Self-monitoring, "SMART" REBCO coated conductors

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Overview

The most important High Temperature Superconductors (HTS) for applications are $(RE)Ba_2Cu_3O_{7-x}$ (REBCO) and $Bi_2Sr_2Ca_1Cu_2O_y$/Ag alloy (Bi2212).

REBCO wires and cables are a very interesting solution for numerous applications. Their current carrying capability at very high magnetic fields allows the generation of the highest fields required in

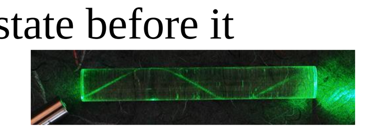
- future generation of particle accelerators (such as *High Energy* - Large Hadron Collider (Rossi 2011)).
- nuclear fusion magnets (like the compact reactors proposed by the PSFC at MIT (Whyte, Minervini et al. 2016))

Their high current density also allows for compact power devices such as motors and generators.

Any superconducting device can be destroyed by an irreversible transition to normal state (*quench*), unless it's adequately protected against these events.

Problem: HTS have a slower propagation of normal zones that leads to inefficacy of voltage based quench detection.

Proposed solution: using distributed fiber optic sensors to detect any local transition to normal state before it irreversibly leads to a quench.



Telecommunication grade optical fibers can also be used as sensors of temperature and strain. When they are interrogated by Rayleigh scattering, they offer mm-range spatial resolution and potentially high temporal resolution.

Research Goal

Develop a quench detection system for superconducting devices that is more effective than the currently used voltage based method, particularly for HTS.

The Smart Conductor concept

Integrating optical fibers directly into a 2G HTS wire, making it able to self-monitor. AMSC's wire architecture is a perfect fit.

Builds up on successful work on co-wound optical fibers interrogated by Rayleigh scattering but add:

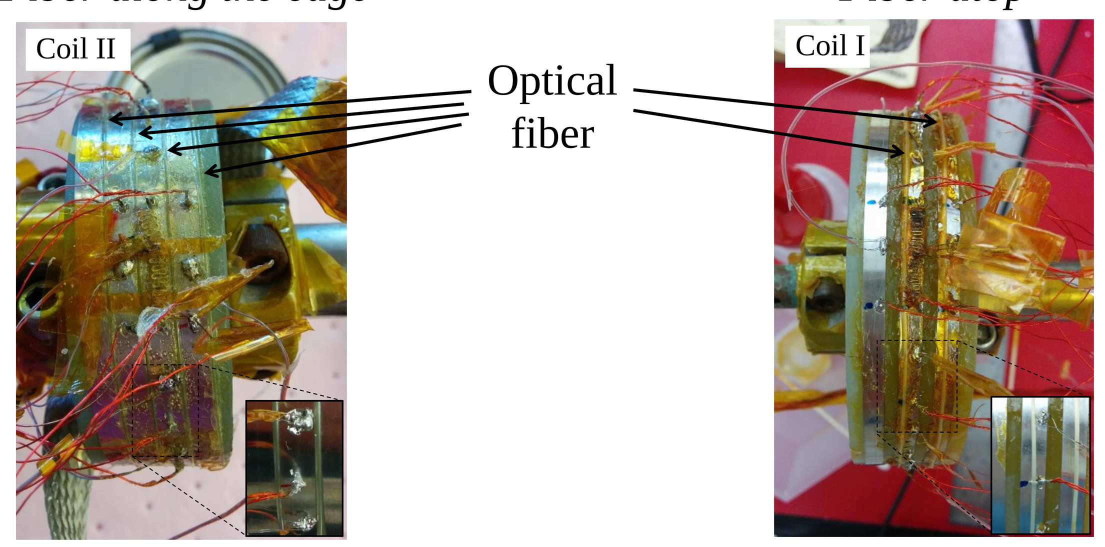
- Intimate contact between fiber and conductor that leads to highest sensitivity
- No reduction in winding packing density
- No change in winding process or magnet design

Rayleigh backscattering interrogated optical fibers

- Telecommunication grade optical fibers used as distributed sensors of temperature and strain
- Working principle similar to fiber Bragg gratings (FBGs) but truly distributed instead of point sensor
- No need for gratings or expensive fibers

Co-wound fiber approach

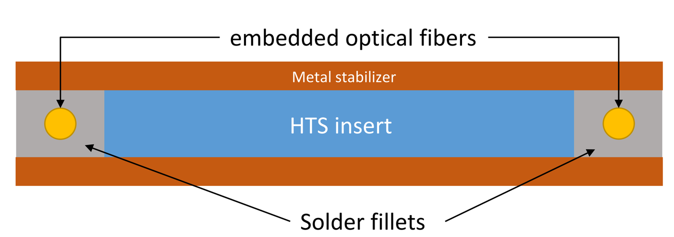
- Different HTS coils fabricated co-winding optical fibers with superconducting wire, with different winding schemes
- Spectral shift guarantees early detection of normal zones and always anticipates voltage onset (Scurti et al. 2016)

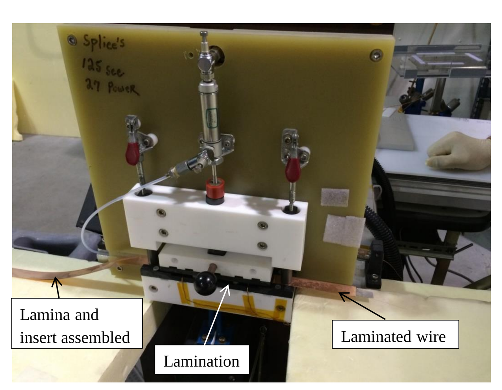


Smart REBCO conductor approach

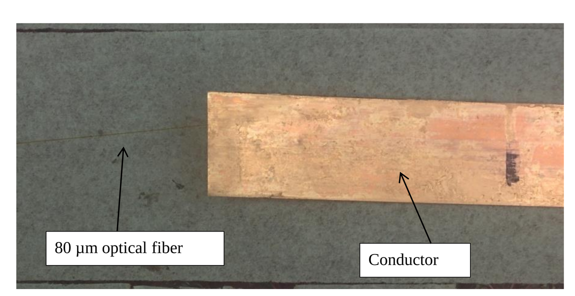
- Another approach to integrate a fiber into a superconducting coil is to design a superconducting wire that already includes it.
- REBCO is the most promising HTS material for applications. It features strengths and performance at high magnetic fields.
- AMSC 2G wire is a perfect fit to realize the smart conductor: optical fibers embedded into the solder fillet during the lamination process

Smart REBCO conductor architecture (cross section)





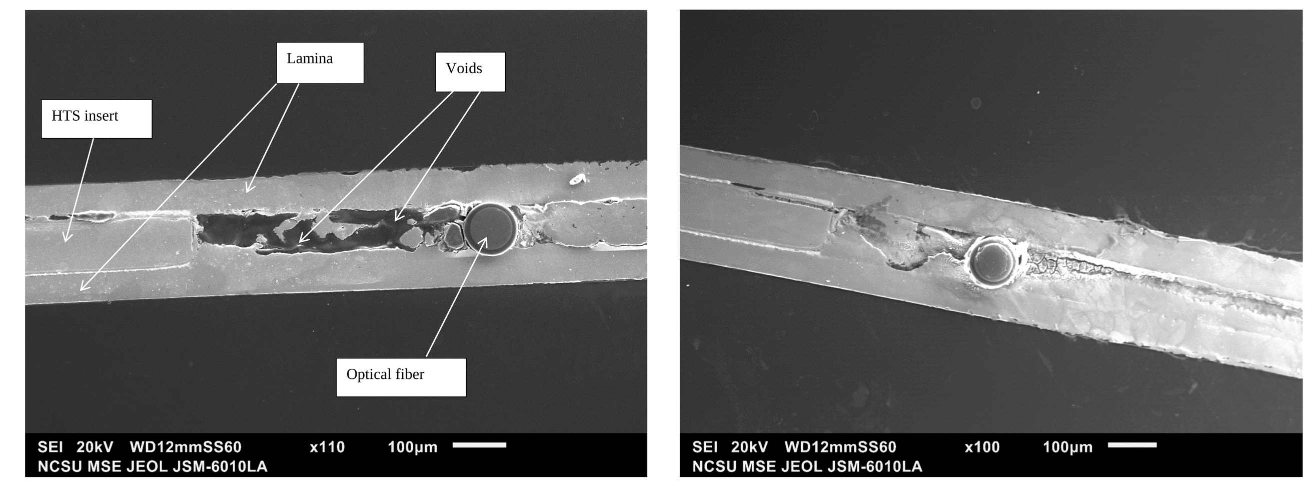
AMSC's static lamination apparatus



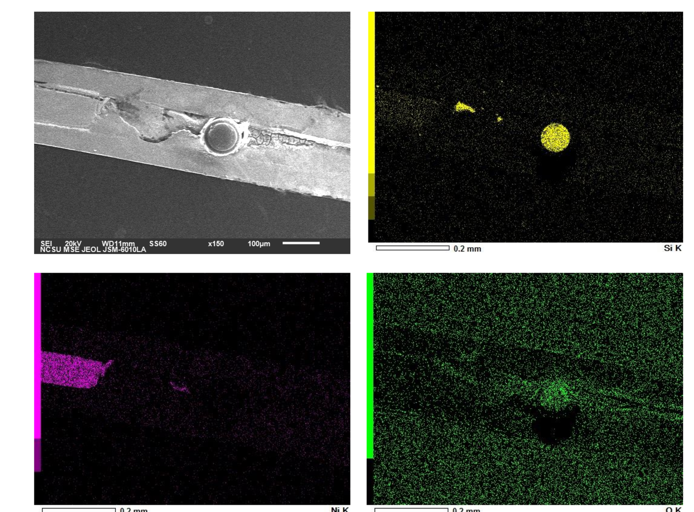
Smart wire that highlights the optical fiber extending out of the conductor end. The other end of the conductor is analogous.

Results

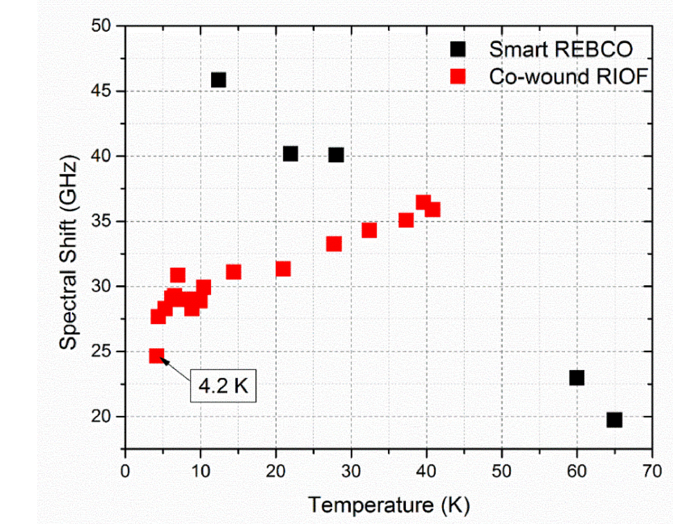
SEM micrographs showing a cross section of the smart conductor that includes the region of the fillet where the optical fiber is embedded



EDS maps showing elemental compositions of a cross section of smart conductor

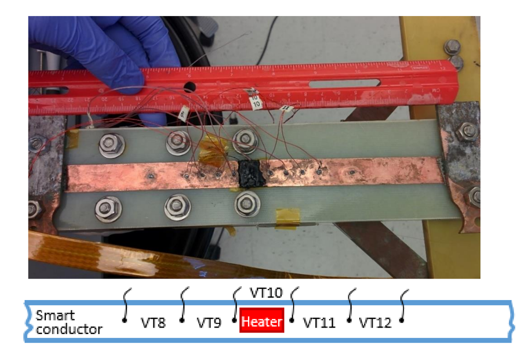


Thermal sensitivity as a function of temperature

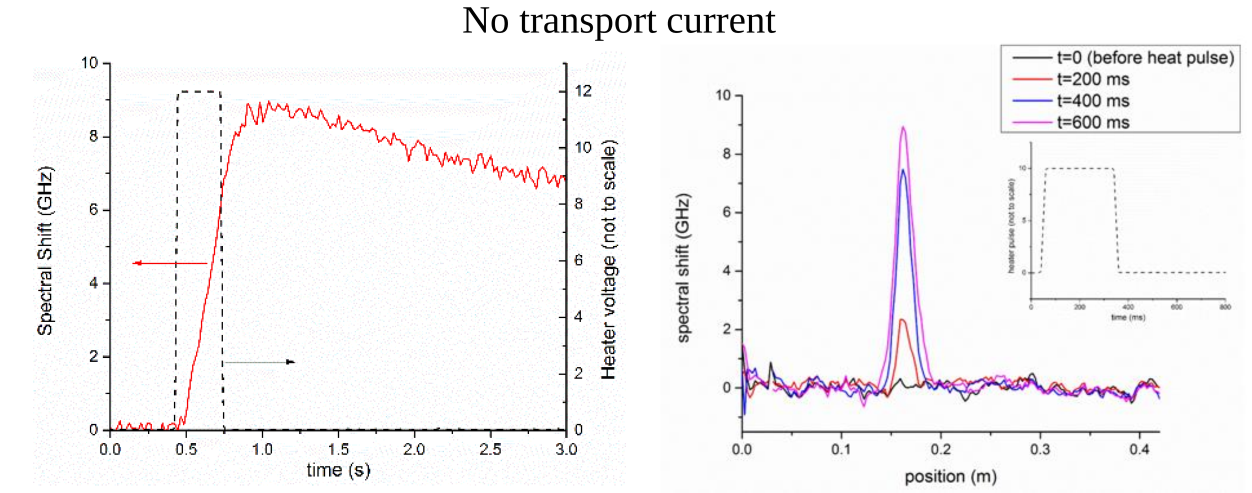


30 cm straight sample of smart conductor

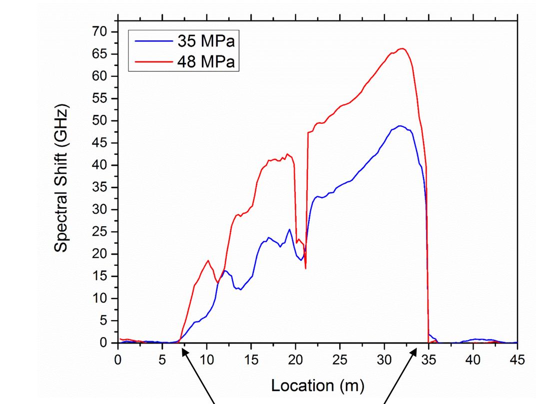
Experimental setup. The black region is the heater embedded in stycast epoxy



Spectral shift during a thermal disturbance at 79 K in Nitrogen vapor. No transport current



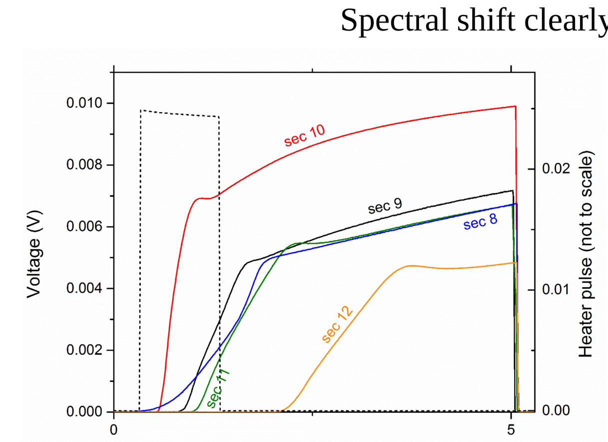
Tensile test
Spectral shift proportional to strain

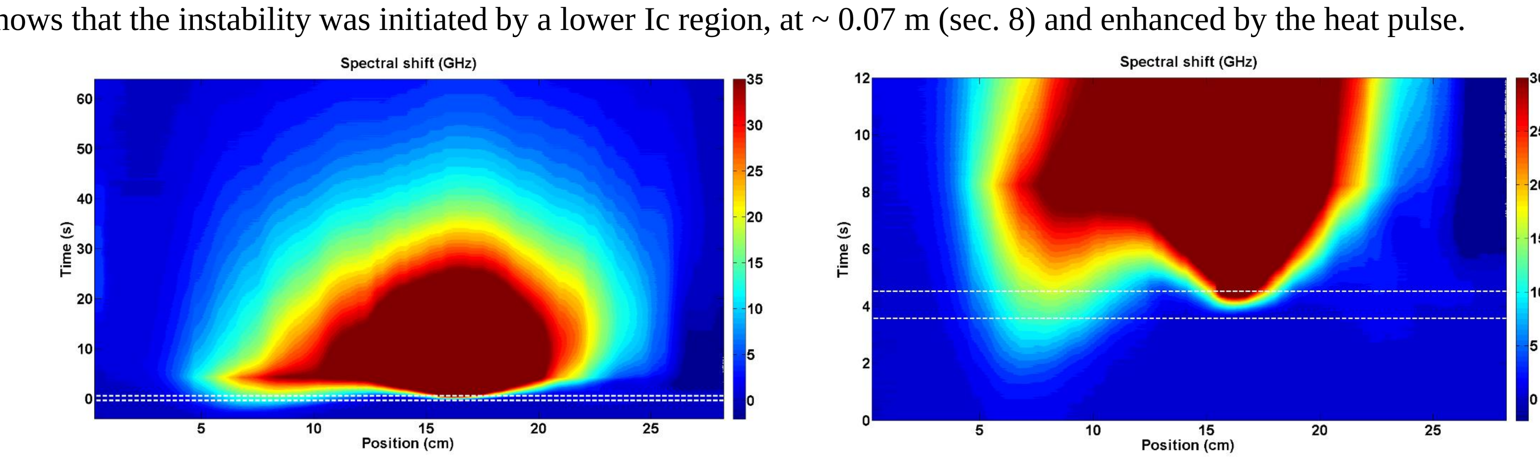


Grips location

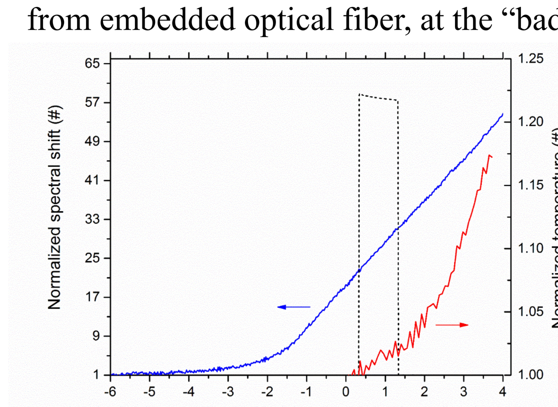
Quench condition - spectral shift, voltage and temperature evolution during a quench. Initial temperature 81 K. Nitrogen vapor cooling.

Spectral shift clearly shows that the instability was initiated by a lower Ic region, at ~ 0.07 m (sec. 8) and enhanced by the heat pulse.



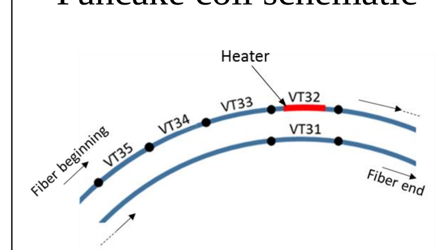


Temperature from thermocouple vs Spectral Shift from embedded optical fiber, at the "bad spot"

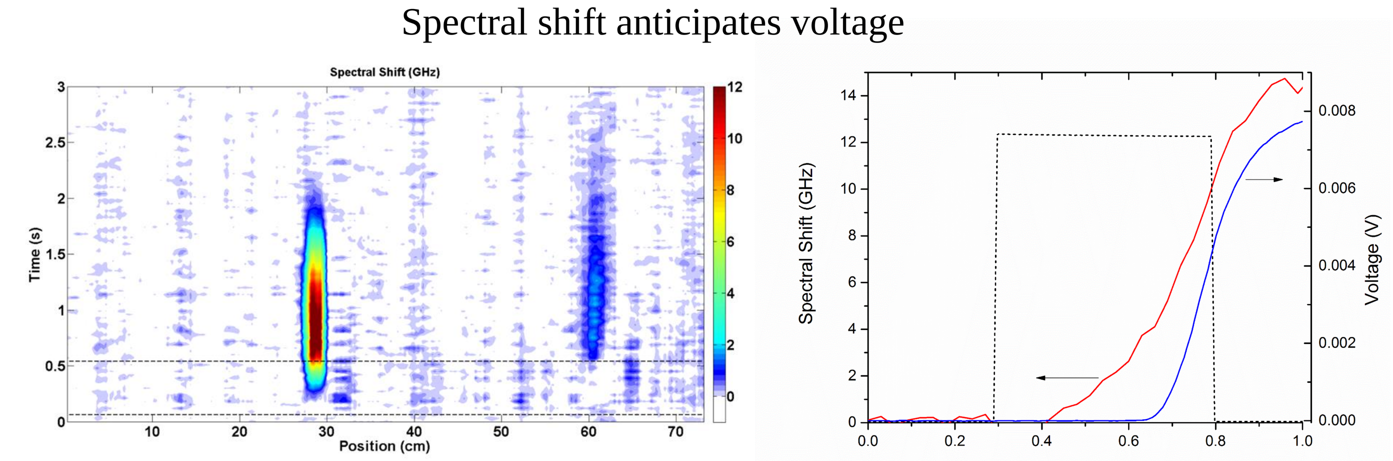


Pancake coil wound with smart conductor

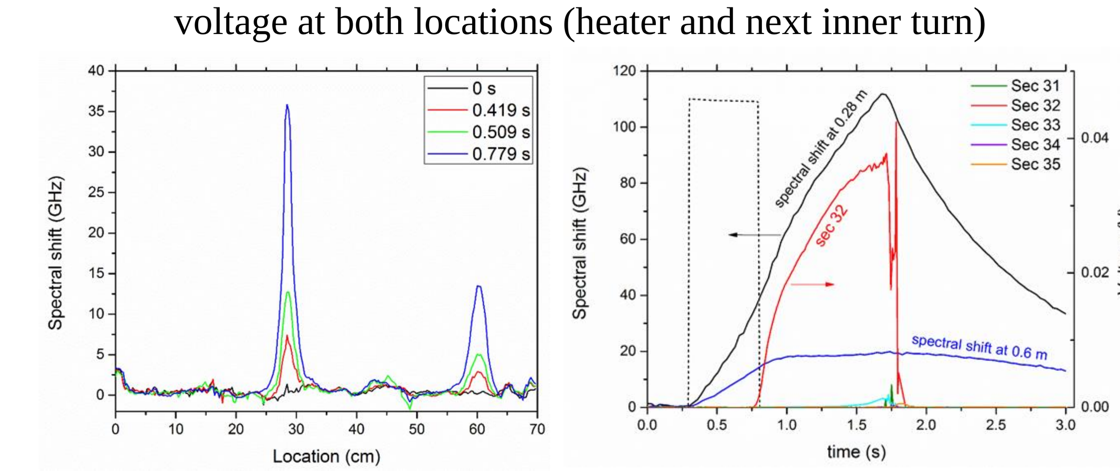
Pancake coil schematic



77 K (liquid nitrogen), 235 A (80% Ic). Only heater section shows voltage. Spectral shift anticipates voltage



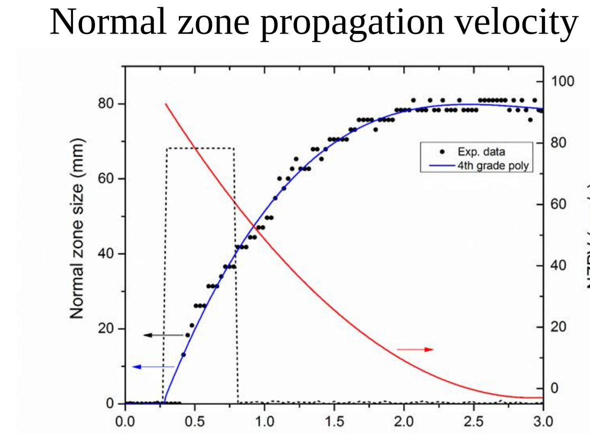
14.6 K (helium vapor), 500 A, self-field. Spectral shift anticipates voltage at both locations (heater and next inner turn)



Next steps

- Improve fiber integration to avoid void and to guarantee homogeneity over conductor length
- Scale up the integration process to a reel-to-reel continuous system
- Extensive mechanical, materials, optical and electrical characterization at 4.2 K

Normal zone propagation velocity



Acknowledgements

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