microwave, millimeter wave communication system
- Dielectric ceramics as resonators, filters, oscilators
- Miniaturization continuing trend

Piezoceramic materials"
- Change in shape of reflector to improve signal quality
- Vibration control
- Positioning control

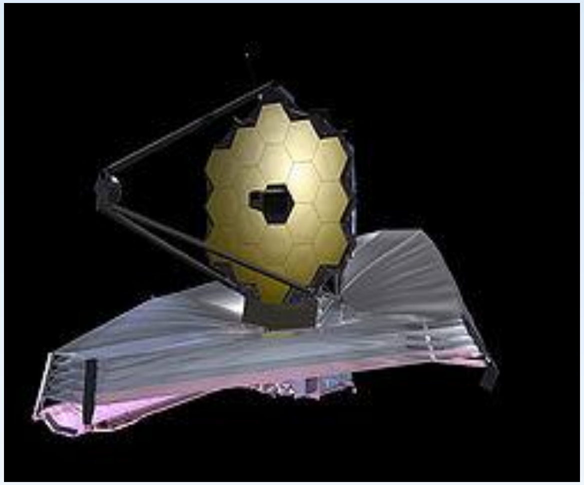
Use of Ceramics in Space Telescope Mirror



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 > 2700ºF; cost reduction required
- Goal of Durable 3000ºF 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