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Rapid SiC: Room Temperature Roll-to-Roll Production of Polymer-Derived SiC Fibers

2023 FECM/NETL Spring Project Review Meeting

DE-SC0022875

Luna Labs and Rapid SiC Team

The Rapid SiC Team

Josh Smith, PhD
Principal Investigator

Sean Davis
Prototyping Lead

Adam Goff
Subject Matter Expert

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Technical Lead

JT Brosnahan
Subject Matter Expert

Sean Barker, CCMA
Contract Specialist

Brendan DeLacy, PhD
President and Founder, Ceramic Expert

Jeffery Morse, PhD
Roll-to-Roll Fabrication Director

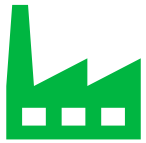
Heather Hunter
Program Manager

Luna Labs Overview

Founded in 1989 as the technology development division of Luna Innovations.

In March 2022, senior management and internal/external investors established Luna Labs

A diverse team of almost 100 scientists, engineers, contracts, and business professionals.



Luna Labs utilizes its 55,000 sq. ft. advanced research and development facilities.

Luna Labs Organization

Biotechnology

- Biomaterials and Bioengineering
- Biophysics and Mechatronics
- Diagnostics and Lab-on-a-chip

Materials

- Polymer Resins and Composites
- Signature Control
- Green Technology
- Coating and Corrosion Control

Engineered System

- Corrosion and Asset Monitoring
- Data Analytics And Machine Learning
- Non-Destructive Evaluation
- Software Development

Mission: Getting game-changing technology out of the lab and into customer hands – fast.

Green Technologies

Carbon Sequestration

Developed novel membrane technologies to separate CO_2 from exhaust systems.

Applications

CO_2 capture

Natural Gas Power Plants

Maritime Exhaust

Green Manufacturing

Developing new strategies and feedstocks to produce materials with reduced carbon footprint.

Application

Green Production

Plastic Recycling

Fertilizer Manufacturing

Batteries and Energy Storage

Developed novel materials and technologies to address current energy storage needs.

Applications

Solar and Wind Storage

Electric Cars

Space Exploration

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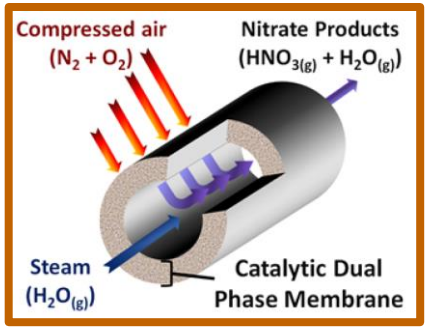
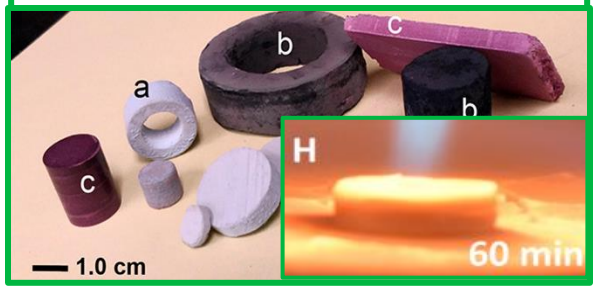
Green Engineering technologies

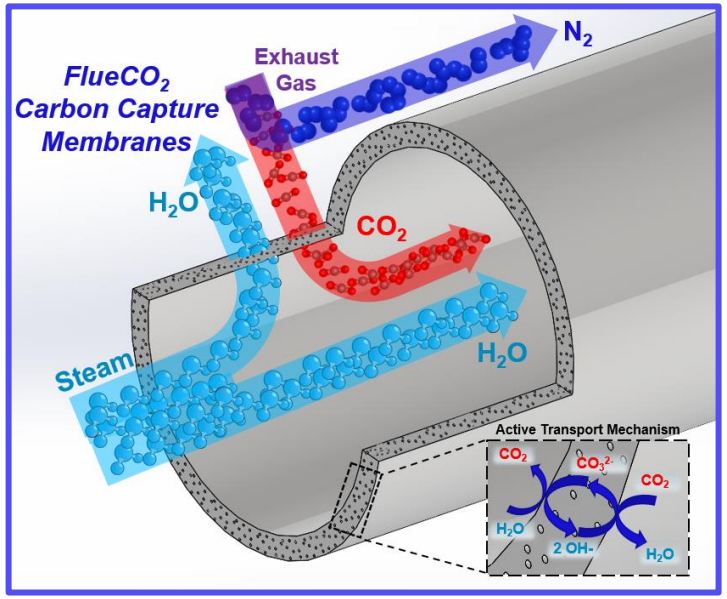
Efficient Steam Utilization
Excess steam can be diverted to a nitric acid production process facilitated by the $LuNO_x$ dual-phase membranes



SiC Thermal Protection
Developing low conductivity thermal SiC thermal insulation



Cost-Effective Carbon Capture
Luna Labs' $FlueCO_2$ membranes are powered by steam and effectively remove CO_2 from NGCC flue gas with minimal parasitic effect on HRSG efficiency.



Luna Labs develop unique material solution to reduce environmental impact and product costs such as capture CO_2, upcycling plastics, and enable high temperature combustion.

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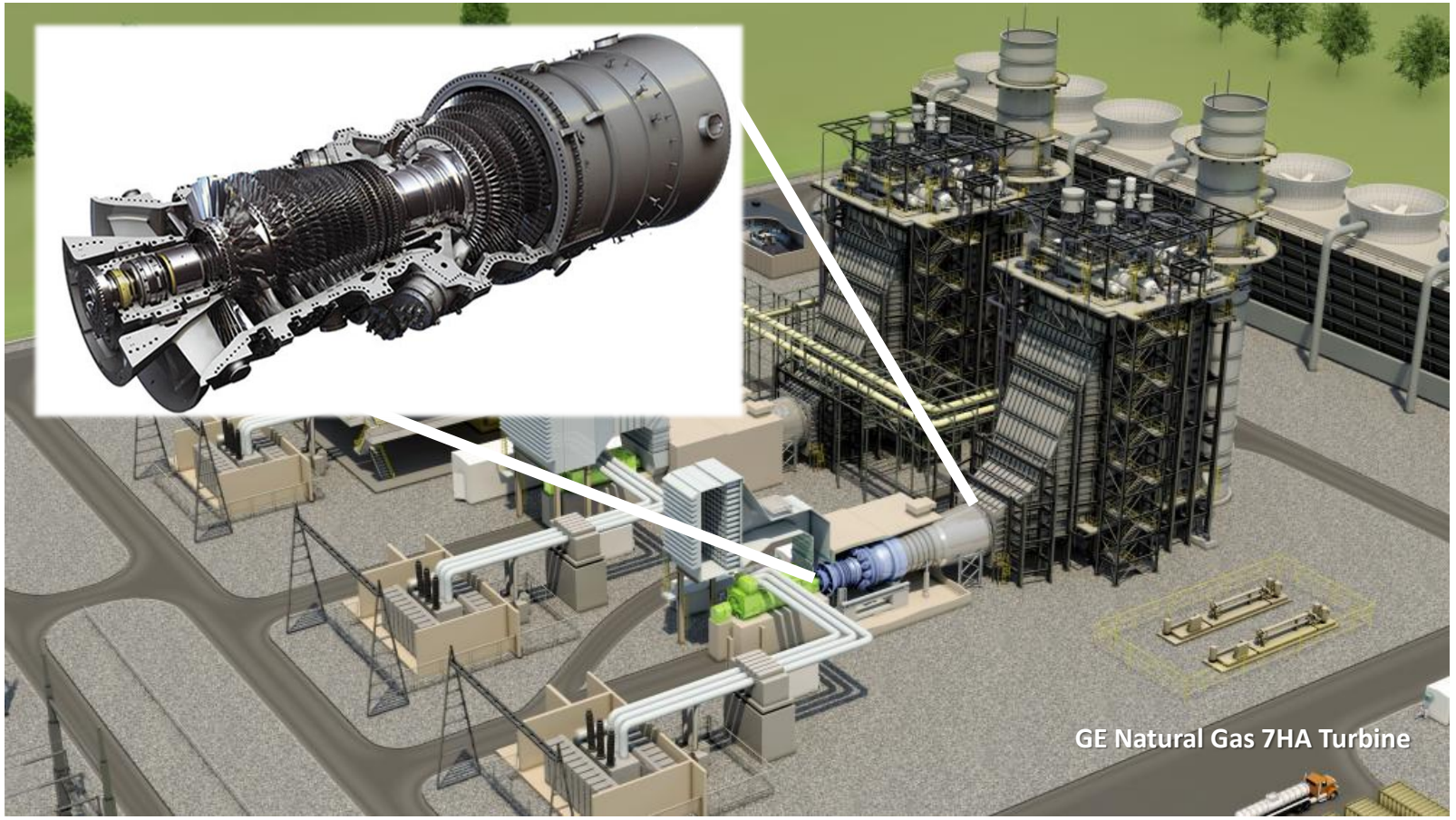
Project Motivation

High Temperature Turbines:



GE SC Alloy Turbine Blade

Material	Melting Point
Inconel 738	1315°C
GTS 111	1250°C
Ni-Tungsten	1250°C
SC Alloys	1500°C

High temperature turbines that operate over 1400°C can achieve over 60% net efficiencies or successfully combust hydrogen. Yet, current material properties limits the development of high temperature turbines.

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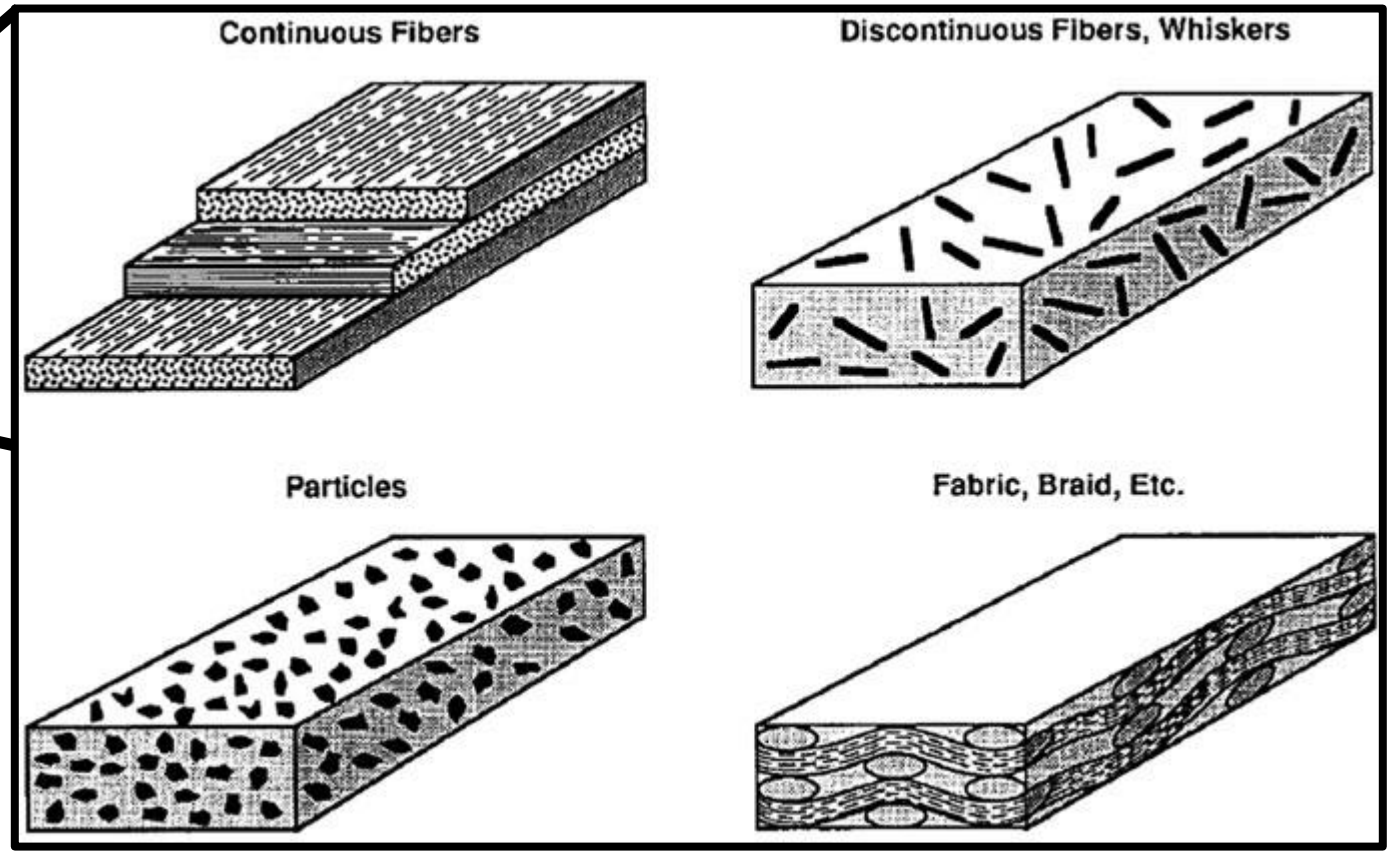
Ceramic Matrix Composites:

GE CMC Turbine Blade



J. Subramanyam, *Aerospace Materials and Material Technologies* **2017** pg 374

Ceramic matrix composites (CMCs) are a well-established class of material that has been used throughout the aerospace industry. SiC-SIC CMCs are stable over 1600°C and are of interest.

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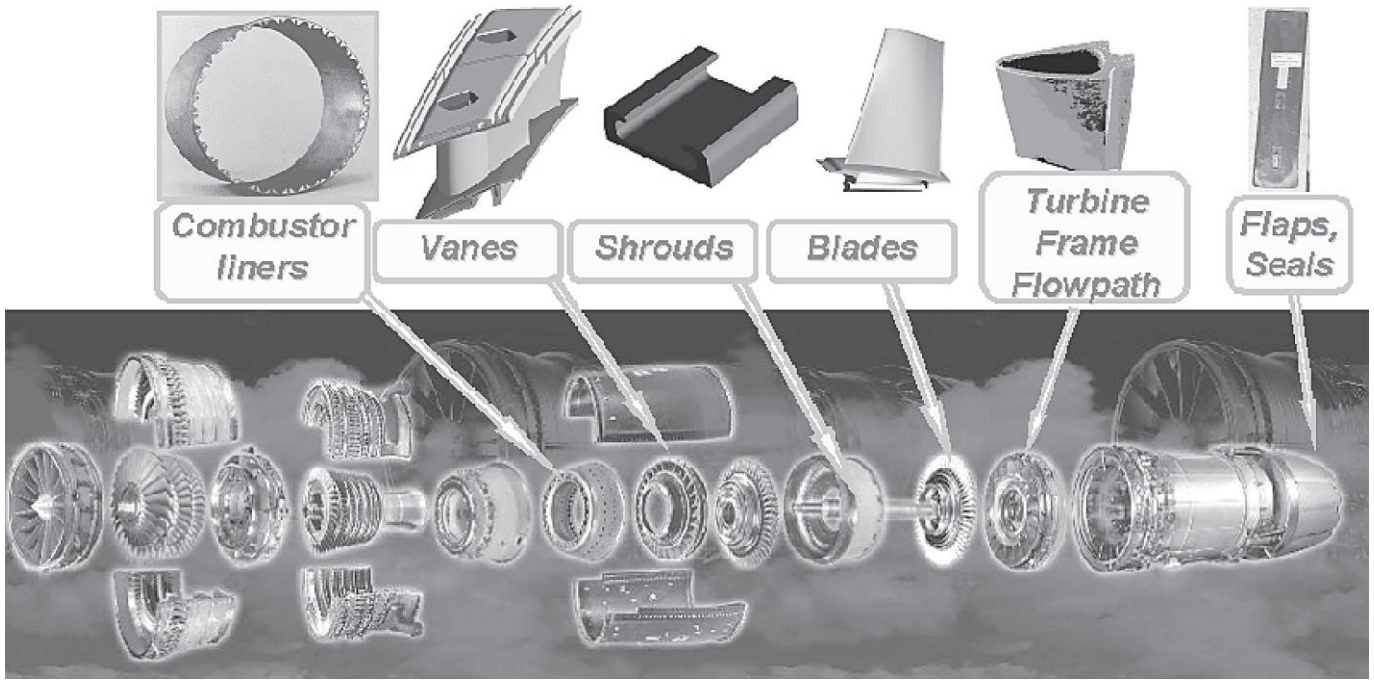
Cost of CMCs in High Temp. Turbines:



J. Subramanyam, *Aerospace Materials and Material Technologies* **2017** pg 374

Materials	Trade-Name	Cost $/kg
SiC Fiber	Hi-Nicalon Type S	13,000
SiC Fiber	Tyranno SA 1-3	10,000
SiC Fiber	Sylramic	15,000
SiC Fiber	Sylramic iBN	15,000
SiC Fiber	Ultra SCS	9,000
Alloy	Inconel 738	23.00
Alloy	GTS 111	3.12
Alloy	Ni-Tungsten	58.00

Non-Oxide (Silicon Carbide) Fibers. *Handbook of Ceramic Composites*; Bansal, N. P., Ed.; Springer US: Boston, MA, **2005**; pp 33–52.

Considering all of the components required for high temperature combustion, significant cost reduction is required to reduce the overall cost of SiC-SiC composites. Interestingly, SiC fibers account for 2/3rd

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Technical Approach

Program Overview:

DoE Sponsor: Dept. of Energy, Office of Fossil Energy

Award Date: 6/27/2022

Funding Agreement No.: DE-SC0022875

Phase I PoP: 6/27/2022 – 4/9/2023

Phase I

- Synthesize chopped Rapid SiC Fibers via photothermal pyrolysis
-Achieve less than 6% Oxygen
-Perform initial cost analysis
-Design Production line

COMPLETED

Phase II

-Synthesize continuous Rapid SiC fibers
-Achieve less than 1% Oxygen -Conduct technoeconomic and life cycle analyses.
-Confirm performance requirements

PROPOSED

Phase IIA/IIB/III

-Demonstrate pilot-scale production of continuous and chopped Rapid SiC Fibers.
-Finalize business agreements and transition
-Integrate Rapid SiC fibers into CMC-based platforms.

FUTURE

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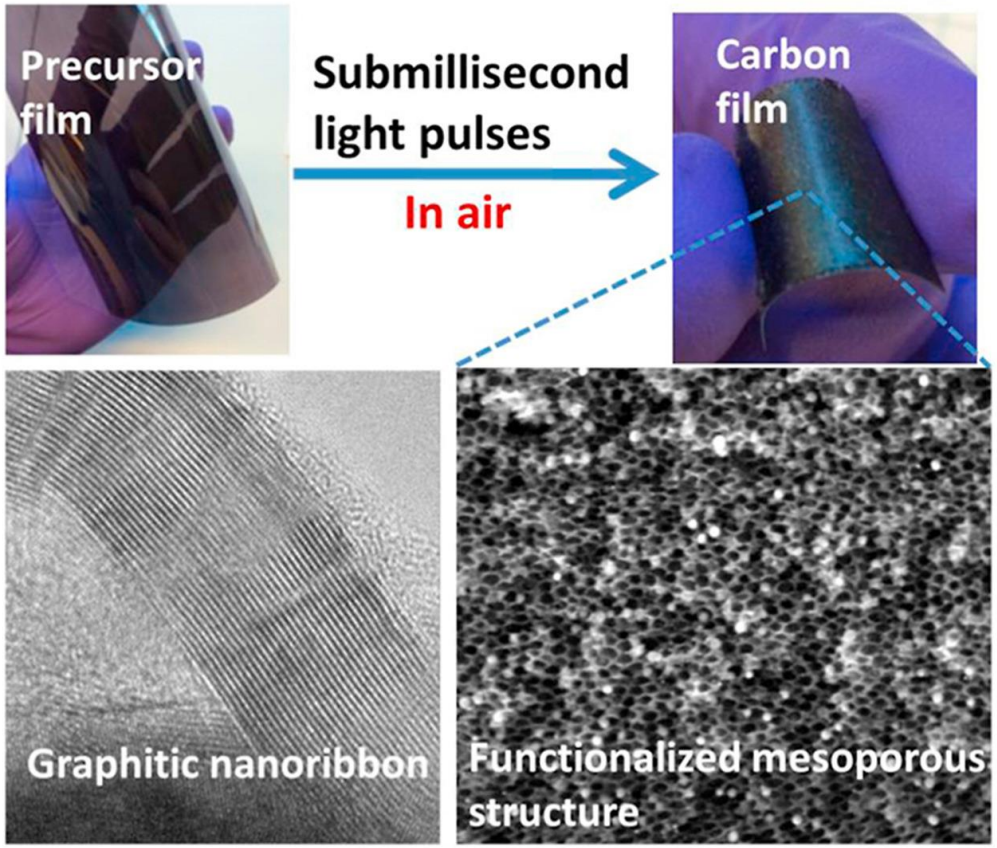
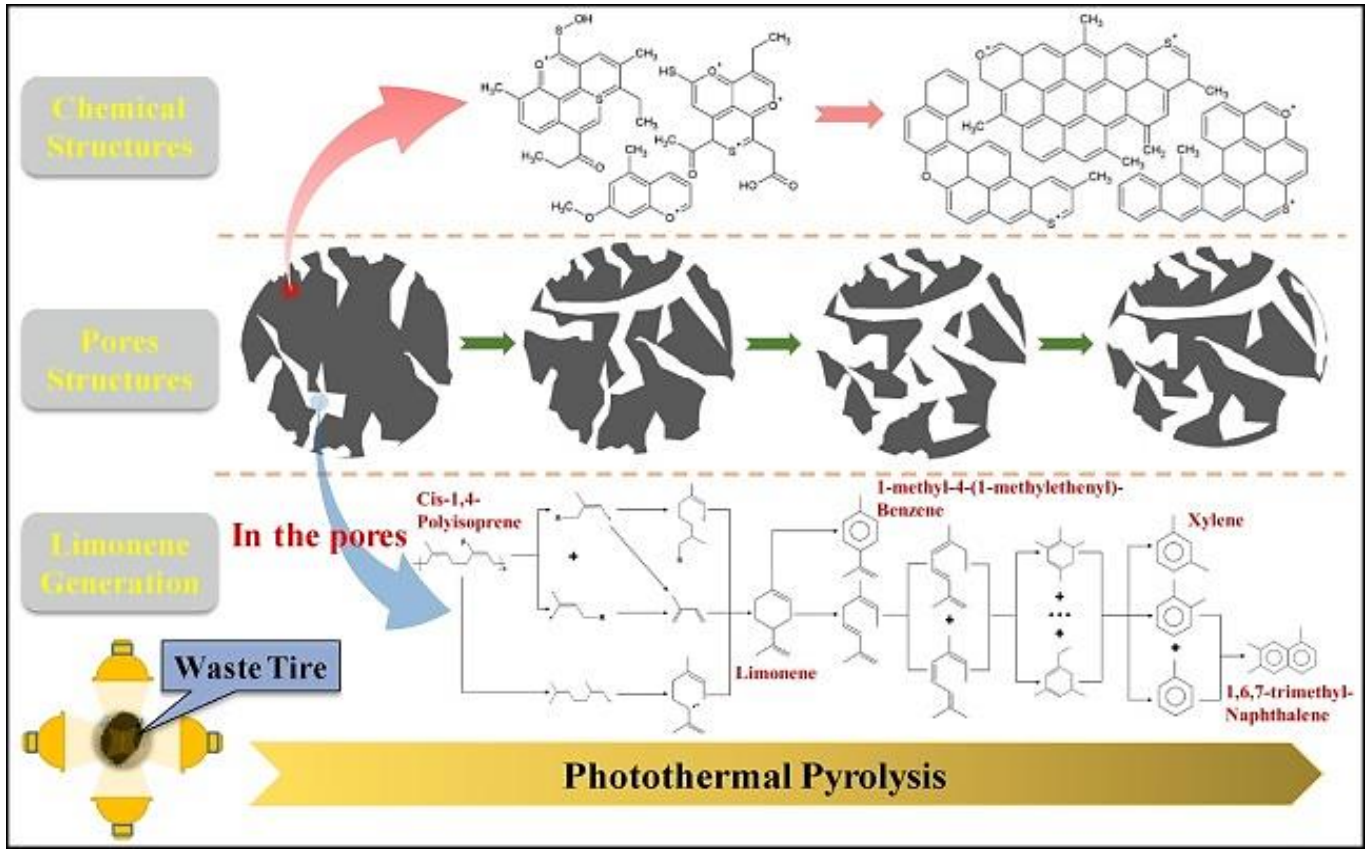
Photothermal Pyrolysis:



James J. Watkins et. al "Millisecond Photothermal Carbonization for In-situ Fabrication of Mesoporous Graphitic Carbon Nanocomposite Electrode Films." Carbon (2020).



Jun Xiang et al. “Novel photothermal pyrolysis on waste tire to generate high-yield limonene”, Fuel (2022)

High intensity light has been demonstrated a novel method to generate value-adding materials for energy, electronics, and preparing recycled products. W

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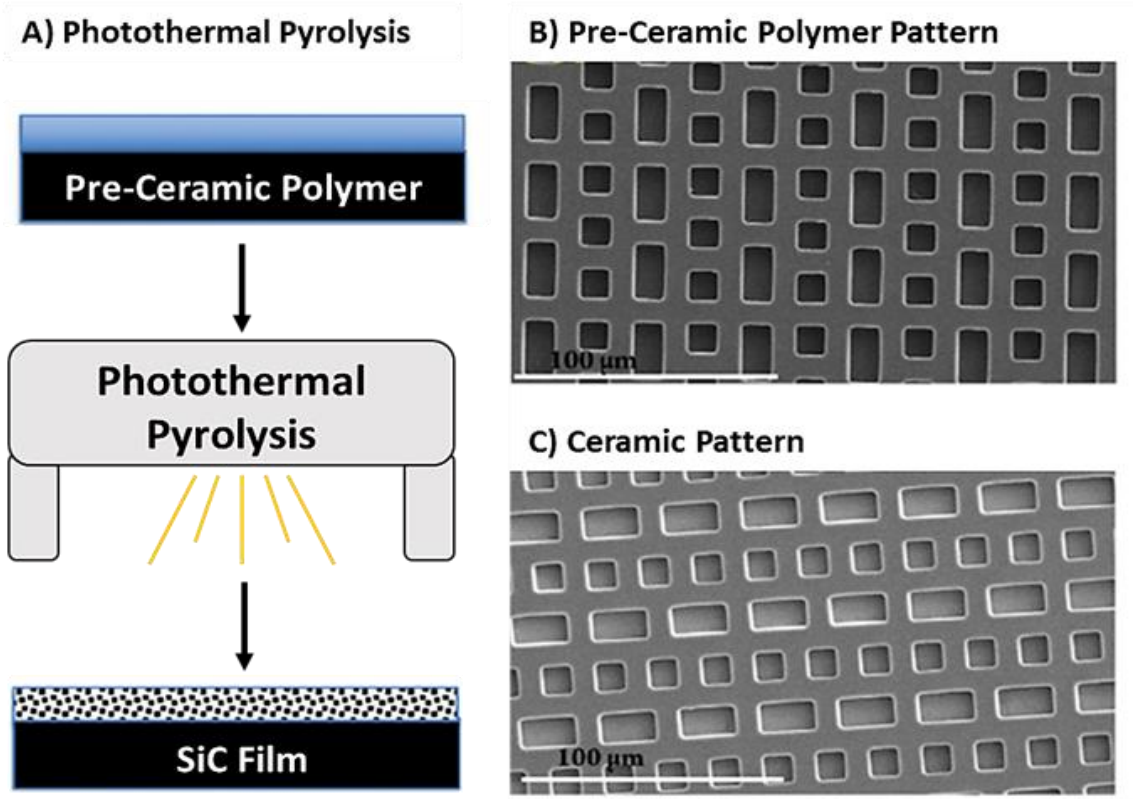
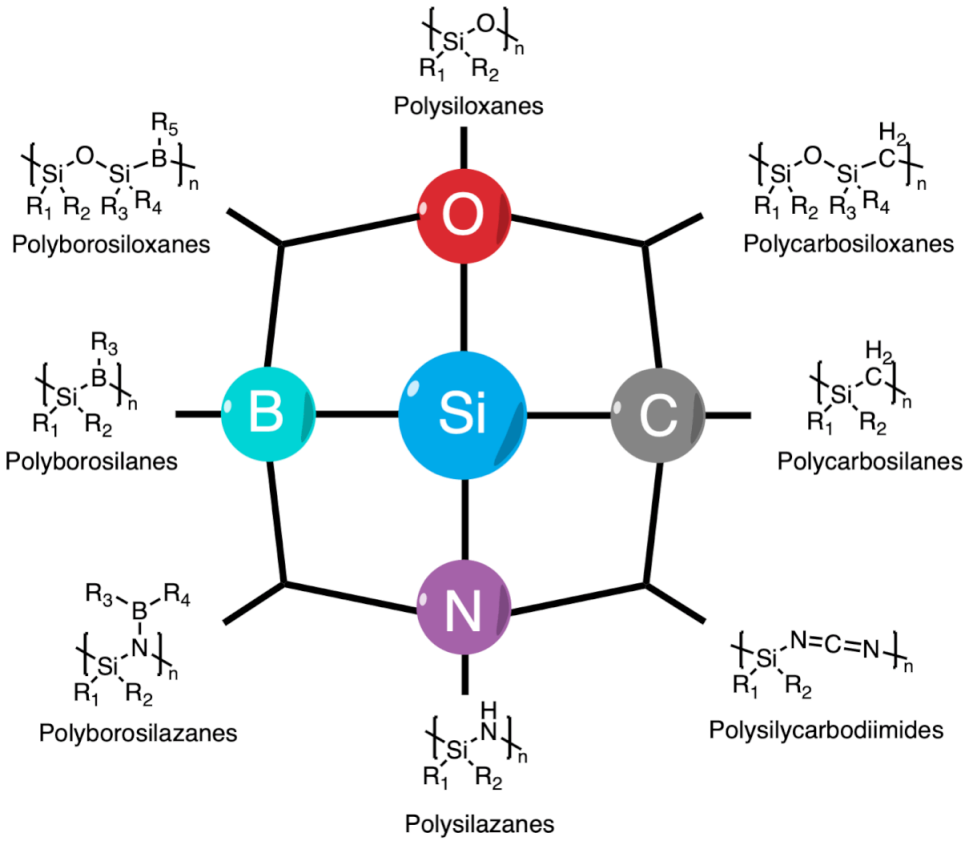
Photothermal Pyrolysis:



Okoroanyanwu, U.; et. al *Chem. Mater.* **2021**, *33*, 678–694.



To generate SiC materials, Luna Labs and the team developed a unique photothermal pyrolysis method to convert pre-ceramic polymer to SiC.

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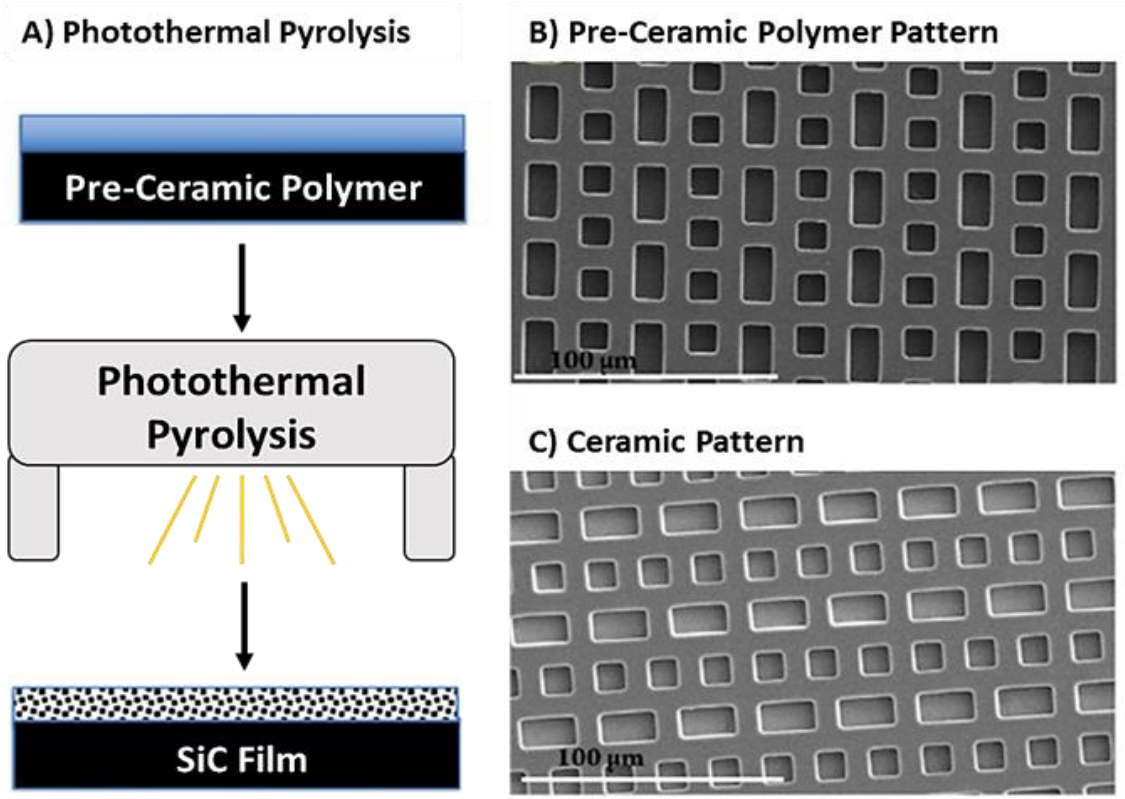
Photothermal Pyrolysis:



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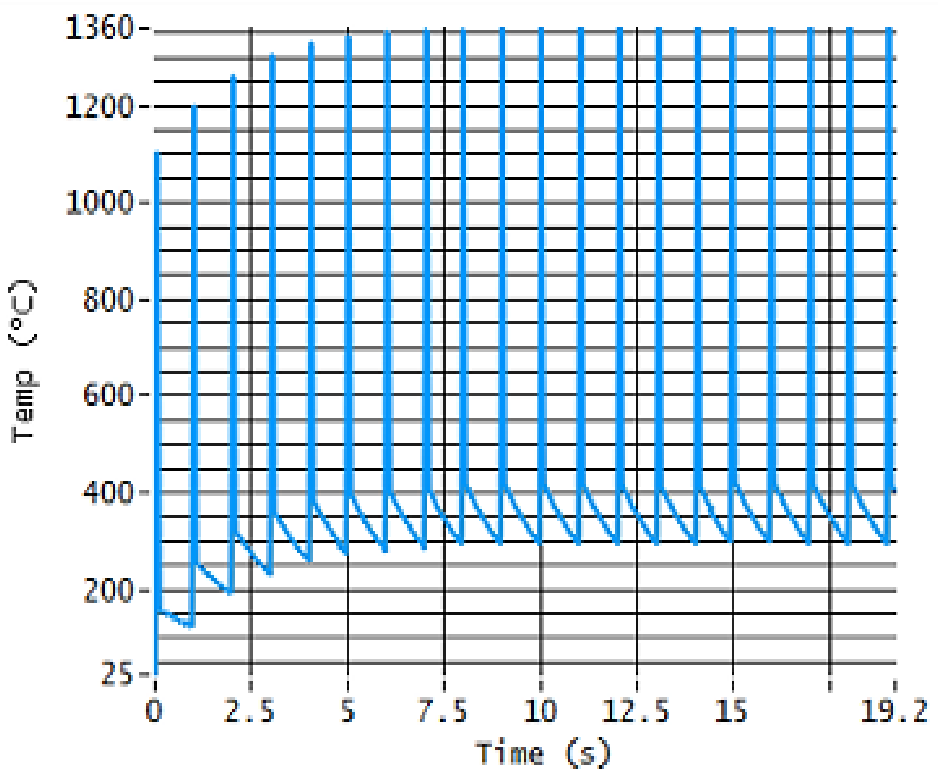

Using high-intensity light pulses, the team will build upon previous work that successfully converts a crosslinked pre-ceramic polymer into SiC materials. Here, the pattern will transition to lines.

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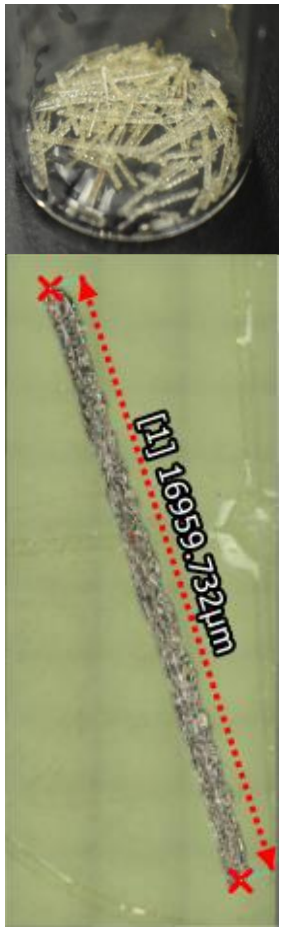
Generation of Chopped Sic Fibers:



Overall, Luna Labs was able to generate chopped SiC fibers that were photothermally converted to SiC fibers within 10 seconds. Energy dispersive X-ray spectroscopy confirms less than 5% oxygen.

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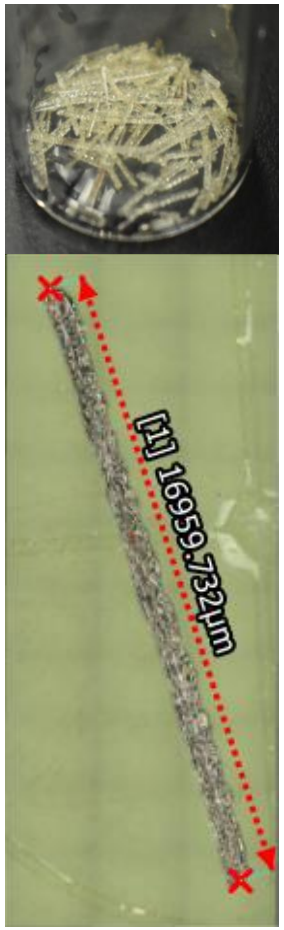

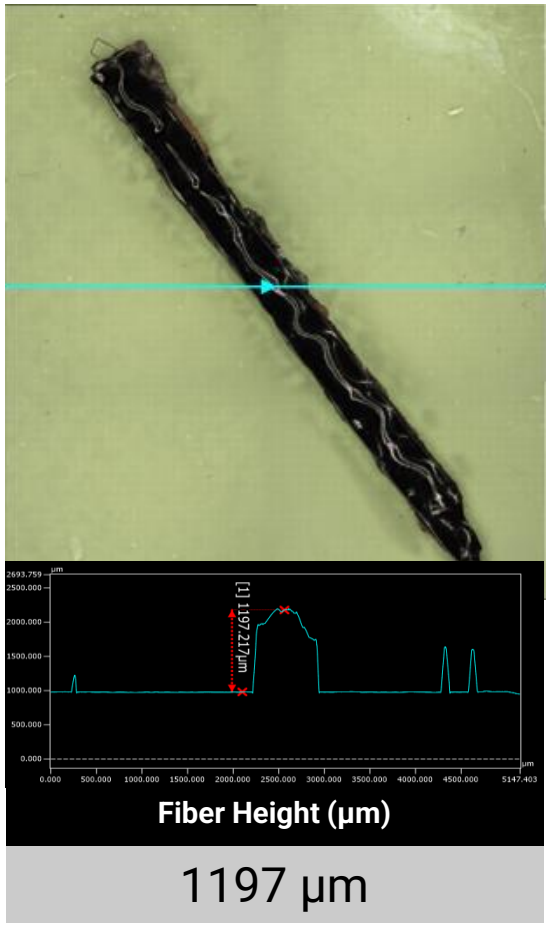

1197 µm

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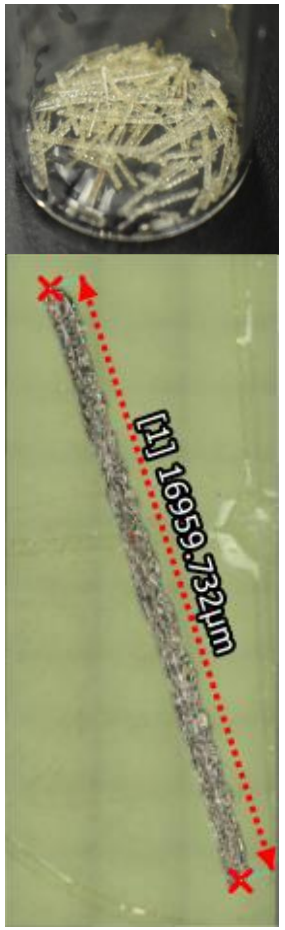

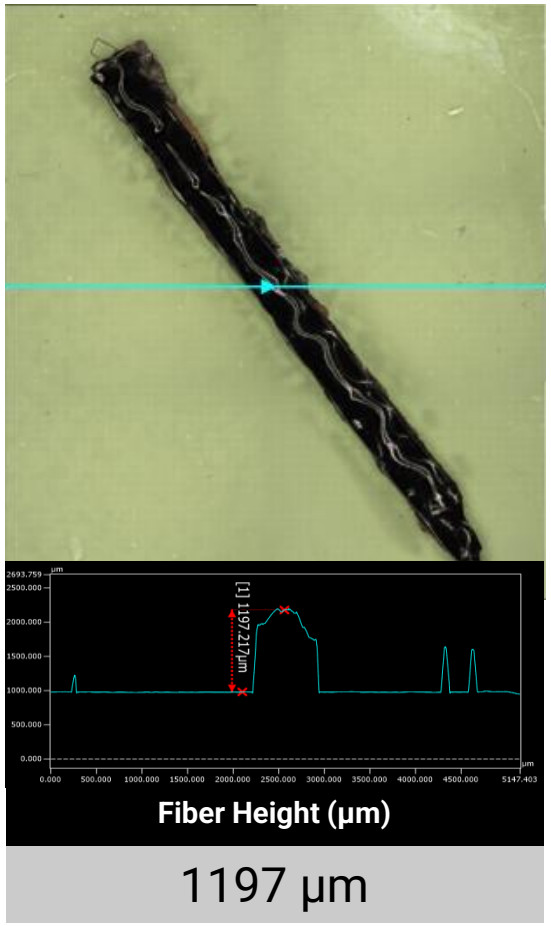

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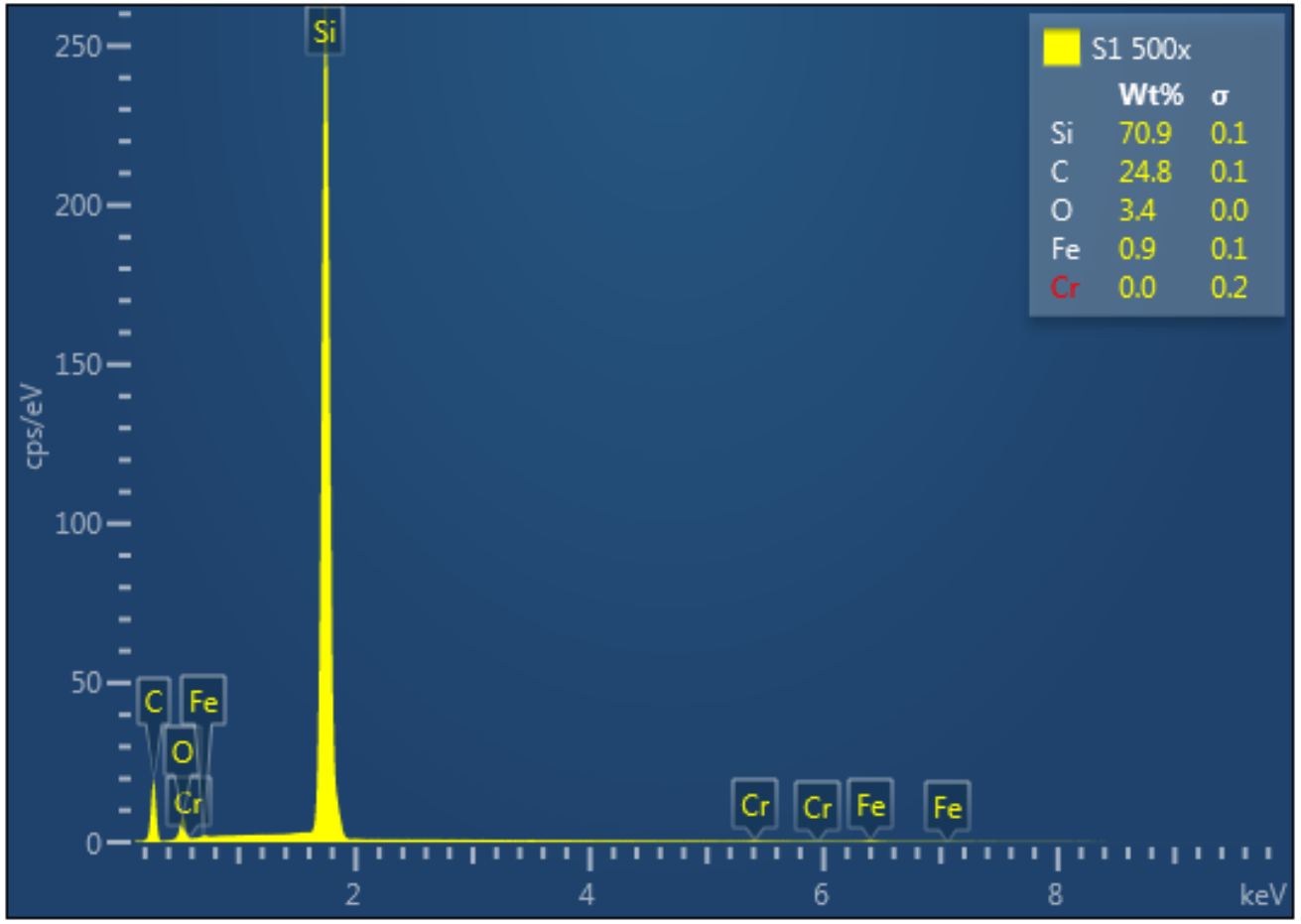

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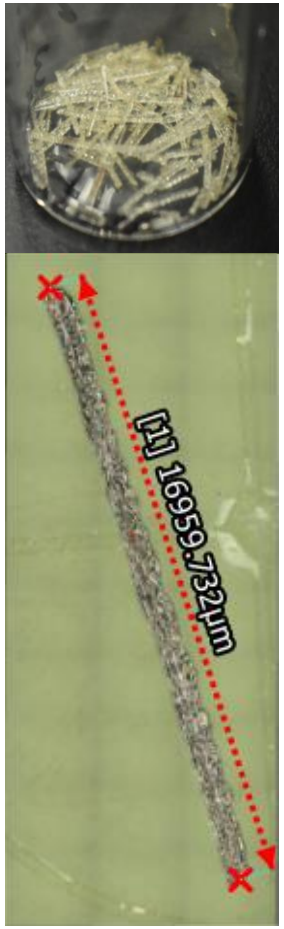

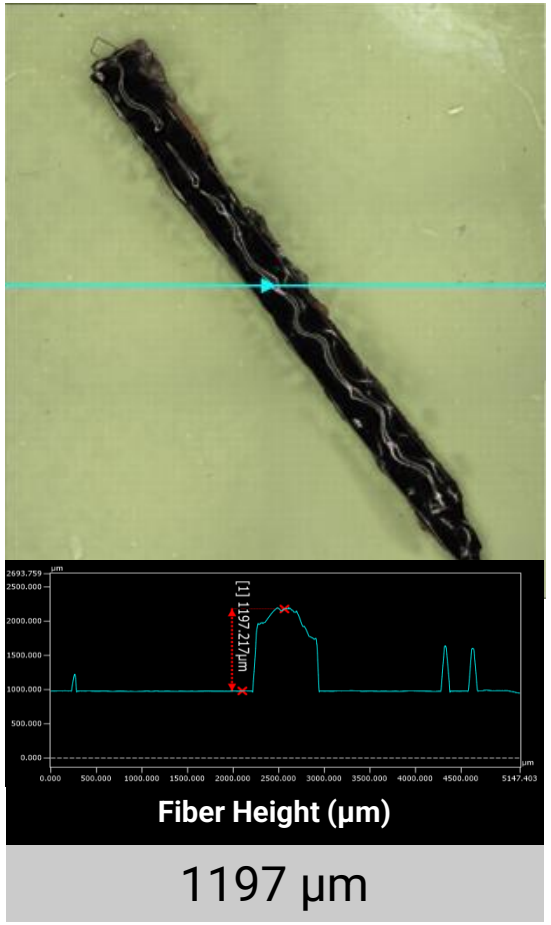

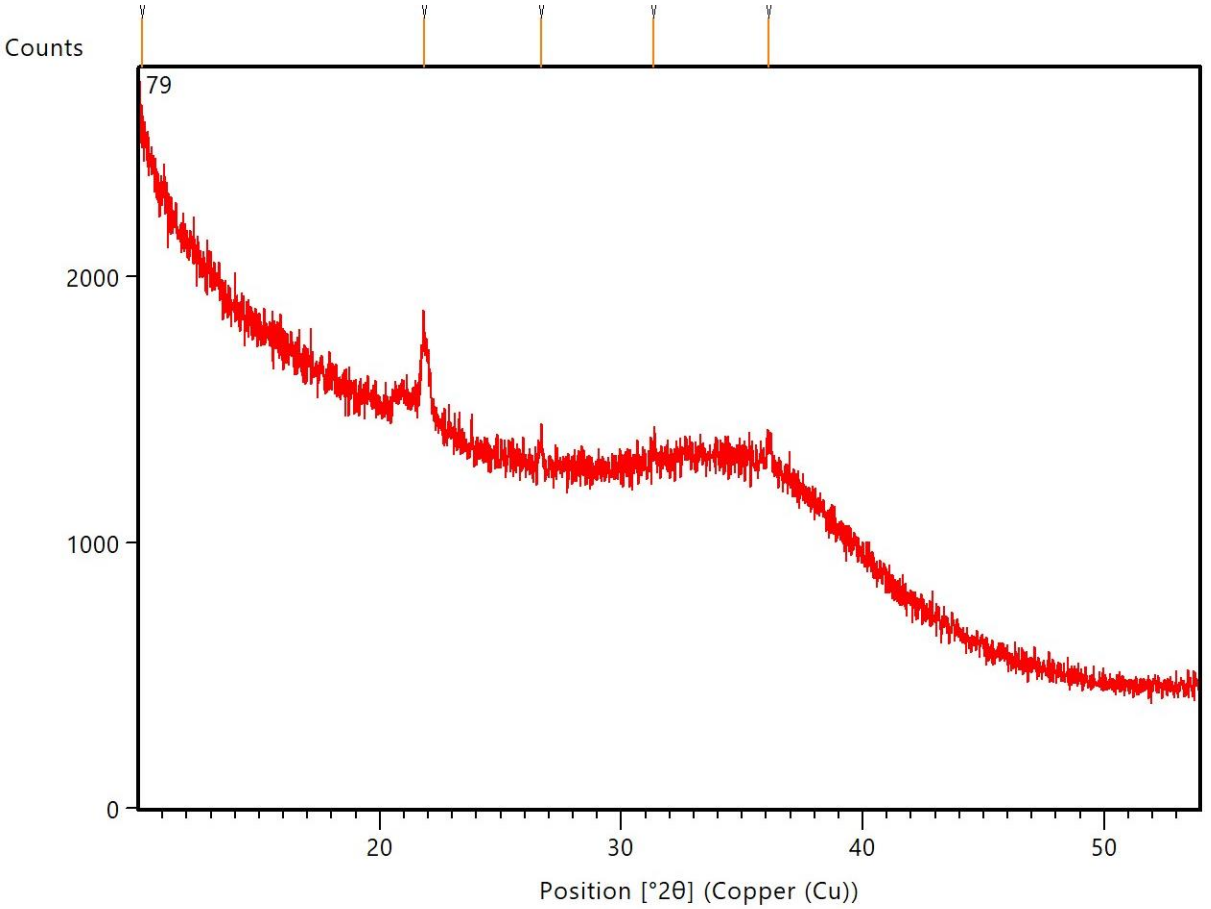

Powder X-ray diffraction confirms that the SiC chopped fibers are amorphous in nature. Overall, providing a low-cost alternative to current commercially available products.

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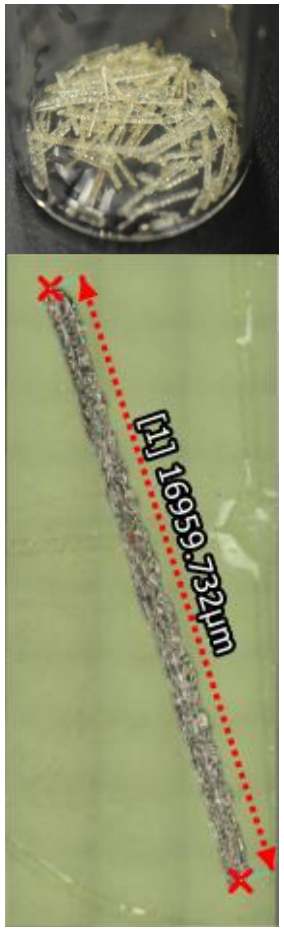
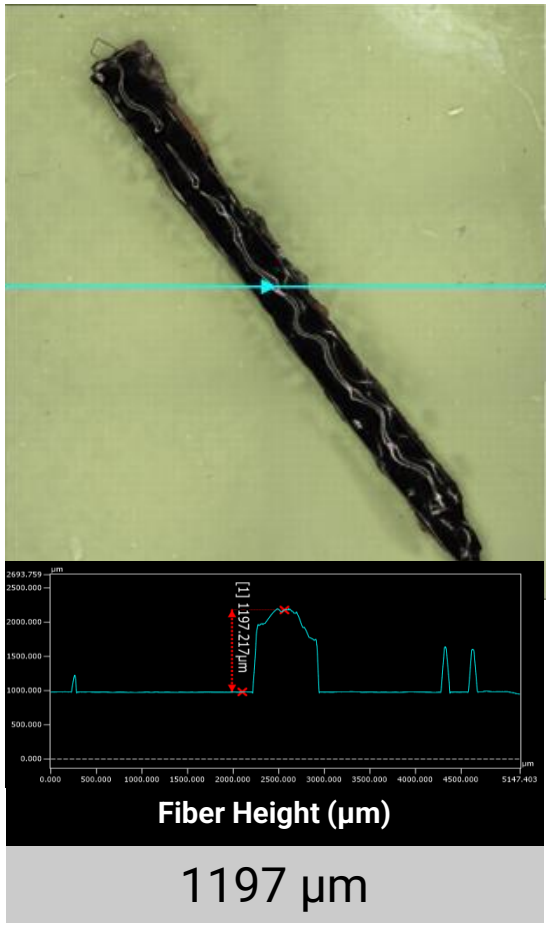
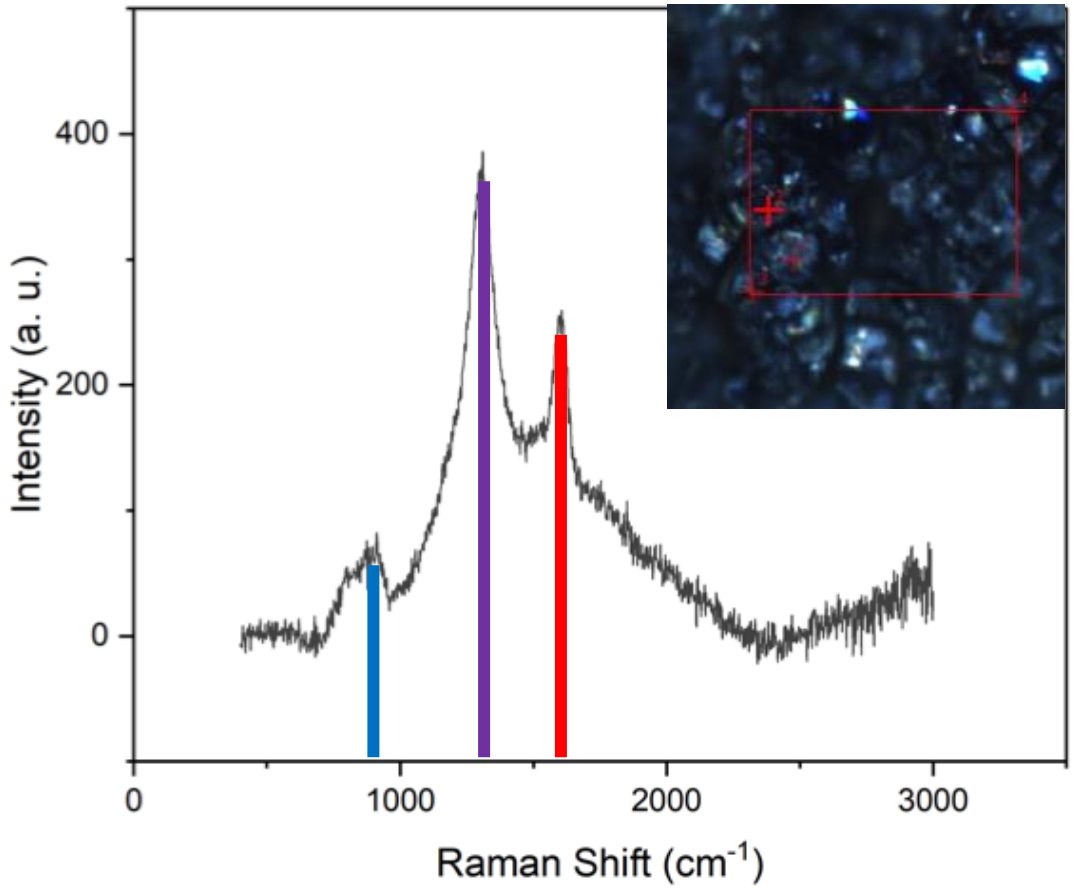
Generation of Chopped Sic Fibers:







Based upon monolithic and nanostructured SiC, literature Raman microscopy reveals the presence of both single-crystal and nanocrystalline SIC materials. Thus, amorphous SiC is generatable from Rapid SiC.

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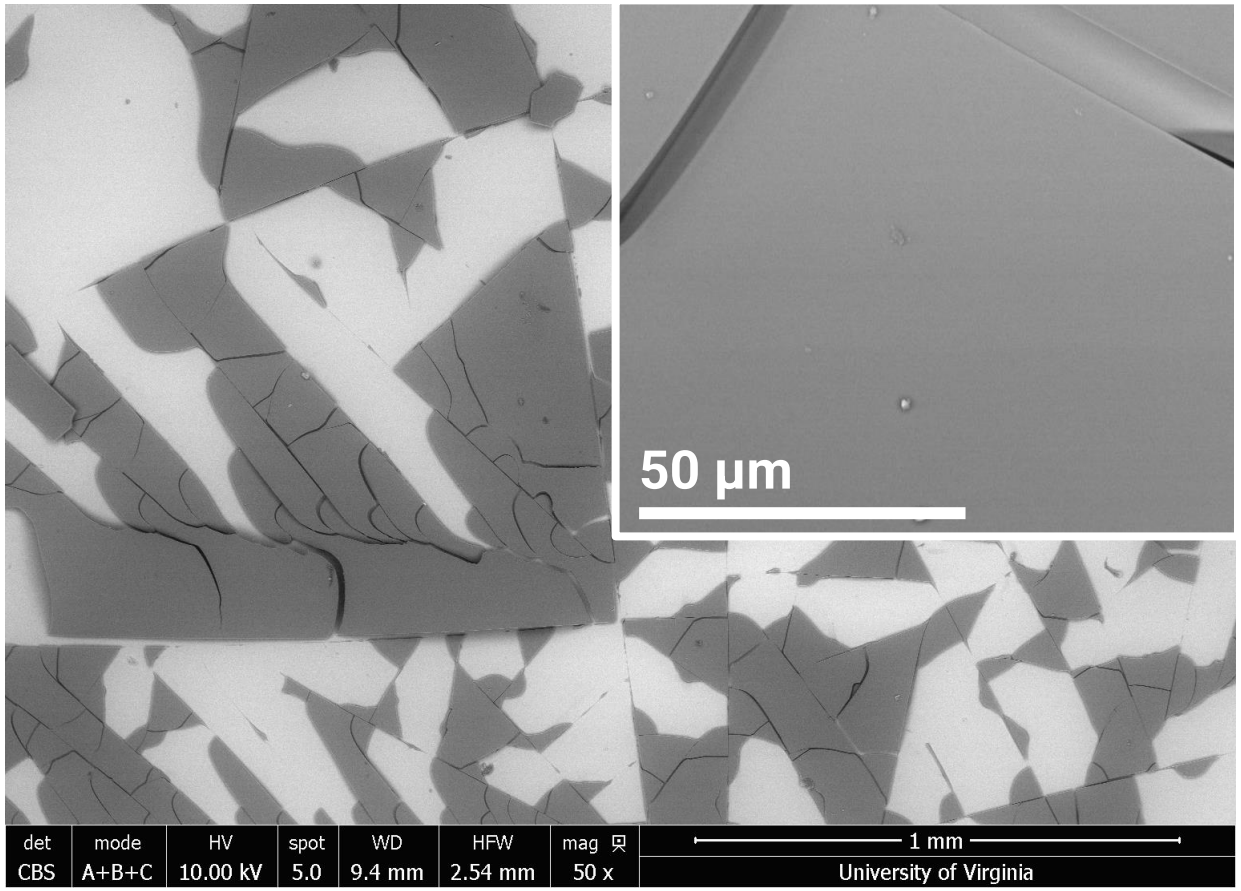
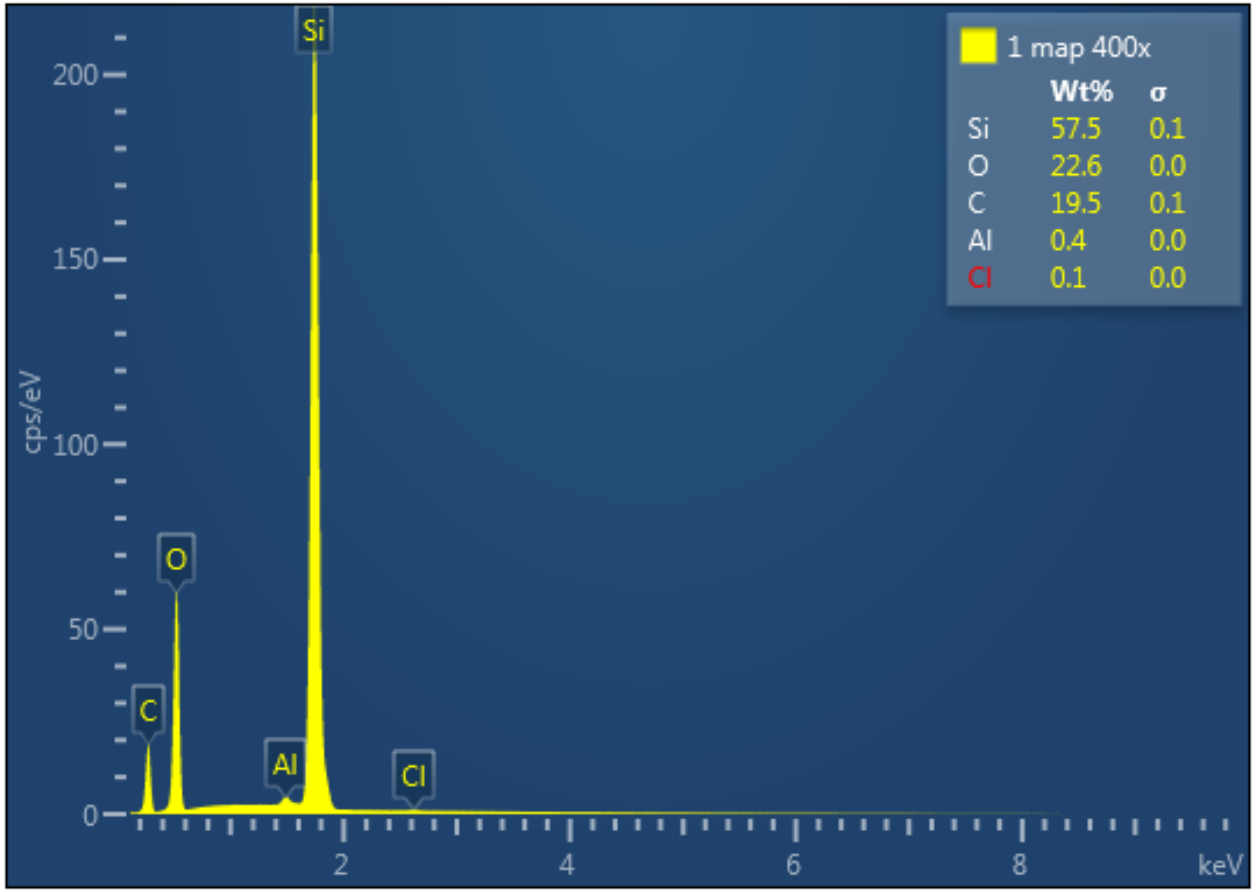
Synthesis of Silicon Oxycarbide Coating:





SiO_xC_y coatings were made using similar principles. This may be a consequence of the glass substrate used for the coating. Overall, we can create ceramic coatings by photothermal pyrolysis.

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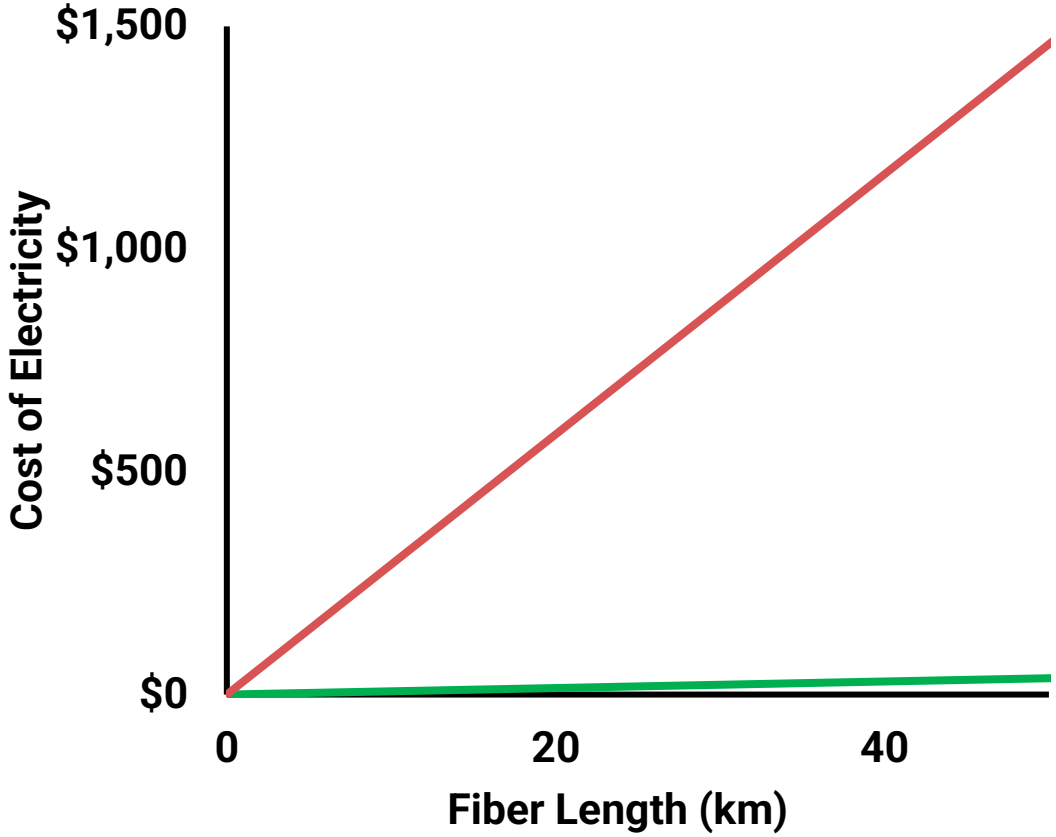
Cost and Emission Saving of Rapid Conversion:

Metric	Rapid SiC Process	Old Thermal Pyrolysis
Power	18 kW/hr	12 KW/hr
Practical Line Speed	30 m/min	0.5 m/min
Total Energy per 1 kg	0.3 MW	12 MW
Time to 30 km (1 kg)	1000 min	60000 min
Electricity Cost at 30 km	$ 21.90	$ 876.00
CO_2 Emission	245 lb	9816 lb



Overall, photothermal pyrolysis results in a 60-fold increase in production speeds, a $850 decrease cost in electricity, and a 9500 lb reduction in CO_2 emission. Note, each manufacturer has different line speeds.

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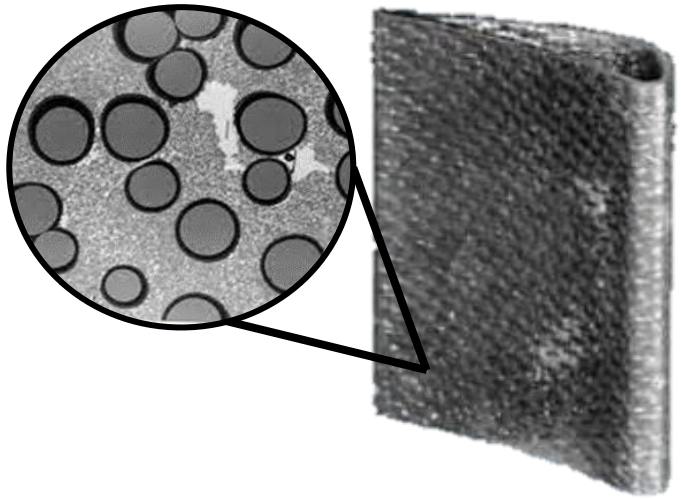
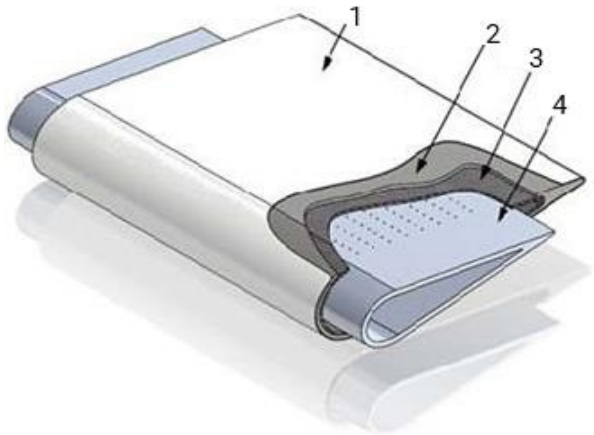
Future Directions:

Rapid SiC: Room Temperature Production of Polymer-Derived SiC Fibers

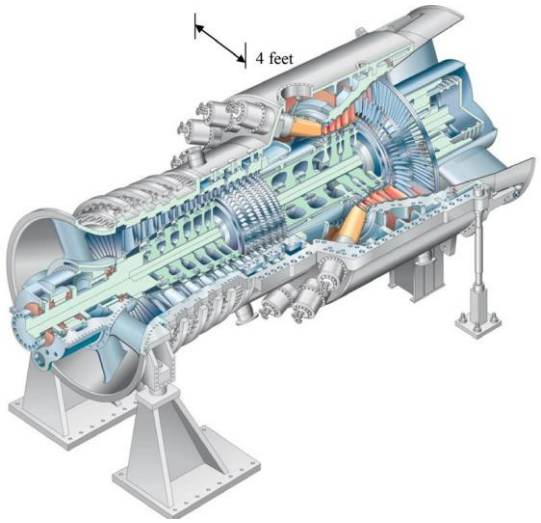
Fiber Reinforced SiC-SiC CMC



Component Integration



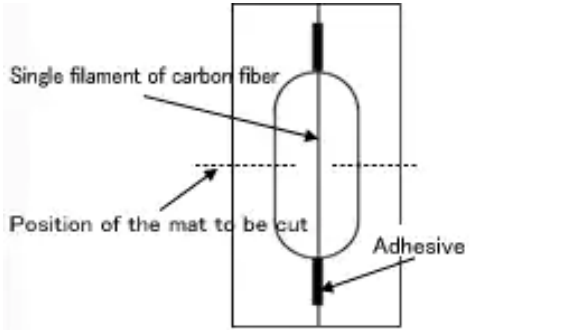
Turbine Assembly

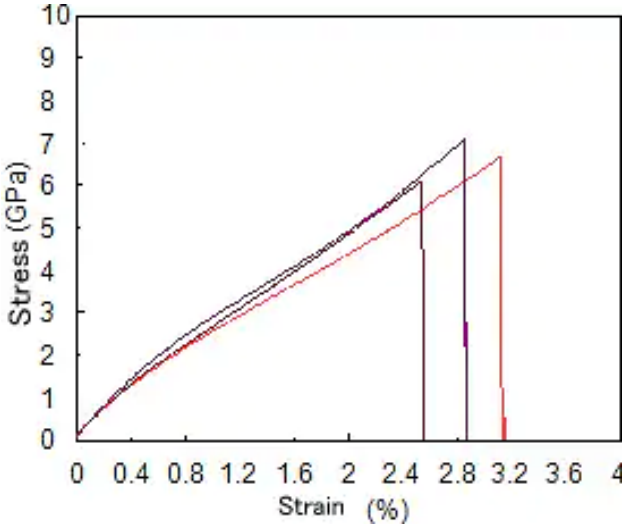


Integration Path

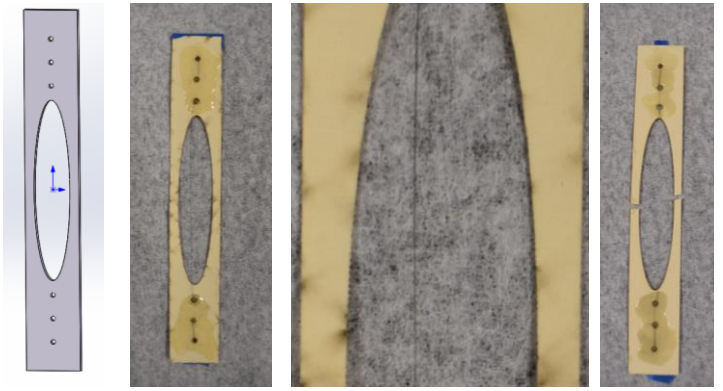
*Future work of this program will focus on generating and **testing** continuous SiC fibers that can be readily integrated in SiC-SiC CMCs for use in high-temperature combustion.*

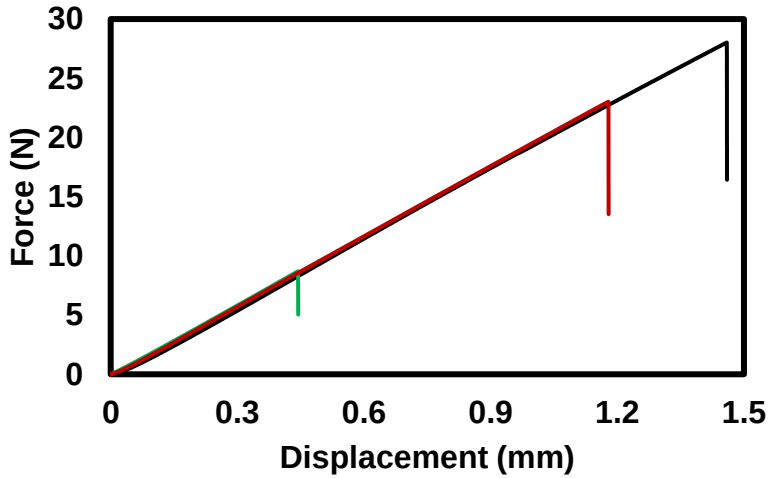
Mechanical Evaluation of Future SiC fibers:





https://www.shimadzu.no/industries/hpi/carbon-fibers





Using ISO 11566:199, Luna Labs developed a novel testing procedure to evaluate the tensile strength of cont. commercial SiC fibers. Luna Labs will evaluate continuous Rapid SiC fibers in the future.

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Questions?

Josh.Smith@lunalabs.us

Please reach out if you would like detailed discussions!