Forcespun Polymers as Precursors to Boron Nitride Fibers

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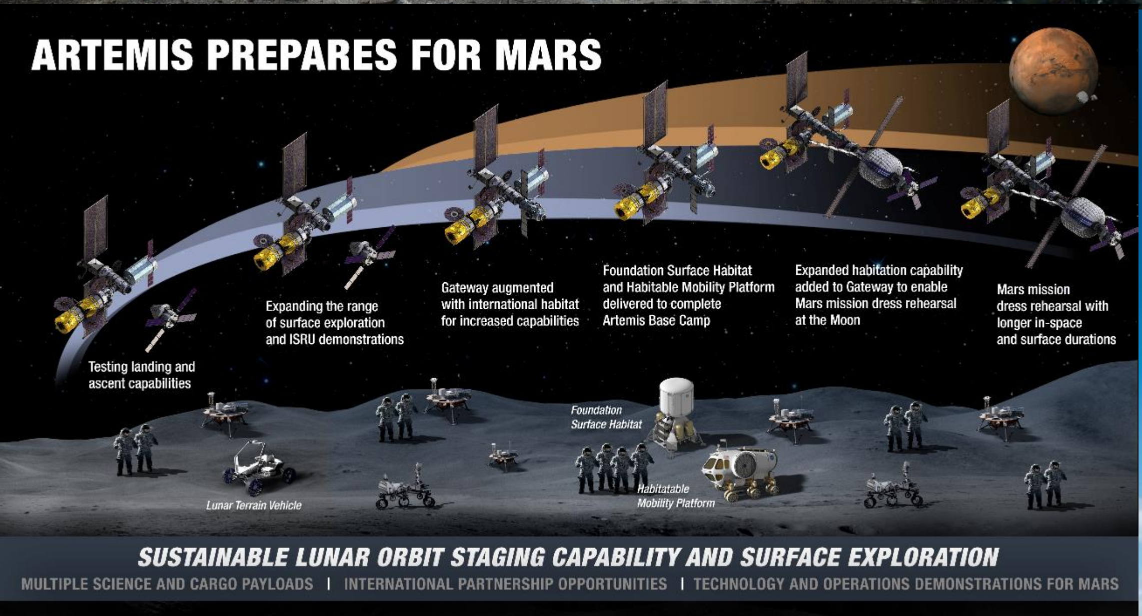
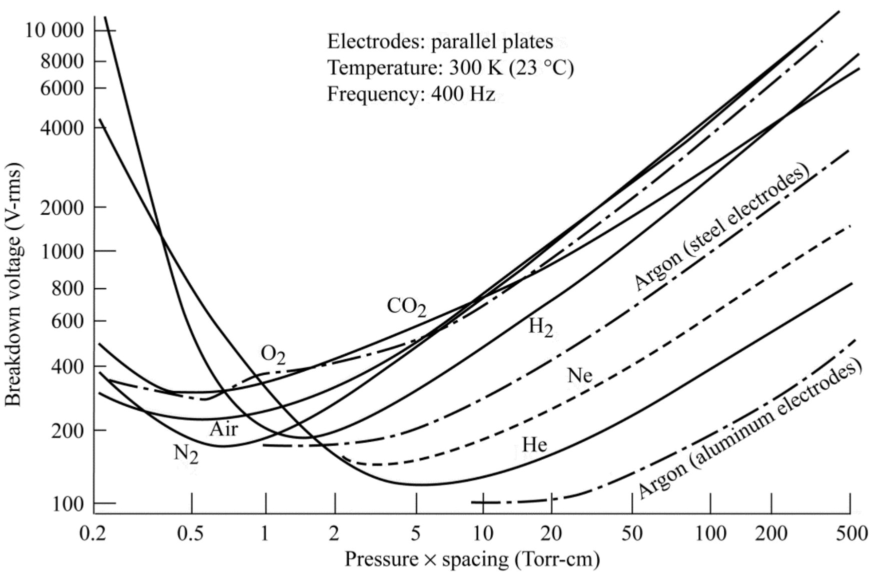
Advances in Aeronautics and Space Technology



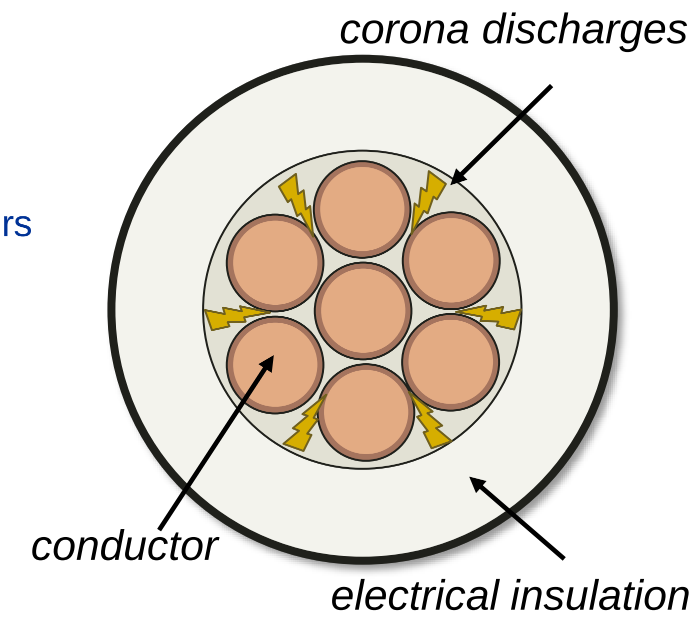
Electric Aircraft Power Requirements

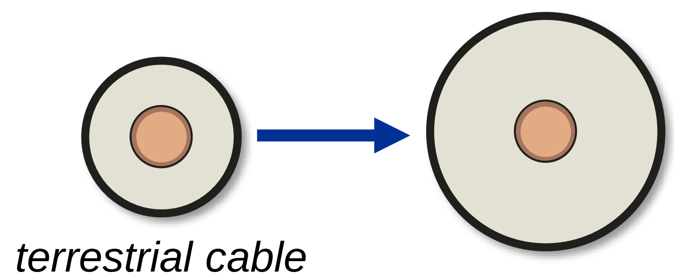
Technology Challenge: Electric Aircraft need high power

- Higher power will require high voltage power transmission cables
- Increasing voltages can utilize lighter/smaller gauge conductors
  - MORE insulation is needed at higher altitudes due to partial discharge & corona activity!



Paschen curves illustrate the dependency of breakdown voltage on distance between conductors and altitude.
↑ Altitude requires ↑ Conductor spacing





Terrestrial SOA cables *cannot* solve aeronautics problems.

Mazzanti, G.: High voltage direct current transmission cables to help decarbonization in Europe: recent achievements and issues. *High Volt*. 7(4), 633– 644 (2022).
3M Power Cable Splicing and Terminating Guide. 2018.

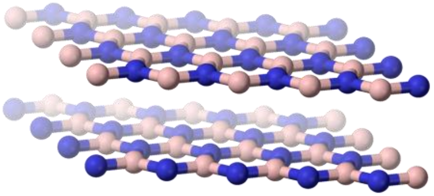
Technology Solution: Boron Nitride Composite Materials

HV Insulation Requirements

- Thermal conductivity > 1 W/m·K
- Operating temperature > 200 °C
- Push temperature > 260 °C if possible
- Compatible with other component materials
- Retain dielectric strength of SOA materials (>20k V/mm or better)
- Increased resistance to partial discharge and corona effects

Goal: Development of a material that combines chemical inertness, lightweight and high strength with high electrical resistivity and high thermal conductivity for the insulation component of high voltage power transmission.

BN meets ALL required metrics when compared to other possible materials.



***h*-BN**

Good Insulation Properties

- Constant wide band gap around 6 eV
- Nanotubes are independent of diameter, chirality or number of tubular walls

High Thermal Conductivity

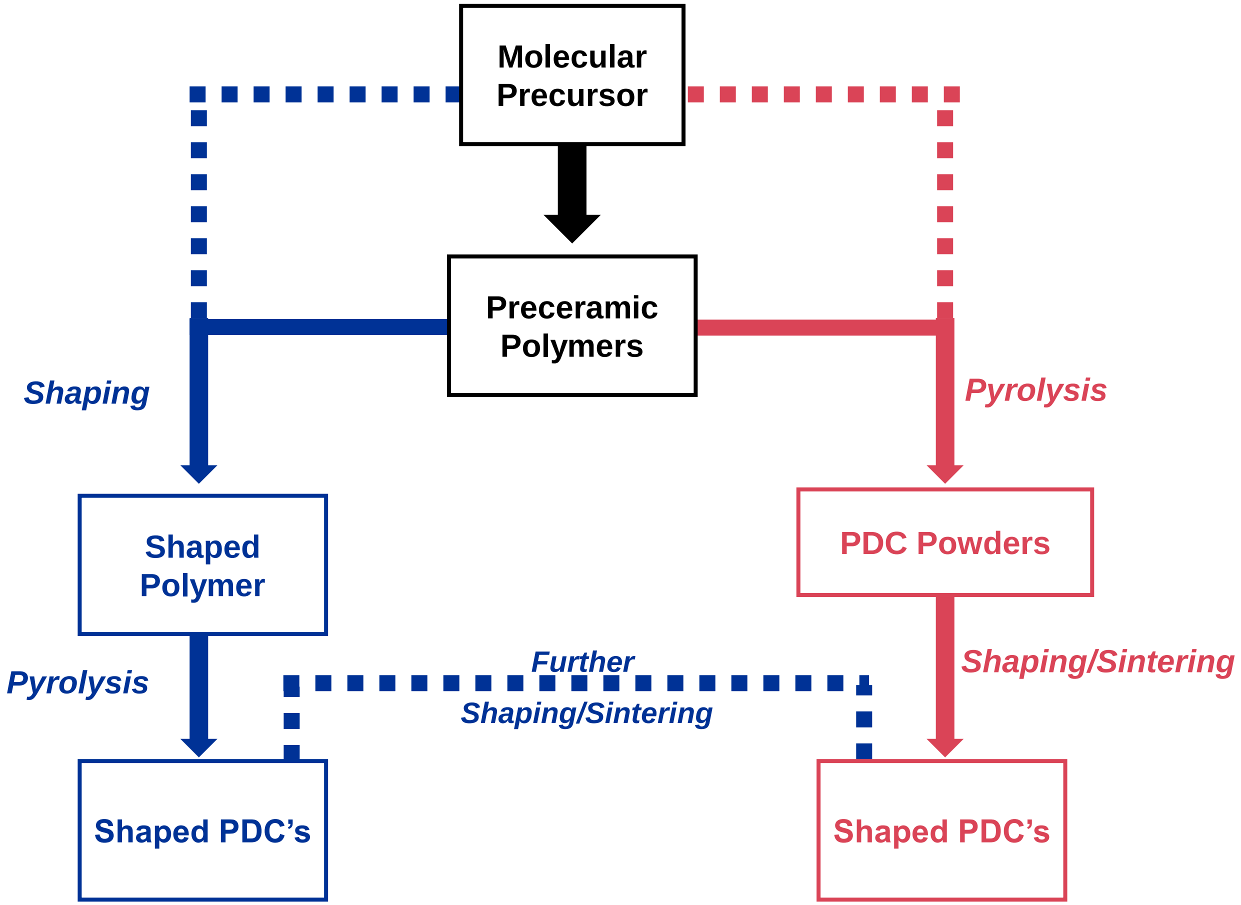
- Thermal Conductivity >100 W/(m·K) in plane
- Ability to dissipate heat in nanoelectronics
- Promising results in thermal shock experiments

Chemically and Thermally Stable

- Hydrophobic
- Chemical stability
- Oxidation in air above 1000°C

O. Shinpei, S. Fukushima, M. Shimatani, Materials 2023, 16(5), 2005

BN via the Polymer Derived Ceramic (PDC) Route

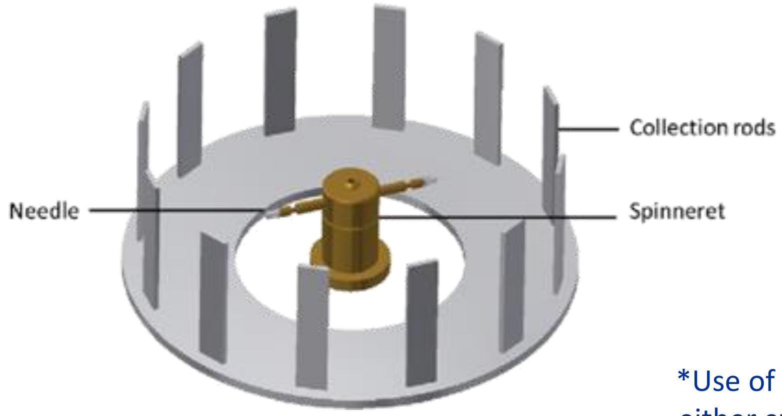


S. Bernard and P. Miele, *Materials* ***2014**, 7, 7436-7459.*

Forcespinning™ Method for Fiber Production

Forcespinning™ Fibers

- High-yield
- Fibers are formed through centrifugal spinning of a polymeric solution which evaporates into fine continuous fibers
- Fibers can be formed up to 6 ft in length
- Fiber diameters can be tailored to ranges between ≈ 200 nm to 5 μm by changing
  - Precursor polymer molecular weight
  - Viscosity of precursor solution
  - Spinning speed (RPM) of Forcespinner



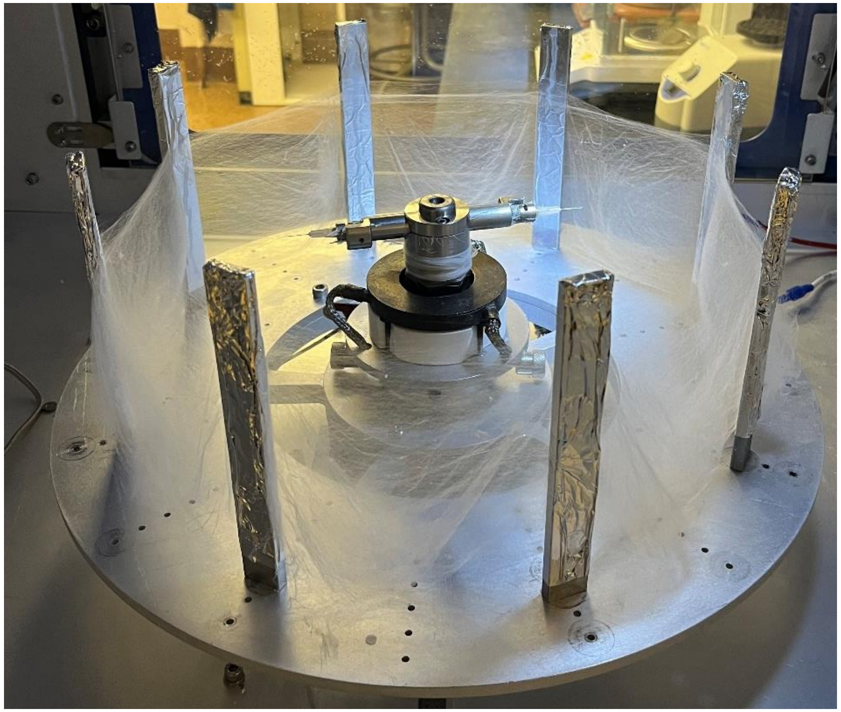
Fiberlab L1000-D

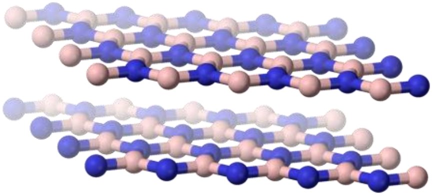
*Use of trade names or manufacturers does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

Fiberio. Operations Manual. Fiberlab L1000 Series. 2013.

Methods

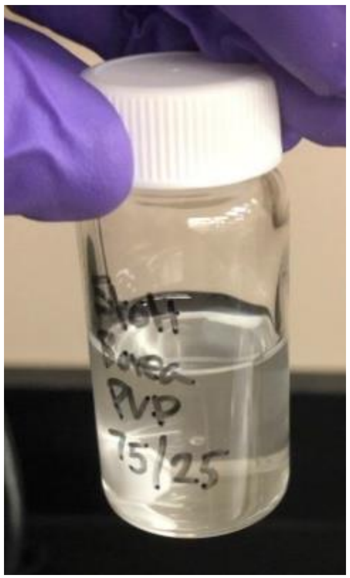
Precursor solution preparation → **Fiber Formation** → **UV Cure Fibers** → **Fiber Heat Treatment** → **Incorporation into polymer composite**





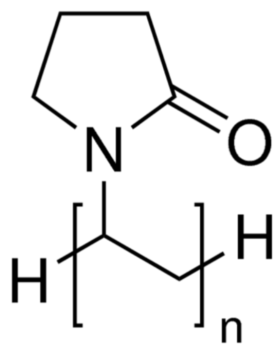
***h*-BN**

BN Precursor Polymer Solution Preparation

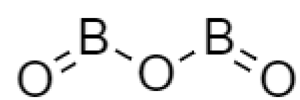


Components

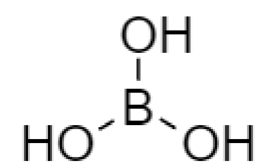
- Volatile solvent
- Polymer
- Boron-containing molecule



PVP
Poly(vinylpyrrolidone)

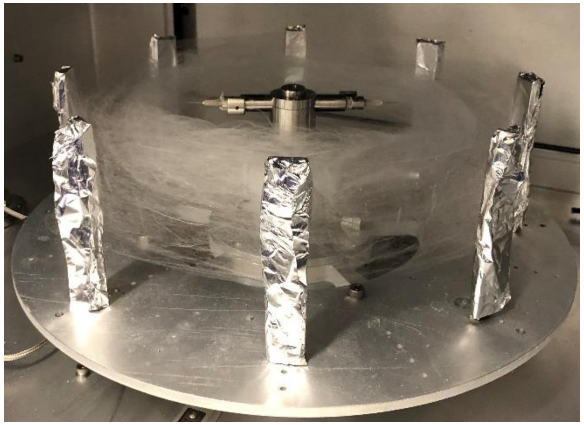


B_2O_3
Boron Oxide (Borea)



H_3BO_3
Boric Acid

Precursor Fiber Formation & Crosslinking



Boric Acid/PVP Fibers

Fiber quality depends on:

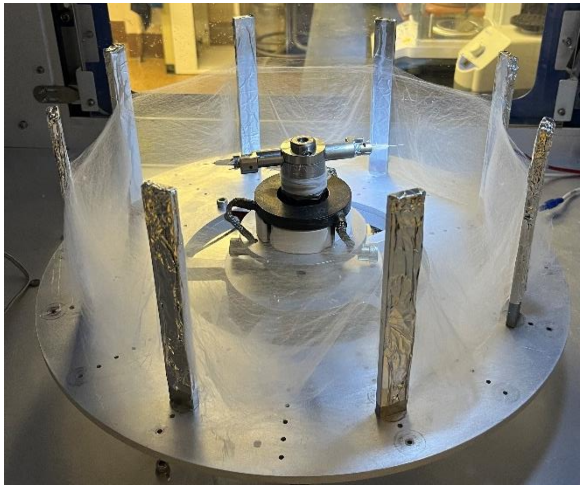
- RPM rate of centrifugal spinning
- Distance to the collection rods
- Composition of precursor solution
  - % Boric Acid
  - % Boron Oxide
  - Mixture of Boron Oxide/Boric Acid
- Humidity

Fibers Tested:

- 25%, 26%, 27% Boron Oxide
- 25% Boron Oxide/Boric Acid
- 25% Boric Acid

Boric Acid/PVP Fibers

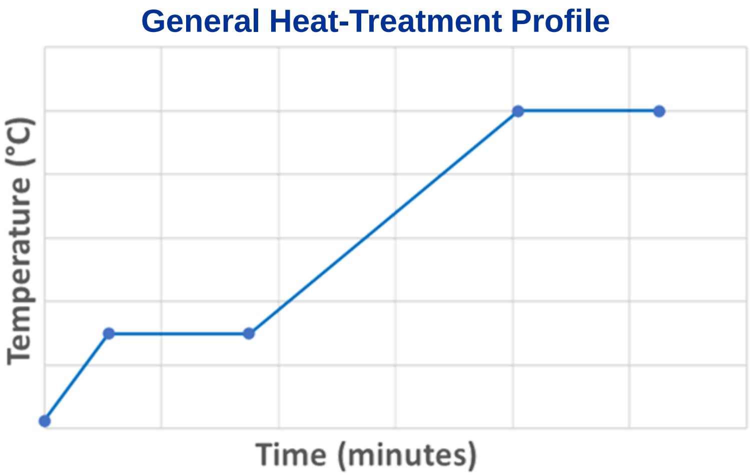
25% Boron Oxide/ 75% PVP solutions formed optimal fibers

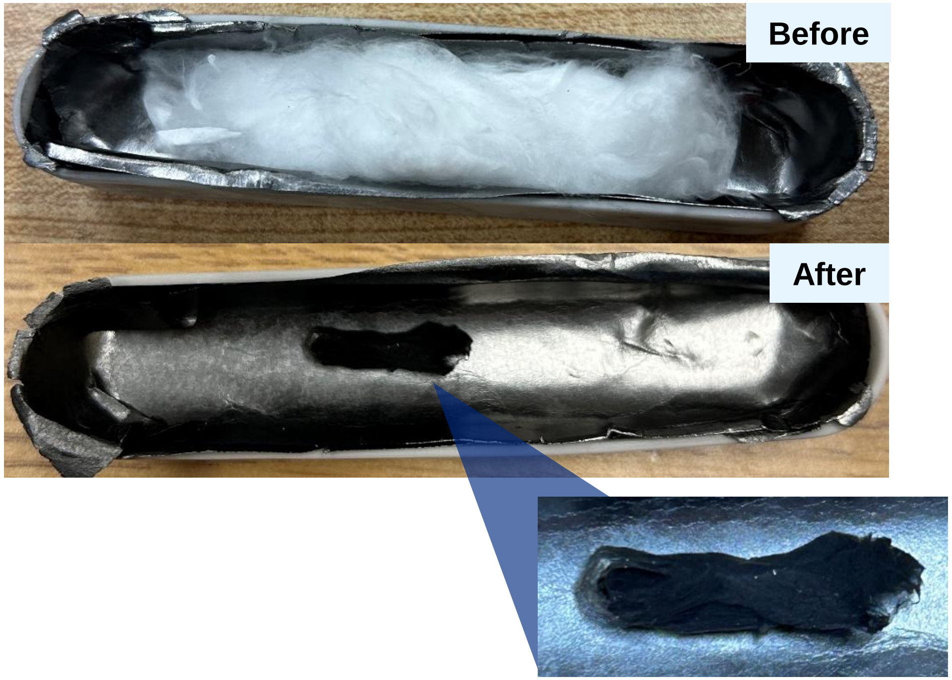


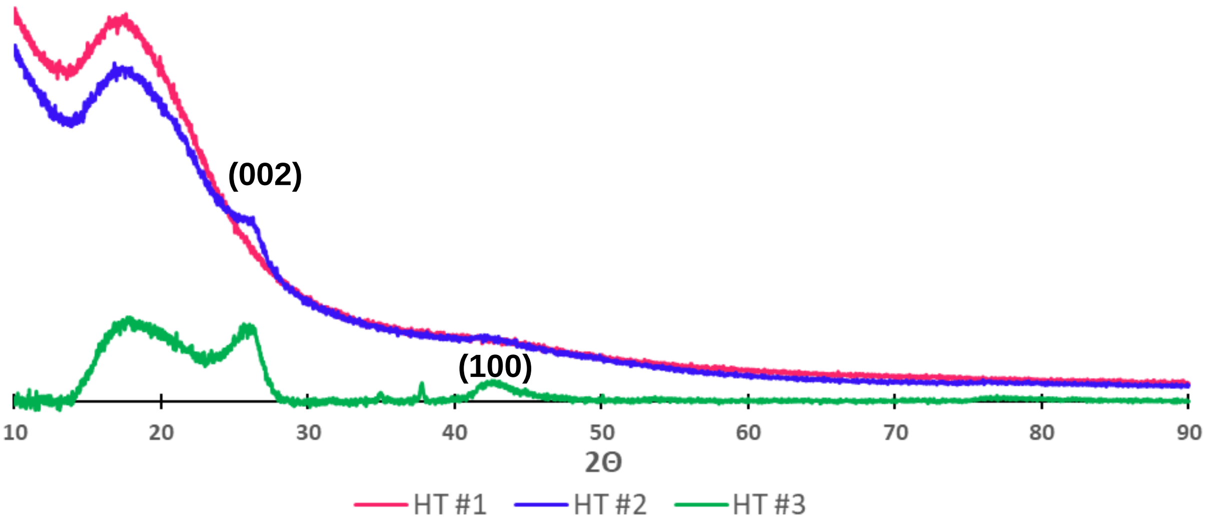
Boron Oxide/PVP Fibers

Boron Oxide/PVP Fibers

XRD of Heat-Treated Fibers

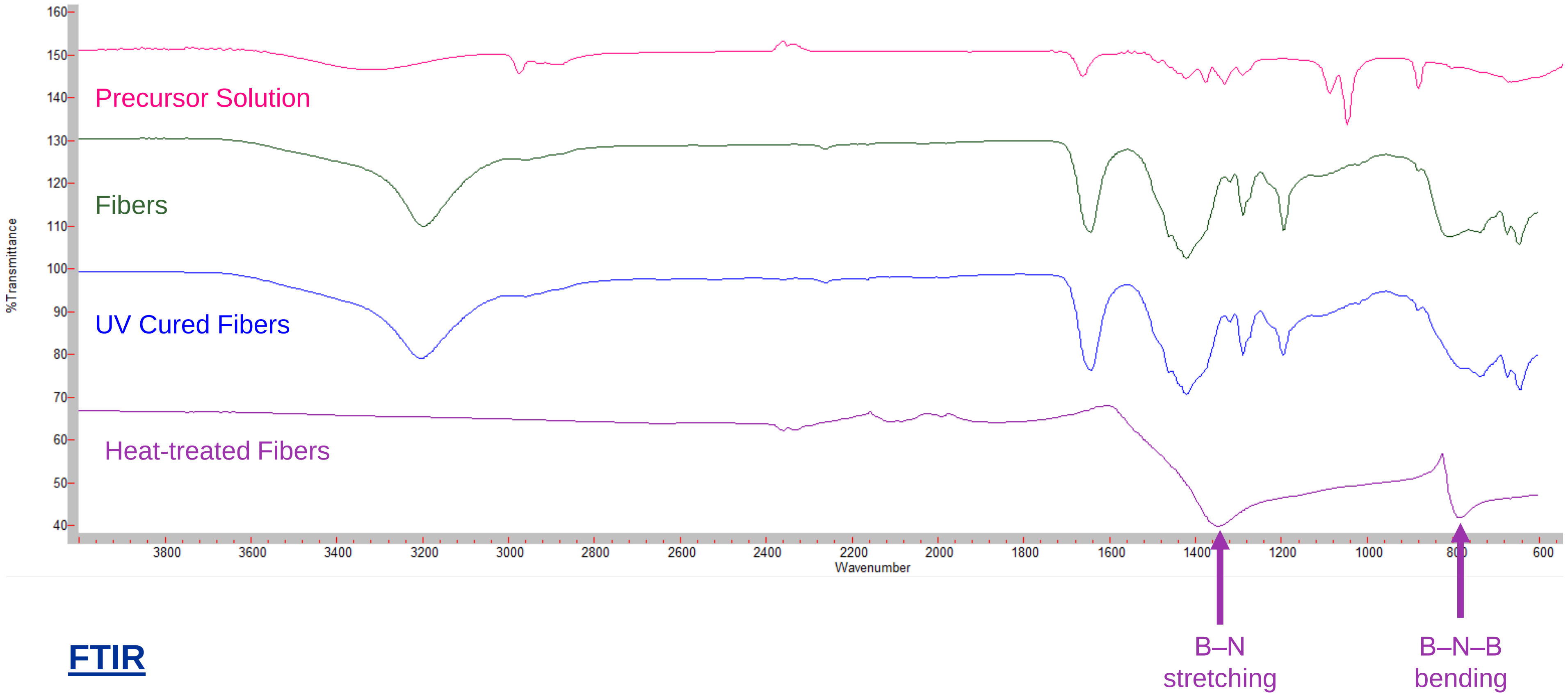






XRD shows improving crystallinity of BN via the (002) and (100) peaks at 26° and 42°.

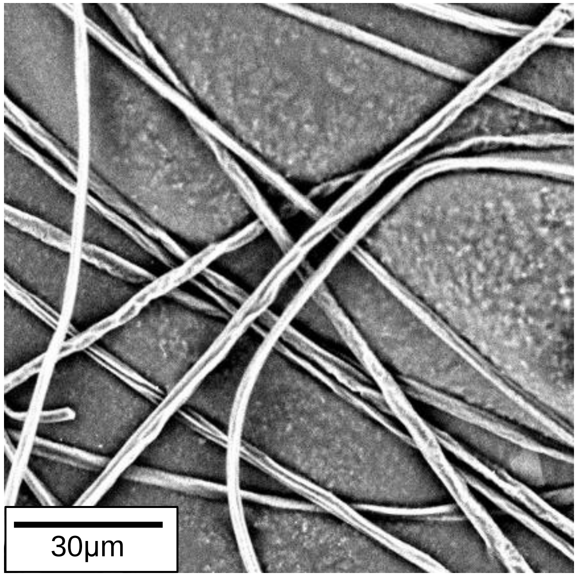
FTIR Analysis of Fibers



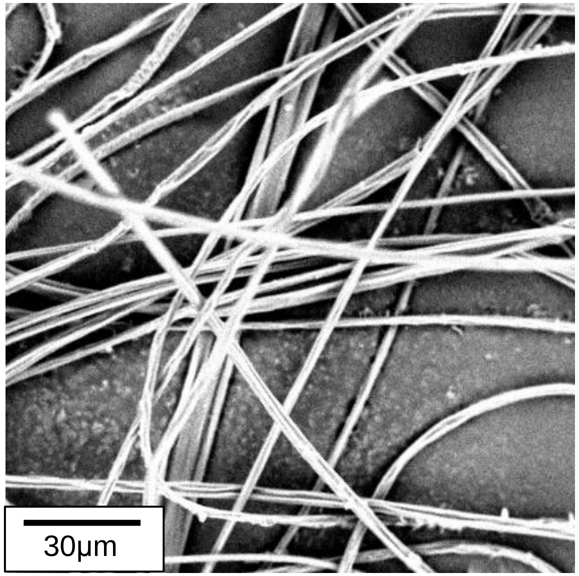
FTIR

– Successful conversion to BN as shown by the characteristic BN peaks at 1347 cm^{-1} and 783 cm^{-1}

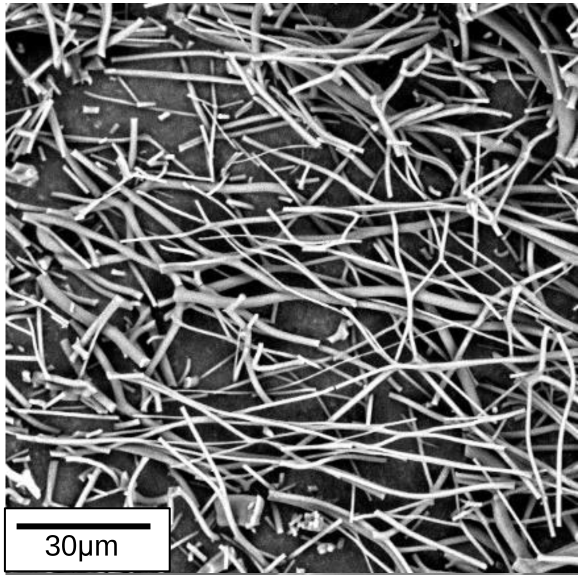
SEM Analysis of Fibers

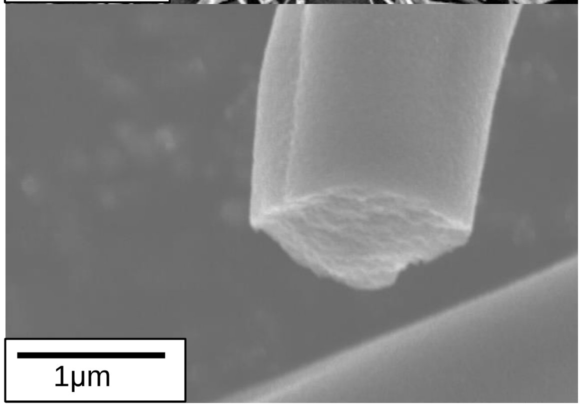


Forcespun Fibers



UV Cured Fibers





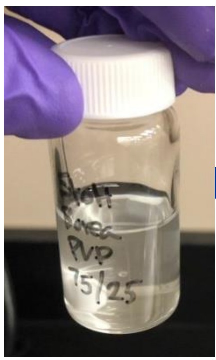
Heat-treated Fibers

SEM

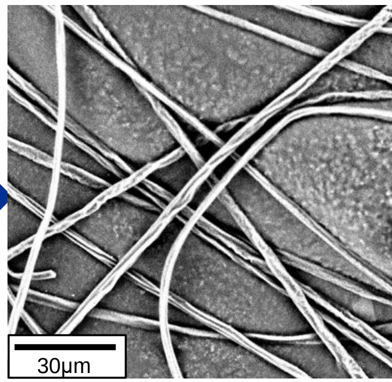
- Heat-treated fiber diameter: ~1μm
- Long continuous fibers contract during ceramic conversion to form short nanofibers

Summary & Next Steps

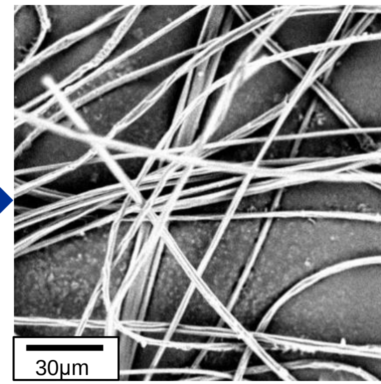
Precursor solution preparation → Fiber Formation → UV Cure of Fibers → Fiber Heat Treatment/ Conversion → Characterization → Incorporation into polymer composite



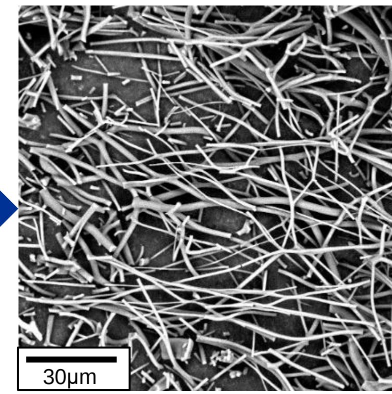
Precursor Solution



Forcespun Fibers



UV Cured Fibers



Heat-treated Fibers

→ **BN Fiber Polymer Composite**

Next Steps

- Continue heat treatment optimization with heating under tension
- Increase %B in precursor solution to further optimize BN conversion
- Incorporate BN fibers into polymer composites
- Characterize BN composites

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Thank You!