A NEW CHANCE FOR Bi-2212 WIRES TO BOOST THEIR APPLICATIONS IN HIGH MAGNETIC FIELDS

Andrea Malagoli

CNR-SPIN

CNR-SPIN INSTITUT

SPIN research activity is organized into six “Activities” :

Novel superconducting and functional materials for energy and environment
(P.I.: Andrea Malagoli)

Superconducting and correlated low dimensional materials and devices for quantum electronics and spintronic
(P.I : Procolo Lucignano)

Innovative materials with strong interplay of spin orbital charge and topological degrees of freedom
(P.I : Mario Cuoco)

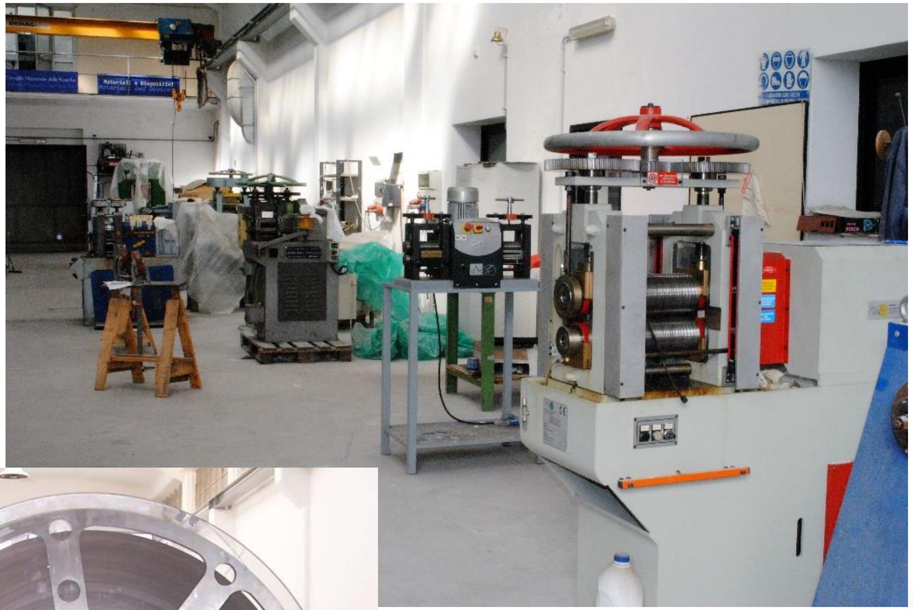
Light-matter interaction and non-equilibrium dynamics in advanced materials and devices
P.I : Roberto Cristiano)

Advanced materials and techniques for organic electronics, biomedical and sensing applications
(P.I : Annamaria Massone)

Electronic and thermal transport from the nanoscale to the macroscale
(P.I : Giovanni Cantele)

WIRE DEVELOPMENT LAB @

Our lab has the unique capability to combine wires development and long length production



First in the world
1.6 km long batch of MgB_2 tape
18 batches realized

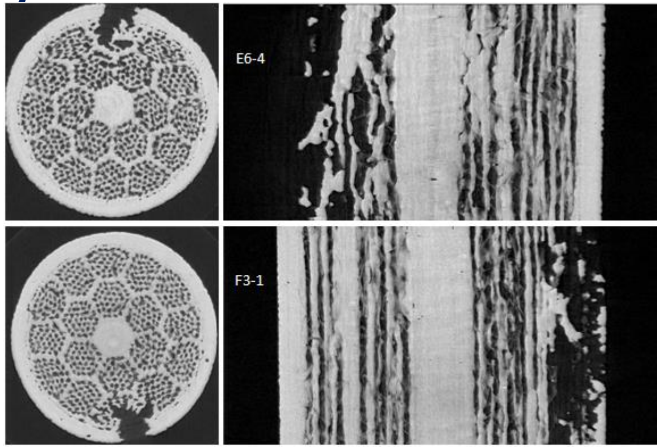
BI-2212 WIRES STATU

KEY POSITIVES

- A flexible conductor technology
  - Round, rectangular, square…..
  - Fine filaments
  - Twisted
  - Multiple architecture
- Excellent conductivity matrix without any need for diffusion barrier
- If reacted under OP (50-100 bar) the properties are well above the applications requirements: $J_E \approx 800$ A/mm^2 @16T
- The fabrication route is the same industrialized for Nb-based and MgB_2 superconductors

CRITICAL POINTS TO FACE

- Mechanical properties: low E and low Yield Strength
- Bubbles and internal pressure formation in long length (≥1m) wires due to **Carbon impurity** (evolving in CO_2) and **porosity**

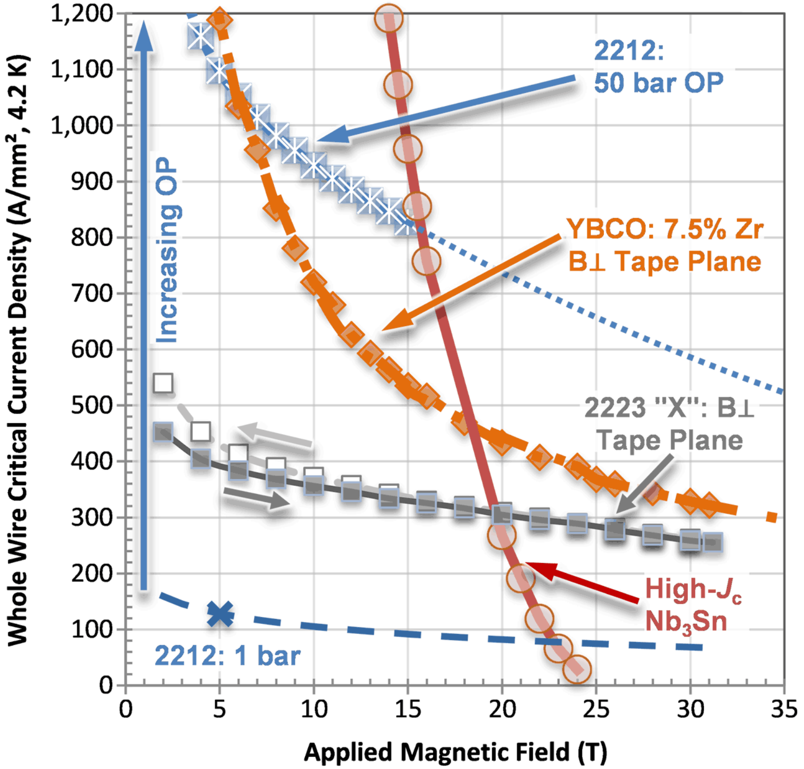


- Wind and react technique like Nb_3Sn but, if OP needed, more complex
  - 890 C, not 670 C
  - 50/100 bar overpressure, not 1 bar
- Costs

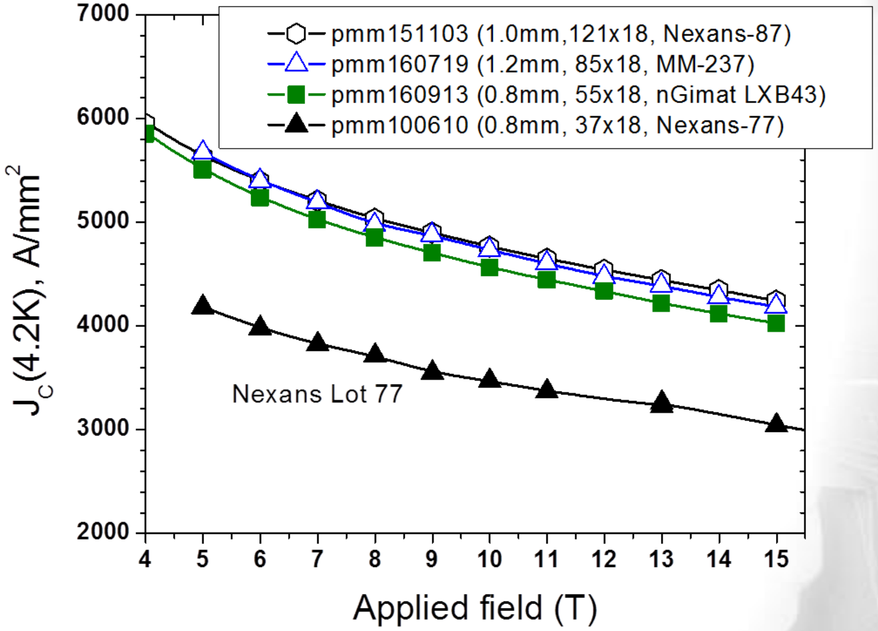
OP HEAT TREATMENT @

Courtesy by D. Larbalestier

OP-furnace:
6 zone, active vol. 13 cm x 40 cm



Properties have significantly improved



successfully replaced the classical powder producer Nexans with two new suppliers, nGimat and MetaMateria

J.Jiang 4MO1-03

Bi-2212 wires status

Key positives

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Critical points to face

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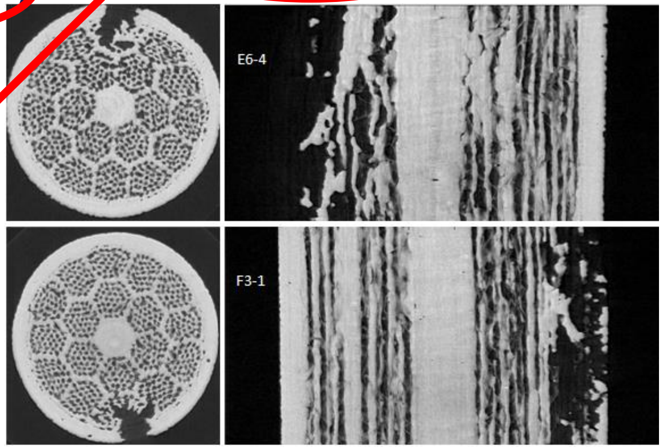
≈30% in the wire

≈20 ppm in the powders



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CERN/CNR-SPIN COLLABORATION

ADDENDUM FCC-GOV-CC-0086/EDMS 1750320/KE 3507 OF THE MEMORANDUM OF UNDERSTANDING FOR THE FCC STUDY

The scope of this collaboration is to advance the performance of three superconducting materials (Bi-2212, MgB_2, IBS), using industrially scalable productive methods, to make them suitable for high-field magnet applications.

- **MgB_2:** increase the operating field by adopting an original doping method;
- **Bi-2212**: reproduce the performance today obtained by high pressure heat treatment with a mechanical deformation process;
- **IBS:** develop prototype IBS conductors that meet the critical current density (J_c) requirements through reliable, simpler and scalable techniques that would permit industrialisation.

The goals:

Optimisation of the architecture and deformation process of Bi-2212 multifilamentary wire samples for high density

The target J_E is 400–600 A/mm^2 at 16 T and 4.2 K measured on optimised samples, both as short lengths and on a suitable VAMAS sample holder.

ENABLING RESEARCH 2017 – EUROFUSION «ALTERNATIVE HTS WIRES»

PARTNERS: TUW (AUSTRIA) – CNR-SPIN (ITALY) – ENEA (ITALY)

The aim of the project is to **break the ground for the development of a round, multifilamentary, and inexpensive high-performance HTS wire for fusion magnets.** We split this general aim into two main objectives:

1) Optimization of the thermo-mechanical pre-treatment of the Bi-2212 wires to obtain the performance required for fusion magnets without the need of a high-pressure treatment during the formation of the superconducting phase. The wire is aimed to be an alternative to existing HTS and LTS wires for fusion magnets.

2) Development of suitable precursors for the Tl-1223 wire production. Nano-crystalline or amorphous powders which result in textured-growth without the need of heating above the melting temperature are in the focus. Demonstration of textured-growth at interfaces is planned.

The goals :

Optimization of the pre-reaction mechanical treatment, wire architecture and heat treatment to avoid bubble formation and to ensure a high degree of texture.

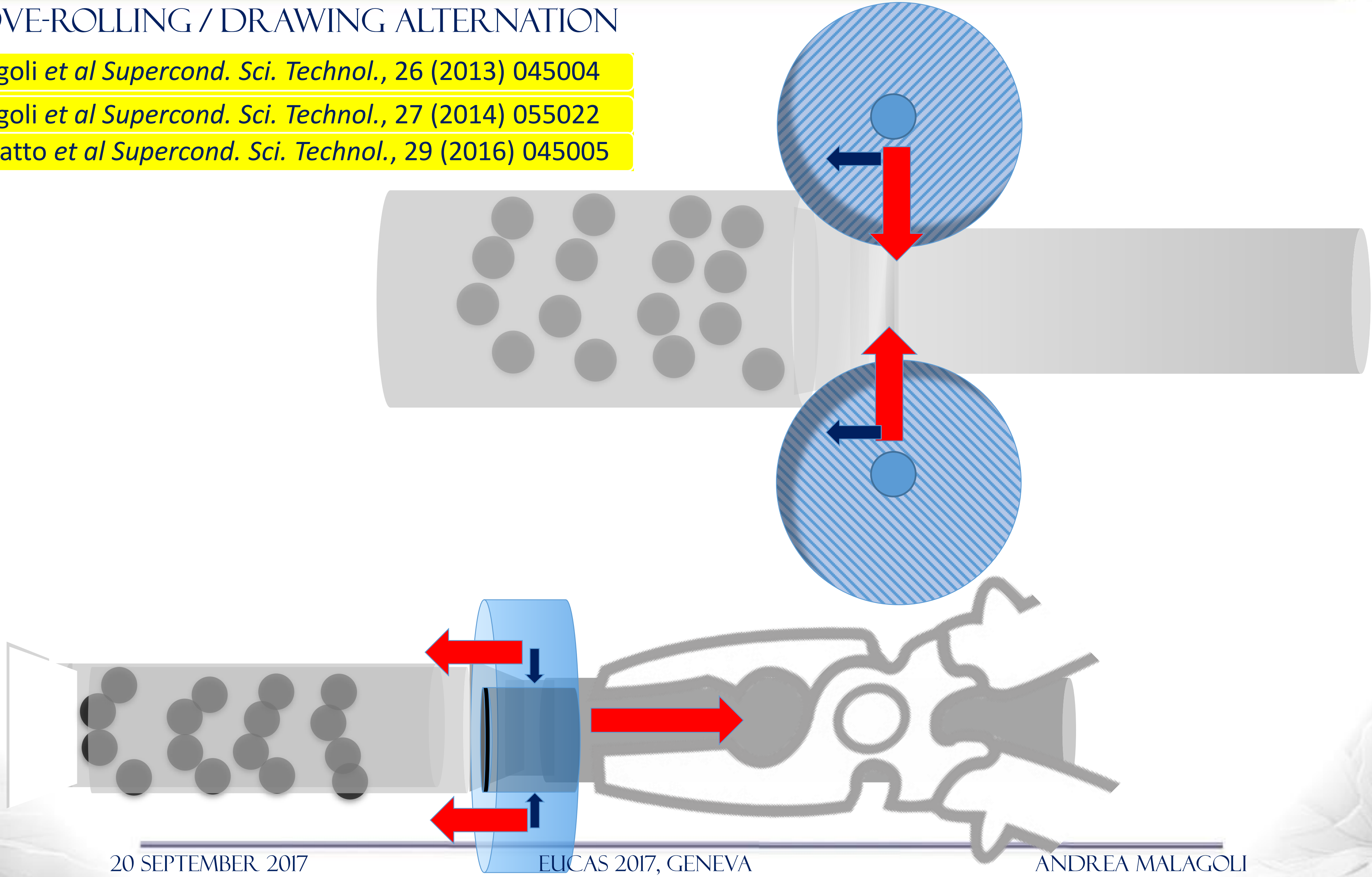
Optimal process parameters and wires protoype with $J_e \approx 500\ A/mm^2$ at high fields

GROOVE-ROLLING / DRAWING ALTERNATION

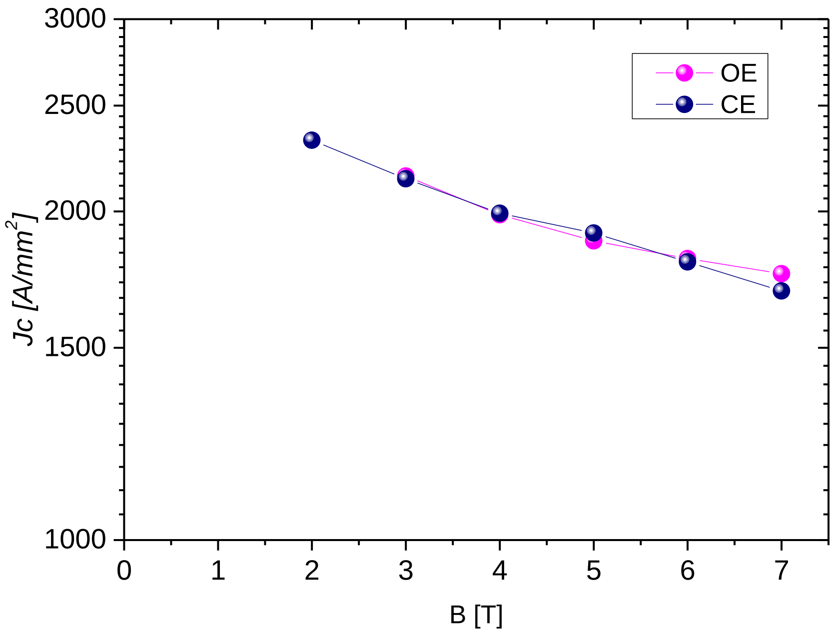
A. Malagoli *et al Supercond. Sci. Technol.*, 26 (2013) 045004

A. Malagoli *et al Supercond. Sci. Technol.*, 27 (2014) 055022

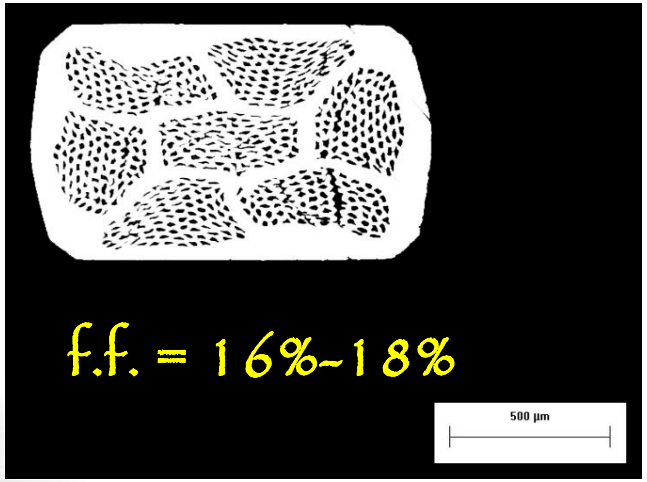
A. Leveratto *et al Supercond. Sci. Technol.*, 29 (2016) 045005

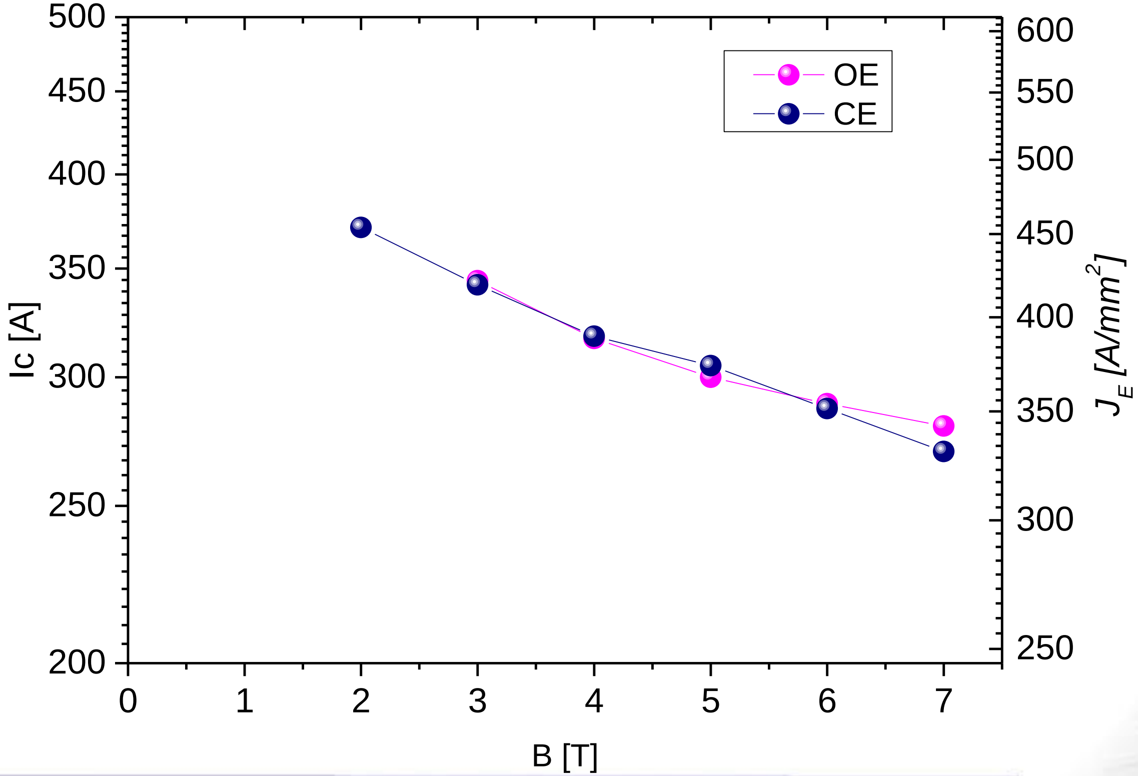


A. Leveratto *et al, Supercond. Sci. Technol*. 29 (2016) 045005

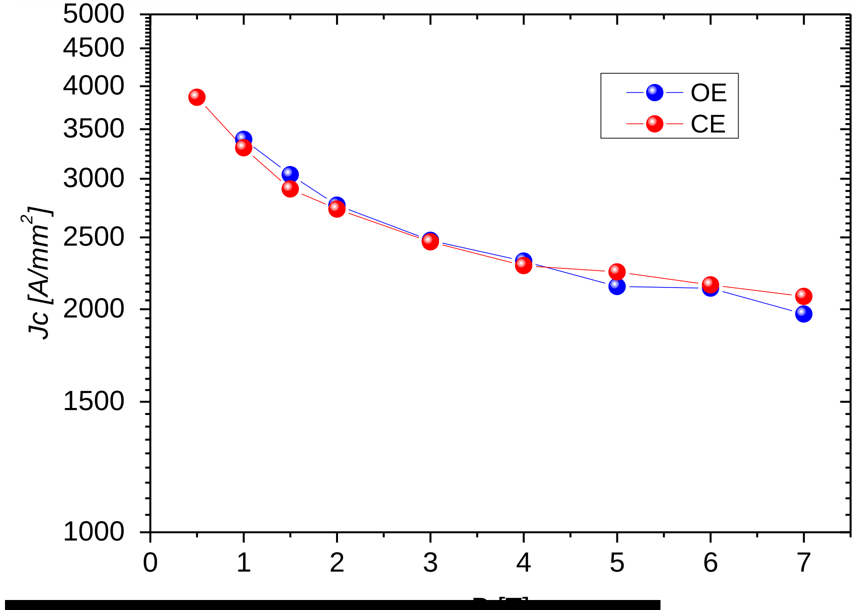


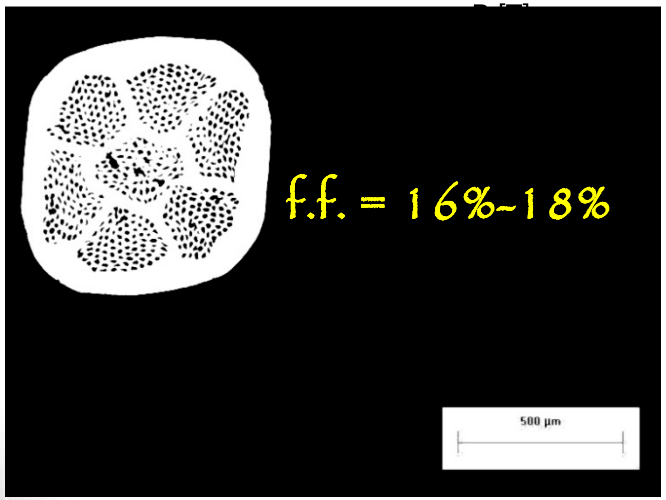
No reduction in Closed Ends-wire!





SQUARE WIRE





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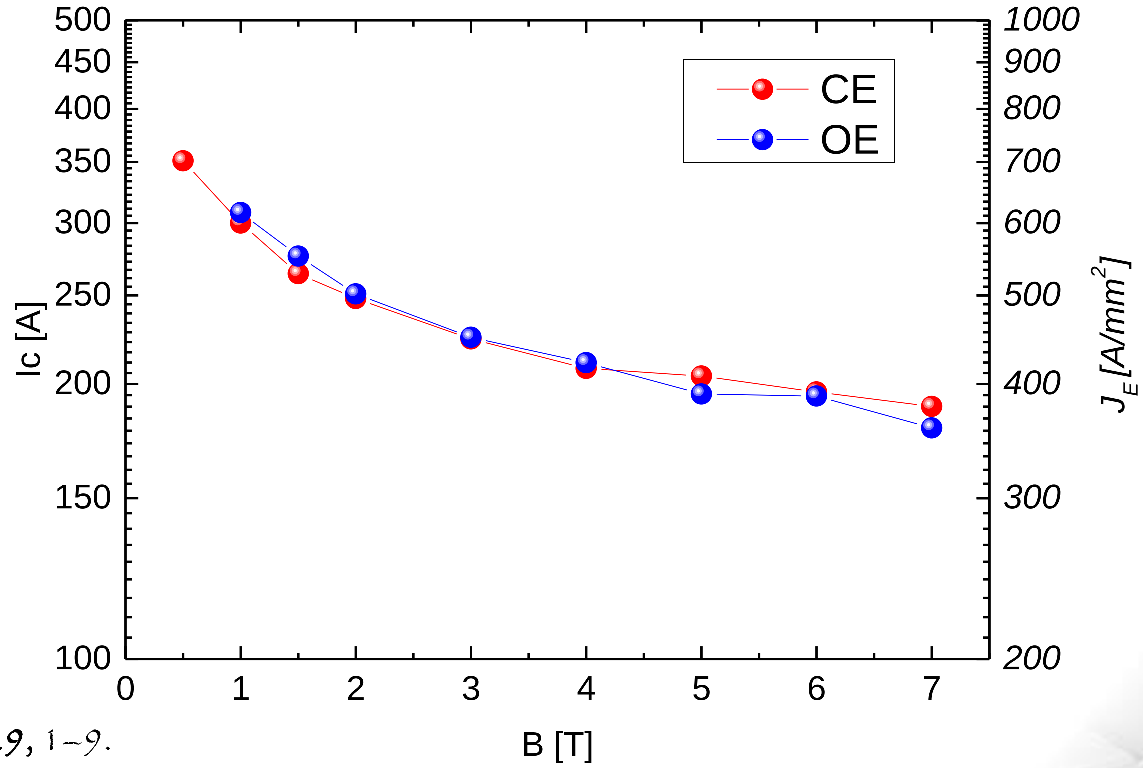
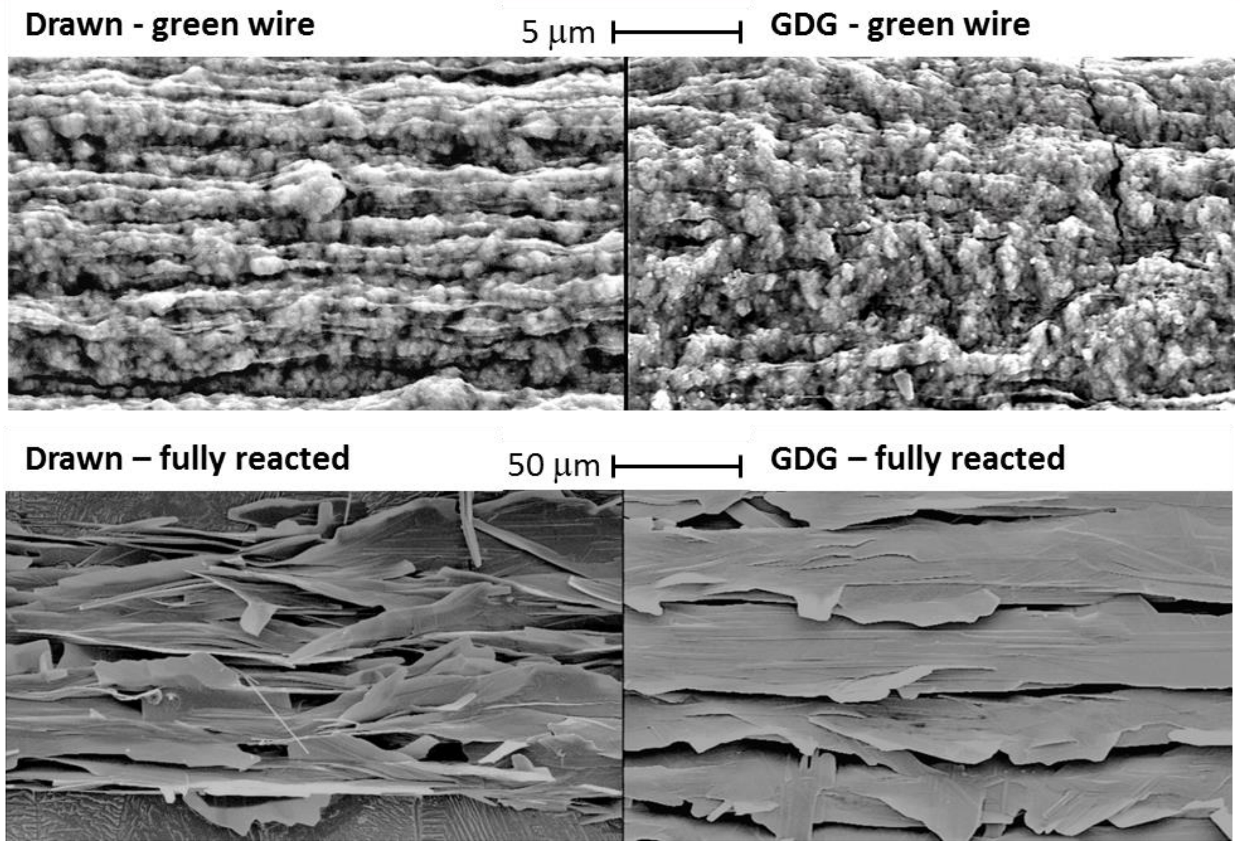


A. Leveratto et al, 2016, *Supercond. Sci. Technol.* **29**, 1-9.

WHAT ACTUALLY HAPPE



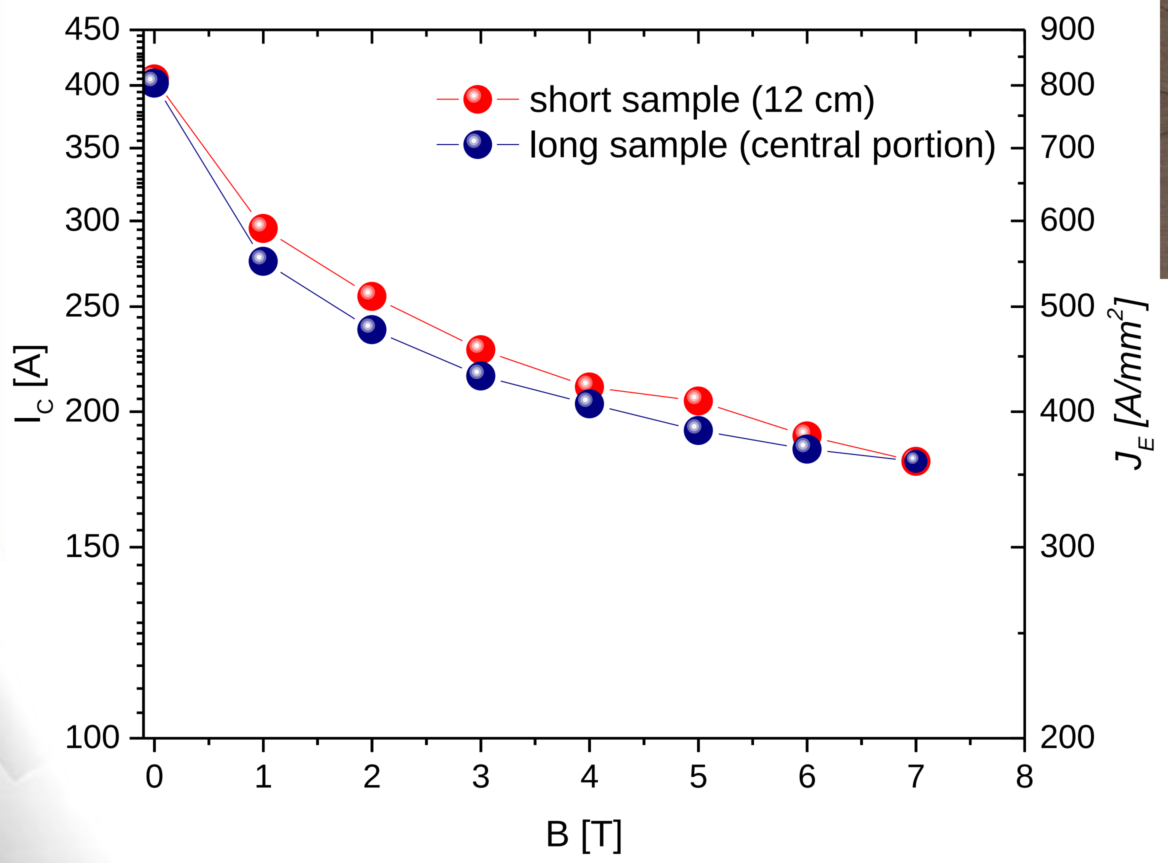
We actually observed what we hypothesized: after flowing in the longitudinal direction the voids (visible in the left figure) were filled thanks to a compression in the transversal direction due to the groove-rolling.

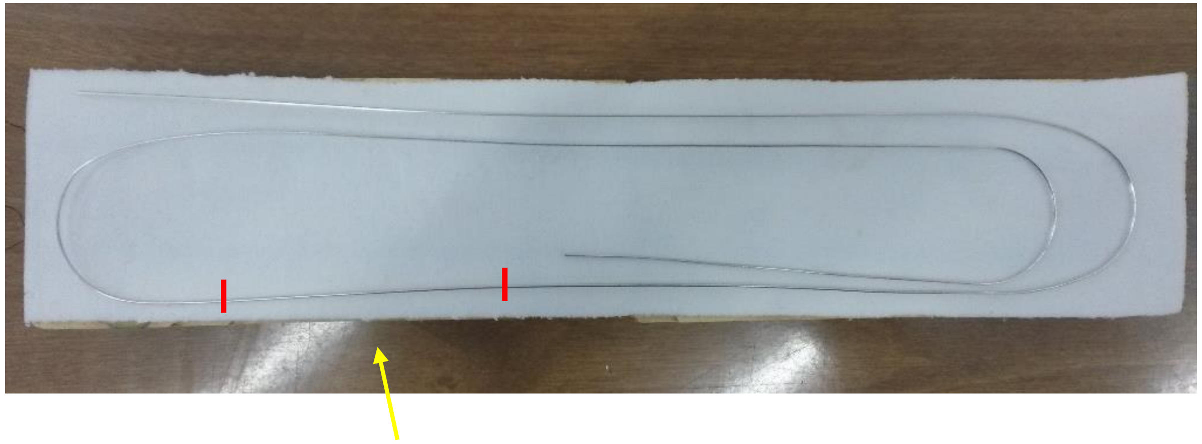
Not a 100% dense wire but the residual porosity is low enough to avoid agglomeration

⬇

<u>No bubbles, no internal pressure</u>

1.4 m long sample



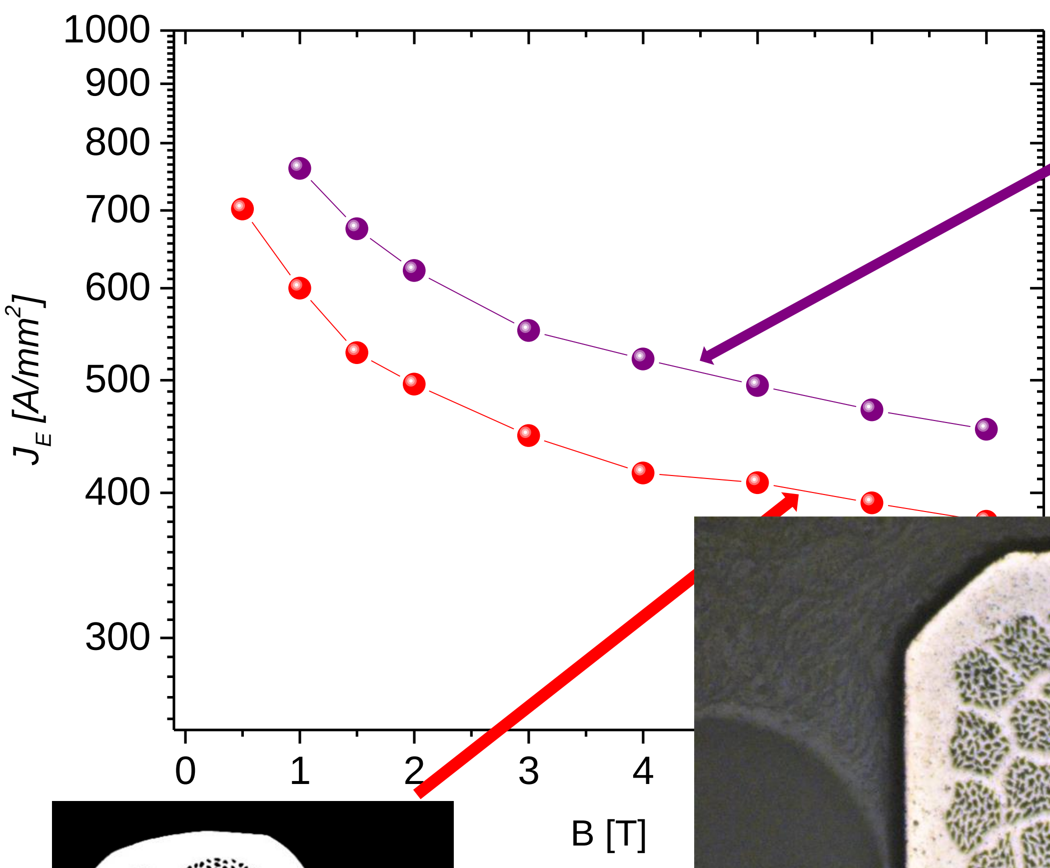


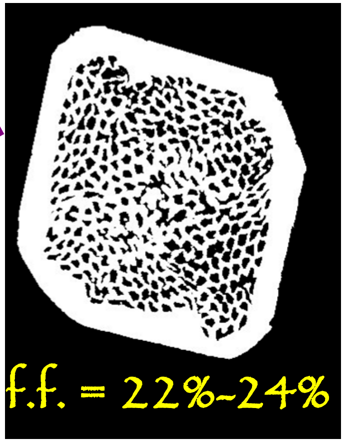
central portion

No Ic degradation!!!!

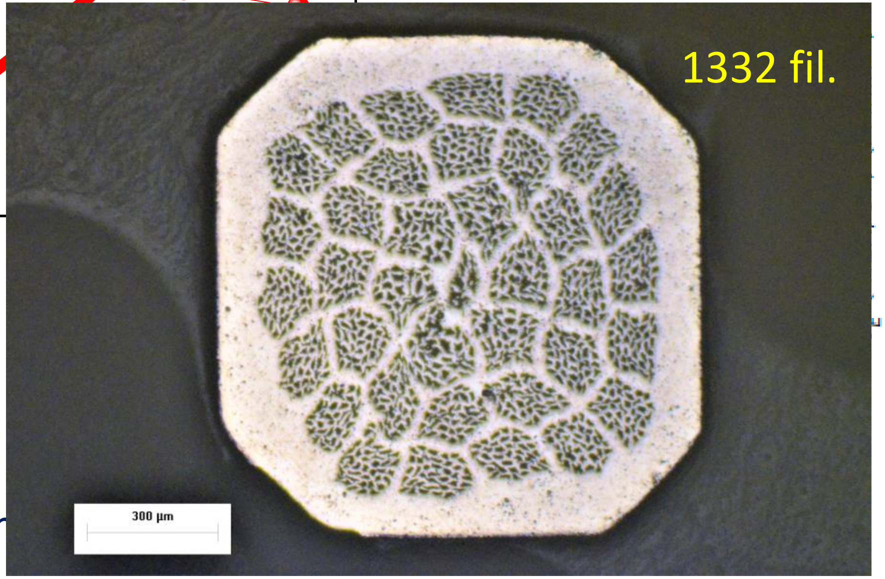
Same results at the ends of the wire

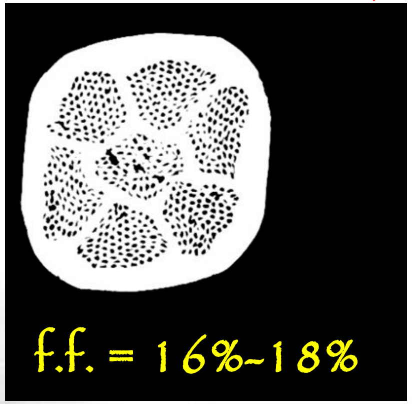
TOWARD THE OPTIMIZ



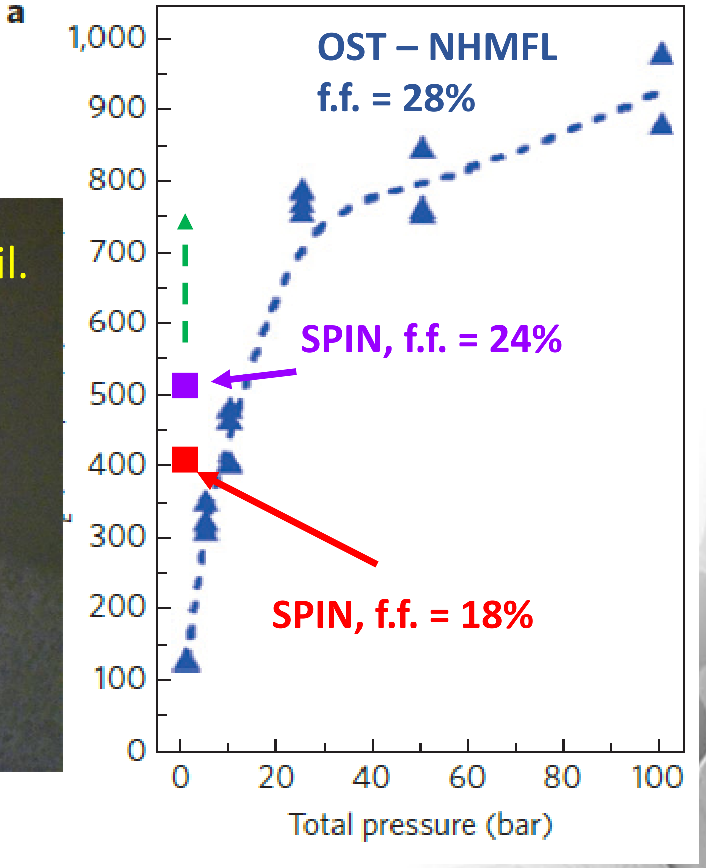


333 filaments



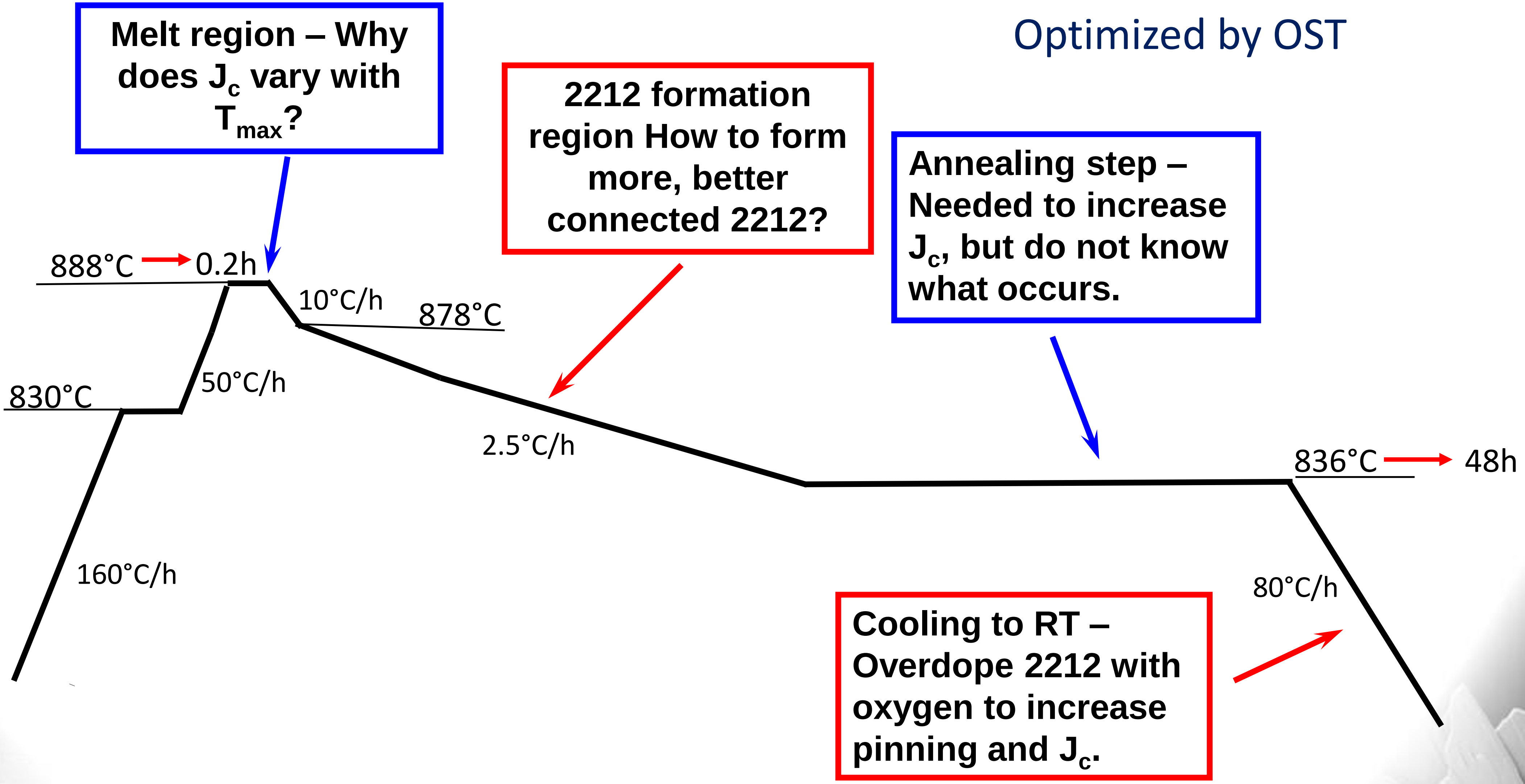


595 filamen



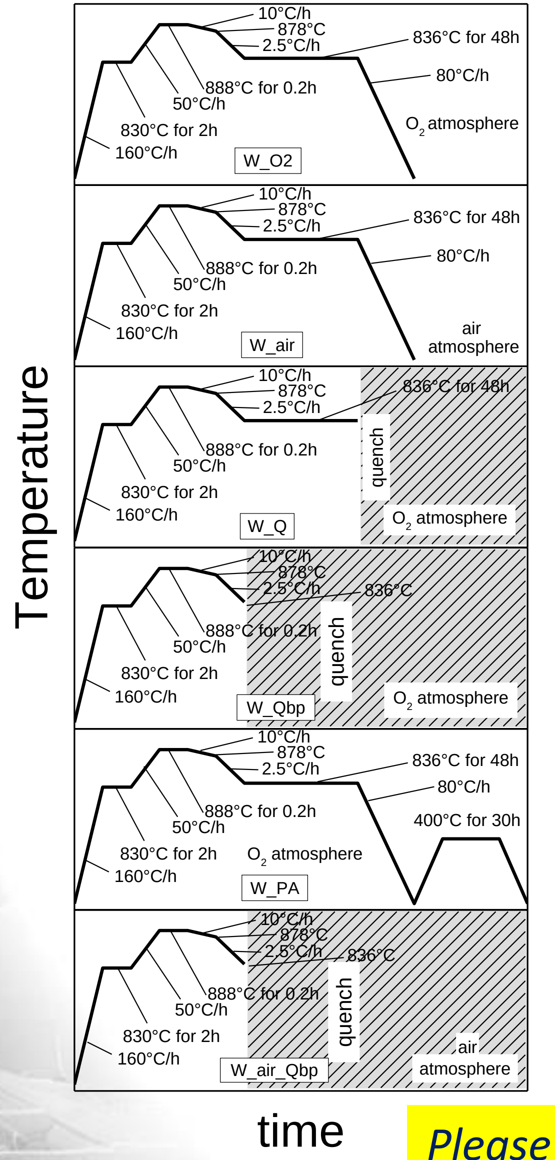
PARTIAL-MELT PROCESS

Optimized by OST

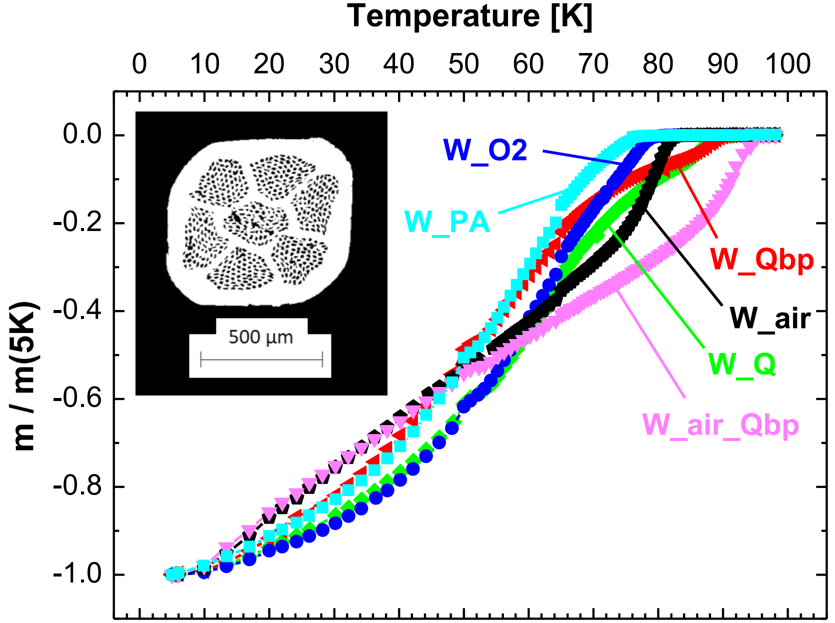


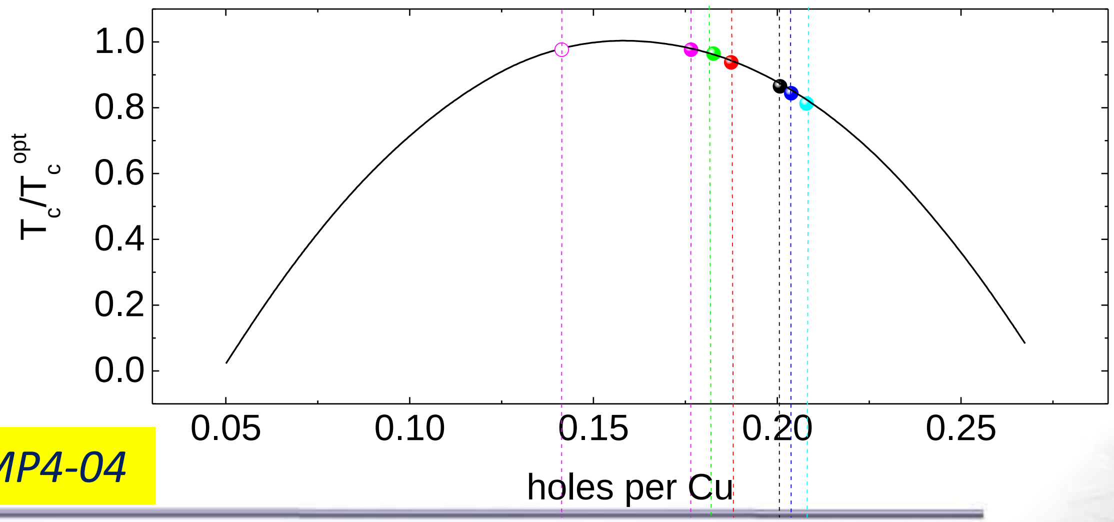
GB–ANALYSIS THROUGH I_C(T) MEA

I. Pallecchi *et al Supercond. Sci. Technol. Supercond. Sci. Technol*. 30, (2017) 095005



Obtained samples with different Oxygen overdoping

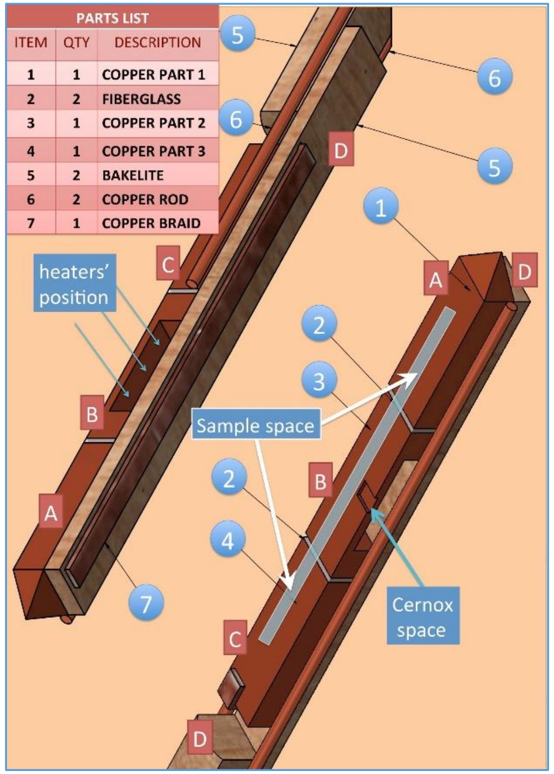


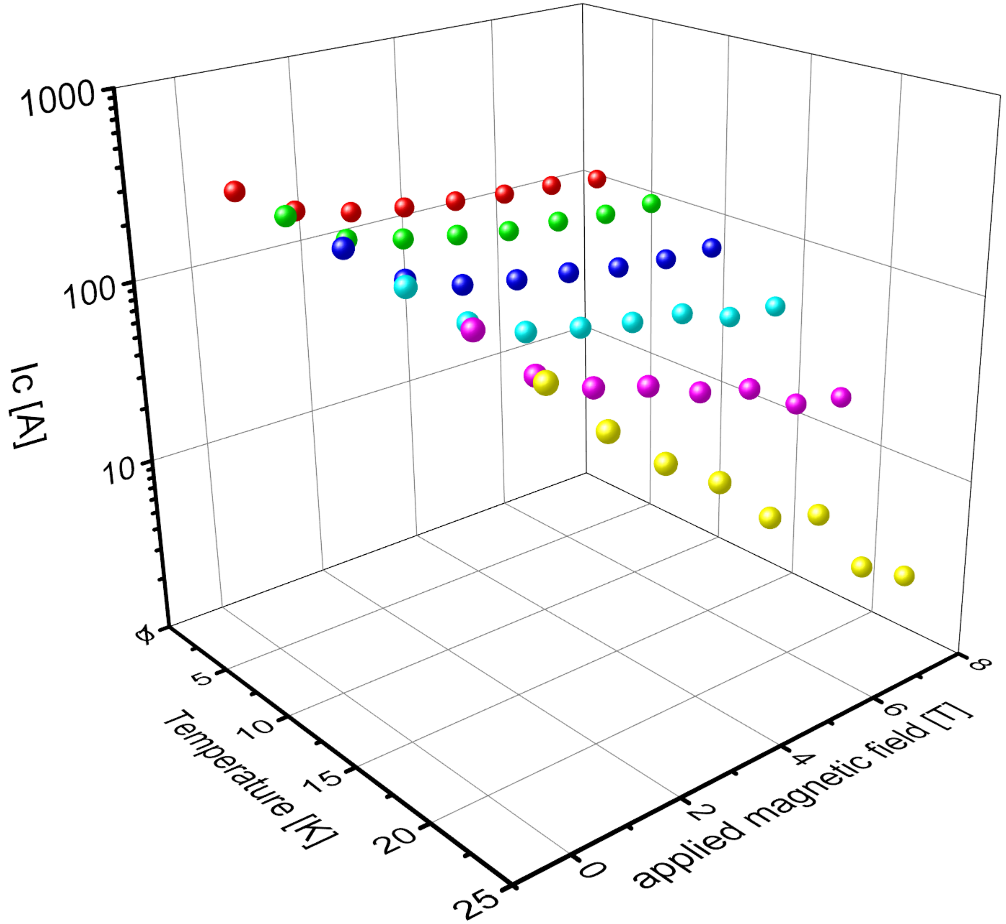


Please see A. Leveratto 3MP4-04

I_C (T,B) MEASUREMENT SYS

A. Leveratto *et al IEEE Trans. Appl. Supercond.* 27(2016), 6400303

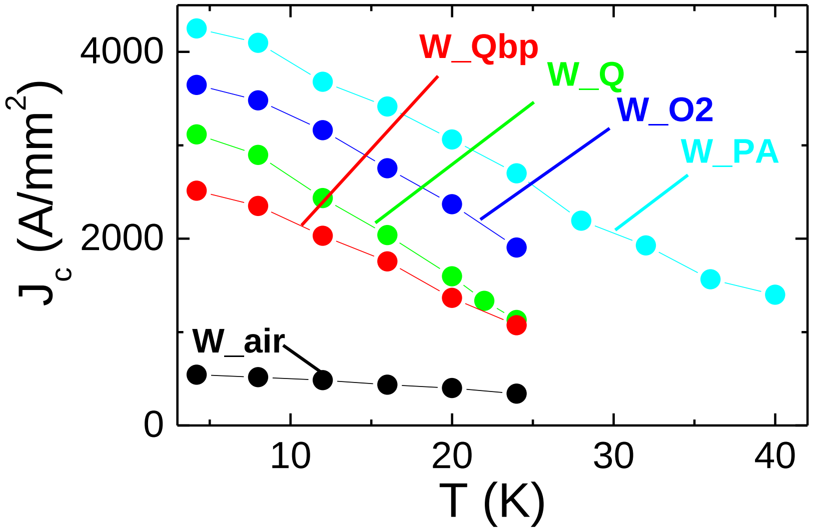


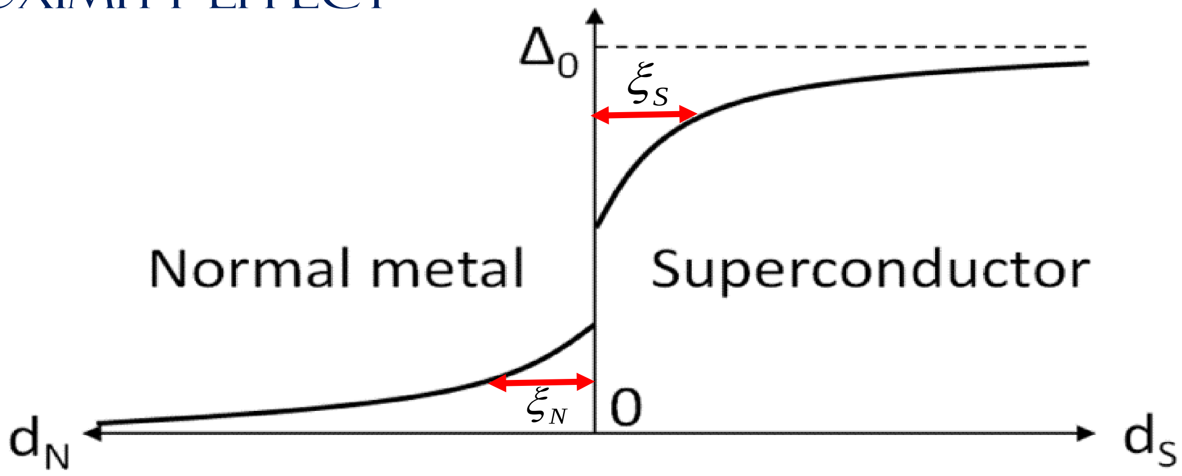


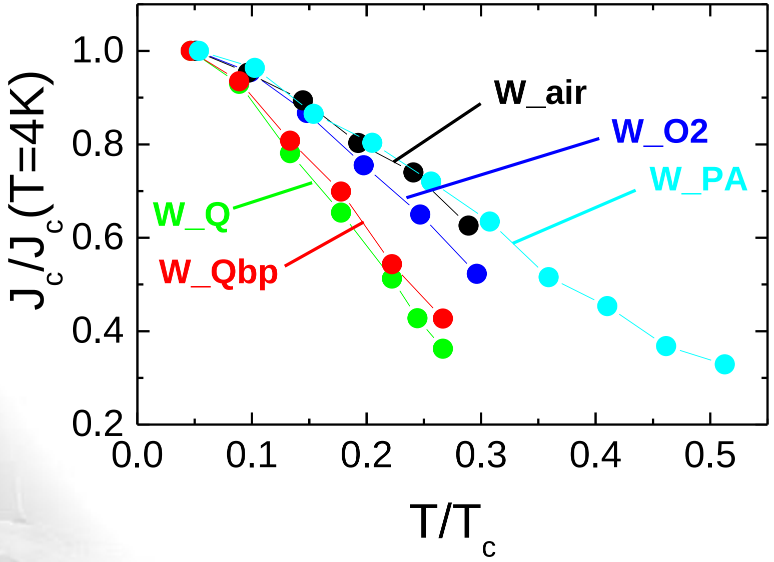
- Both current contacts are kept at low temperature (direct thermal link with the Helium bath)
- The thermometer is in thermal contact with the sample
- Very high homogeneity of the temperature even with high current flow

GB–analysis through $I_C(T)$ mea

Proximity effect



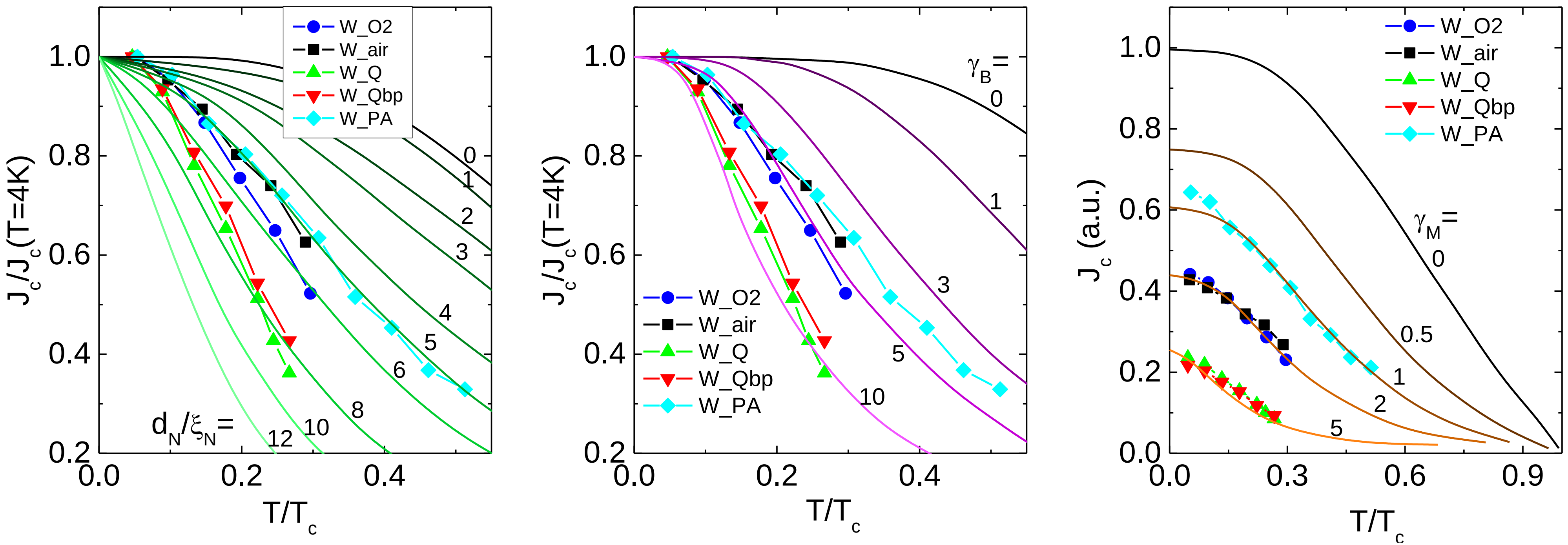




$$\gamma_B = \frac{R_B}{\rho_N \xi_N} \frac{d_N}{\xi_N} \qquad \gamma_M = \frac{\rho_S \xi_S}{\rho_N \xi_N} \frac{d_N}{\xi_N}$$

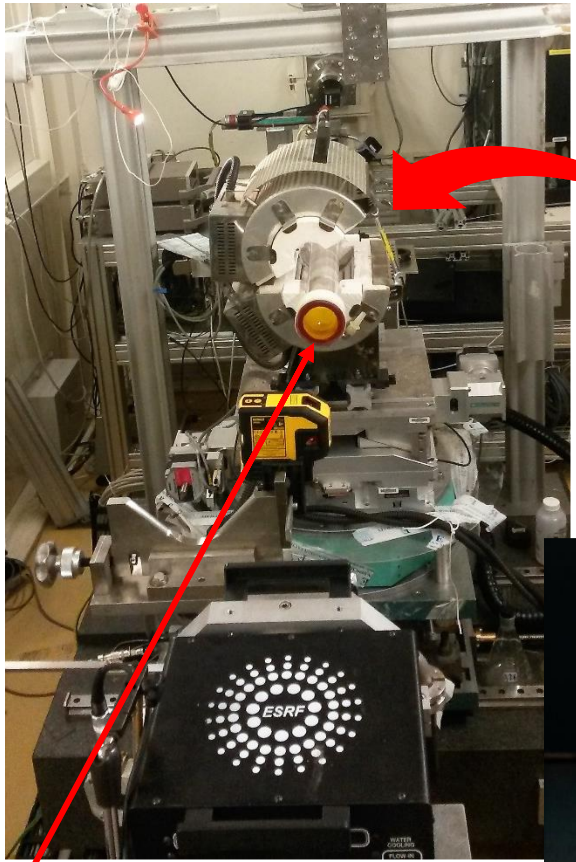
$$\xi_N \propto \frac{1}{\rho_N^{1/3}}, \quad n^{1/3}$$

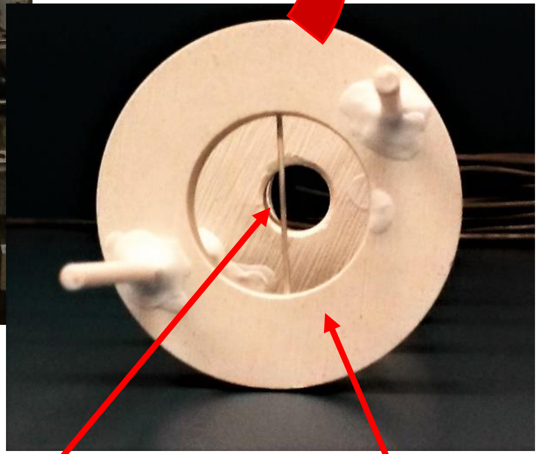
GB–Analysis through $I_C(T)$ mea



- We succesfully applied a model based on the proximity effects and weak link: such a model can be used as well for all superconductors whose weak links are an obstacle to supercurrent (e.g. cuprates, iron pnictides and chalcogenides)
- Among the results what is surprising is that the "quality" of the GBs in Air-sample is very similar to that of O_2-sample: 21% of Oxygen is enough if the heat treatment is complete, but other factors block the transport current. Secondary phases (Bi-2201)?

IN-SITU XRD @ ESRF

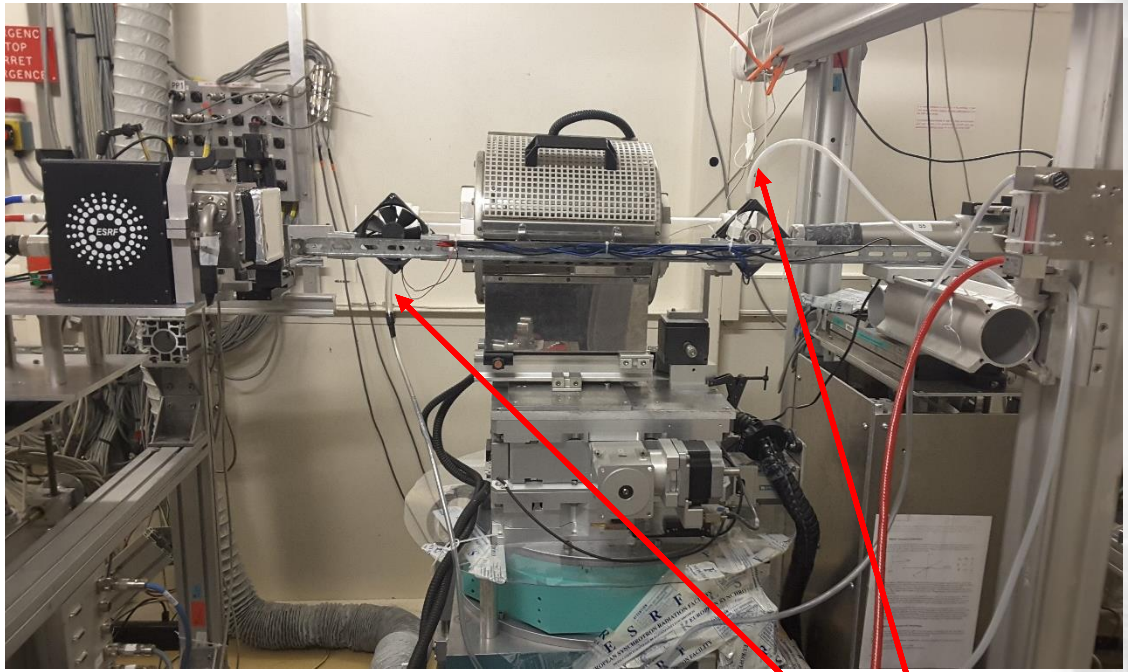




Kapton window

Bi-2212 wire

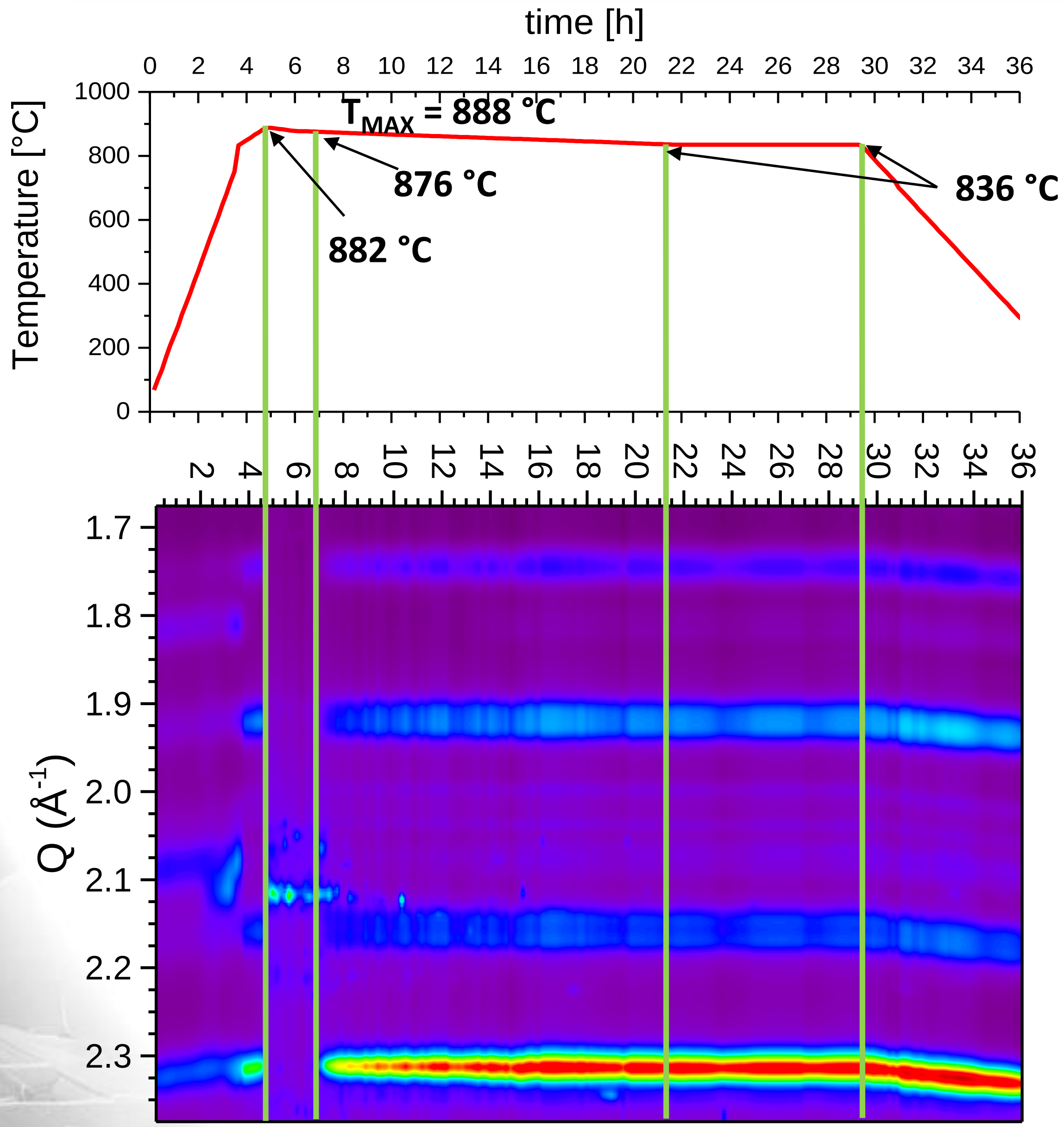
sample holder

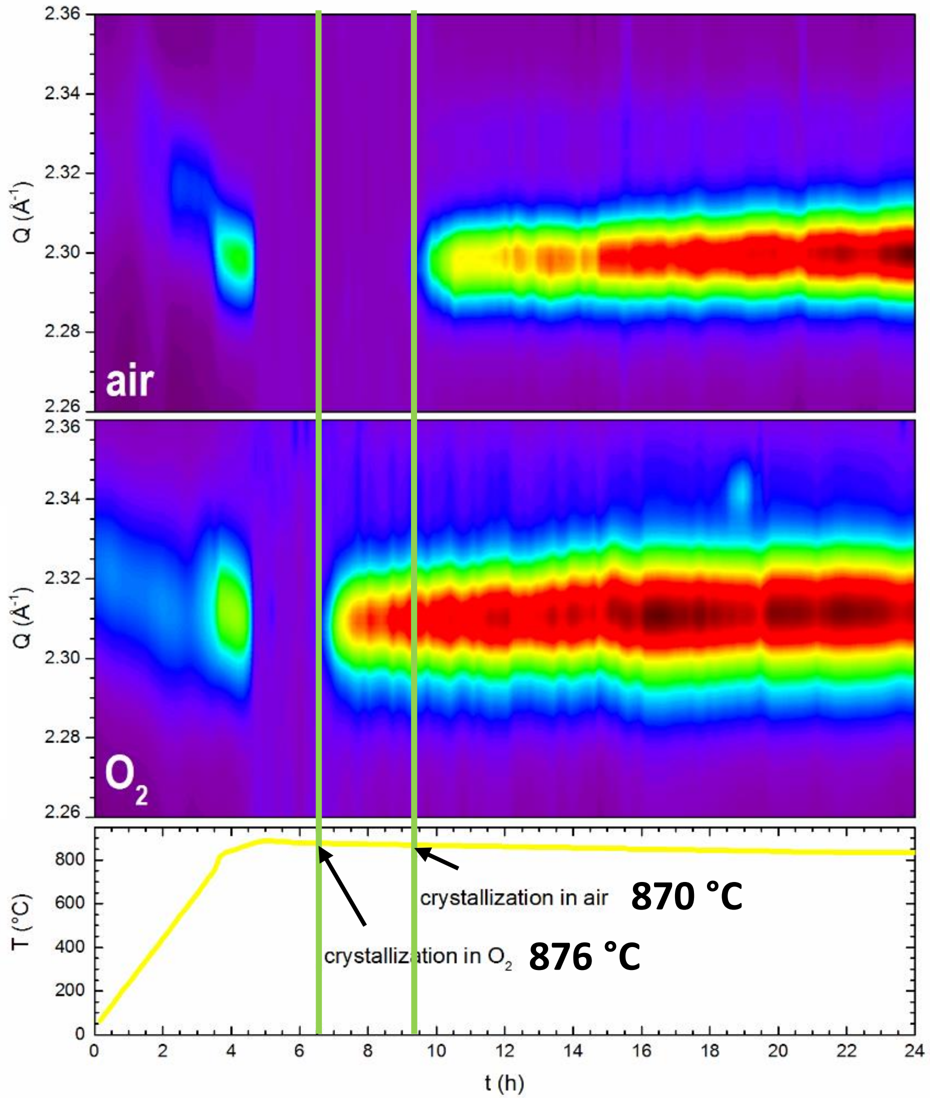


IN and OUT Oxygen flow

Experimental set-up employed during the collection of the XRPD data at the ID11 beamline of ESRF @ Grenoble.

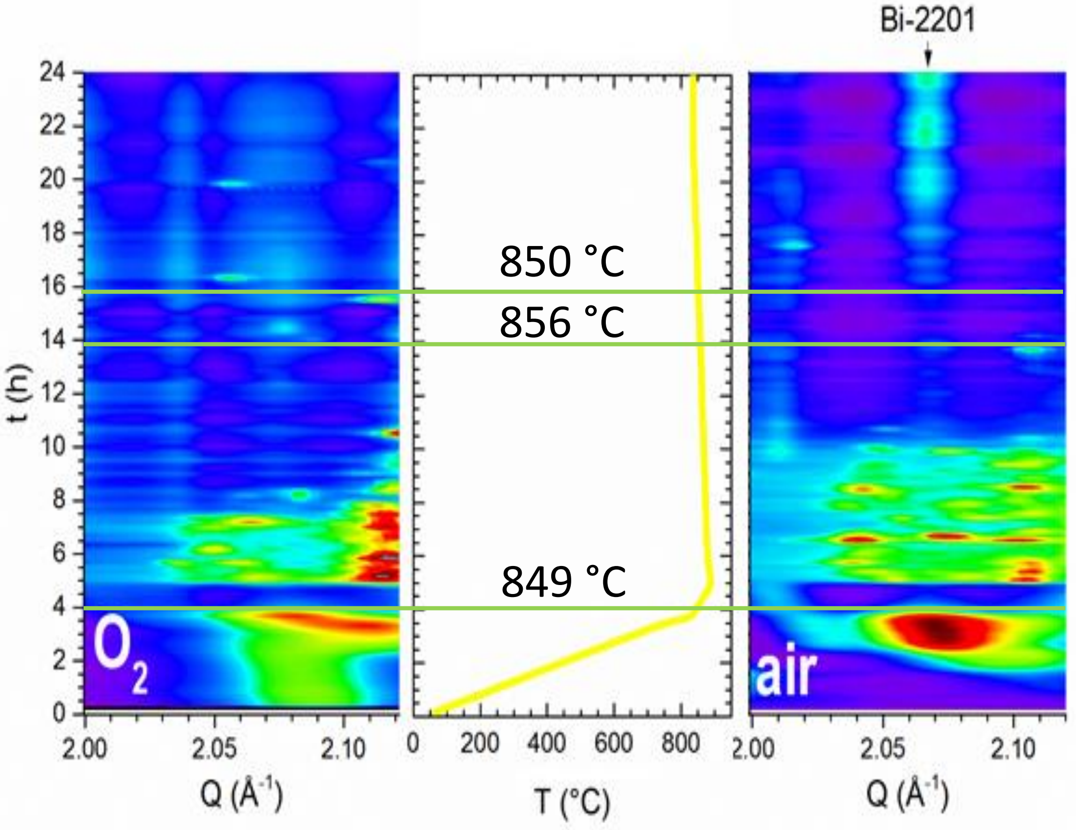
PHASE EVOLUTION & EFFECTS



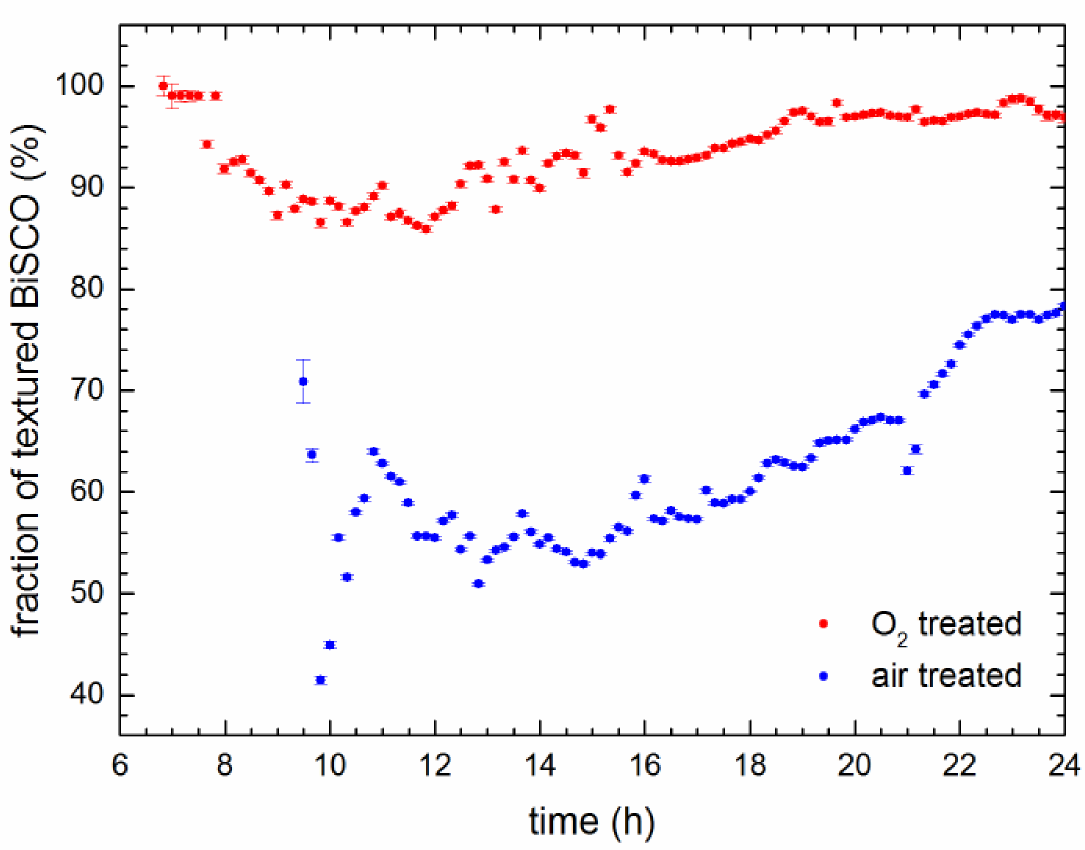


Phase evolution & effects

Bi-2201 evolution



Texturing along [110]



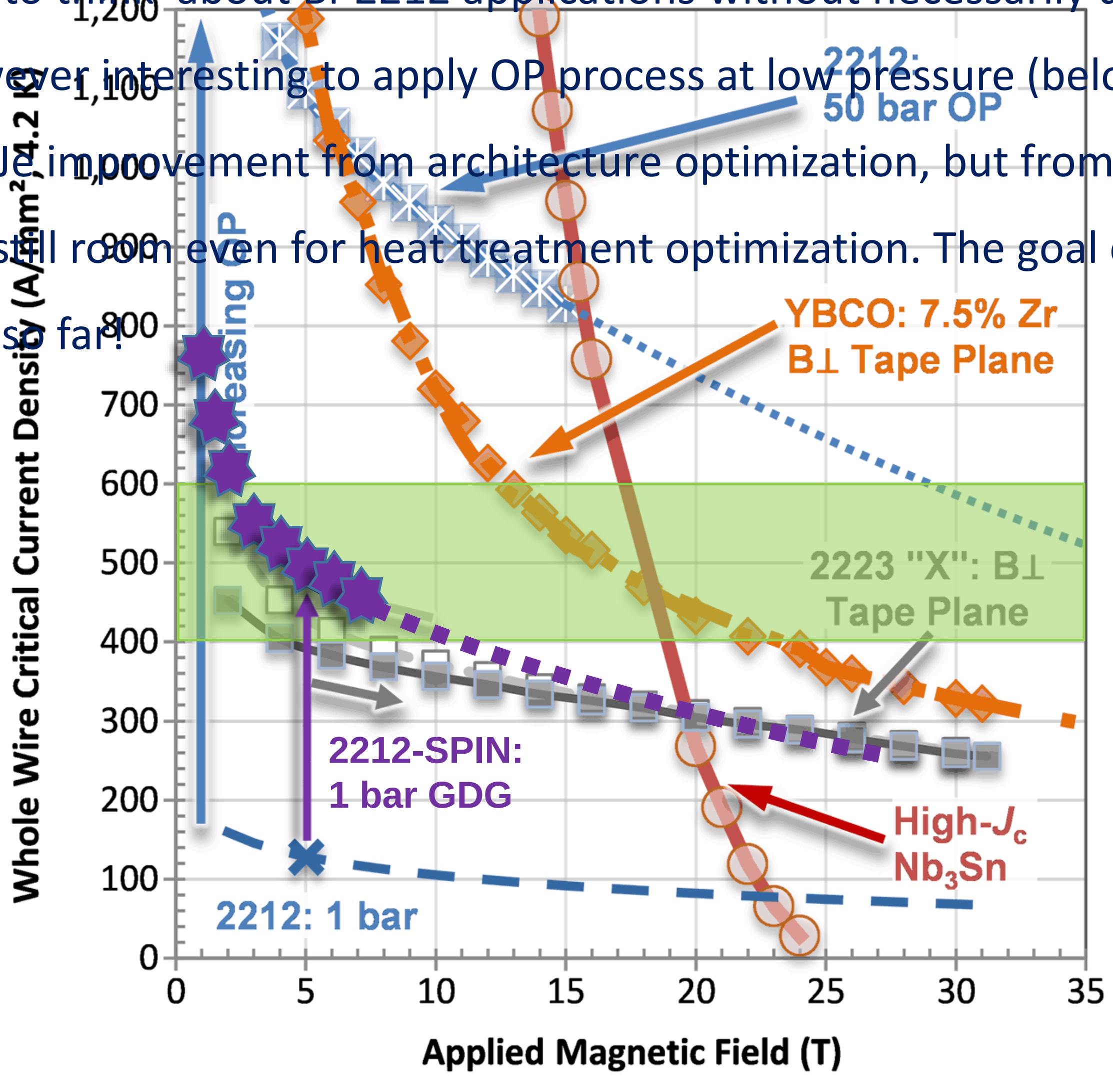
	After 3h@836 °C	After 8h@836 °C	After 8h@836 °C + cooling (295°C)	f.r. 48h@836°C +cooling (T room)
Bi-2201 (wt%) 100% O_2	~3	~3	~5	~5
Bi-2201 (wt%) air	-	-	~9	~9

It seems that Oxygen promotes the Bi-2212 grains orientation

A. Martinelli *et al* in preparation

FINAL REMARKS

- It is reasonable to think about Bi-2212 applications without necessarily using OP
- It might be however interesting to apply OP process at low pressure (below 10 bar) to GDG wires
- Large room for Je improvement from architecture optimization, but from our analysis it comes out that there could be still room even for heat treatment optimization. The goal of 400-600 A/mm^2 at high field (16-20 T) is not so far!



PRICE/PERFORMANCE WITH AG AT $5-30/OZ

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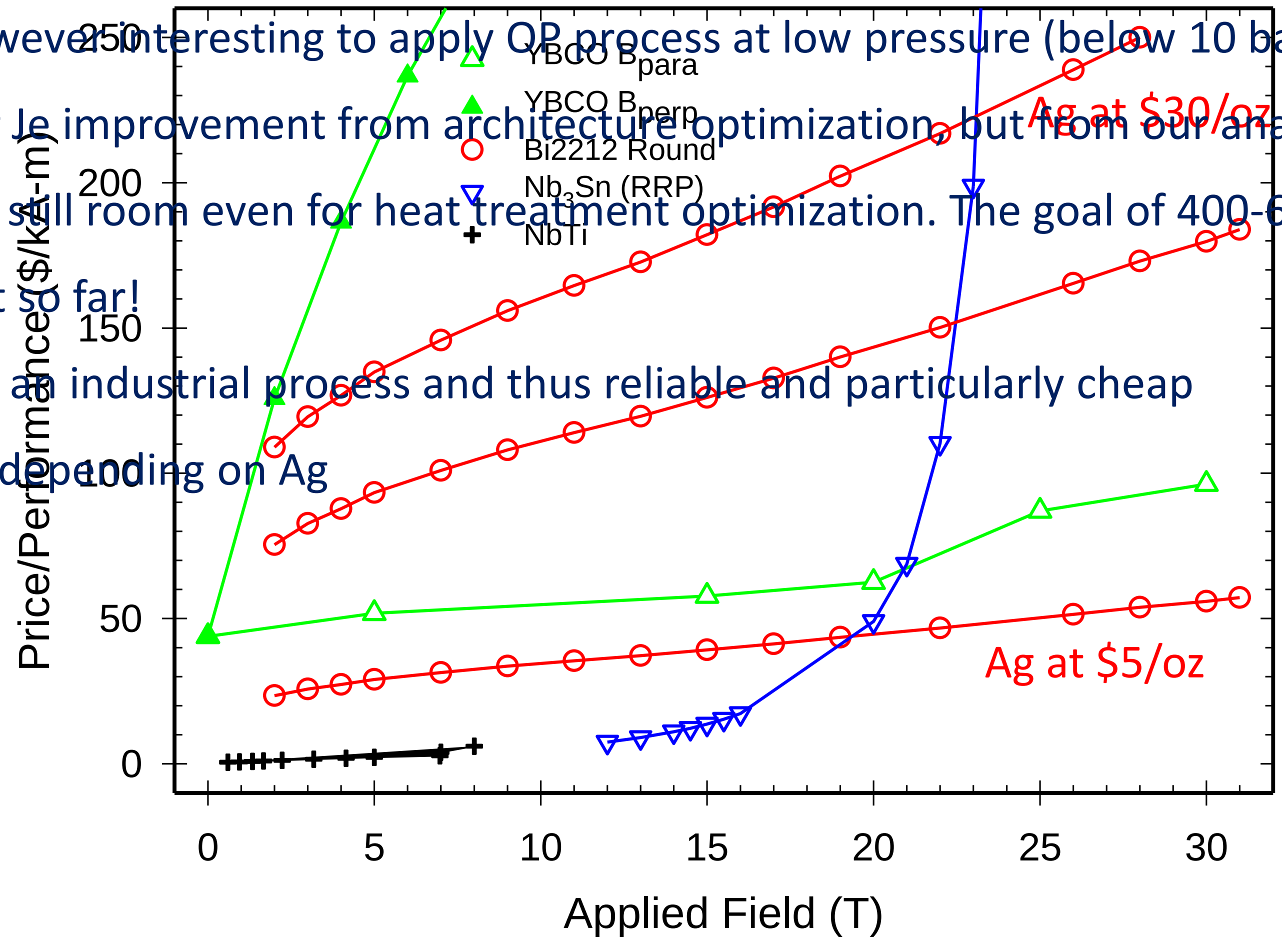
- GDG is already an industrial process and thus reliable and particularly cheap
  - Costs are depending on Ag



Calculations by Strauss and Marken (S4E Paestum May 2014)

Final Remarks

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- It might be however interesting to apply OP process at low pressure (below 10 bar) to GDG wires
- Large room for Je improvement from architecture optimization, but from our analysis it comes out that there could be still room even for heat treatment optimization. The goal of 400-600 A/mm^2 at high field (16-20 T) is not so far!
- GDG is already an industrial process and thus reliable and particularly cheap
  - Costs are depending on Ag
- Mechanical properties are very challenging. Something is going on but a lot has to be done

A. Otto 3LO2-05

- Soon we will start with the realization of long lenght (100-200 m) wires for winding

CO-WORKERS & ACKNOWL

COWORKERS

Alessandro Leveratto, Ilaria Pallecchi, Alberto Martinelli, Valeria Braccini, Luca Leoncino, Emilio Bellingeri, Carlo Ferdeghini

CNR-SPIN Genova, Italy

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