Defects and Defect Tolerance of 2G cables

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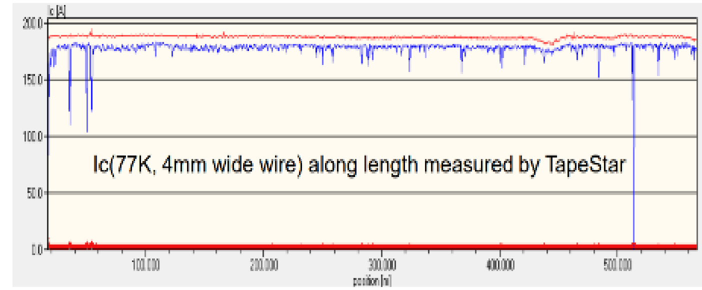
Outline

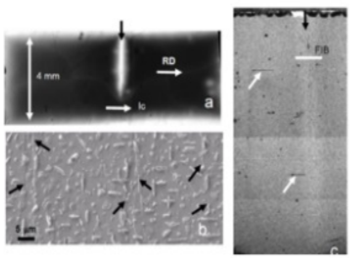
- Motivation: we need to overcome non-uniformity of 2G conductors
- Demonstration of defect tolerance
- Effect of compressive strain on reliability of YBCO layer
- Conclusion and future work

Uniformity challenge of 2G technology

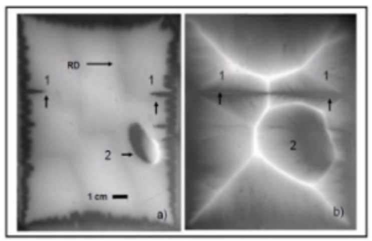


Defects reduce continuous coupon length

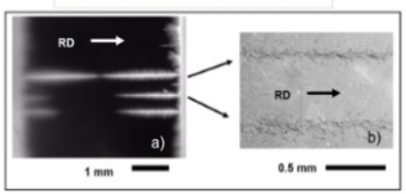
Across-tape defects



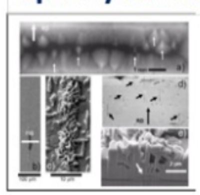
Deposition malfunction



Along-tape defects

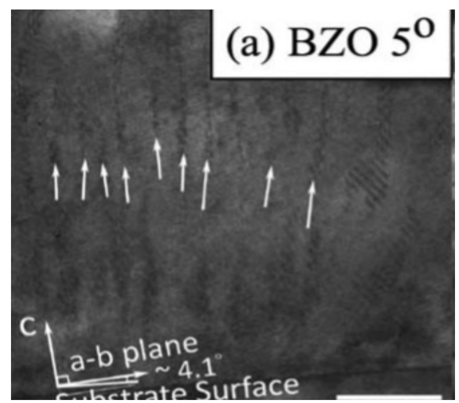


Epitaxy failure

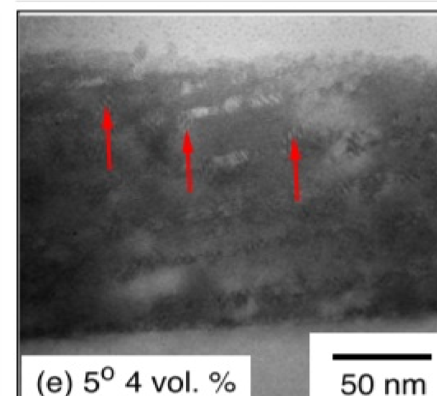


Non-uniform pinning properties, especially for correlated APC

Aligned nano-rods



Splayed-horizontal

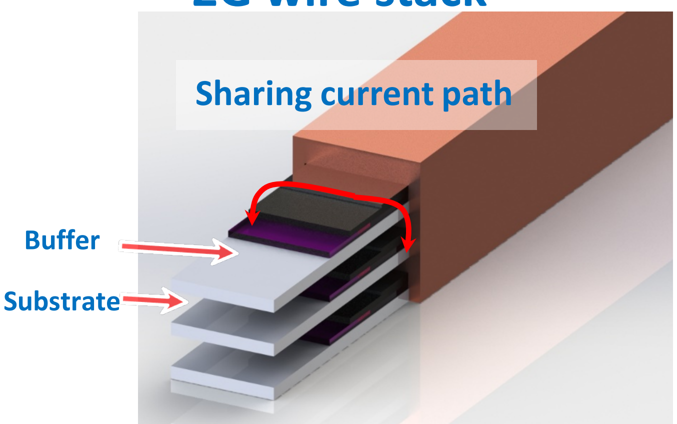


✓ **We need averaging of properties within the cable**

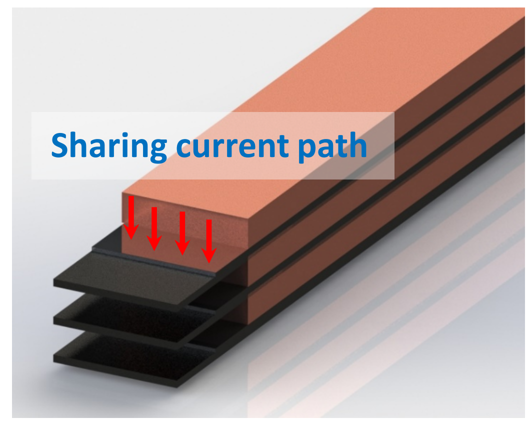
Defect—tolerant, low AC loss cable

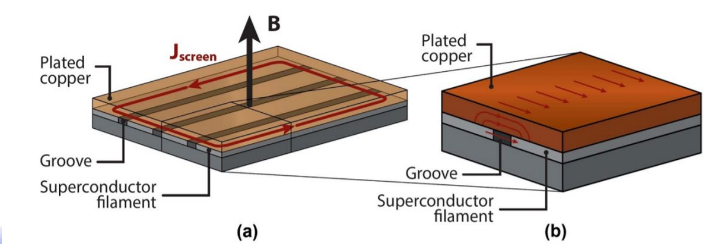
- Single-filament magnets proven difficult to protect against burnout
- Substrate prevents efficient current sharing, especially in narrow, low AC loss cables
- Multifilamentary cable is far more expensive than a single tape

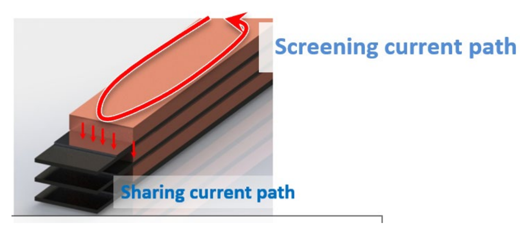
2G wire stack



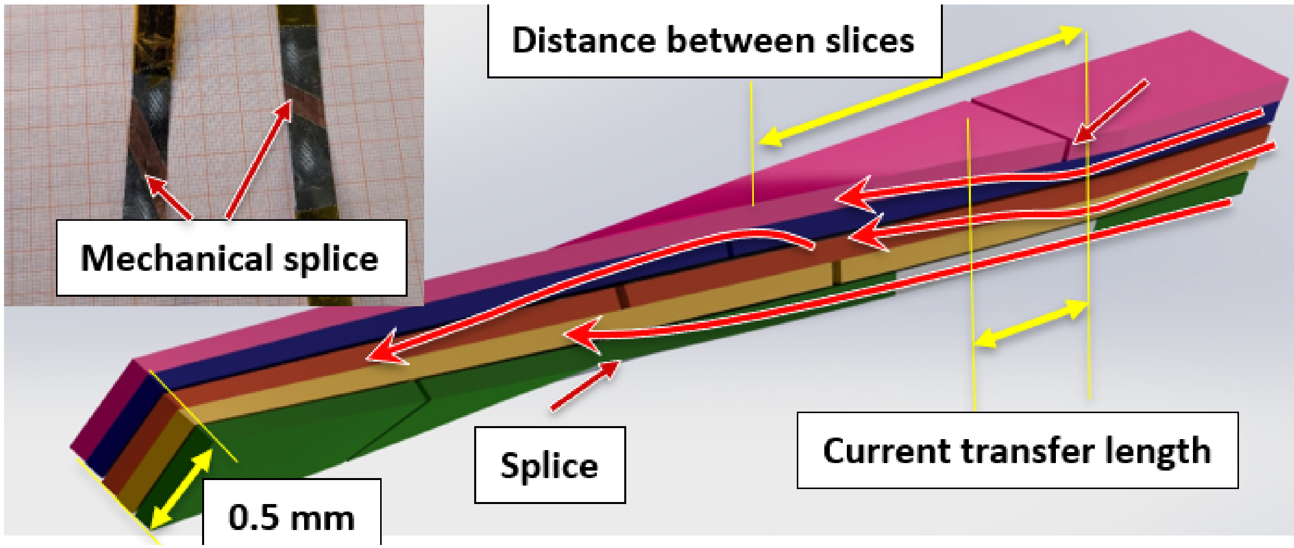
BTG exfoliated filament stack

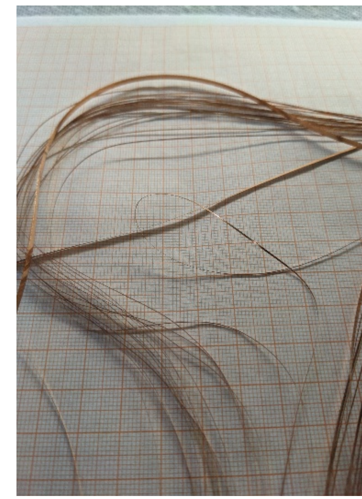






Infinite length, splice-free narrow cable

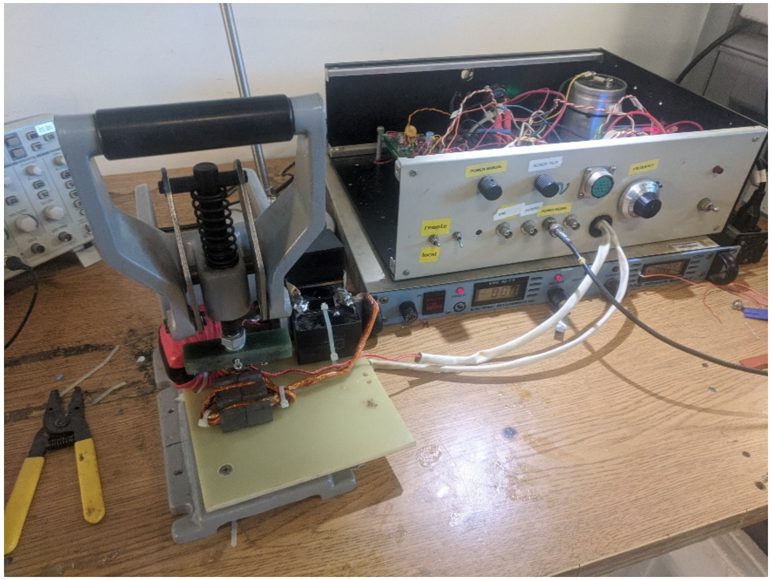


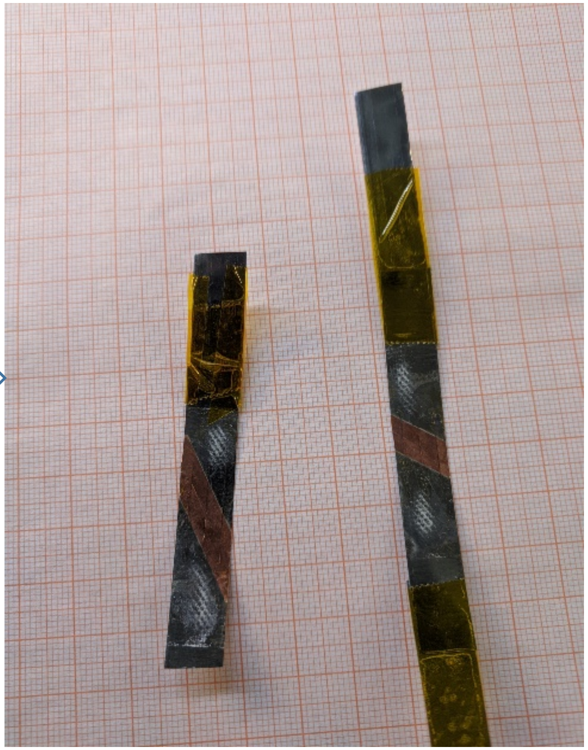


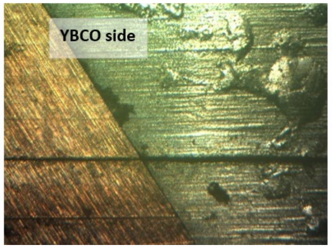
20 0.5 mm filaments

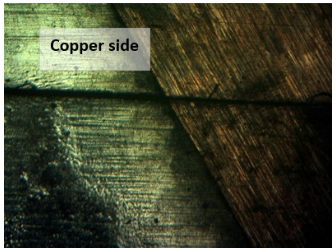
- Human handling < 1 mm filaments is next to impossible
- Only wide, 10-12 mm tape is spliced and handled

Low-profile mechanical bonding of filaments



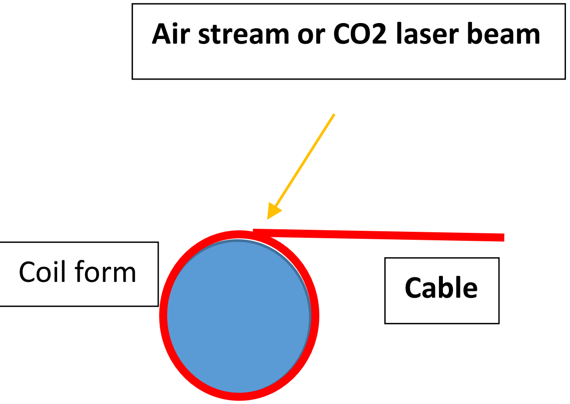


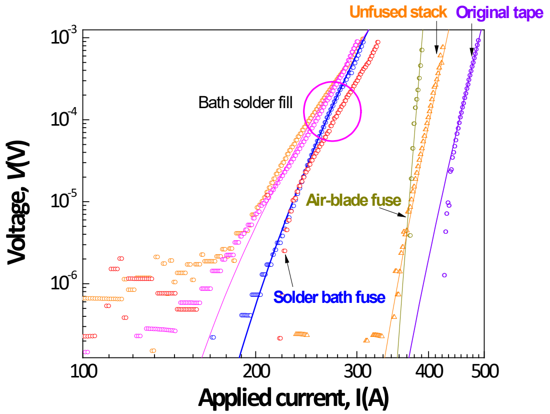




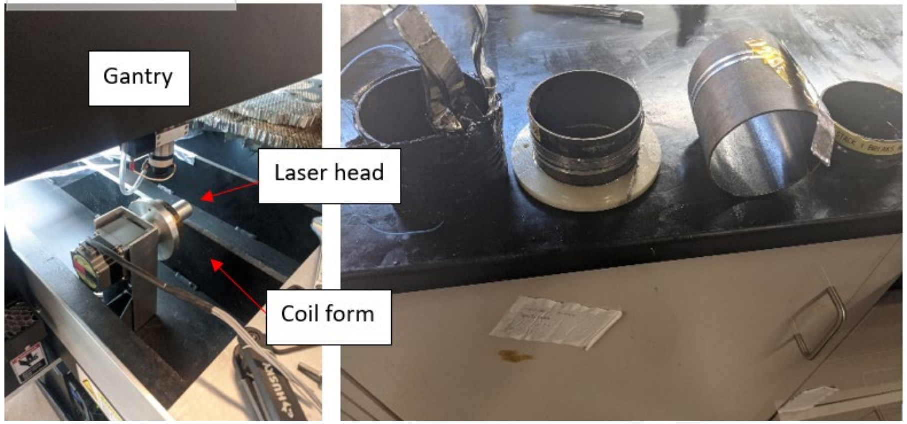
✓ **Low-profile mechanically strong bond: simulated "break"**

Fusing the filaments during the coil winding

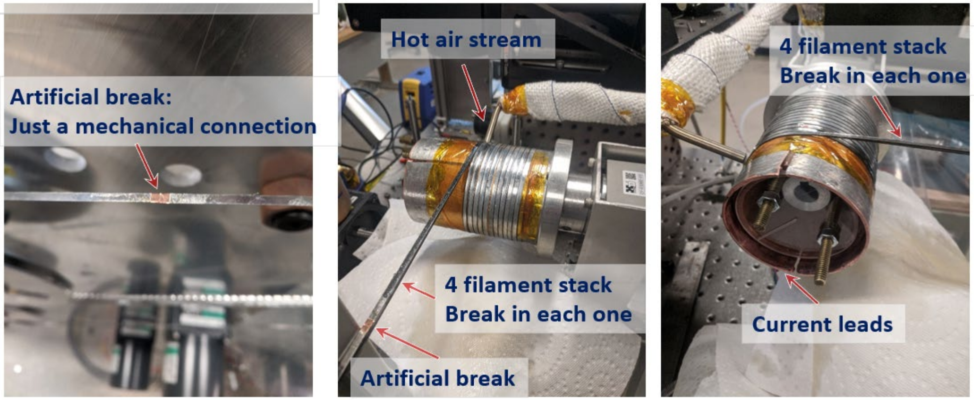




CO2 laser



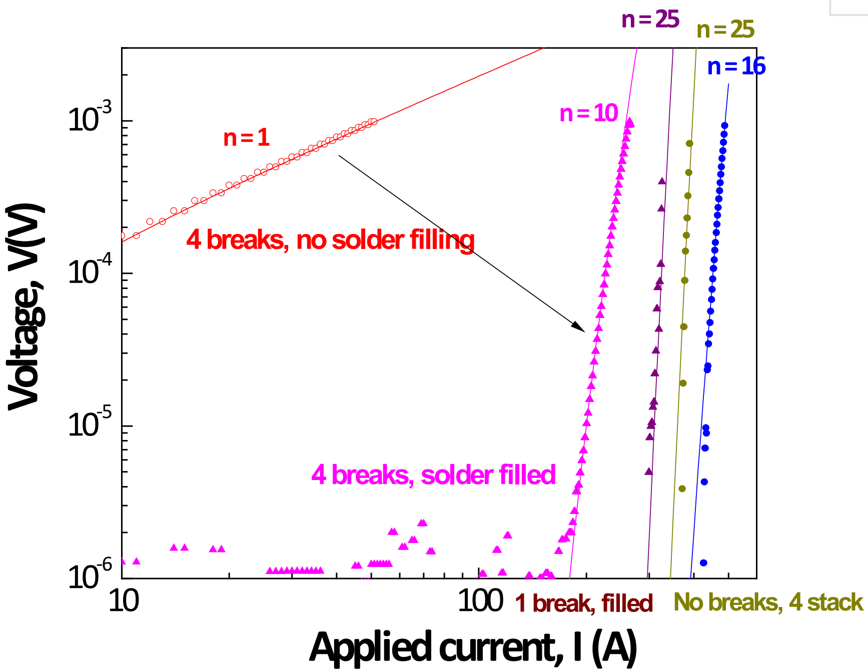
Hot air stream

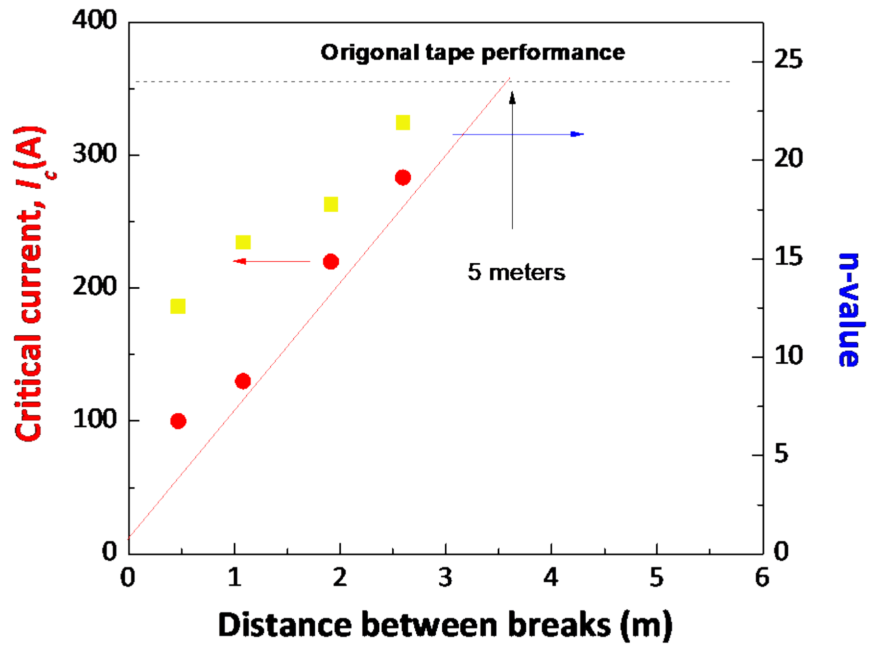


- ✓ Cable needs to be fused right before it is laid on the coilform
- ✓ Air blade method did not degrade I_c and provided the lowest contact resistance

Critical role of filament fusion

When breaks > 5 m apart, the coil would behave as if no breaks are present

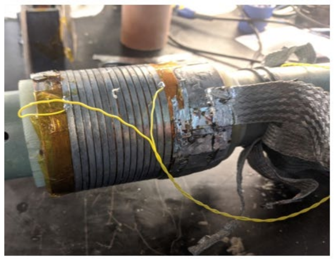




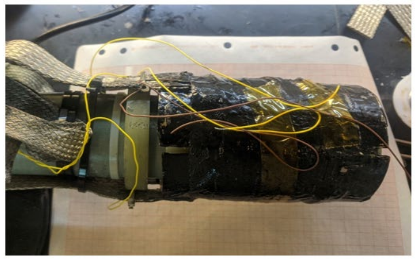
- ✓ Unfused filaments have negligible current sharing: just mechanical contact resistance is very high

Demonstration coil: 4 filaments, layer wound, break in each filament

As wound coil

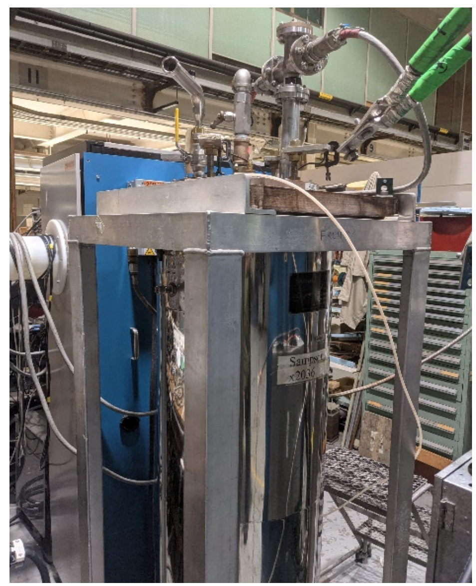


After impregnation



Demo coil:

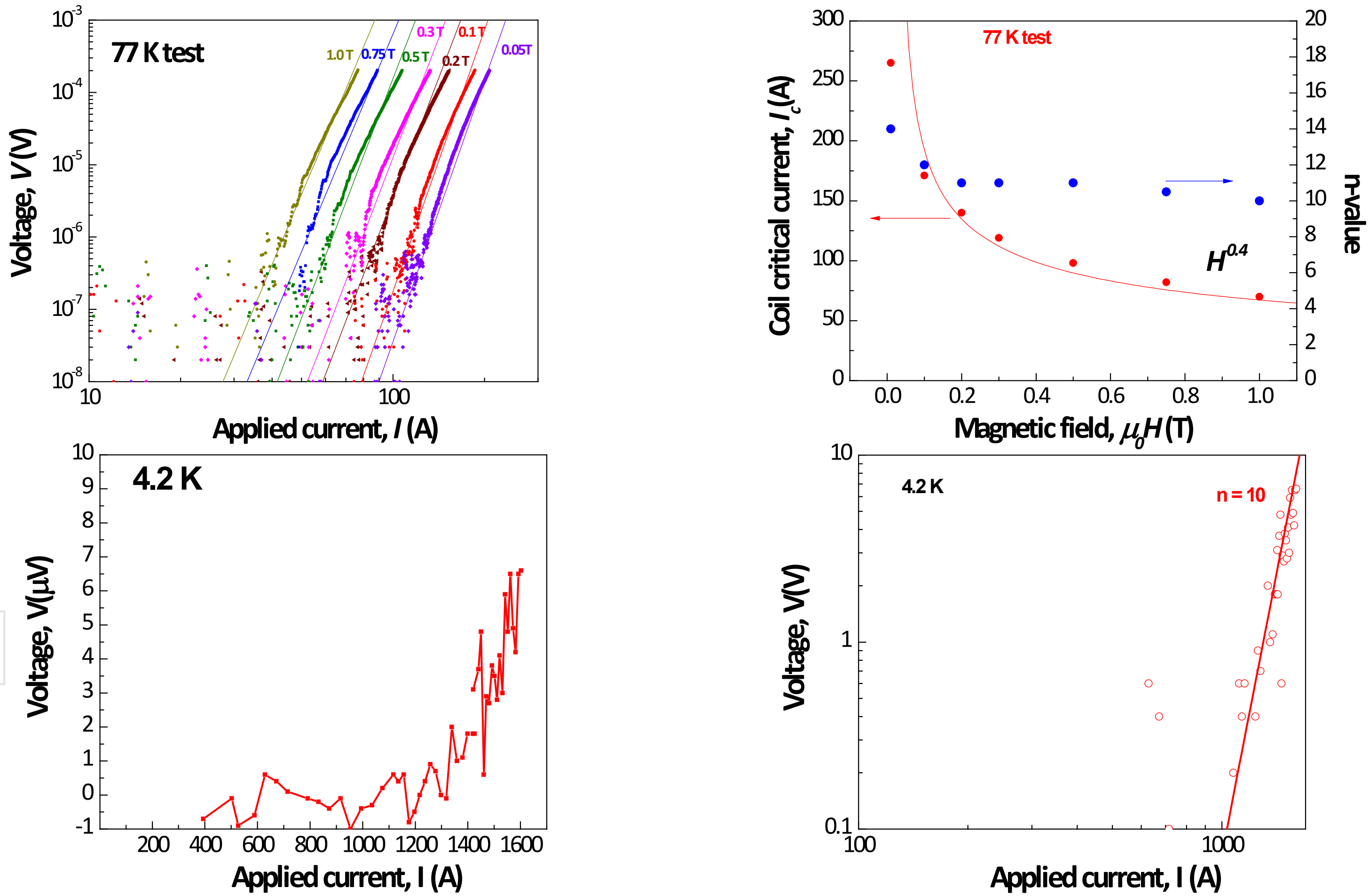
- 5 meters of 2 mm 4 filament cable
- Each filament has a break
- 10 cm ID



Demo coil test at 77 K and 4.2 K

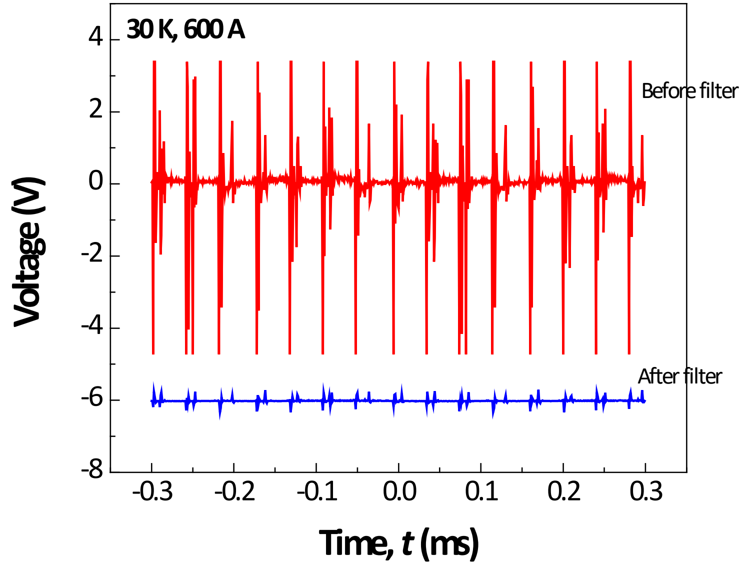
77 K

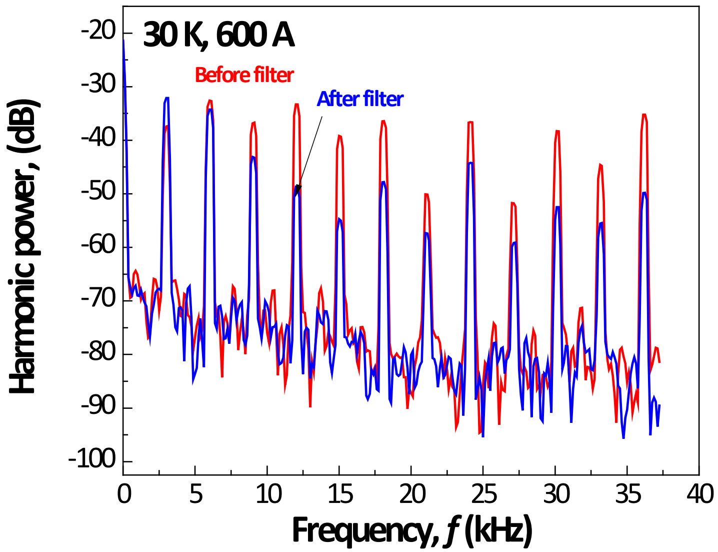
4.2 K

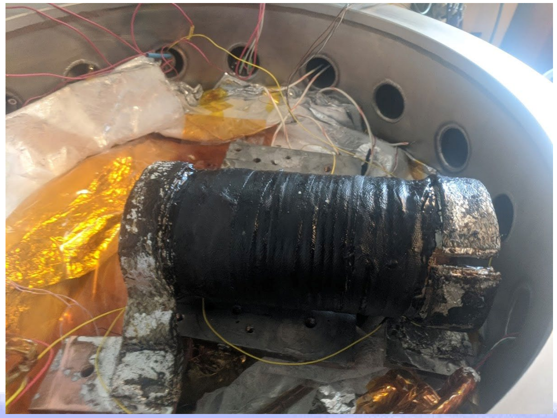


- The coil sustained 1,600 A at 4.2 K, $R < 1$ nΩ
- The n-value is limited by the discontinuities

Application: high current ripple filter for cryogenic power supply





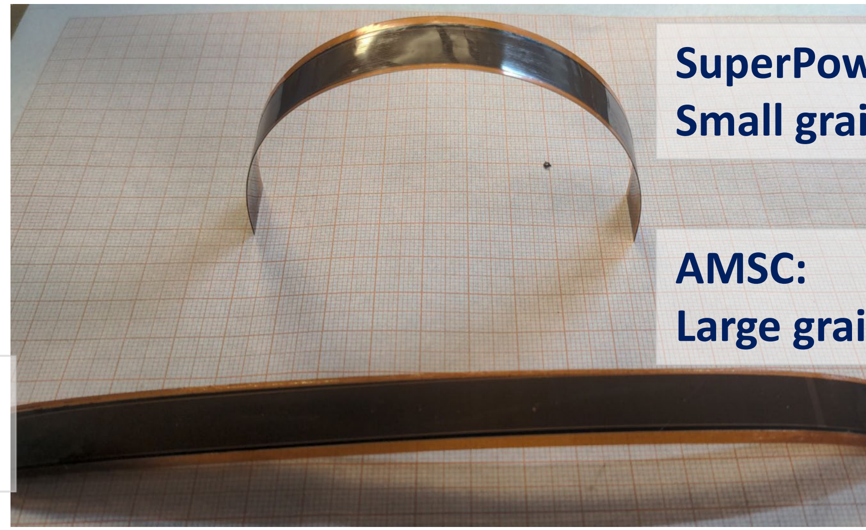


Superconducting ripple filter in the cryochamber

- ✓ **Reliable operation in conduction-cooled mode under high AC ripple load**

Possible source of cracking and delamination: compressive strain in YBCO layer

Effect of compressive strain release after transfer to Kapton:



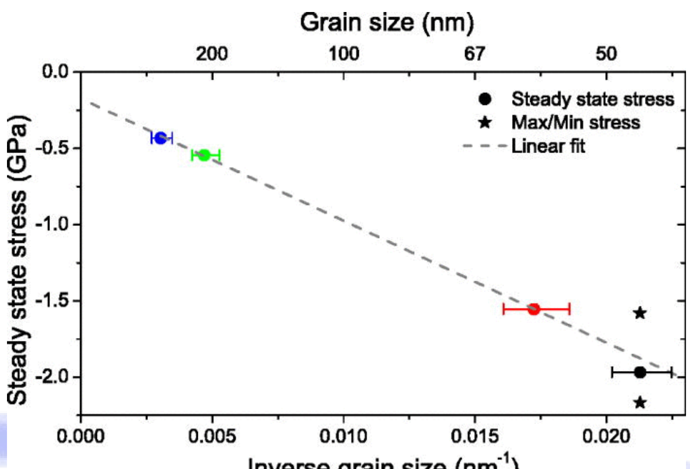
SuperPower: Small grain

AMSC: Large grain

Stoney formula:

$$\sigma = \frac{E_s h_s^2 \kappa}{6h_f(1-\nu_s)}$$

Compressive strain is estimated as high as 200-300 MPa. Variable from batch to batch



Effect is well known, caused by grain boundary densification

Compressive intrinsic stress originates in the grain boundaries of dense refractory polycrystalline thin films
Journal of Applied Physics 119, 055305 (2016);
D. Magnfält et al.

Summary

- Defect tolerance can be achieved if resistivity between the filaments on the order of 100 nΩ cm^2
- Mechanical contact unreliable, rapid solder fusion is critical
- We demonstrated defect tolerance by making a demo coil with each filament cut on purpose
- The coil operated up to 1,600 A (2,000 A/mm^2) at 4.2 K
- Role of compressive strain in defect formation warrants further exploration