Production and qualification of ceramic nanofiber for future high-power targets

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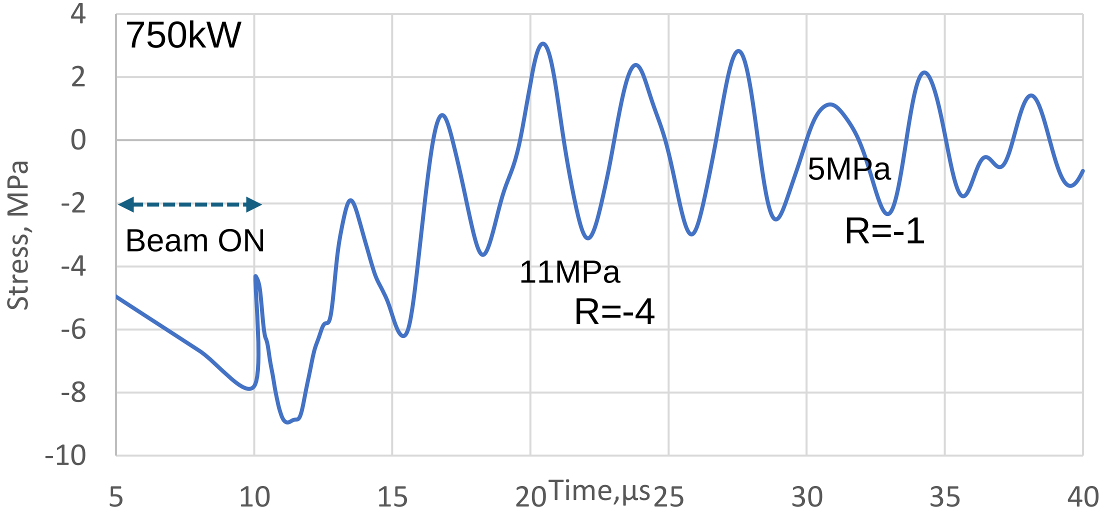
TSD talk 6/20/2024

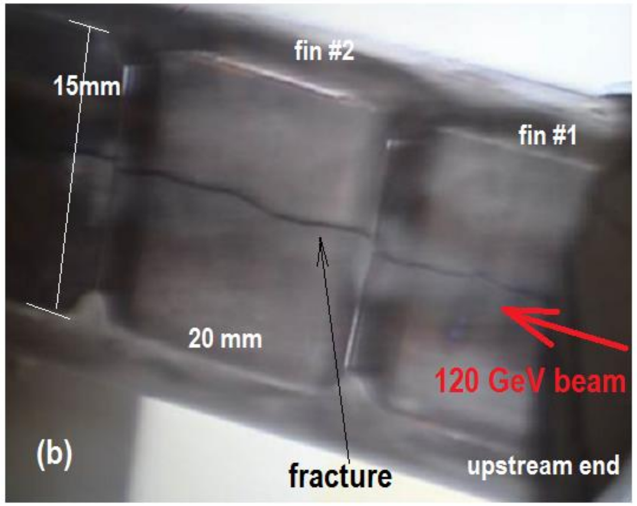
Solid Target- Issues

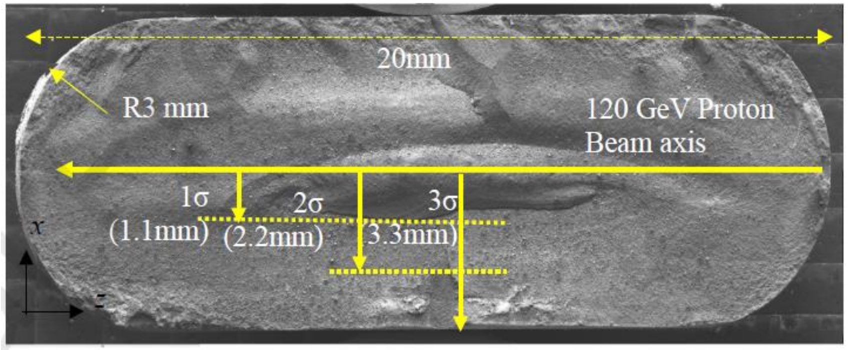
- Stress wave → High cycle fatigue
- Radiation damage
  - Displacement damage, clustering, void
  - Amorphization,seggregation
  - Swelling, hardening, embrittlement

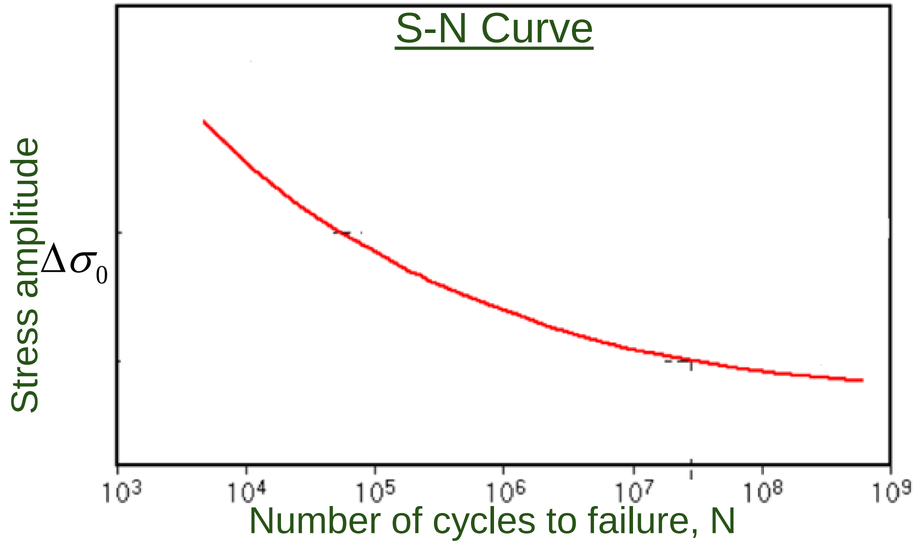
FEA-dynamic stress in NuMI poco-graphite fin



NuMI Target fin





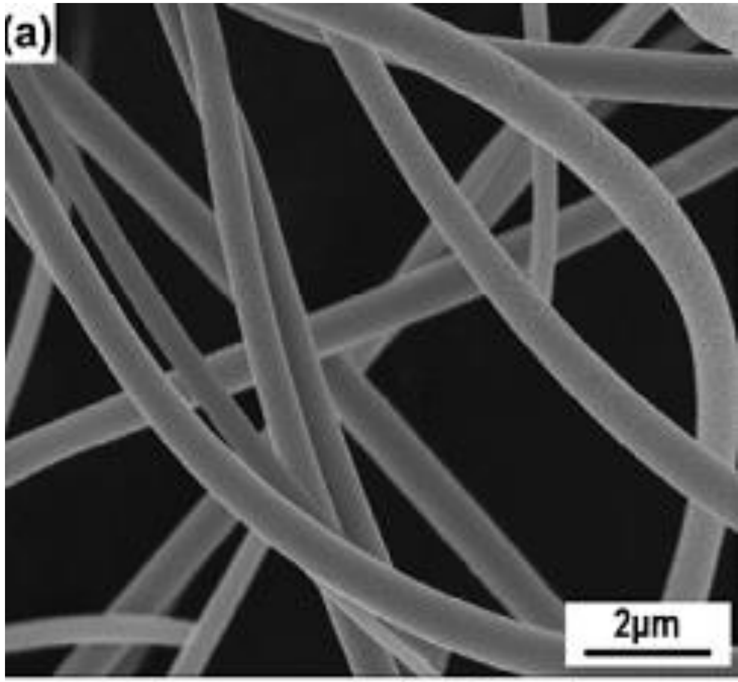


Alternate target design

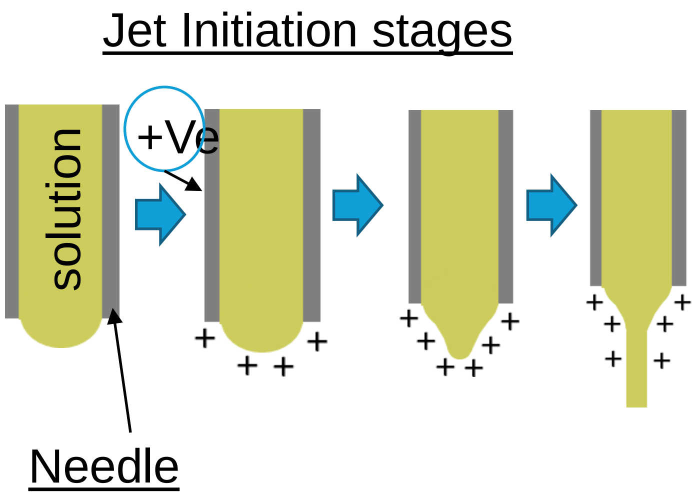
- Liquid –Hg : ORNL, J-PARC
- Powdered
- Spherical rolling balls

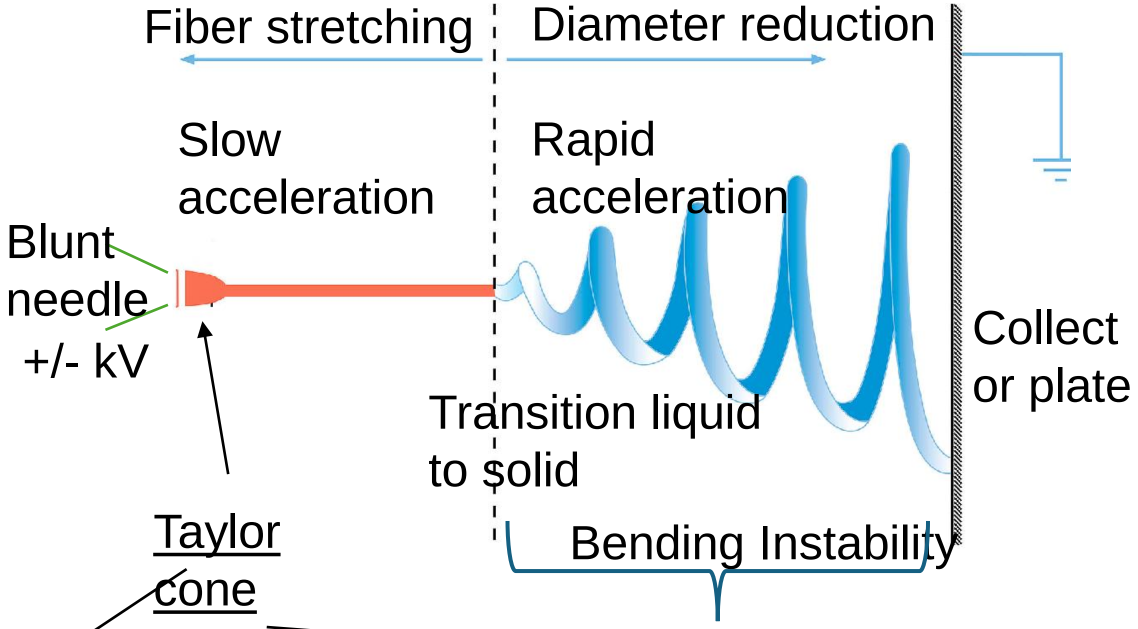
Sinuous target development at Fermilab

- One dimensional long winding, twisting wire like structure sub-micron diameter
- Manufacturing process → Electrospinning



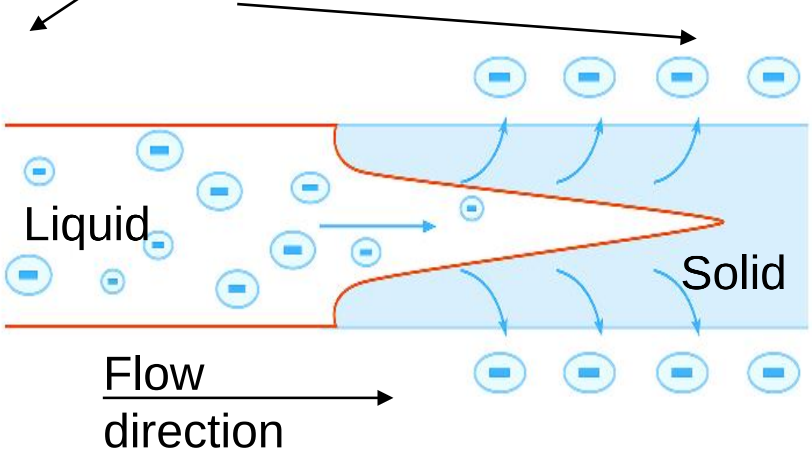
Electrospinning Principle





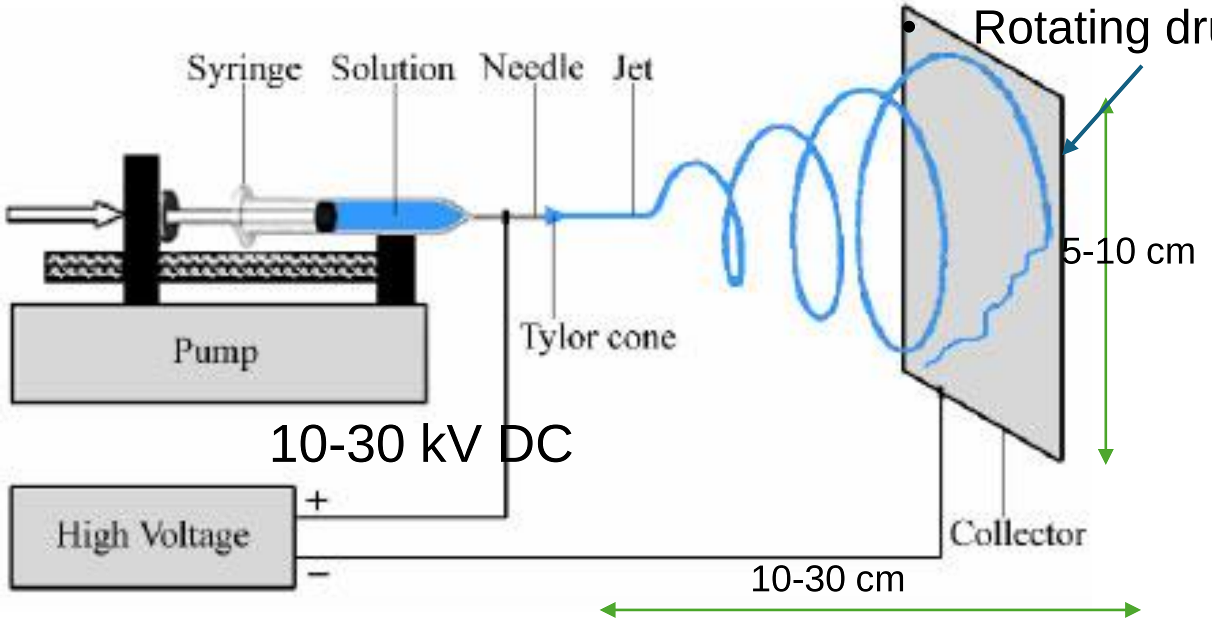
Electrostatic repulsion> surface tension

- Droplet is stretched
- Jet elongated by whipping action

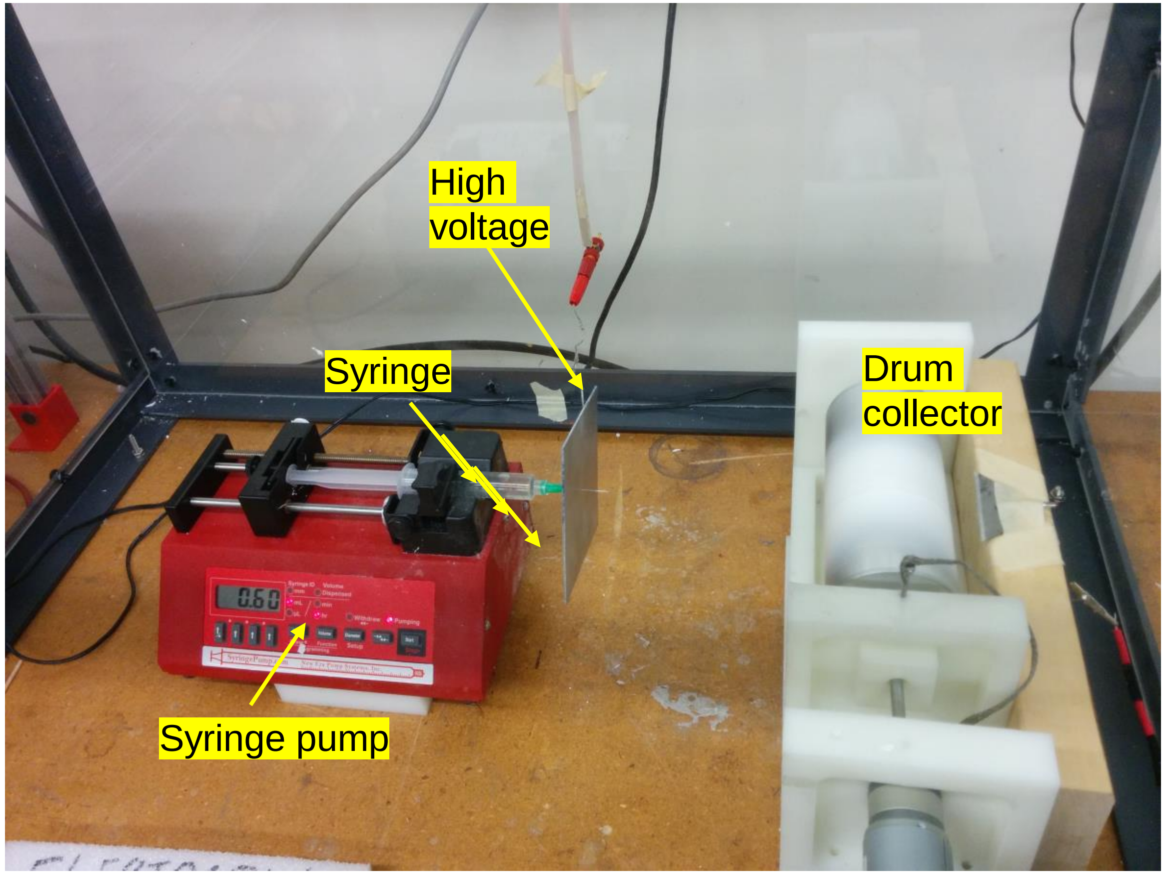


Basic Electrospinning Set up

<u>Collector</u>
- Fixed type
- Rotating drum type



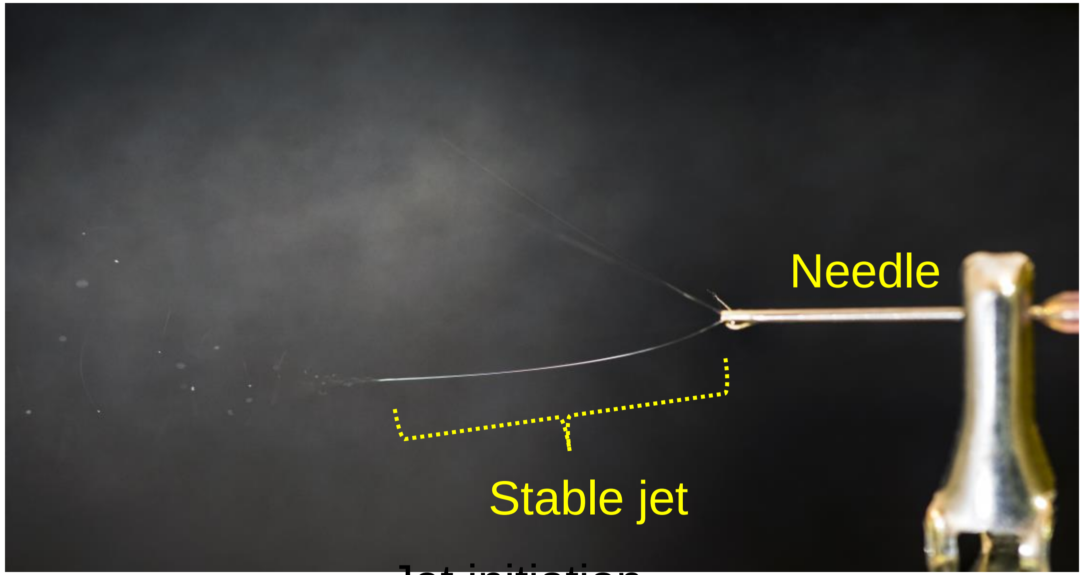
@MI-8



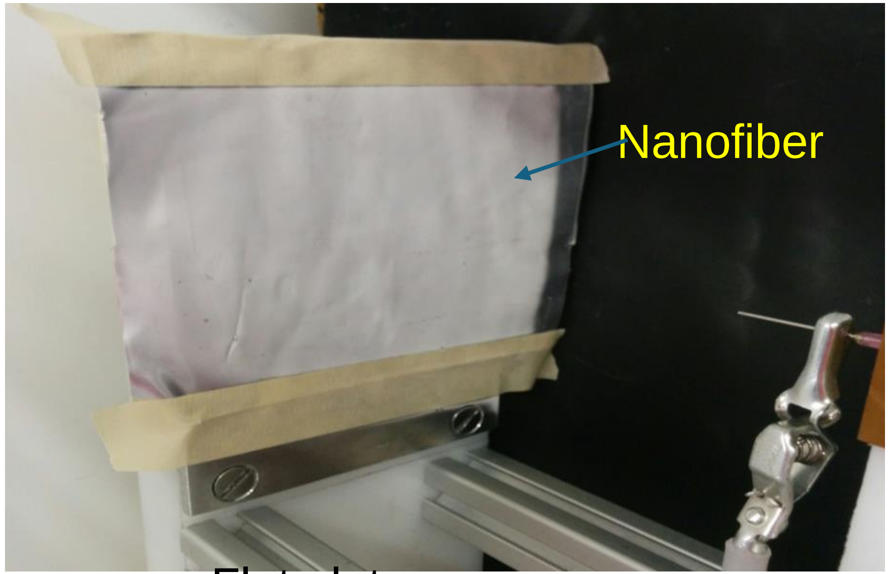
Process carried out at room temp. and atm. Pressure

Flow rate 0.5~1ml/hr
Potential : 1-1.5kV/cm

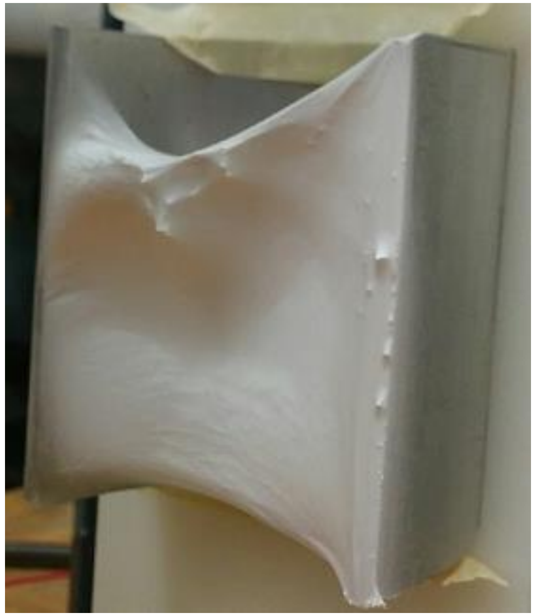
Nanofiber Mat on collector plate



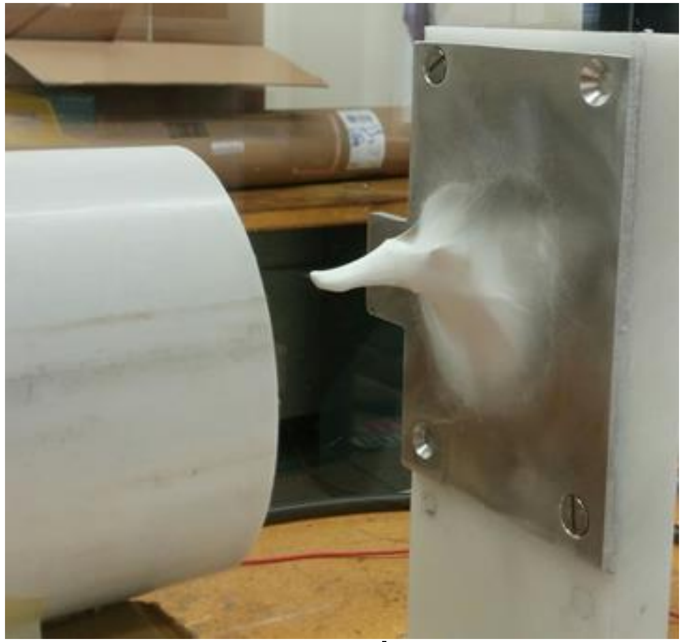
Jet initiation



Flat plate



C-Channel



Focused

Ceramics Nanofiber Fabrication Process

Inorganic precursor(inorganic compound+solvent)

+

Polymer solution(polymer+solvent) ← High molecular weight, long chain polymer, ~1e6g/mol

+

Salt additives (surfactants)

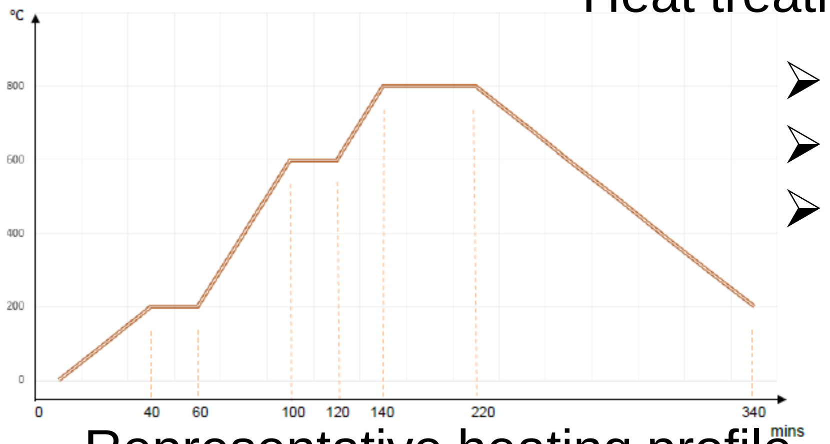
↓

Electrospinning→polymer-ceramic nanofiber

↓

Heat treatment

- Vaporize polymer
- Promotes crystal growth
- Bonding

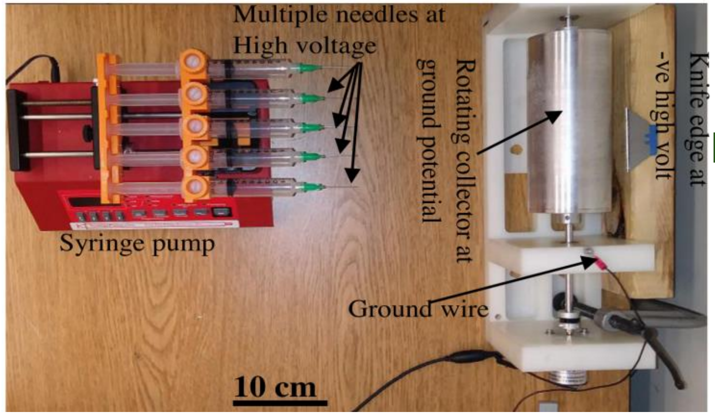


Representative heating profile

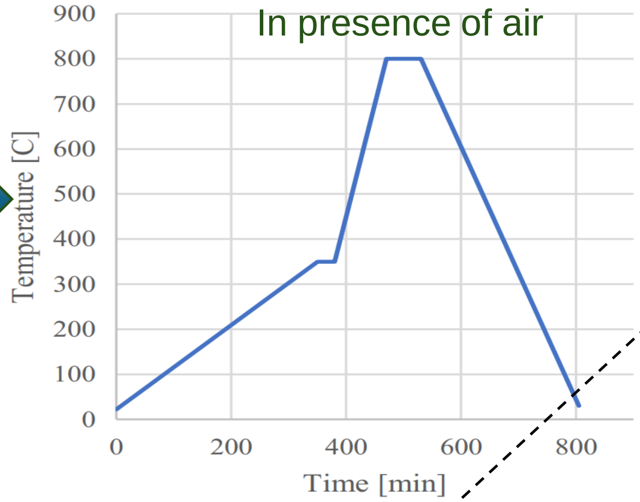
Production of Zirconia Nanofiber

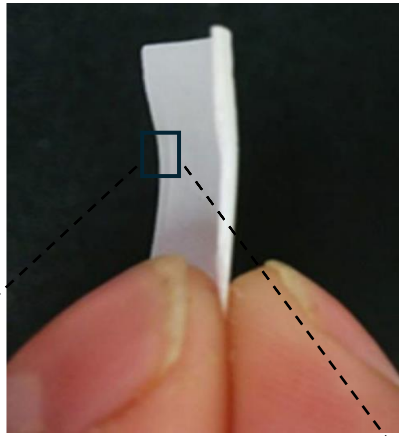
Production

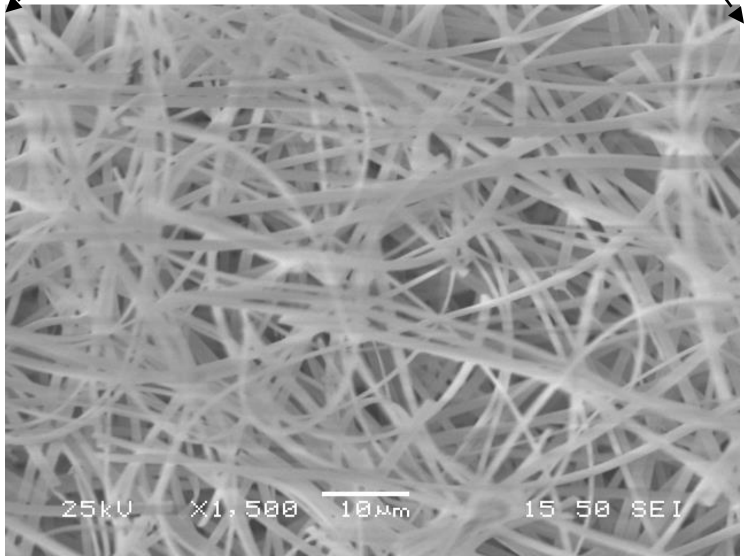
Electrospinning Set up



1mm thick nanofiber coat







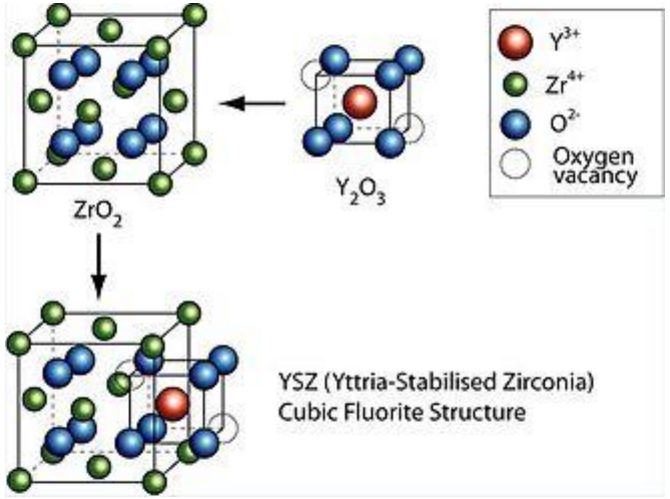
Polymer solution

- PVP+Ethanol+Acetone

Ceramic

- Zirconia →Zirconium Carbonate +Acetic Acid

Zirconia Nanofiber- Yttrium stabilized



Nano-polycrystalline structure
10-30nm grain size

<u>Cubic fluorite structure</u>
FCC lattice of cations +tetrahedral holes with anions

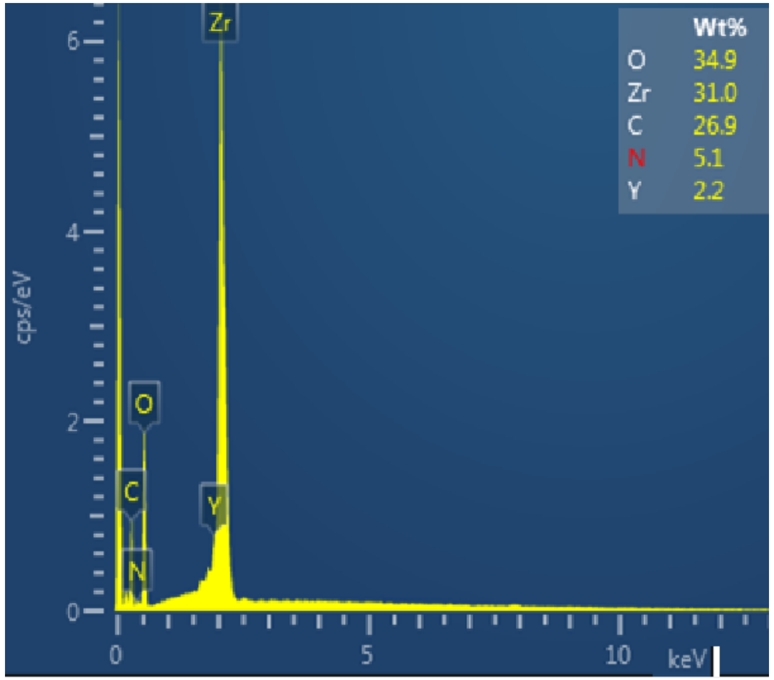
Improve radiation resistance*

- More grain boundaries absorb dislocation, defect movements, enhance defect recombination.
- Fluorite structure→resistance to amorphization.
- High melting point : 2700C

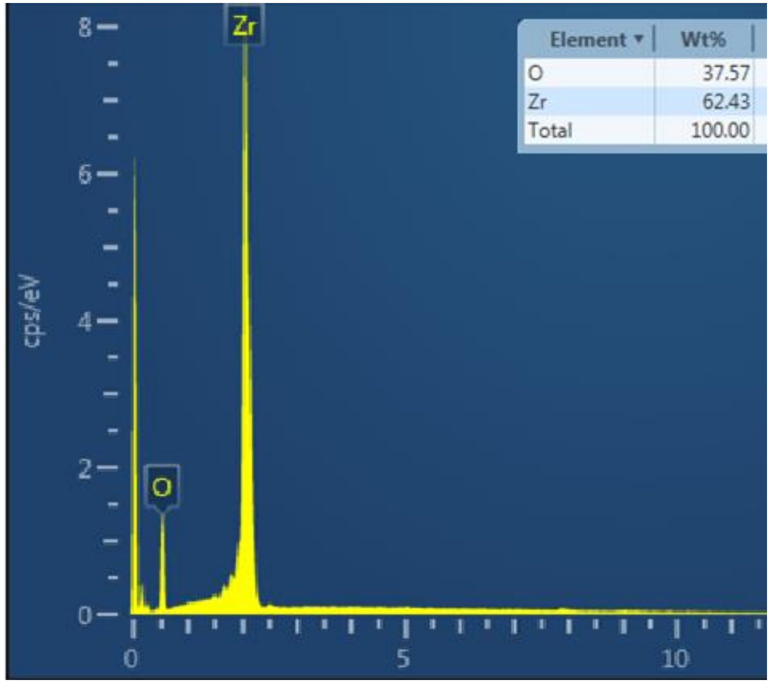
*Sci Rep. 2015; 5: 7746. # European ceramic society 23 (2003)107-114.

EDS Mapping- Zirconia Nanofiber

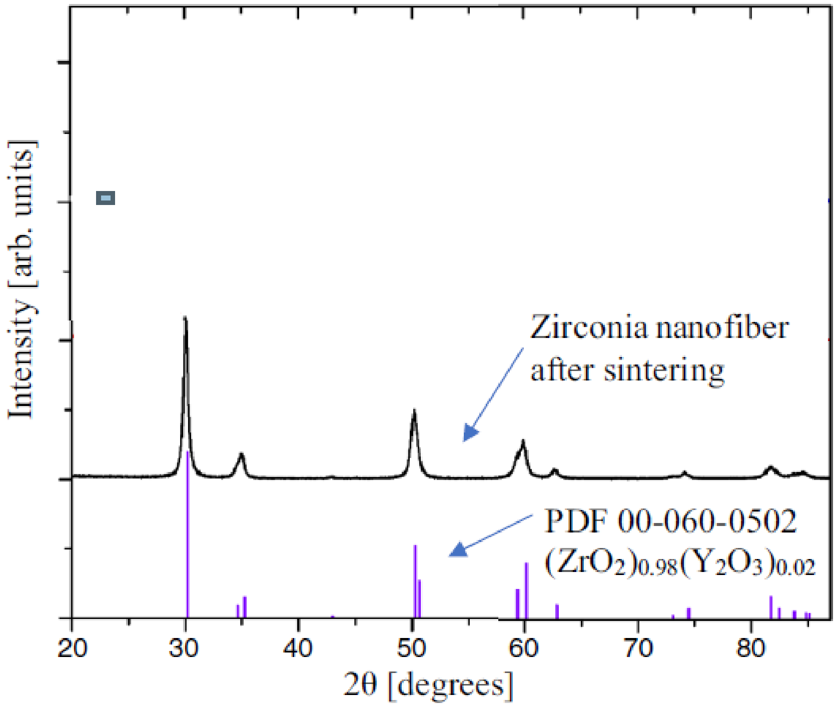
As spun



After heat treatment

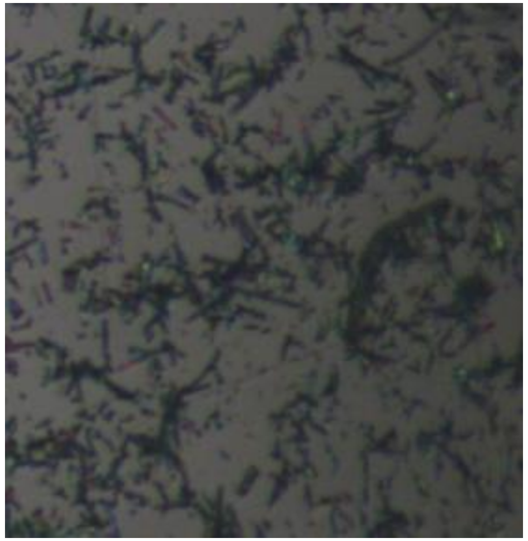


XRD analysis- Tetragonal YSZ

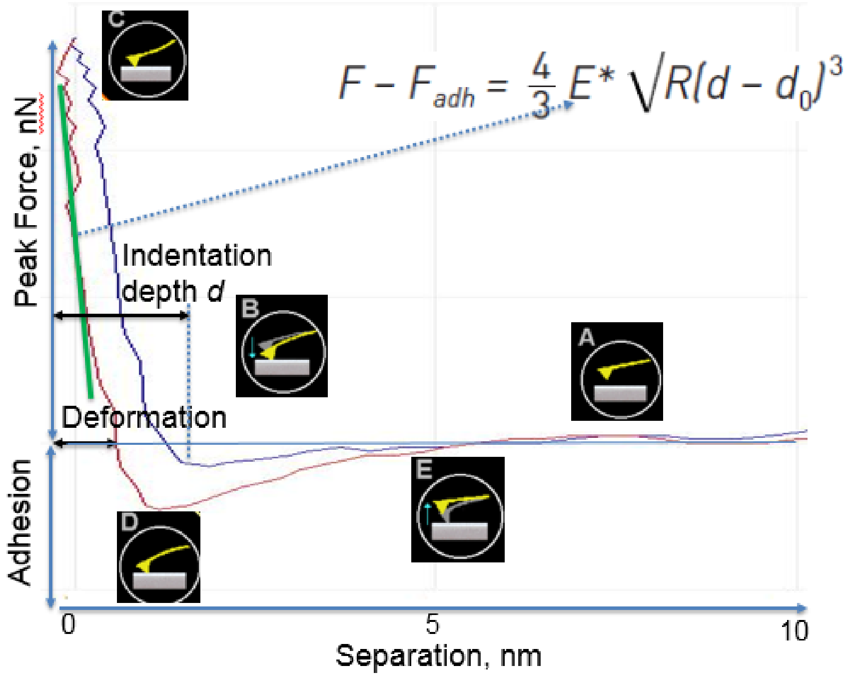


Theoretical Zr wt% in ZrO_2 is 74%
Achieved in actual 62%

Single fiber micro-mechanical test -Atomic Force Microscopy



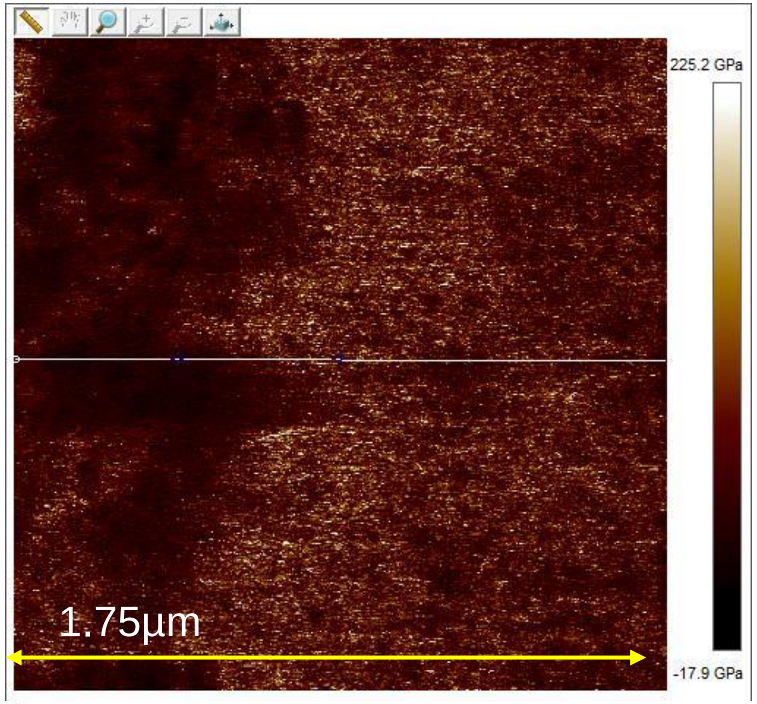
Nanofiber solution casted on harder smooth mica substrate

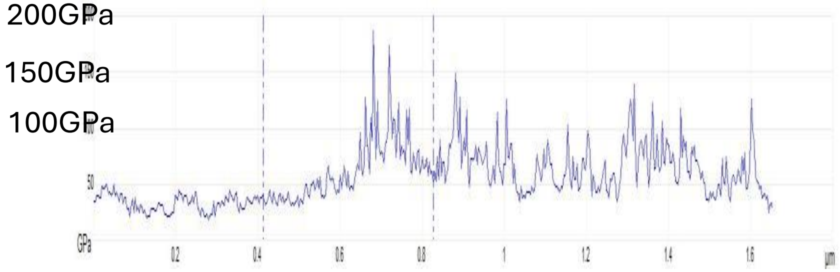


Modulus comparable to bulk zirconia

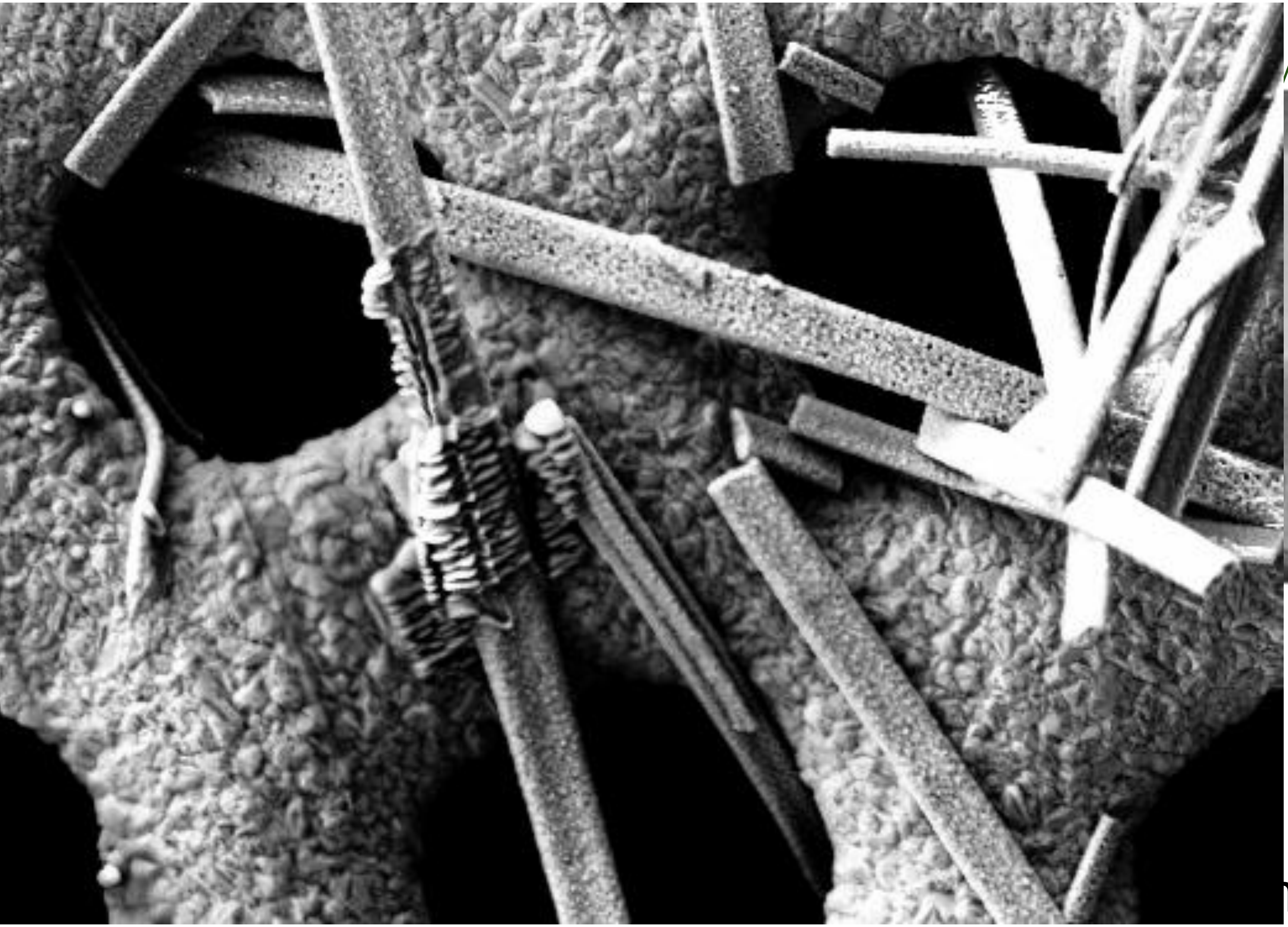
Elastic Modulus map Zirconia

225GPa



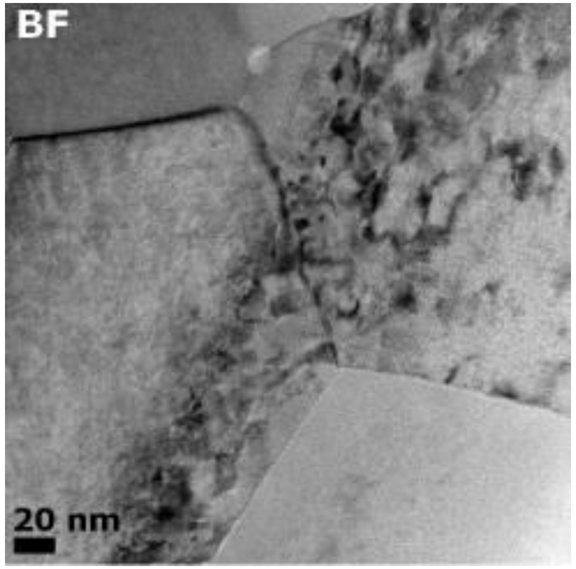


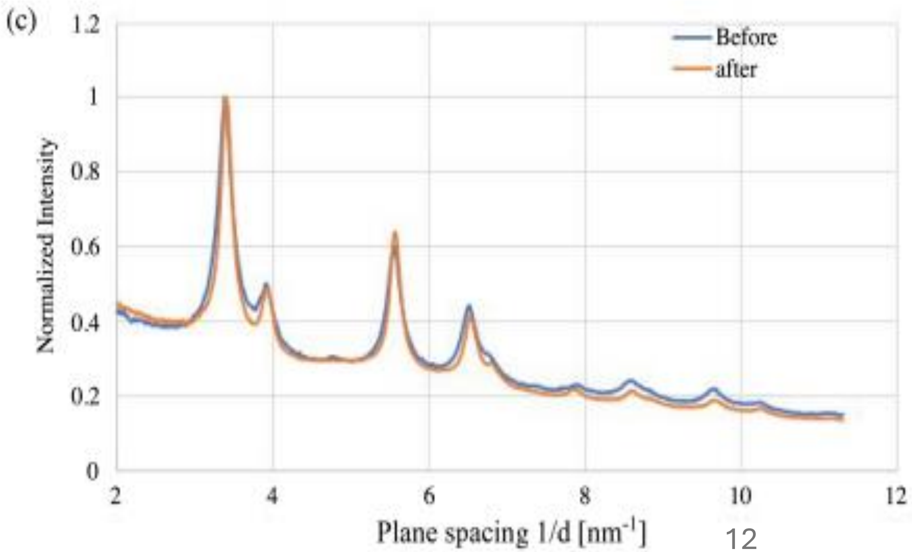
Low energy ion irradiation



M after irradiation

Defect clustering in bulk zirconia



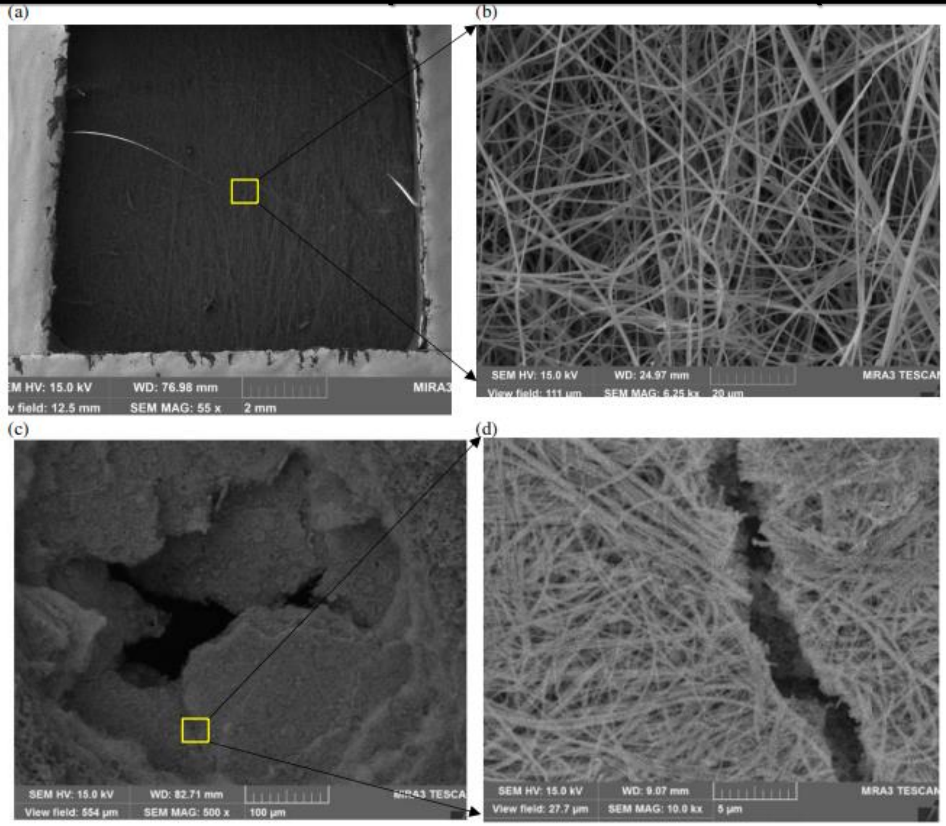


damage.

@ Argonne IVEM Tandem, S. Bidhar, PRAB (24), 2021

In-beam thermal shock on nanofiber

Thermal shock expt- HiRADMat-43 (CERN)



Low packing density

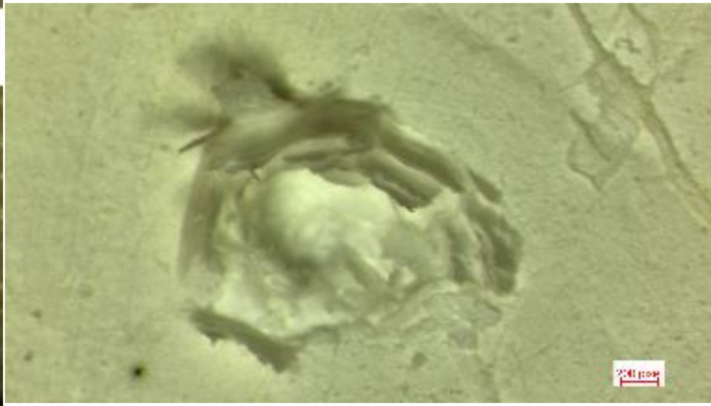
High packing density

Proton beam 440 GeV, Beam σ 0.25mm
1.21×10^{13} protons on nanofiber in 4µsec

Low packing density samples survived.
Holes, crack in higher density samples

HiRADMat-60 (CERN)

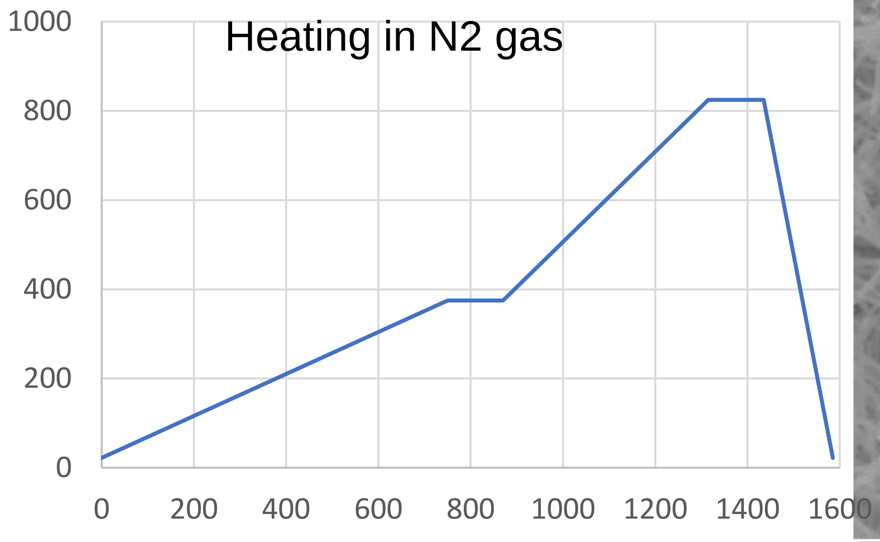
Low packing density

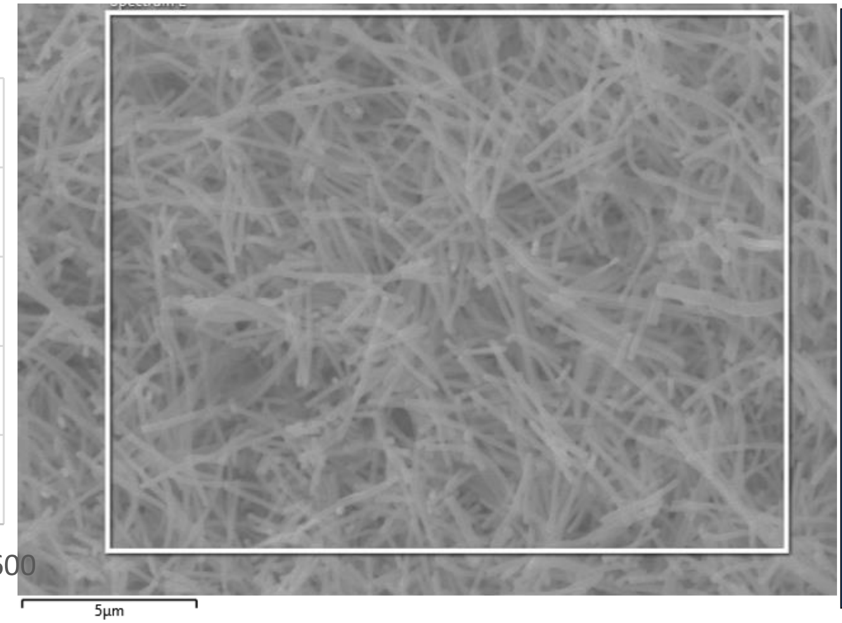


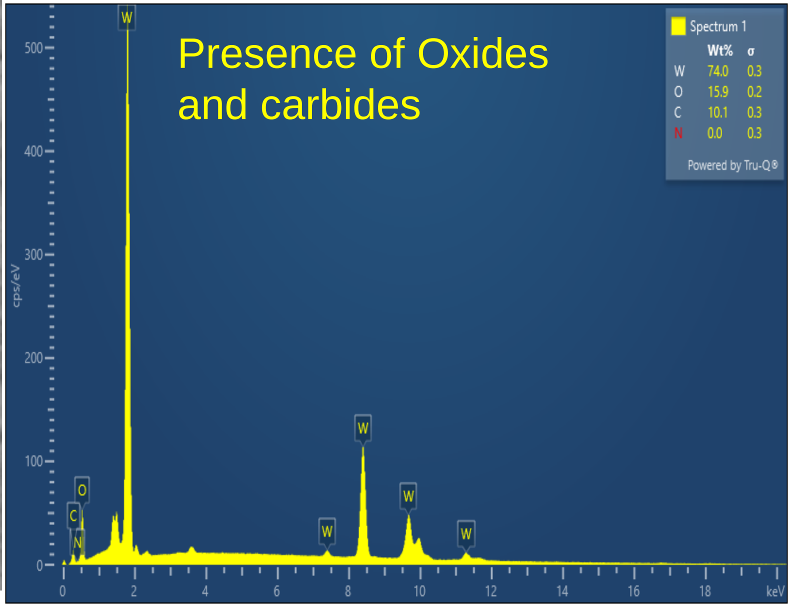
Proton beam 440 GeV, Beam σ 0.25mm, 3.7×10^{13} protons in 8µsec

Detail investigation of mass and heat transport in nanofiber media → Will’s PhD

Tungsten Nanofiber

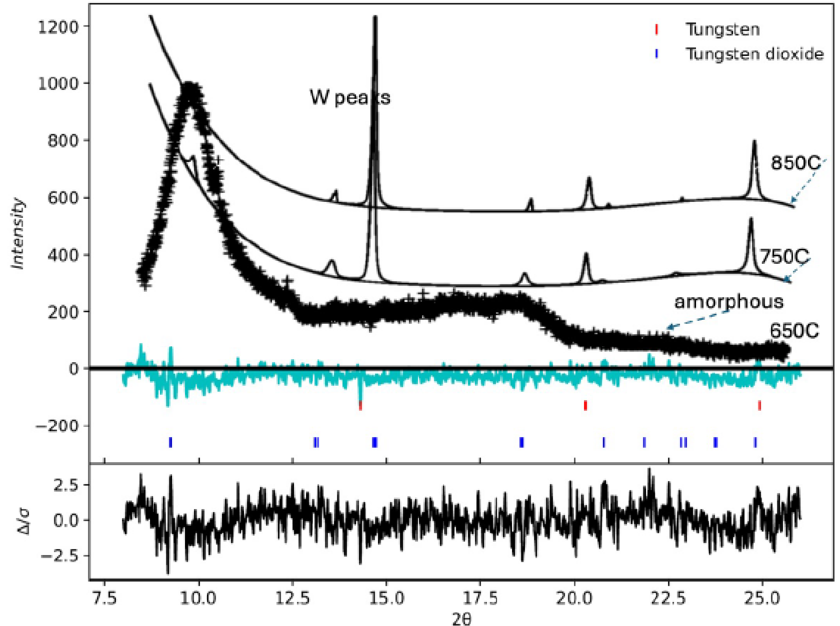






Use high Z-material to compensate for loss of density

In-situ XRD Heating in N2(95%) +H2 (5%)gas



<u>Raw Materials</u>

PVP

De-ionized water

Amonium Metatungstate

Heating in syngas at higher temperature (>850C) yields in pure tungsten nanofiber

Further work

- Understanding fiber level transport phenomena
- Next HighRADMat test→ vacuum effect
- Mechanical and damage characterization of W-nanofiber
- Practical target design

- Collaborative research work
  - CERN →Helped them set up their lab-scale electrospinner to produce zirconia nanofiber
  - ISOLDE → nanofiber for isotope production target
  - ILL France
  - FRIB → isotop production

Thank You