Uniformity and Inter-Filament Current Transfer in "Twisted-Stack" Cables Comprised of Exfoliated YBCO Filaments

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Outline

- Motivation:
  - Single-filament magnets proven difficult to protect against burnout
  - Substrate prevents efficient current sharing
  - Multifilamentary cable is far more expensive than a single tape
  - Not compatible with epoxy impregnation

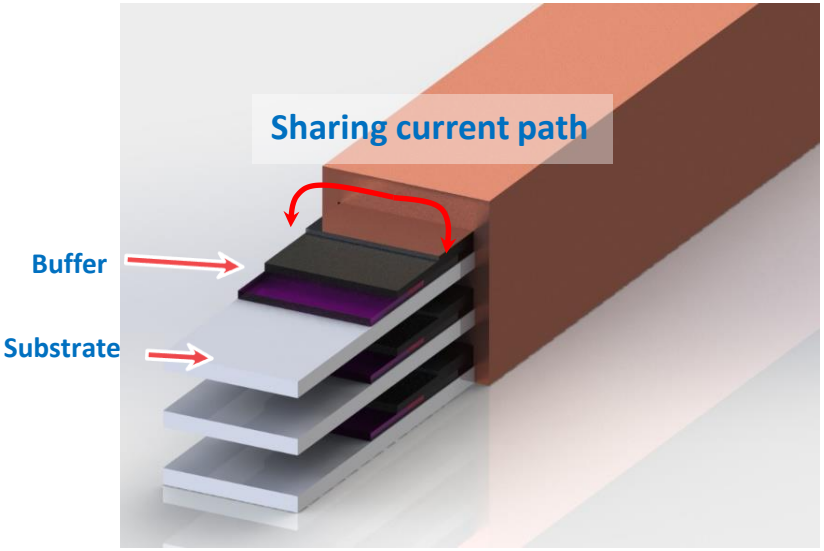
- Outline
  - ExoCable concept
  - Filament structure
  - Slicing and cabling
  - Mechanical properties

About Brookhaven Technology Group

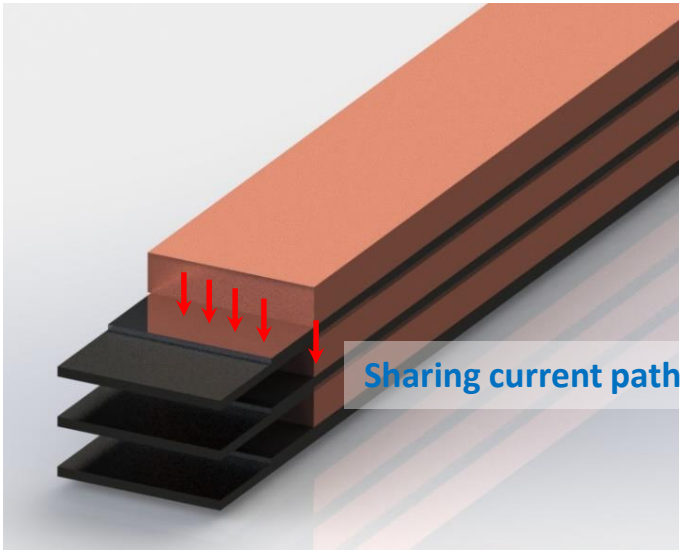
- Located in Stony Brook
- University incubator
- 3 employees and 2 interns
- Doing HTS research since 2014

2G wire cable technologies

2G wire stack

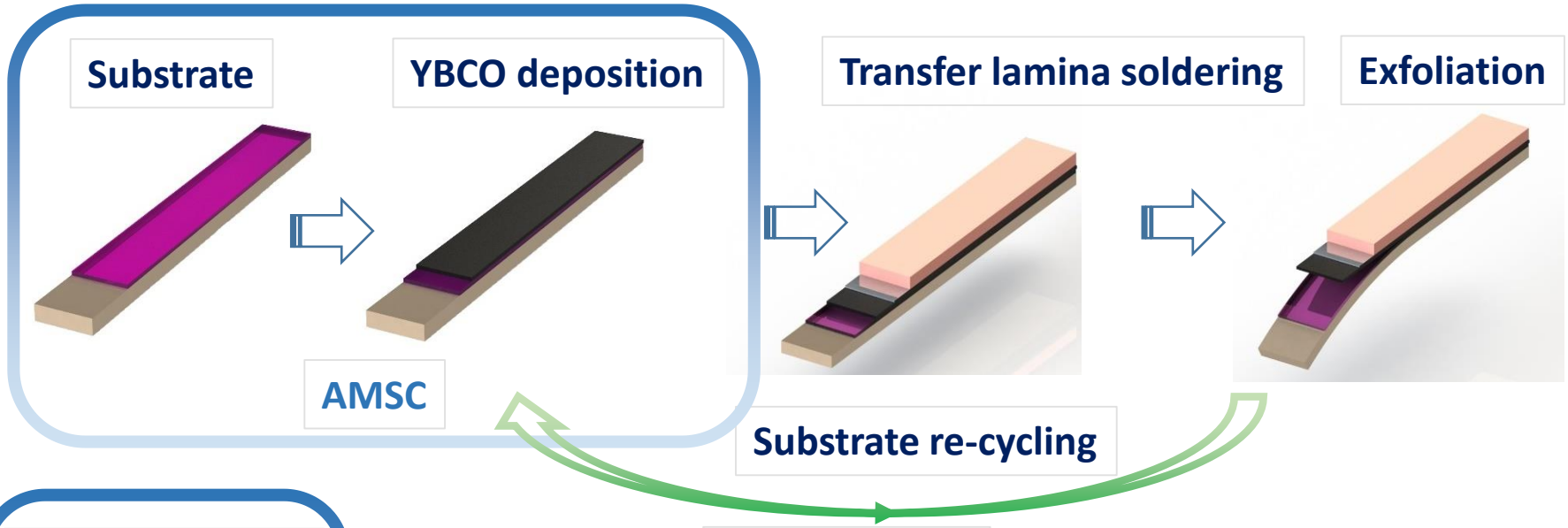


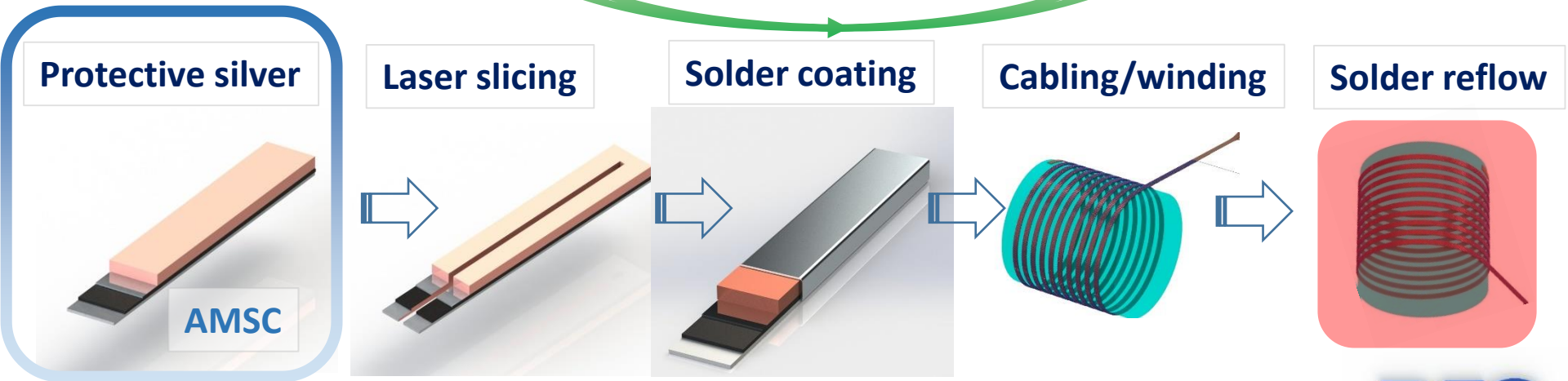
BTG exfoliated filament stack



✓ **Effective current sharing in exfoliated filament stacks allows for short current transfer length and defect-resistant cable**

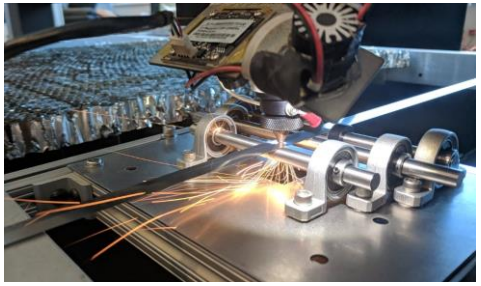
BTG cabling/magnet winding process





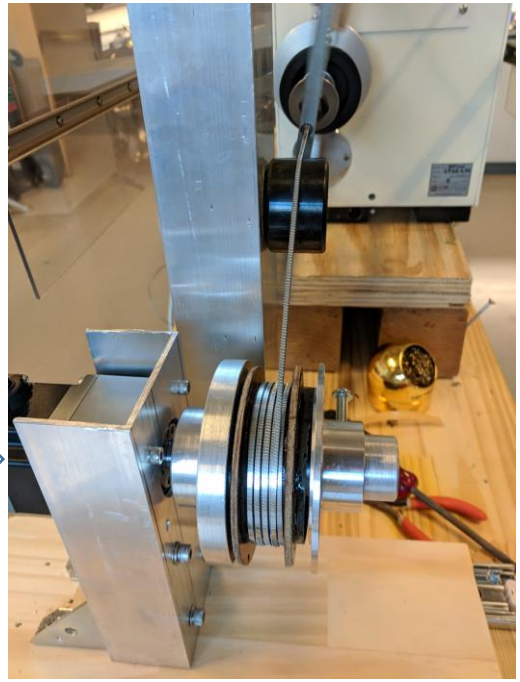
Test coil winding from the exfoliated filament cable

Reel-to-reel laser slicing

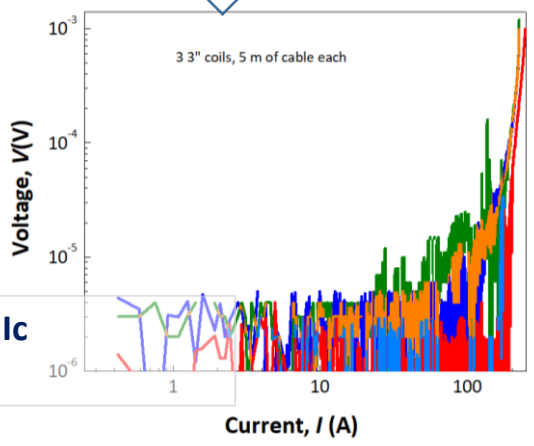


Cabling

Coil winding

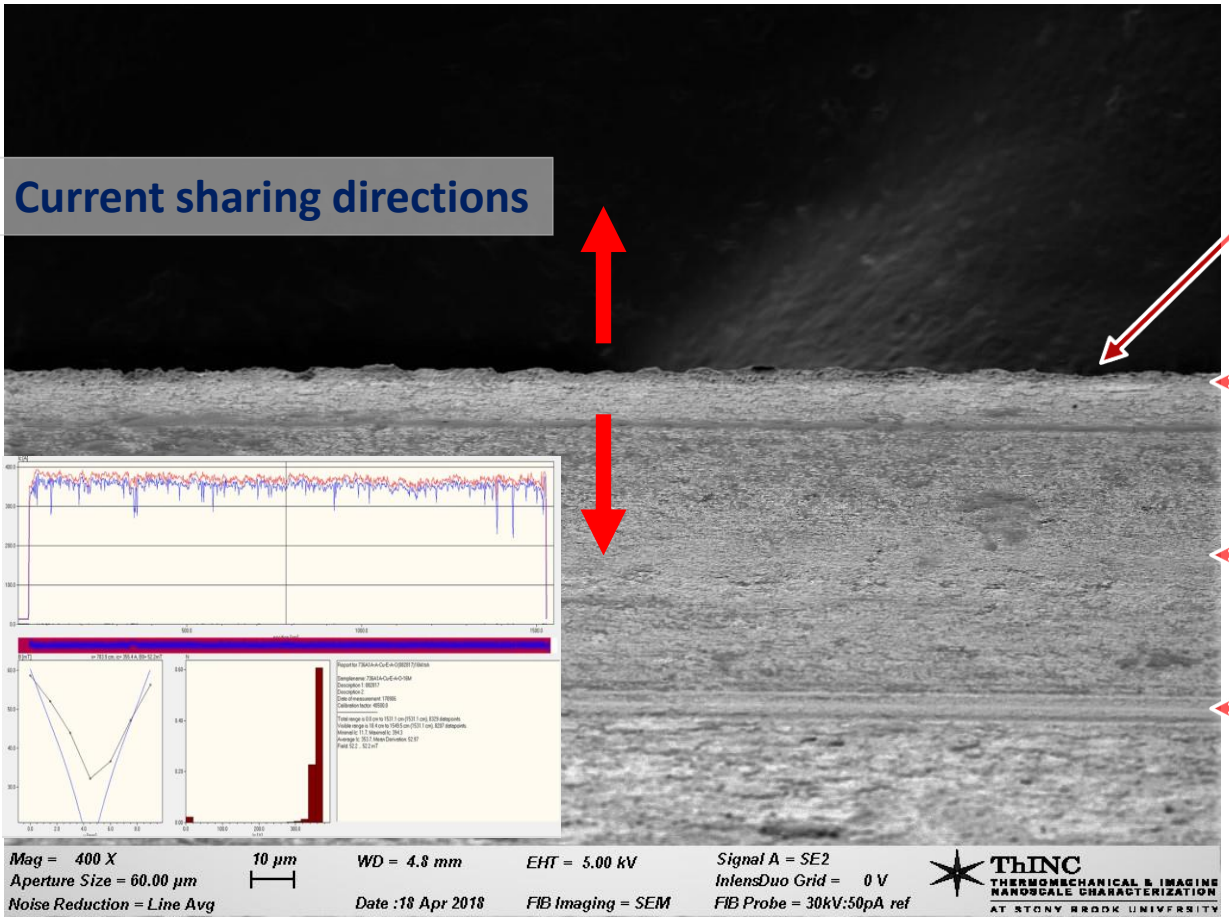


Test coils

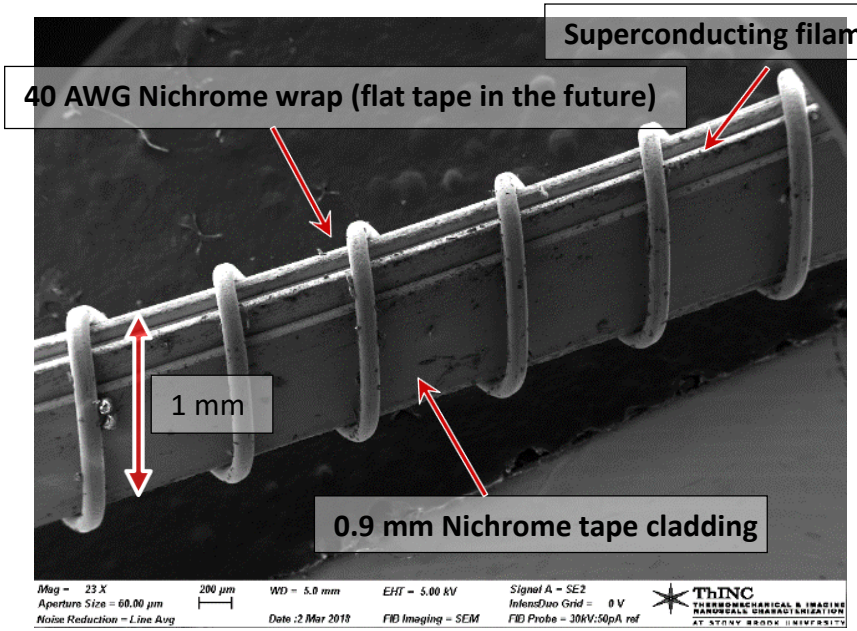


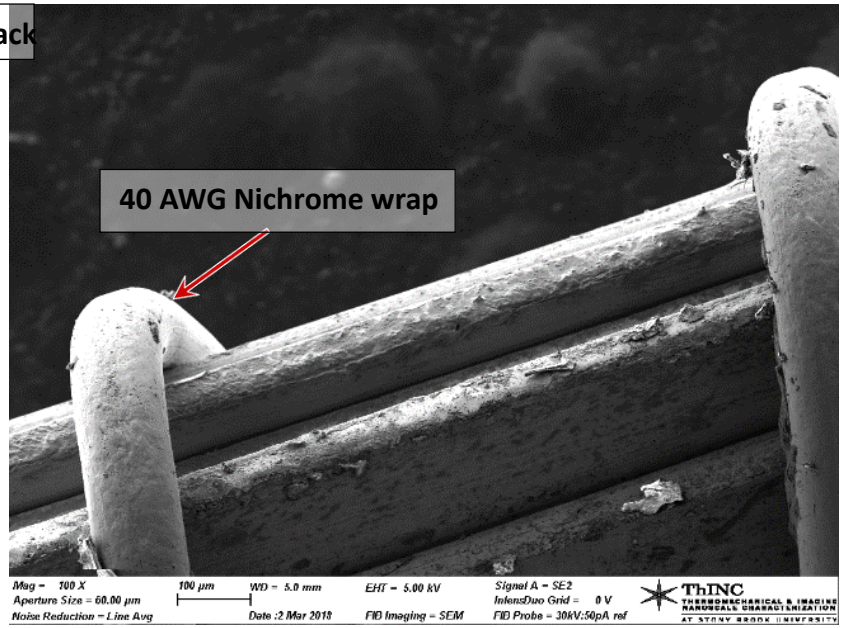
- ✓ 220 A at 77 K for 2.4 mm wide cable, coil level Ic
- ✓ 100 A at 77 K for 1 mm cable, short coupons

BTG filament, two directions for current sharing

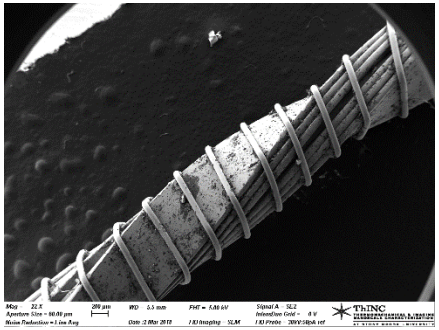


BTG ExoCable





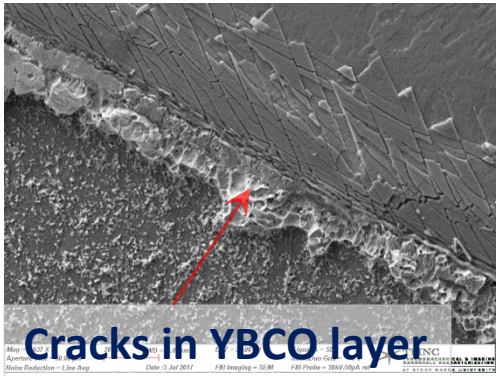
- ✓ Effective use of conductor
- ✓ High fill factor
- ✓ Mechanical strength



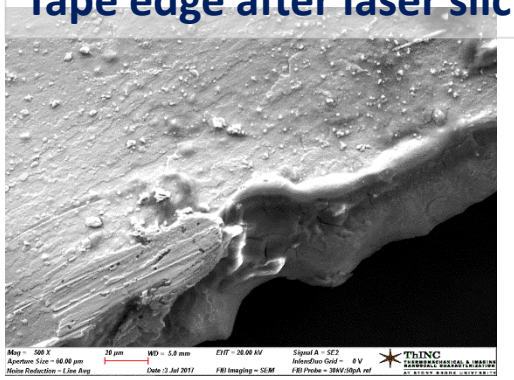
Twisted cable

Advantage of laser slicing for narrow filaments

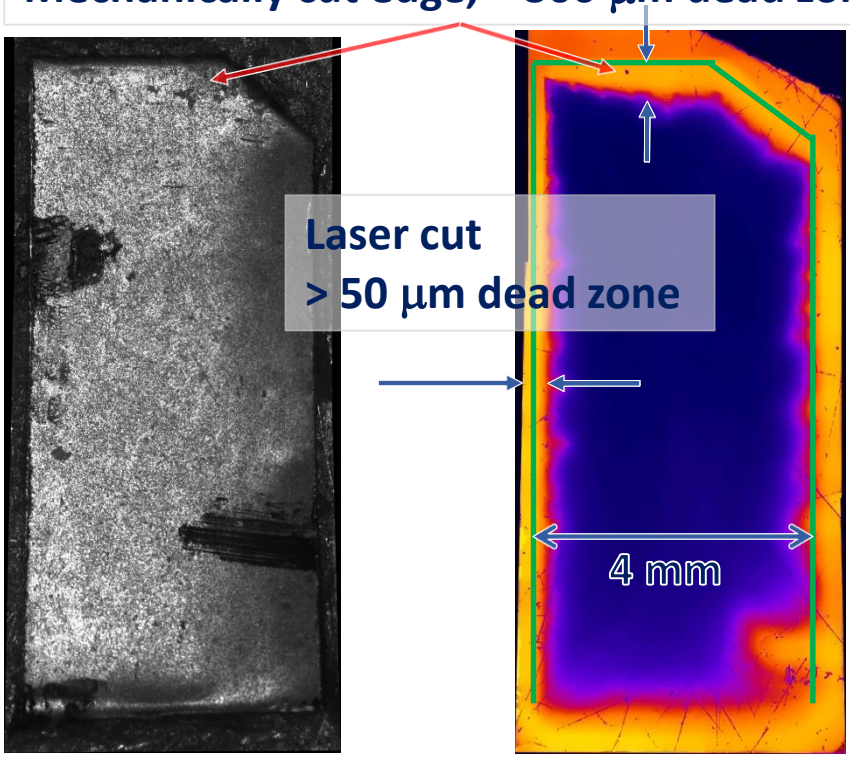
Tape edge after mechanical slicing



Tape edge after laser slicing



Mechanically cut edge, > 300 μm dead zone



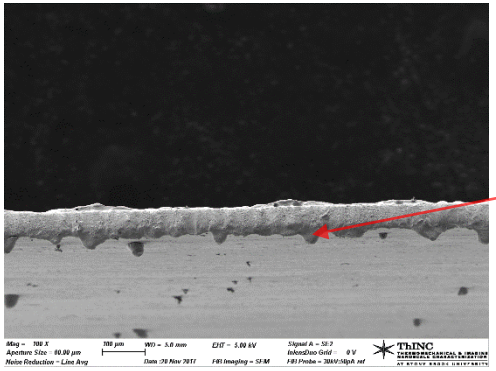
Sample image

ZFC, T = 10K, B = 120 mT

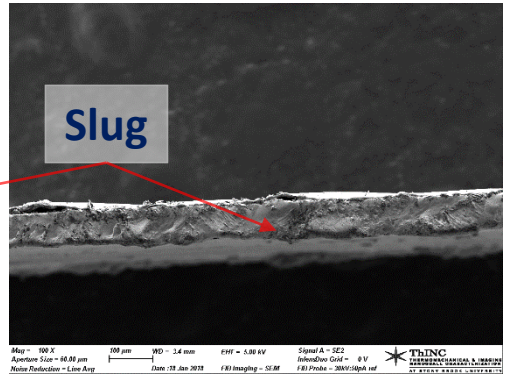
✓ **Laser slicing does not generate edge cracks, enables narrow filaments**

Slicing of copper-supported exfoliated filaments

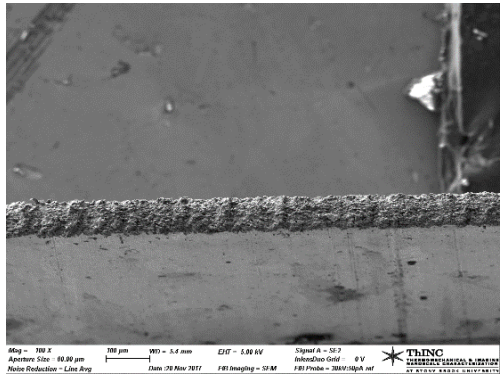
Laser 1

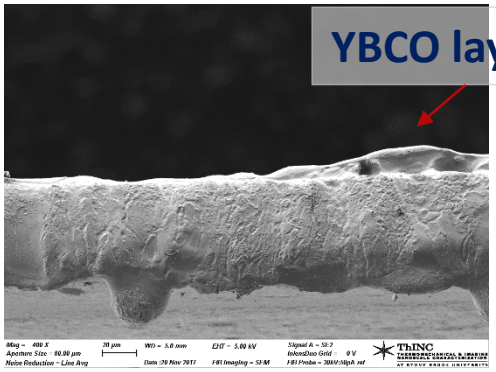


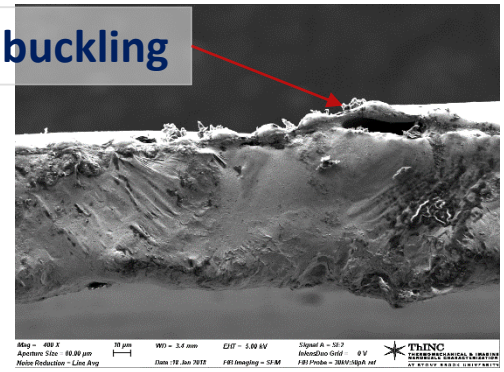
Laser 2

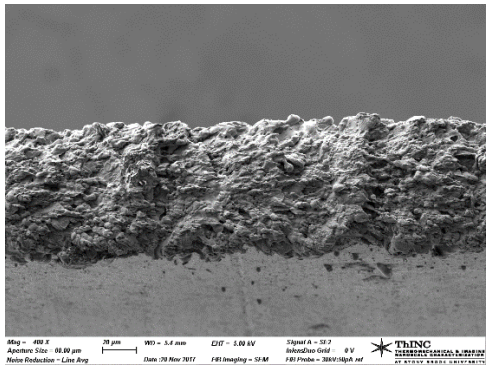


Laser 3



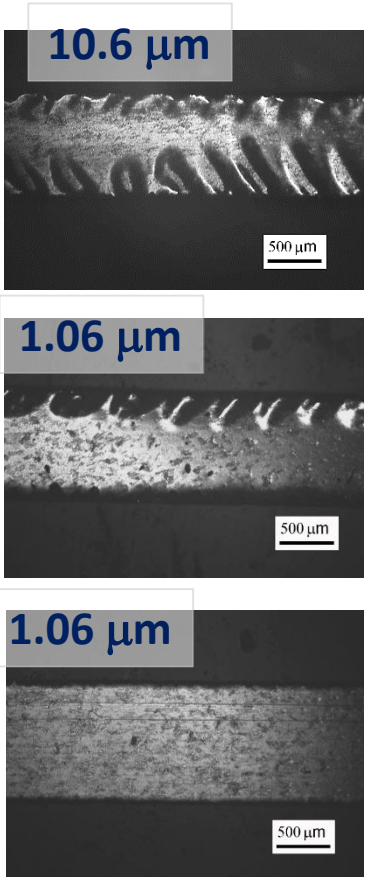


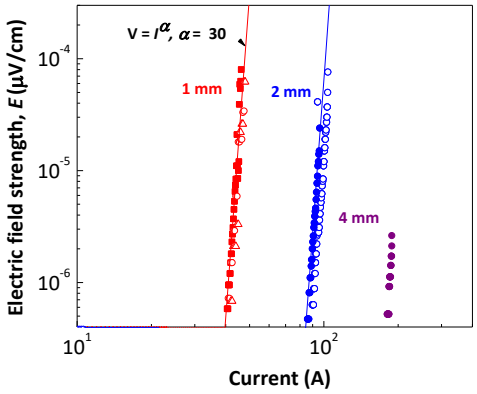


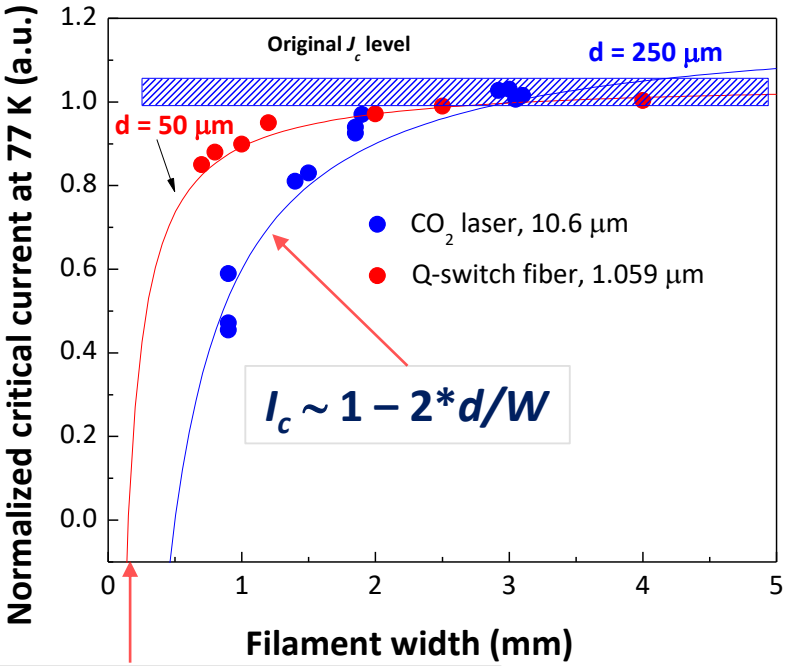


✓ **Laser 3 produced the least amount of slug and heat damage**

Dependence of critical current on the filament width, Q switch laser cut



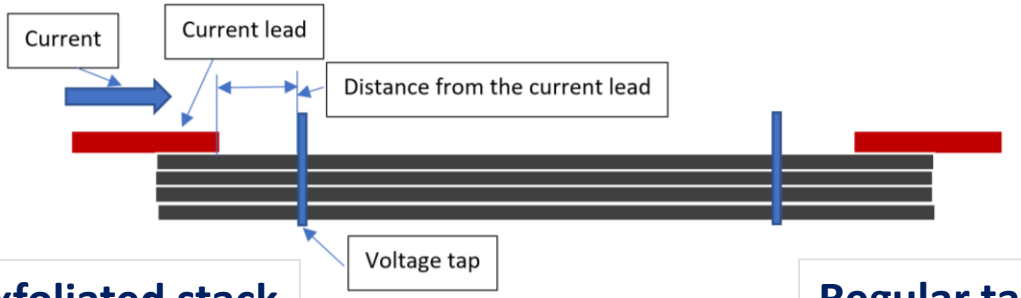




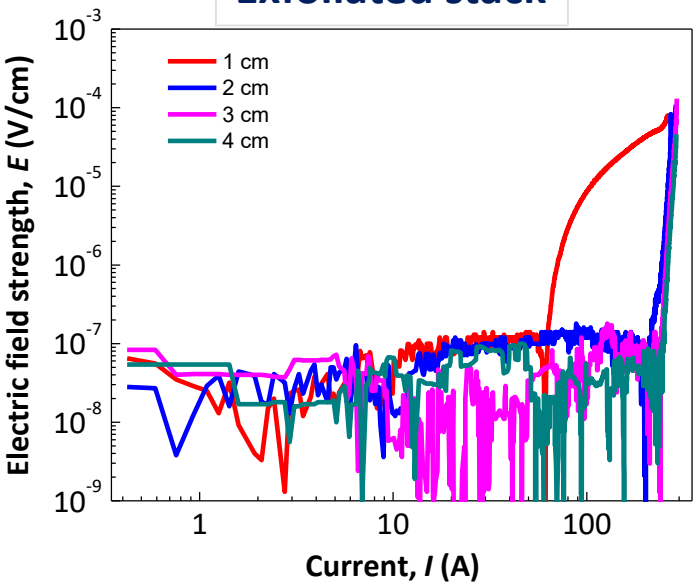
2x*d*, *d* = Heat Damage Zone

✓ Q-switch laser delivers the effective heat damage zone ≈ 50 μm

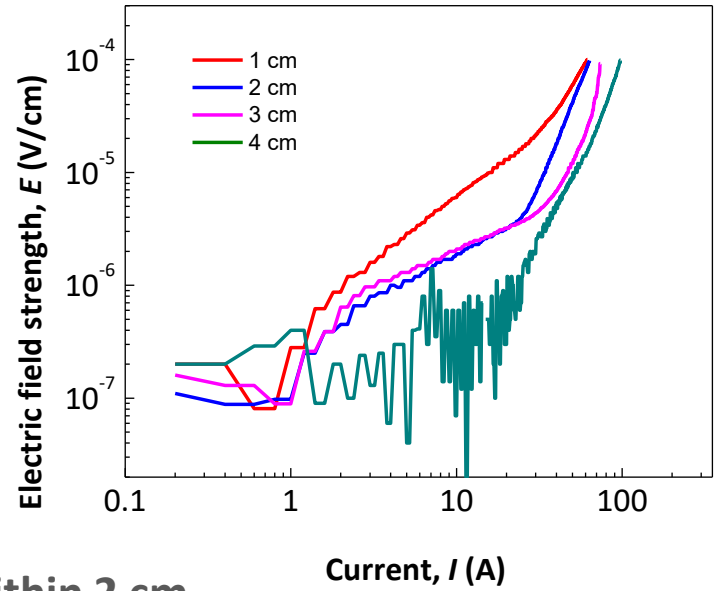
Current transfer in a filament stack: standard vs exfoliated



Exfoliated stack

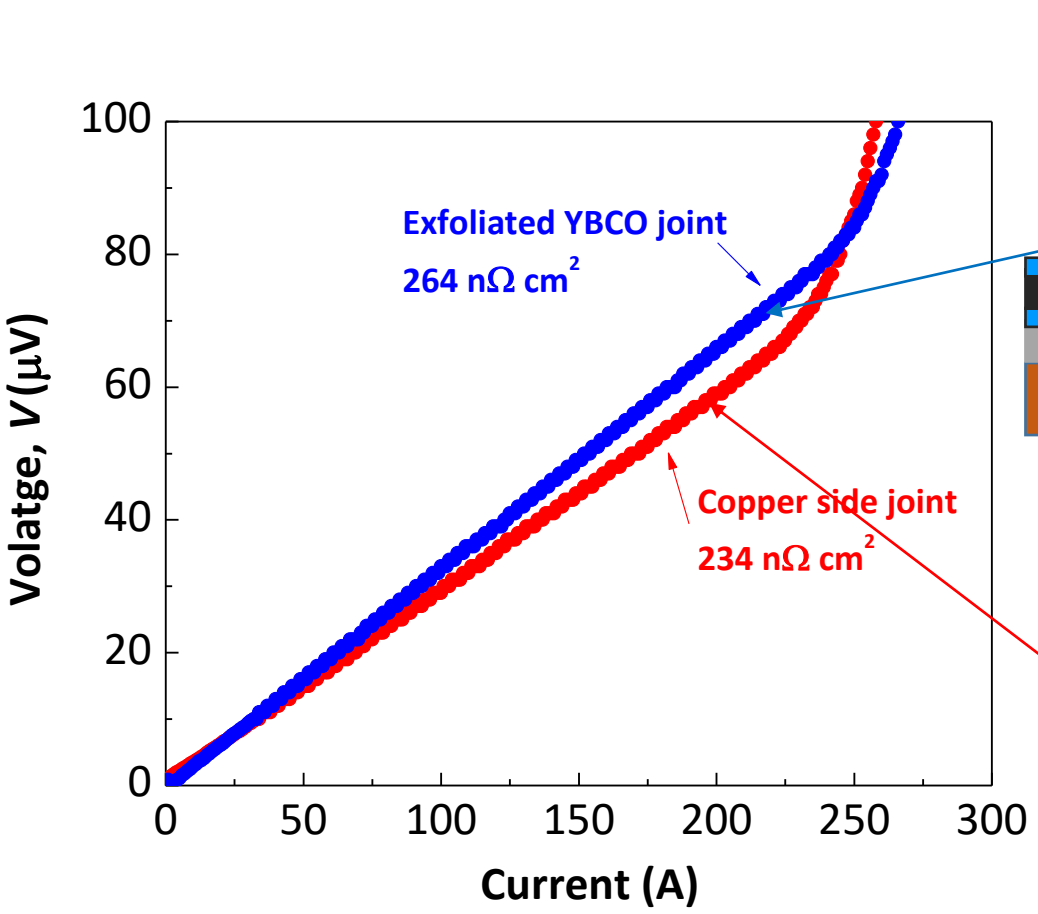


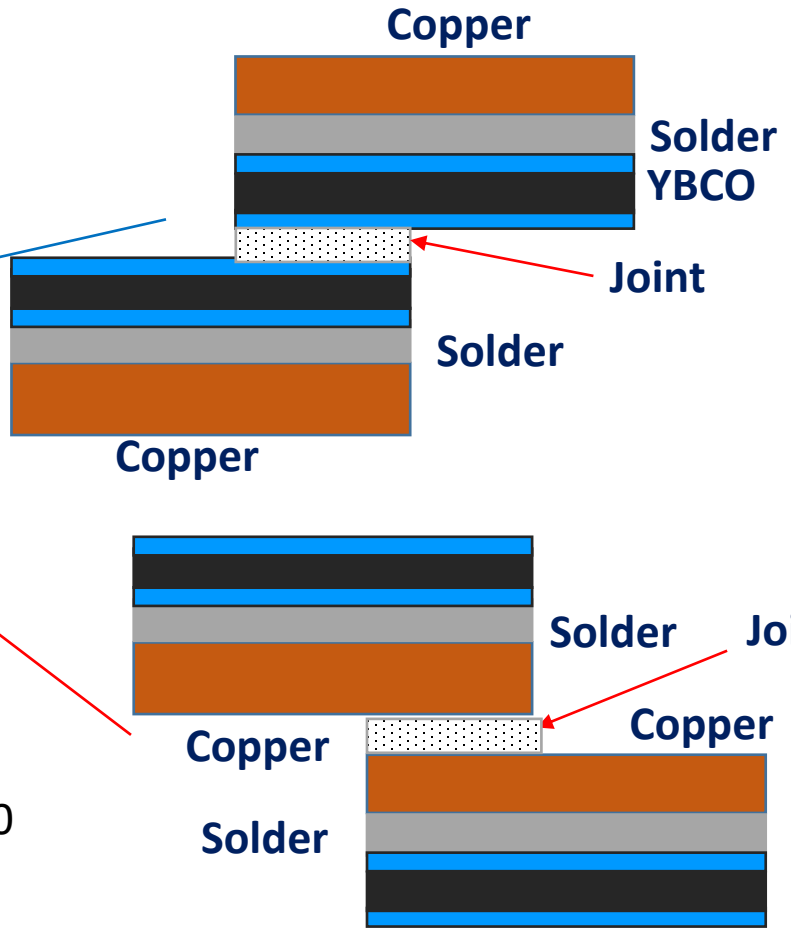
Regular tape



✓ Exfoliated stack enables current sharing within 2 cm.

Symmetric surface resistivity of exfoliated filaments

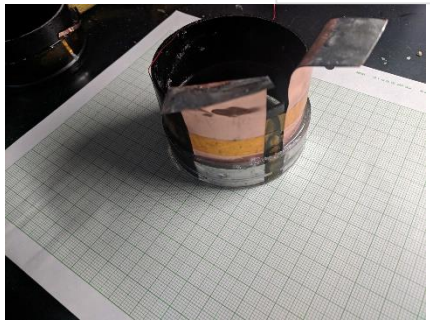


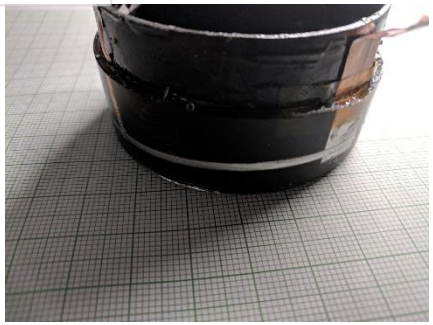


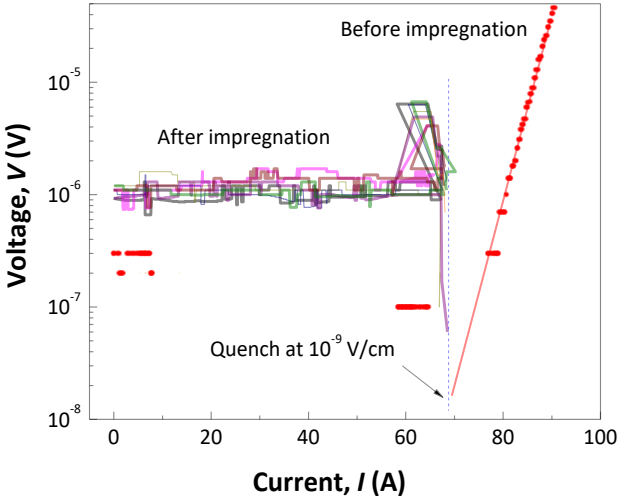
✓ Very little difference between YBCO and copper side contact resistivity.

Epoxy impregnation tests: Stycast 1266

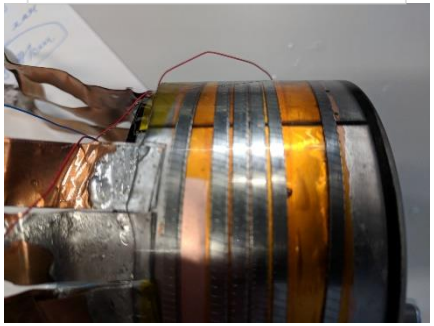
Single filament

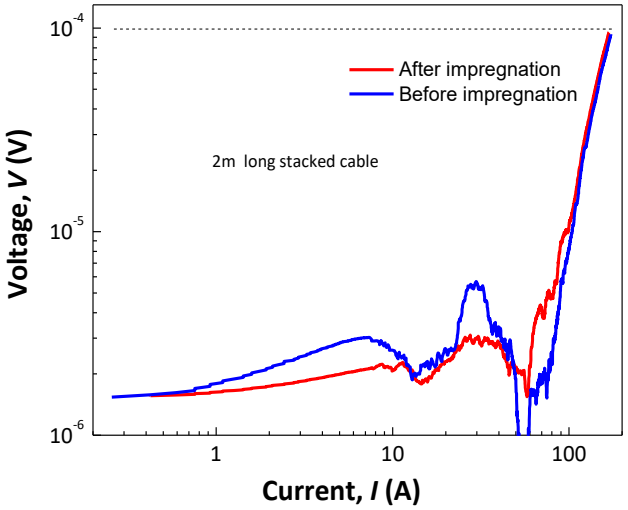






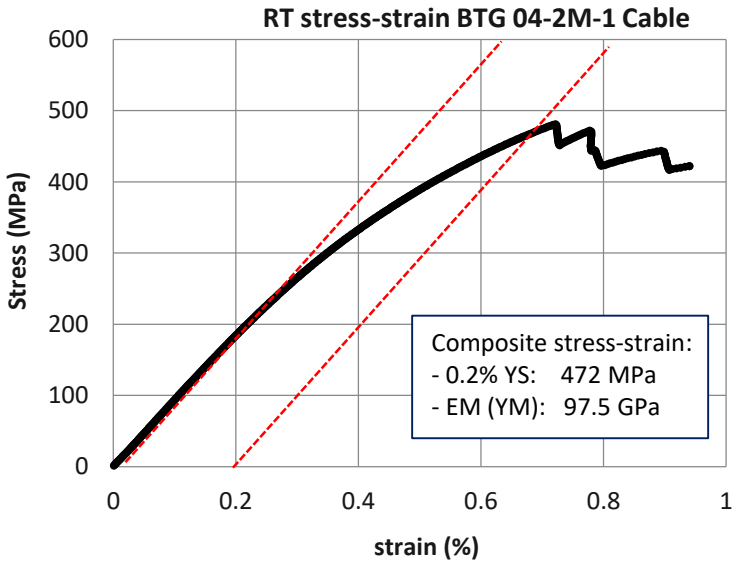
Cable: stack type



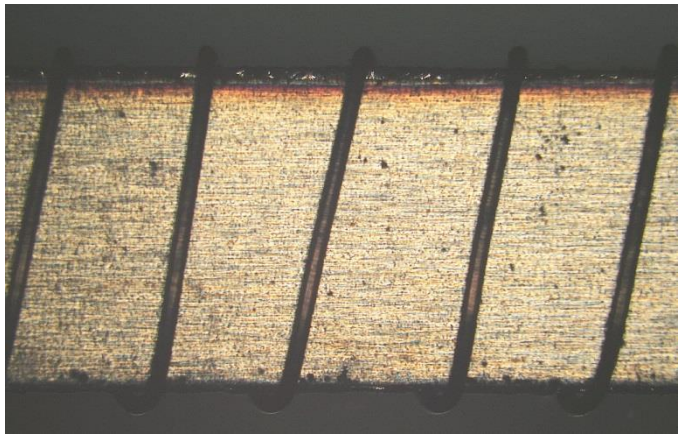


- ✓ Single filament tends to quench at very low electric field
- ✓ Cable survives impregnation and thermal shock

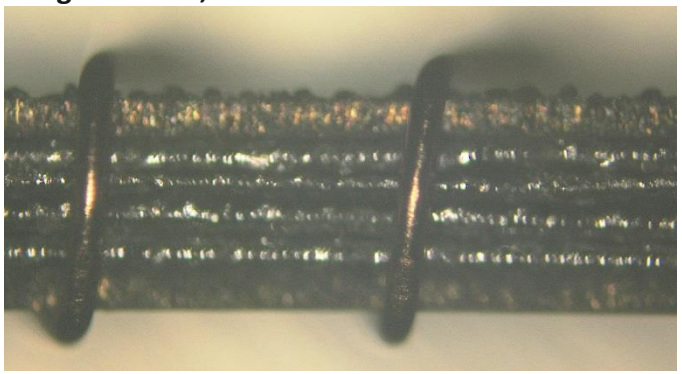
Mechanical tests performed at AMSC facility



Top view, 2.5x lens



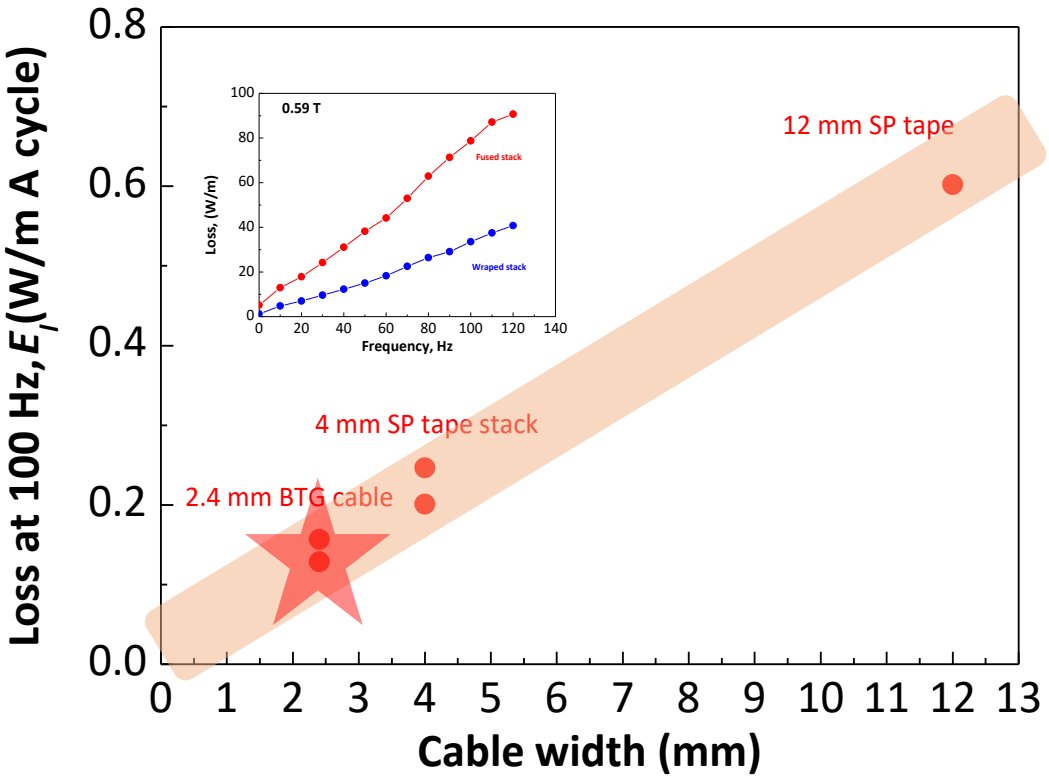
Edge-on view, 5x lens

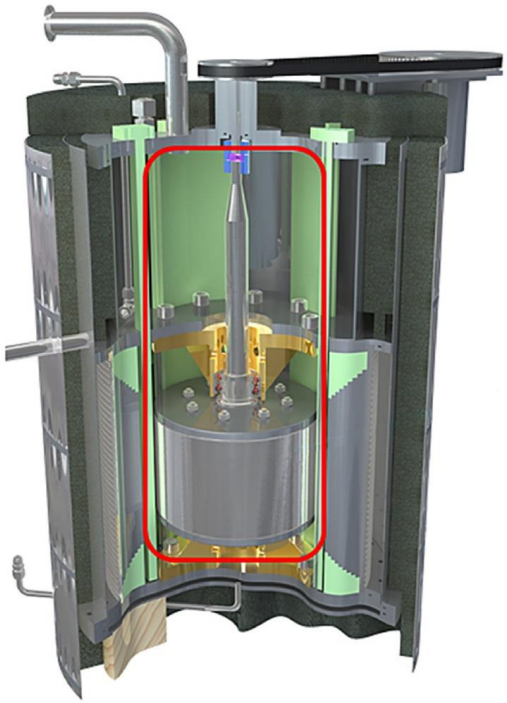


✓ **RT Stress-strain: 0.2% yield stress ~ 472 MPa**

High field AC loss in 2.5 mm cable

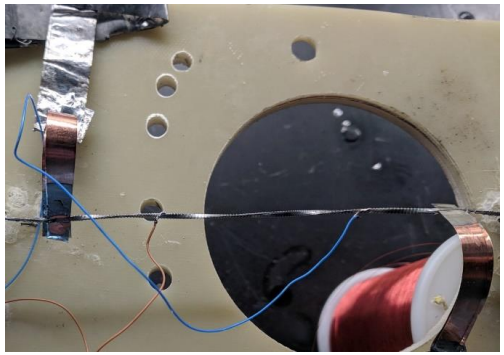
0.6 Tesla AC loss measurement

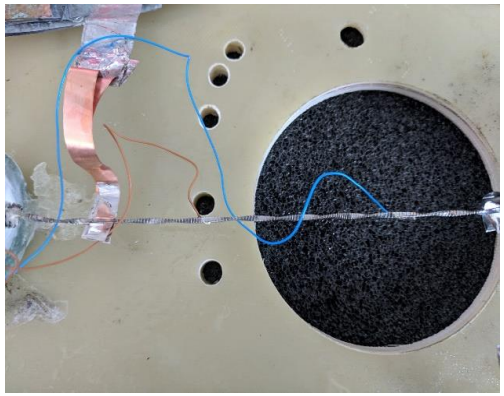


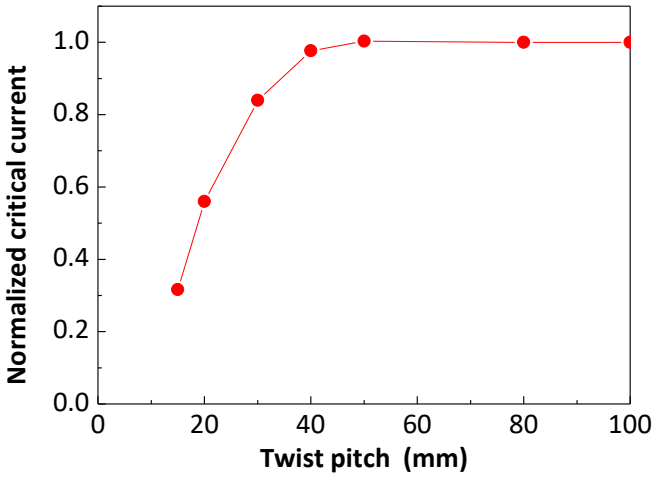


✓ AC los is reduced proportionally to the filament width

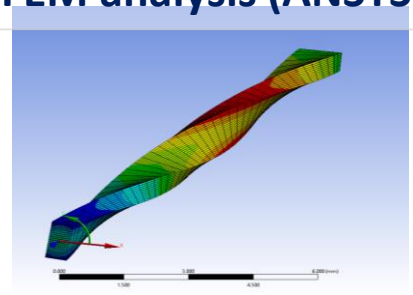
Twisting of the filament stack

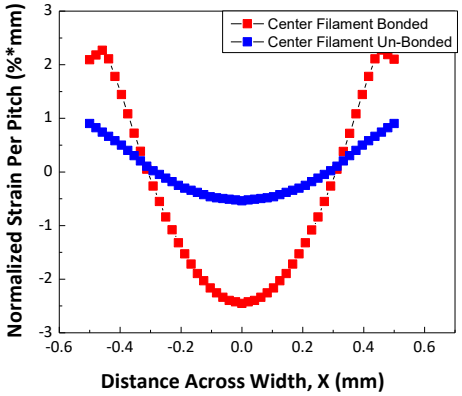






FEM analysis (ANSYS)

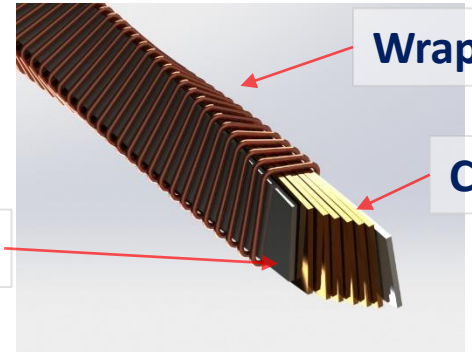




✓ **Twisting before wrapping is expected to reduce stress**

Conclusion and future challenges

Main features of the ExoCable design:

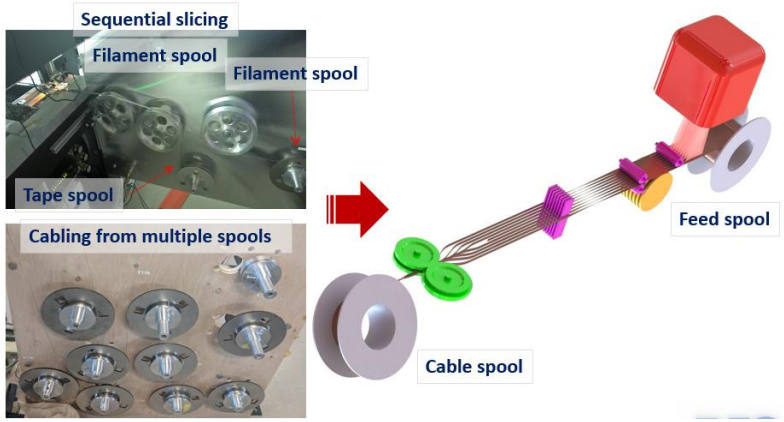


Wrapping provides the transverse strength

Coupled exfoliated filaments

High-strength cladding

- Future work
  - Implementation of pulsed laser slicing
  - Improved inter-filament connectivity
  - Continuous cabling



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