Quench degradation behaviors and limits of REBCO coated conductors

Mattia Duranti

S.Anna Superior Studies School

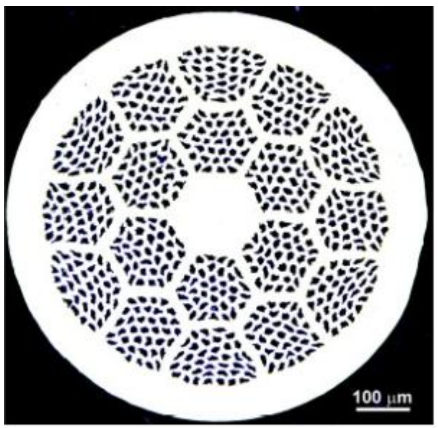
Supervisor: Luciano Elementi
Cosupervisor: Tengming Shen
Experimental support: Liyang Ye, Pei Li

Fermilab

Training program

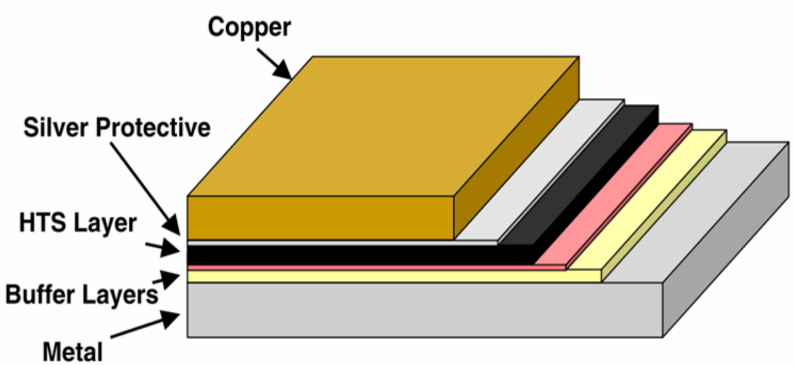
- Develop analytic and FEM models of thermal stresses due to quench non-uniform temperature distribution in Ag/Bi-2212 multi filamentary round wire
- Apply the same analysis to a multilayer YBCO tape coated superconductor
- Experimentally determine the temperature limit to initiate the degradation
- Microstructurally observe the damage and establish the correlation between the microstructure and the stress during the quench.

Two High-Temperature Superconductors with promising applications in High Energy Physics



BI-2212

- Multifilamentary round wire
- Filaments of Bi2Sr2CaCu2O8+x
- Ag-AgMg matrix
- Tc =82 K

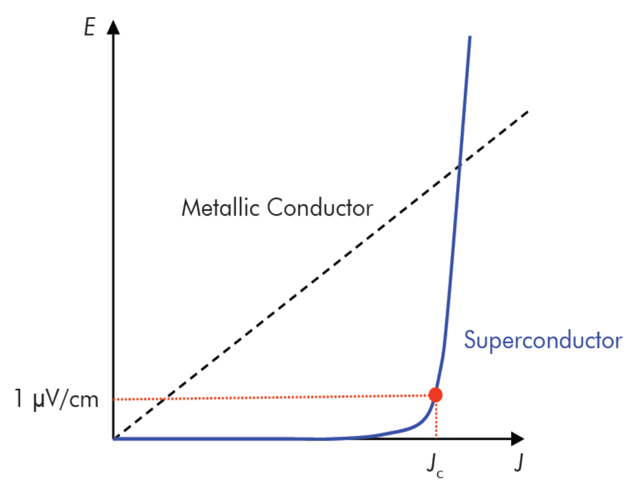


YBCO

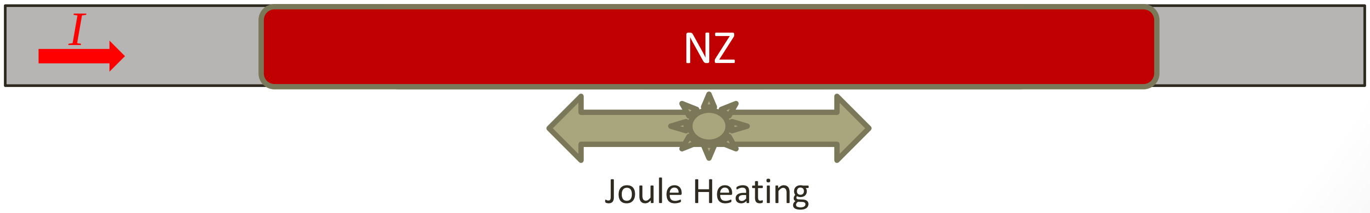
- Multilayered tape
- YBa2Cu3O7-x superconductive layer
- High resistance superalloy layer
- Good performances at 77 K

Quench in superconductors

- When a quench starts, a small region of the HTS shift to normal conductivity
- Joule effect heat the composite superconductor providing a peaked temperature distribution
- Different thermal expansions can induce stresses that cause permanent mechanical damages

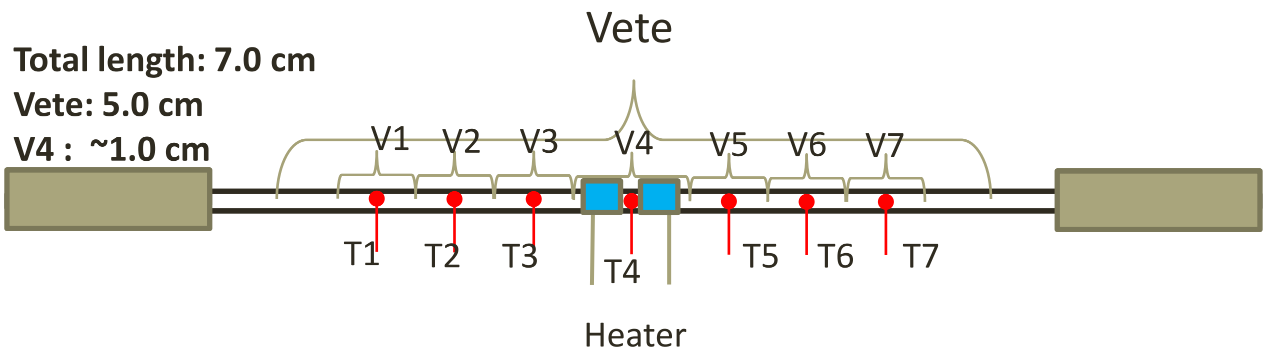


- Quench protection systems are required for magnet operation



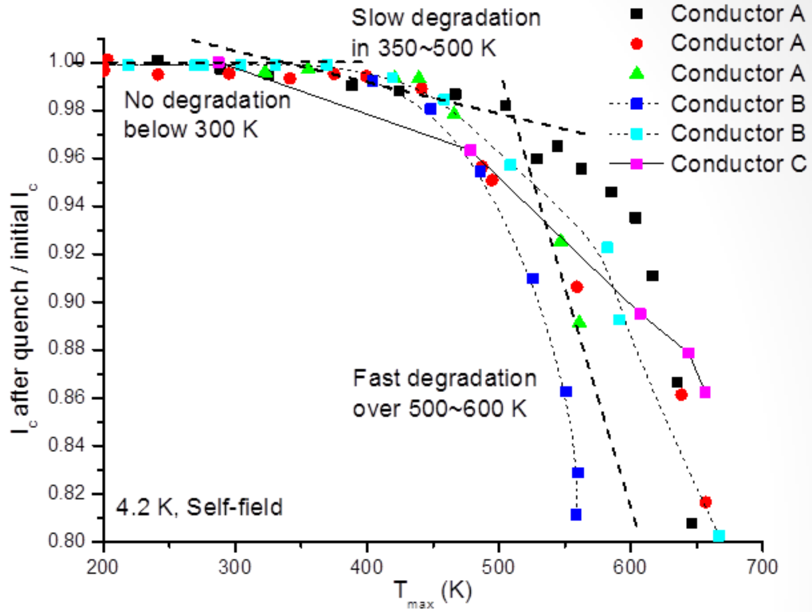
Bi-2212 Wire Analysis

- Simulate and predict stresses and deformations of a Bi2212 wire heated by quench
- Find relations between heating temperature and damages in the material related to Ic permanent drops
- Fit results with previous experimental data about Ic drops
  - Experimental setup consists in one fixed ends wire heated with different temperature distributions.

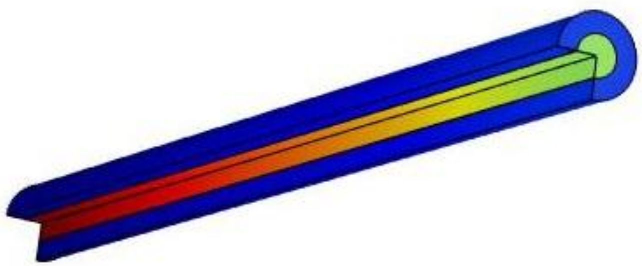


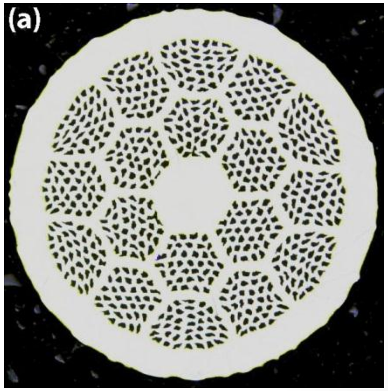
Single Filament Analysis

- Ic falls may be due to breaks of Bi2212 or buckling of the wire.
- Find the behavior of a single filament of Bi2212
- Axisymmetric model with fixed ends
- Analytical and FEM models developed



(Experimental results from Liyang Ye)





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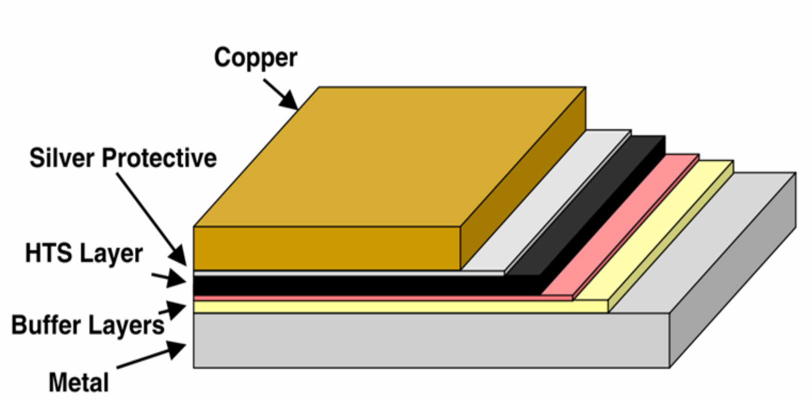
Developments

- Some areas of Bi2212 may be in tensile stress state depending on the temperature distribution
- In compression Silver is much more stressed than Bi2212

- The buckling average stress in the wire is very low (21 MPa)
- To analyze degradation in this experiment, a post-buckling study is needed
- A new experiment with different setup can be implemented for the study of a straight wire.

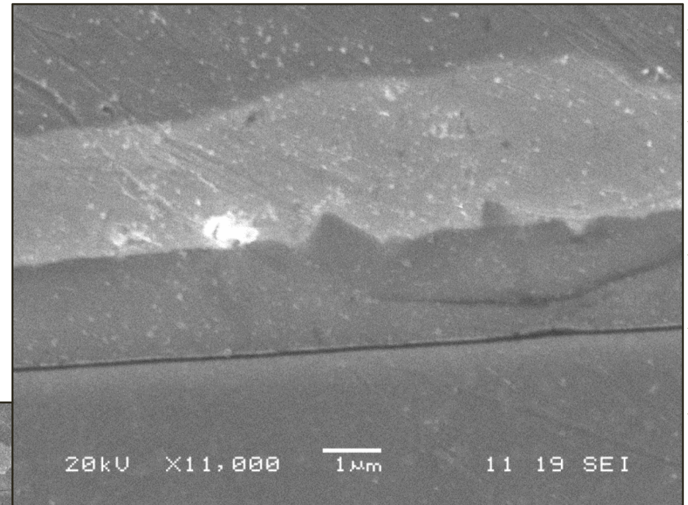
YBCO tape

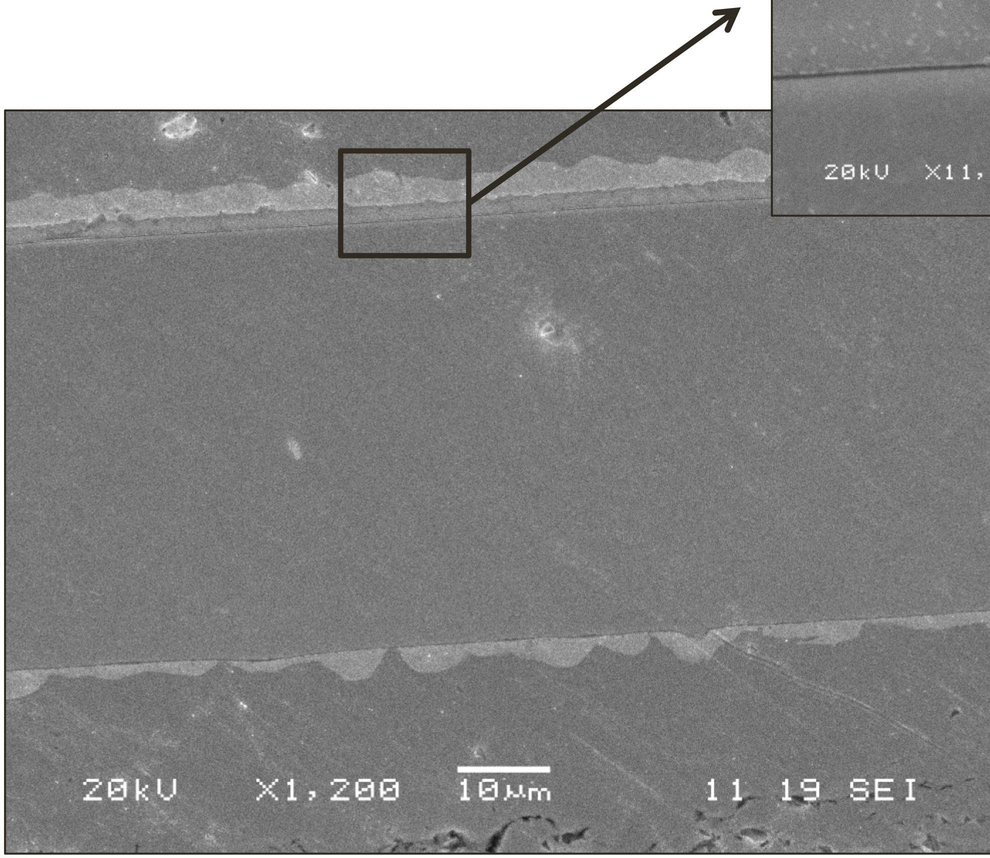


- Copper stabilyzer
- $YBa_2Cu_3O_{7-x}$ superconductive layer
- Very thin Buffer layer
- High strenght Hastelloy layer
- Coated tape

- Stresses due to different thermal contraction can damage the integrity of the YBCO Layer
- After sandpaper polishing and vibratory finishing, we are able to see the layers on electron microscope

Electron microscope analysis

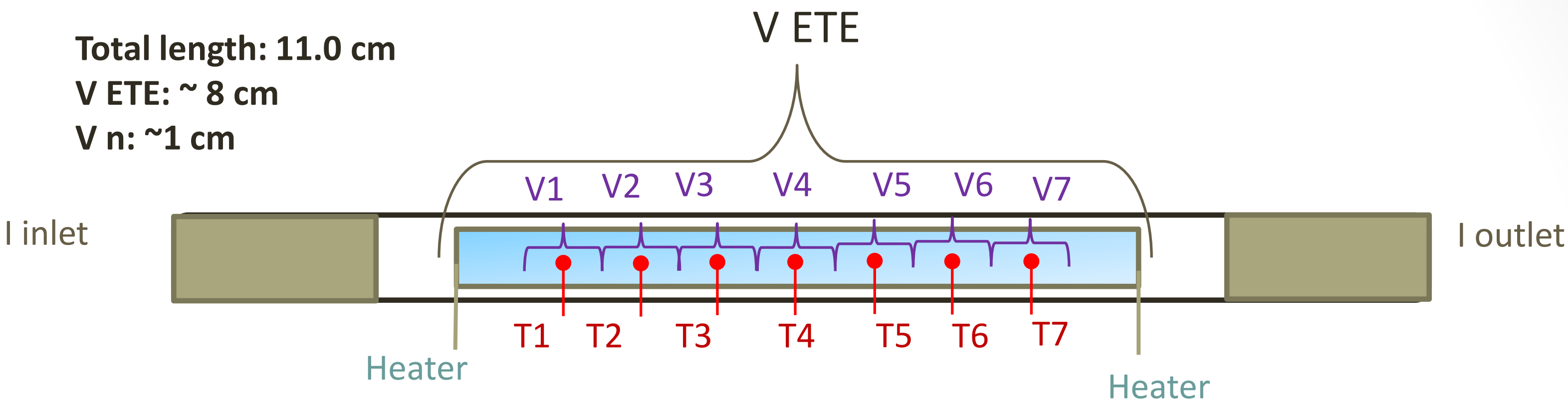




4 mm width tape longitudinal section

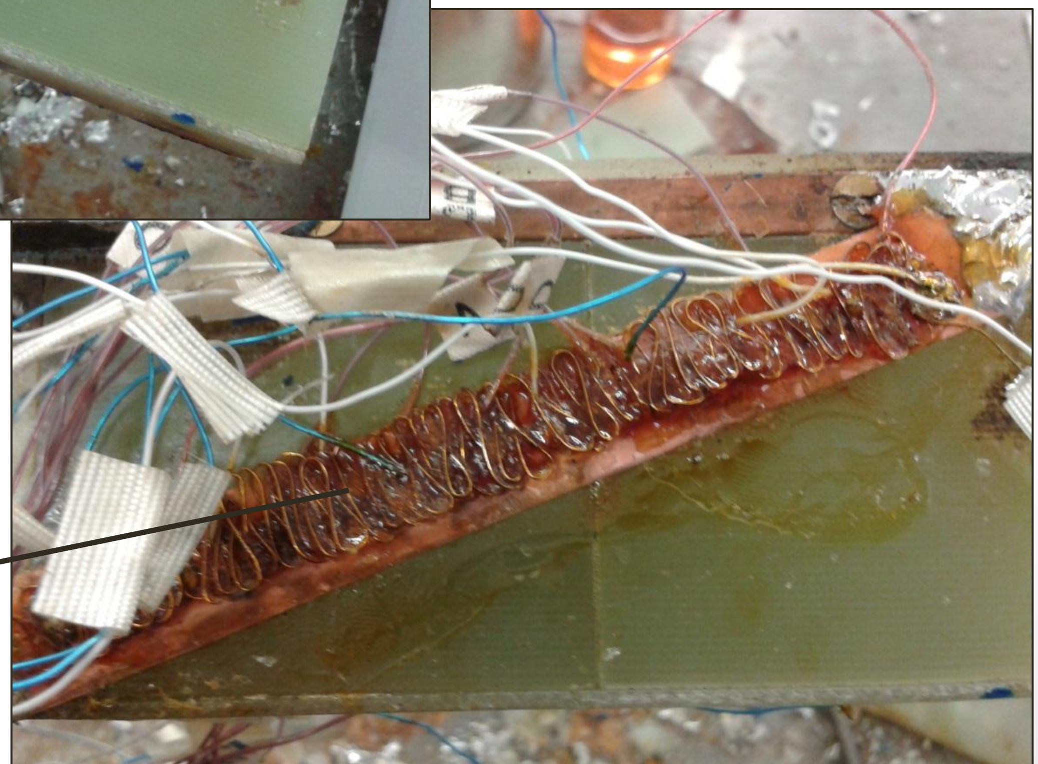
- 20 μm Copper
- 3 μm Silver
- 2 μm YBCO
- <0.2 μm MgO (buffer)
- 50 μm Hastelloy
- Irregular 2 μm Silver
- 20 μm Copper

Experimental setup



- 12mm width tape, supported by a G-10 surface on the hastelloy side and soldered at the ends to copper junctions.
- The tape is covered with sticky varnish in order to fix it to the surface. All immersed in liquid nitrogen (77K)
- 6 samples have been prepared and tested: 3 with epoxy and 3 without epoxy

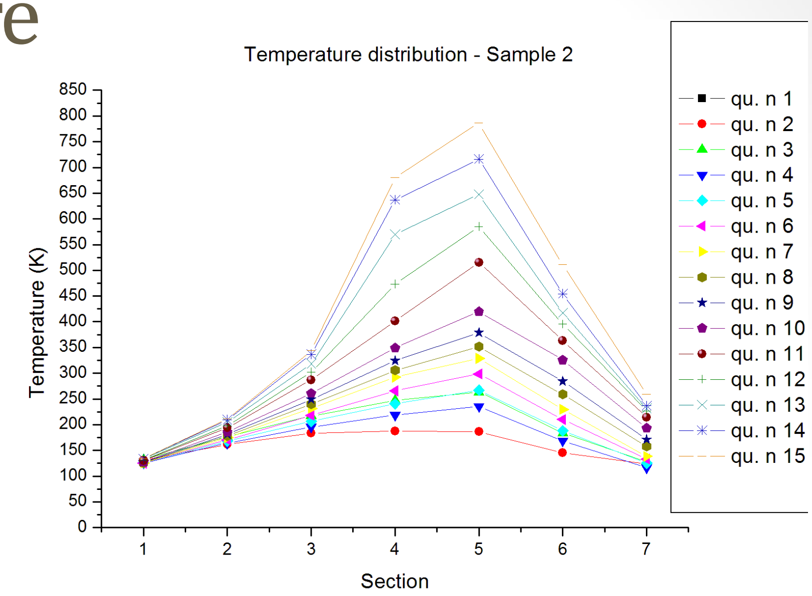
Voltage and thermocouples taps



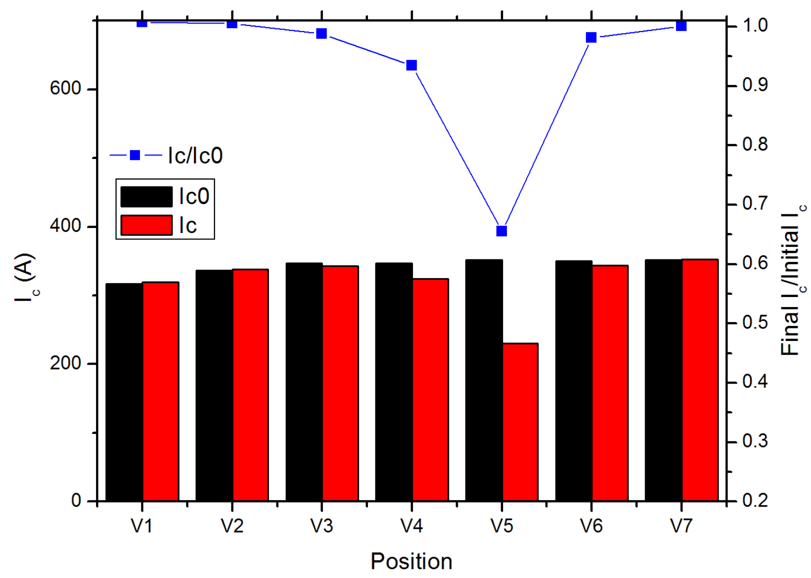
Heater

Experimental procedure

- While quench is induced by the heater, voltages and temperatures are recorded.



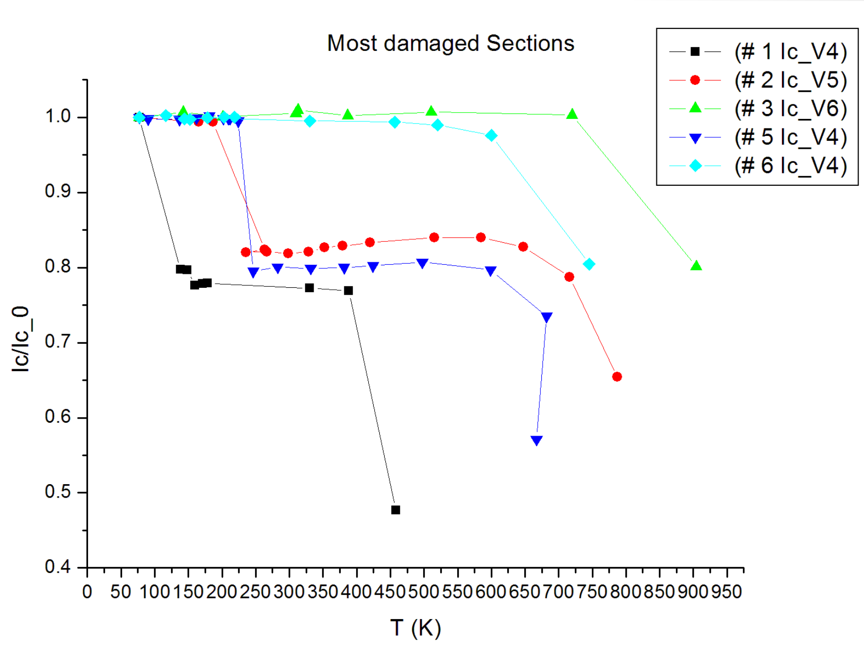
- After cooling, Ic is measured to find irreversible variations



Graphs from Sample 2: long heater, epoxy

Results

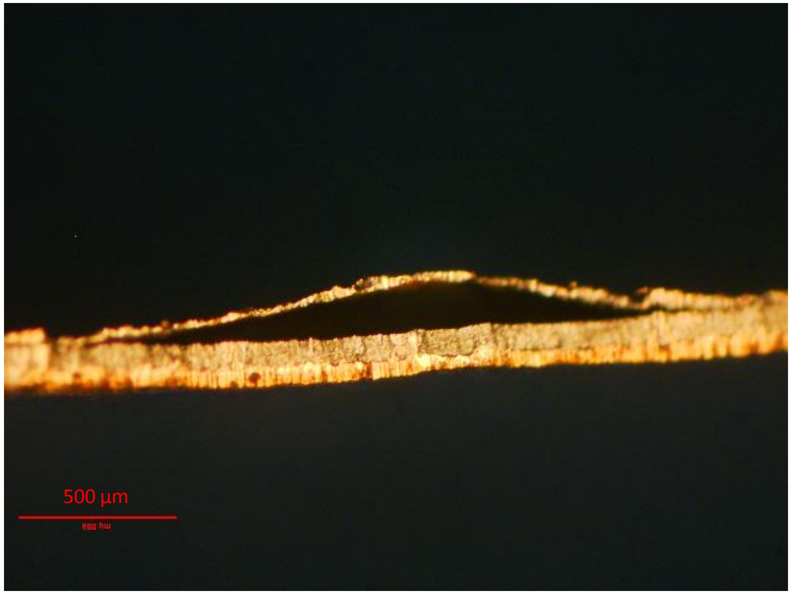
- Epoxy covered samples showed a two step degradation
- The damaging temperature seems to depend on the covering layer.
- A final degradation always occur around 700 K

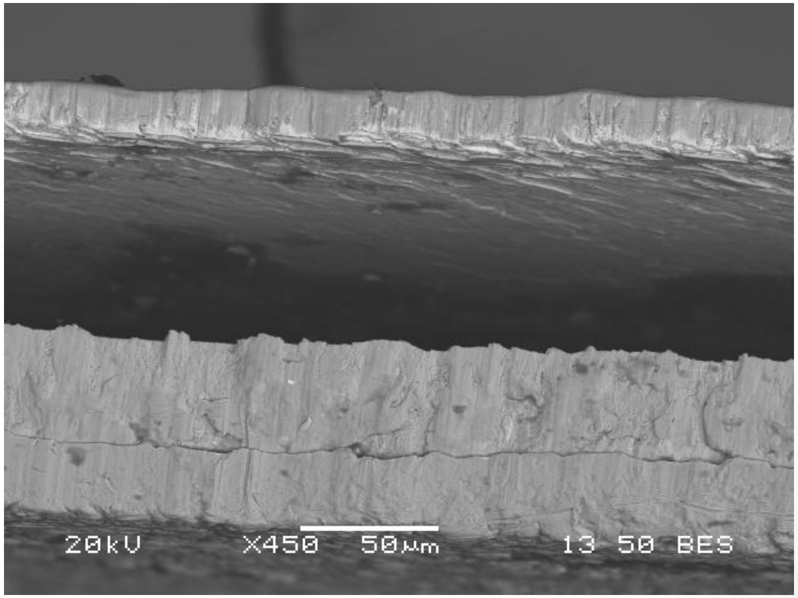


Sample	Heater	Epoxy	Delamination
1	short	yes	140 K
2	long	yes	280 K
3	long	no	850 K
4	flat	no	---
5	long	yes	270 K
6	long	no	750 K

Sample analysis

- After the experiment the samples have been analyzed on optical and electron microscope
- All damaged samples showed delamination between Hastelloy and Silver layer



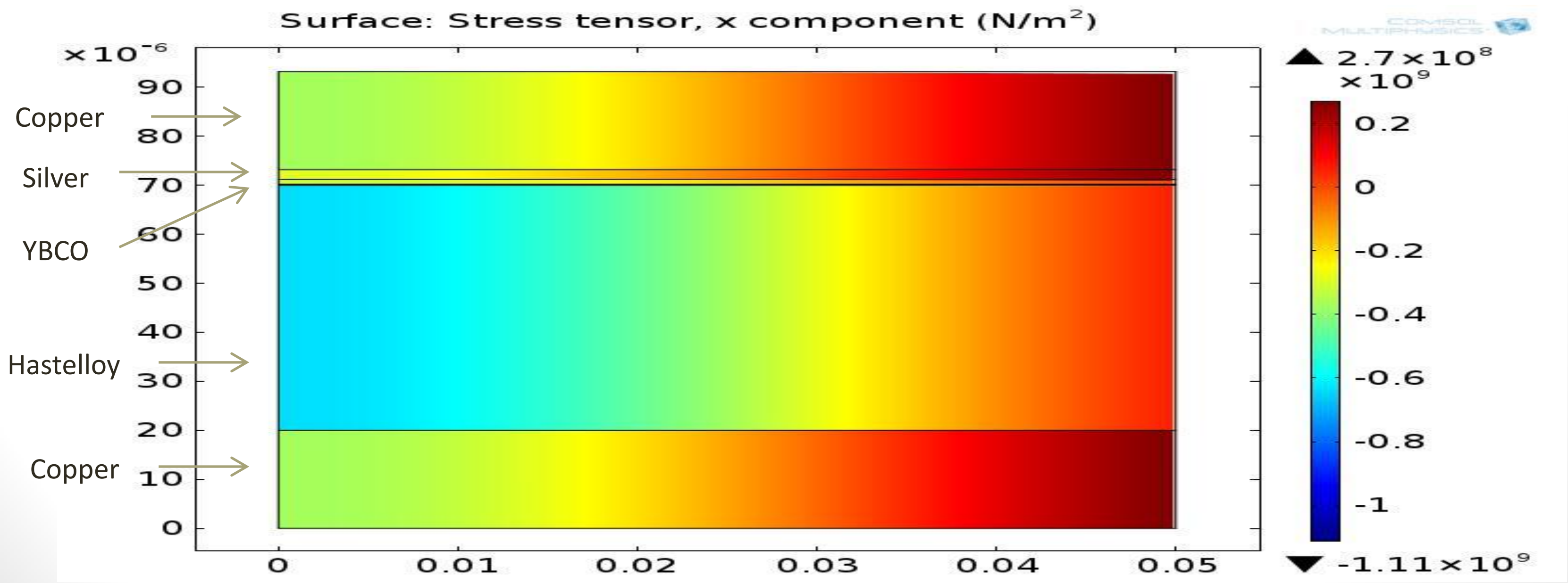


Sample #1

Sample #2

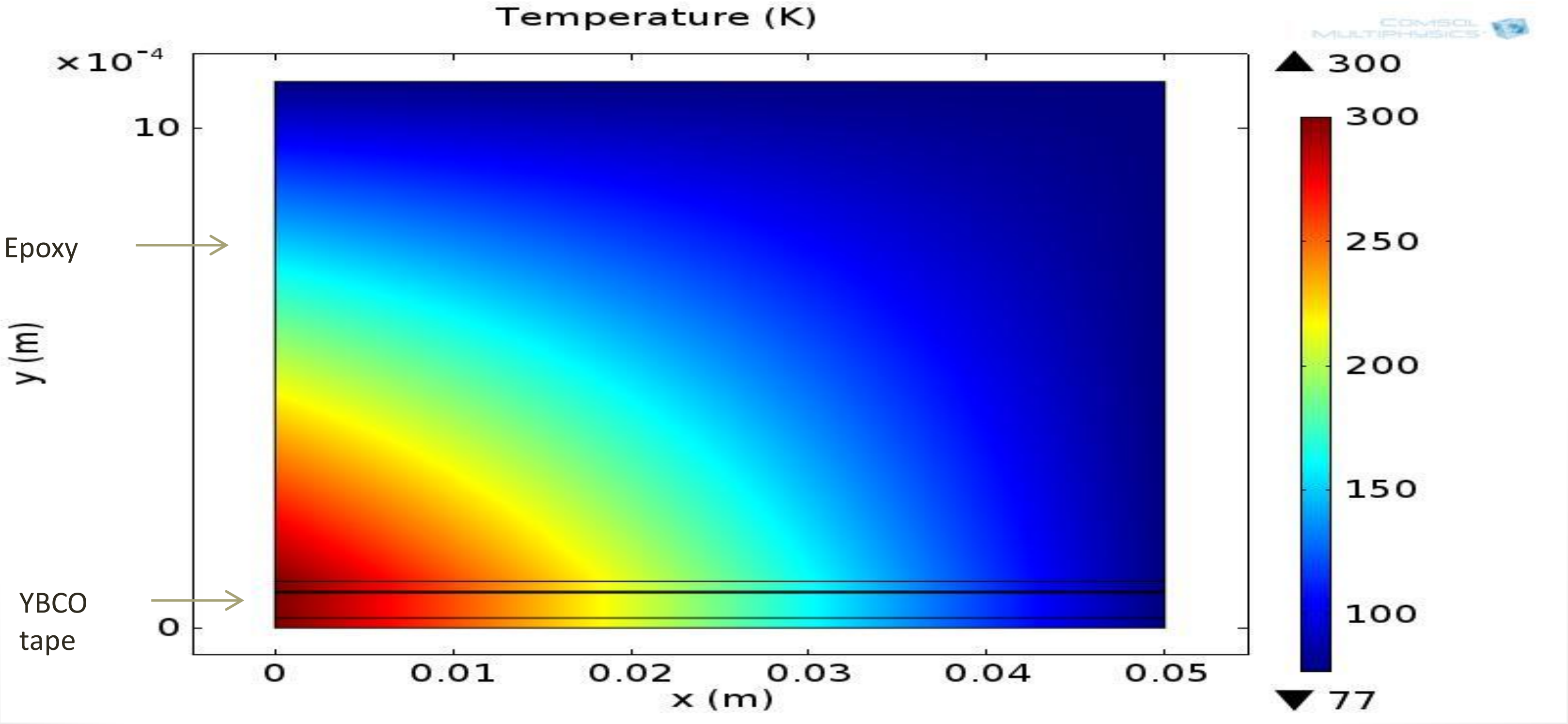
Finite element model

- 2D FEM model
- All layers simulated with 2D mesh
- Anisotropic YBCO thermal expansion implemented
- Reference temperature 293K with imposed displacement due to cooling down



Epoxy covered model

- Addition of 2 mm layer of epoxy
- Thin elastic condition on the border as schematization of glue
- 2D temperature distribution



Stresses from FEM model

	T max	σ x (MPa)	σ y (MPa)	σ z (MPa)	τ xy (MPa)
No epoxy	300 K	-280	0.0045	-100	0.1
No epoxy	500 K	-600	0.005	-390	1
No epoxy	700 K	-900	0.008	-680	1
Epoxy	300 K	-310	0.025	-100	0.6
Threshold		-800	1	-800	20

- Vertical stresses are lower than delamination values (1 MPa)
- Shear stresses are lower than threshold values (20 Mpa)
- Compressive stresses can exceed if temperature is over 600 K
- No significant differences between the two models

Final Considerations

- Experimentally revealed the quench degradation behavior and temperature limits of REBCO coated conductor
- Showed that the epoxy has a strong role in lowering the temperature degradation limit through delaminating the YBCO layers: avoid epoxy or give the YBCO and epoxy a weak bond
- Degradations occured at 700 K are well explained by the 2D model (too high compressive stress).
- The stronger is the connection between epoxy and tape, the earlier the degradation occurs.

Next steps

- A 3D model is necessary to find out if some normal tensile stresses are induced by the temperature rise and epoxy deformation.
- Tests with different heaters and covers should be done to confirm the behaviour of the epoxy impregnation.