

Increasing critical current density in Bi-2212 round wires by overpressure processing

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Collaboration with BNL, LBNL, FNAL, and OST

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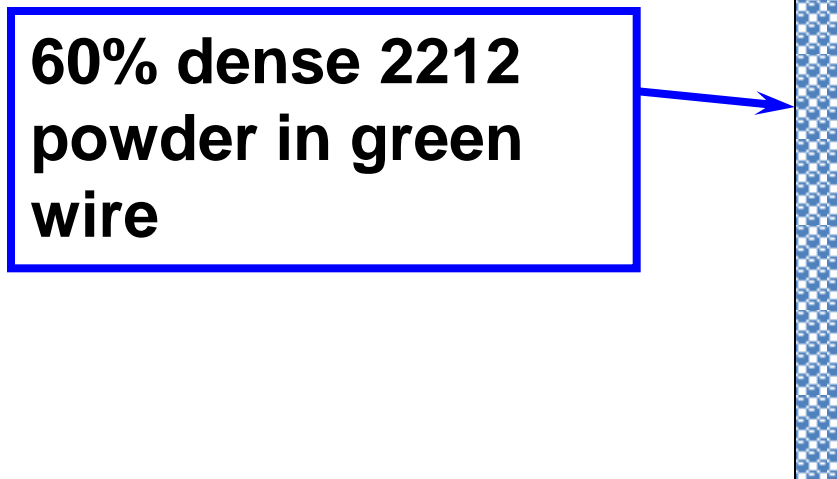
Overview

- **Why 2212 needs overpressure (OP) processing**
- **Increased J_E with OP processing**
- **33.8 T magnet – 10 bar OP processing**
- **Grain boundaries in 2212 wires**



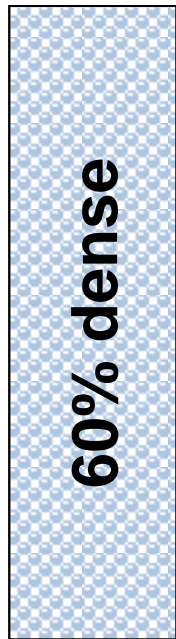
What can happen to 2212 filaments during melt processing?

- Maximum packing density of 2212 powder in filaments is 60-70%
- Focus on the 30-40 vol% of the filament that is gas-filled void space



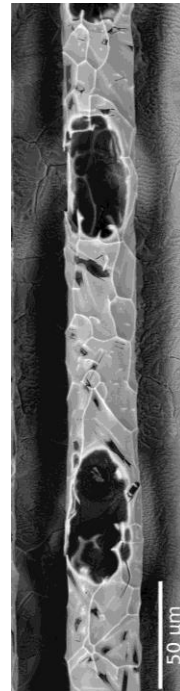


Best case with 1 bar processing: 30-40% gas bubbles in filament

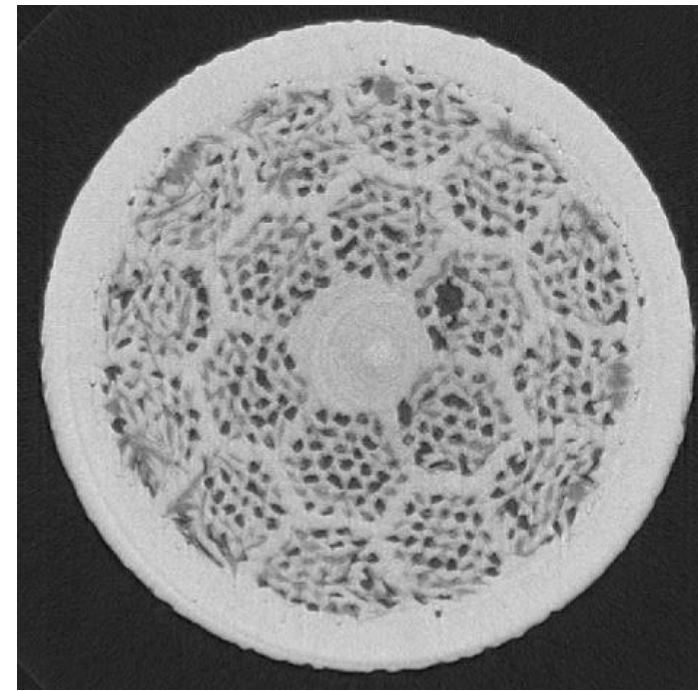


60% dense

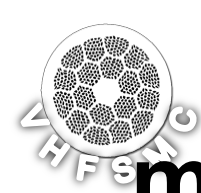
1 bar – clean powder, no CO_2 , H_2O



Kametani



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Real-time, *in situ* x-ray microtomography shows how bubbles form and grow during heat treatment

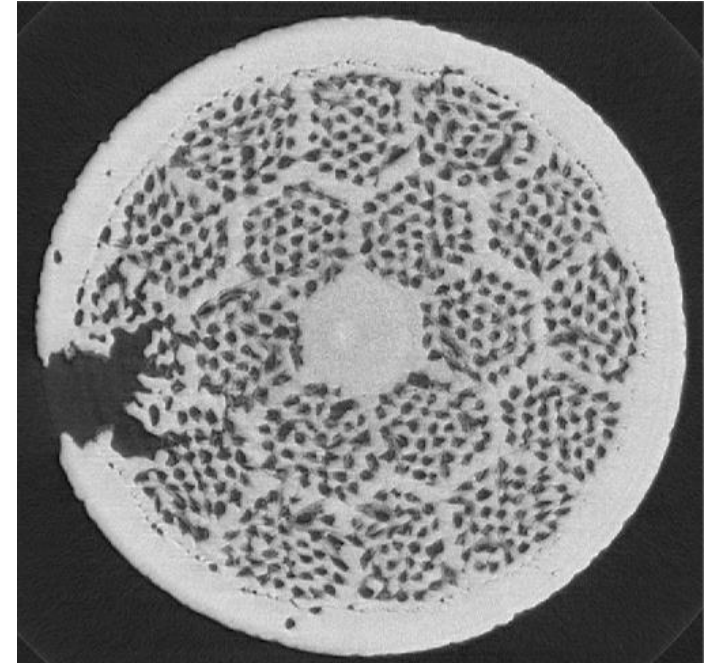
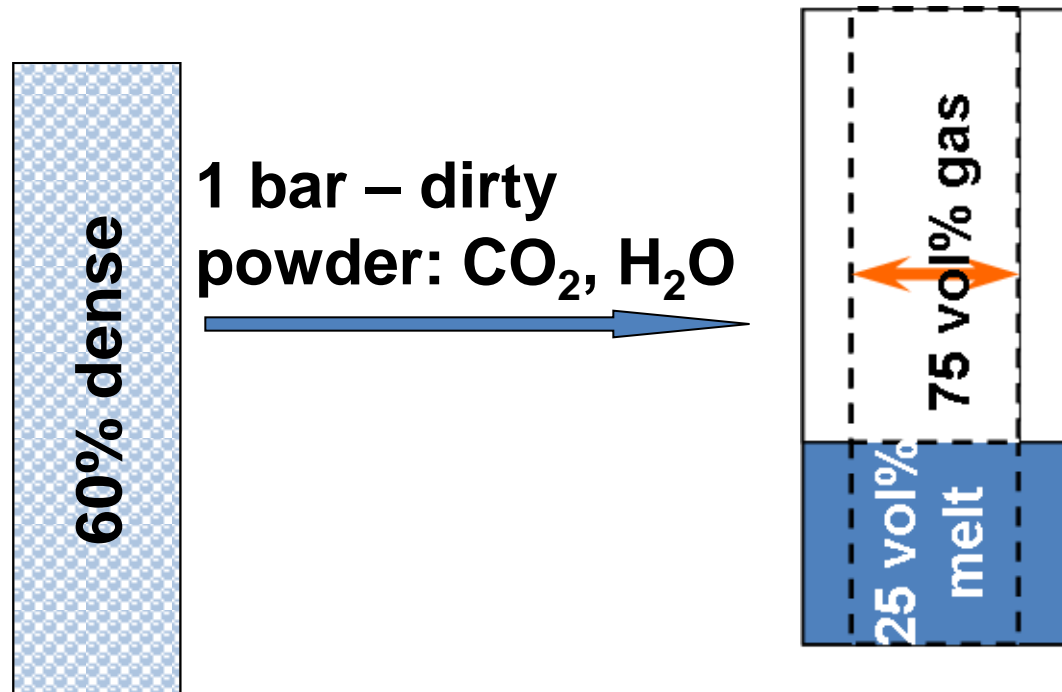
- **Video shows filaments in 2212 wire
during heating and cooling in 1 bar air**

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Worst case with 1 bar processing: dedensification and leakage

Internal gas pressure
expands filament hole



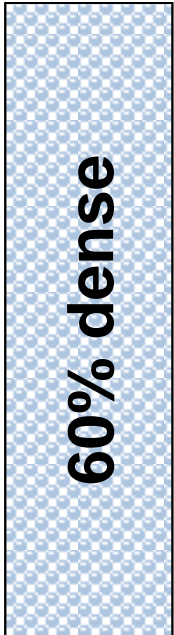
- Malagoli
- Shen

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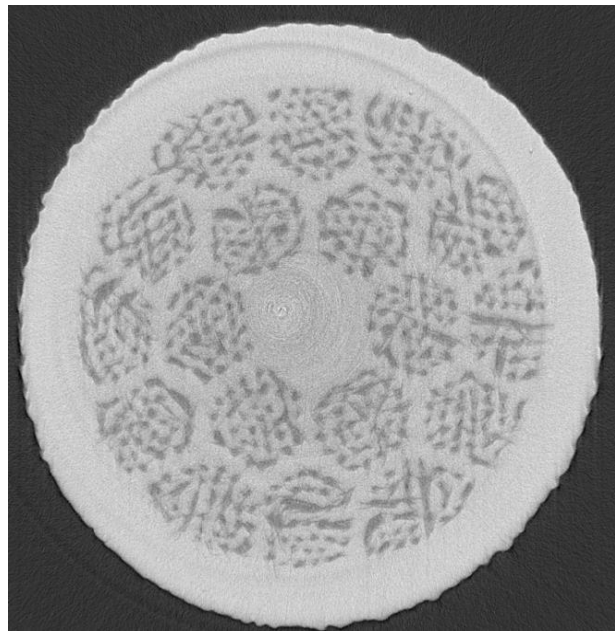
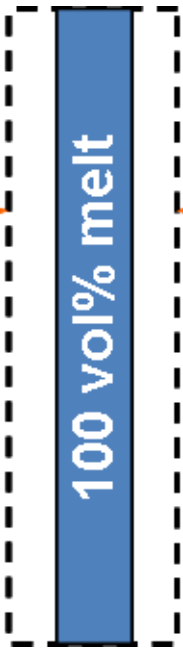


Best processing: apply overpressure to squeeze Ag so filament hole matches 2212 volume \Rightarrow 100% dense

External overpressure decreases filament hole



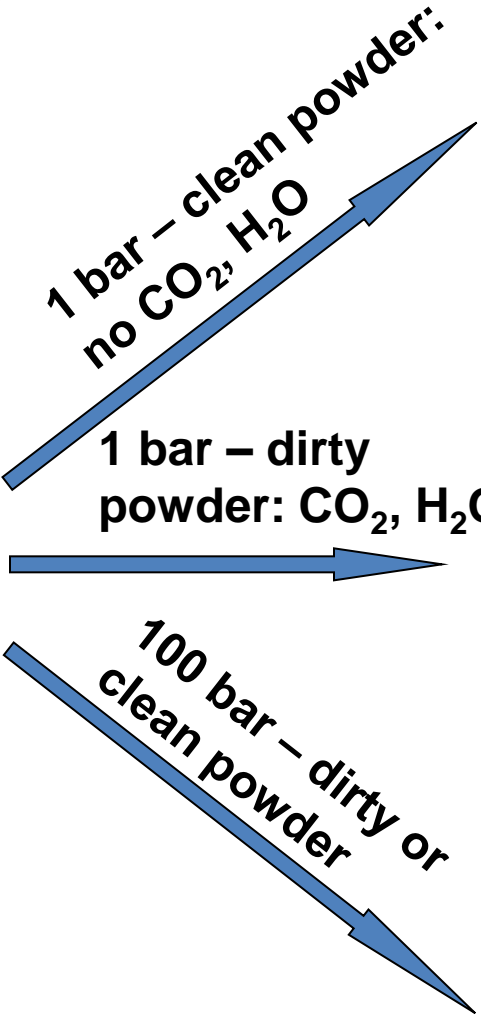
100 bar – dirty or clean powder



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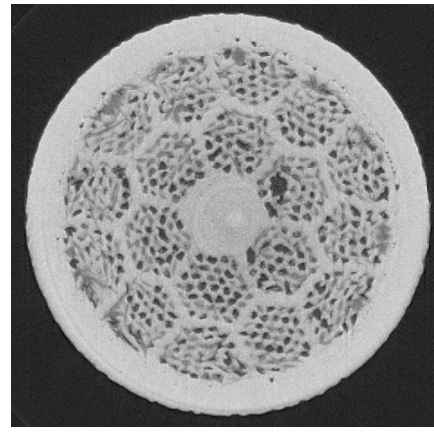


60% dense



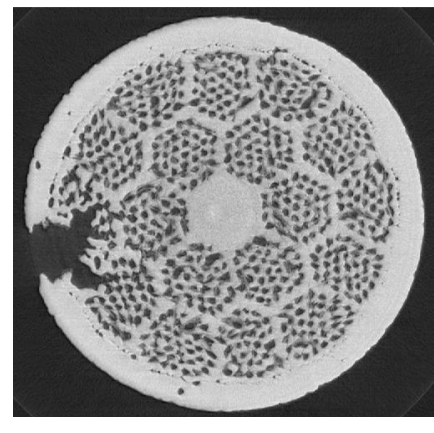
40 vol%
gas

60 vol% melt

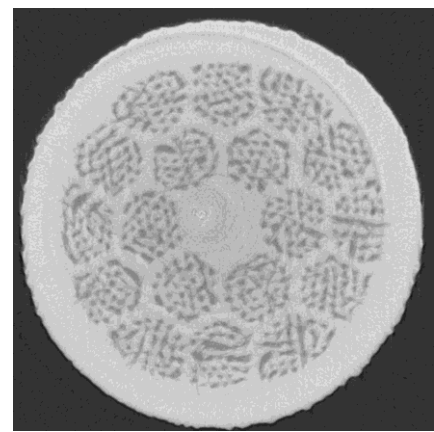


25 vol%
melt

75 vol% gas



100 vol% melt



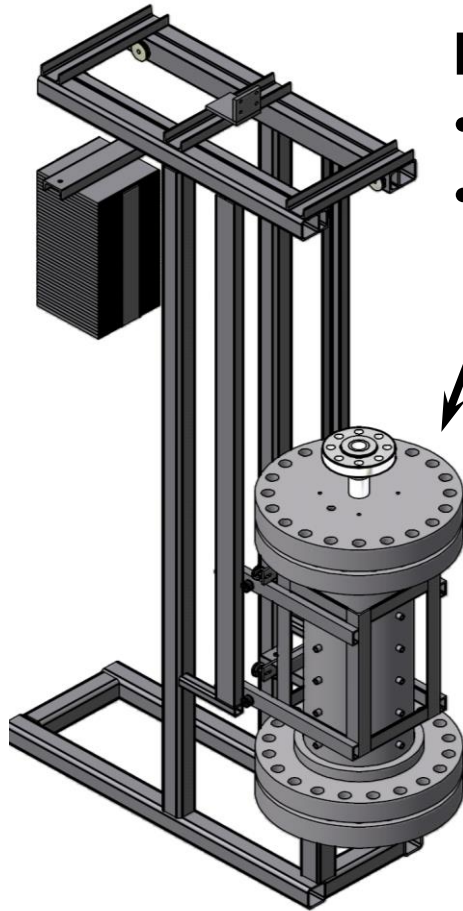


Existing 100 bar OP furnace



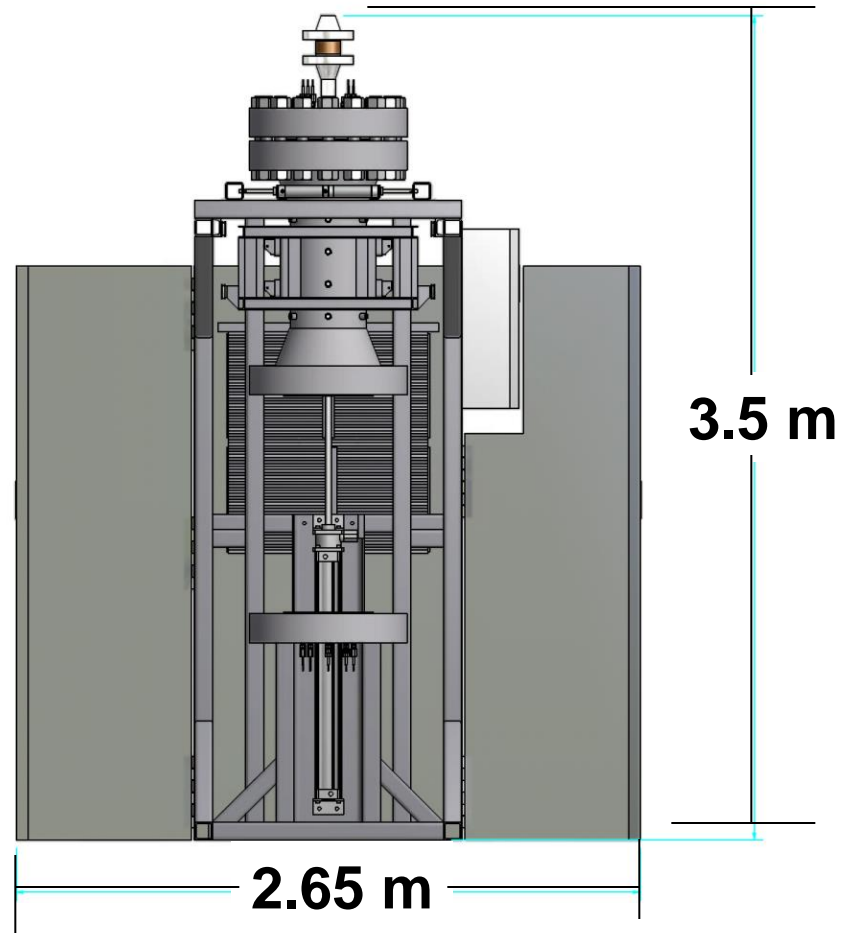


Have ordered 100 bar OP furnace for large coils



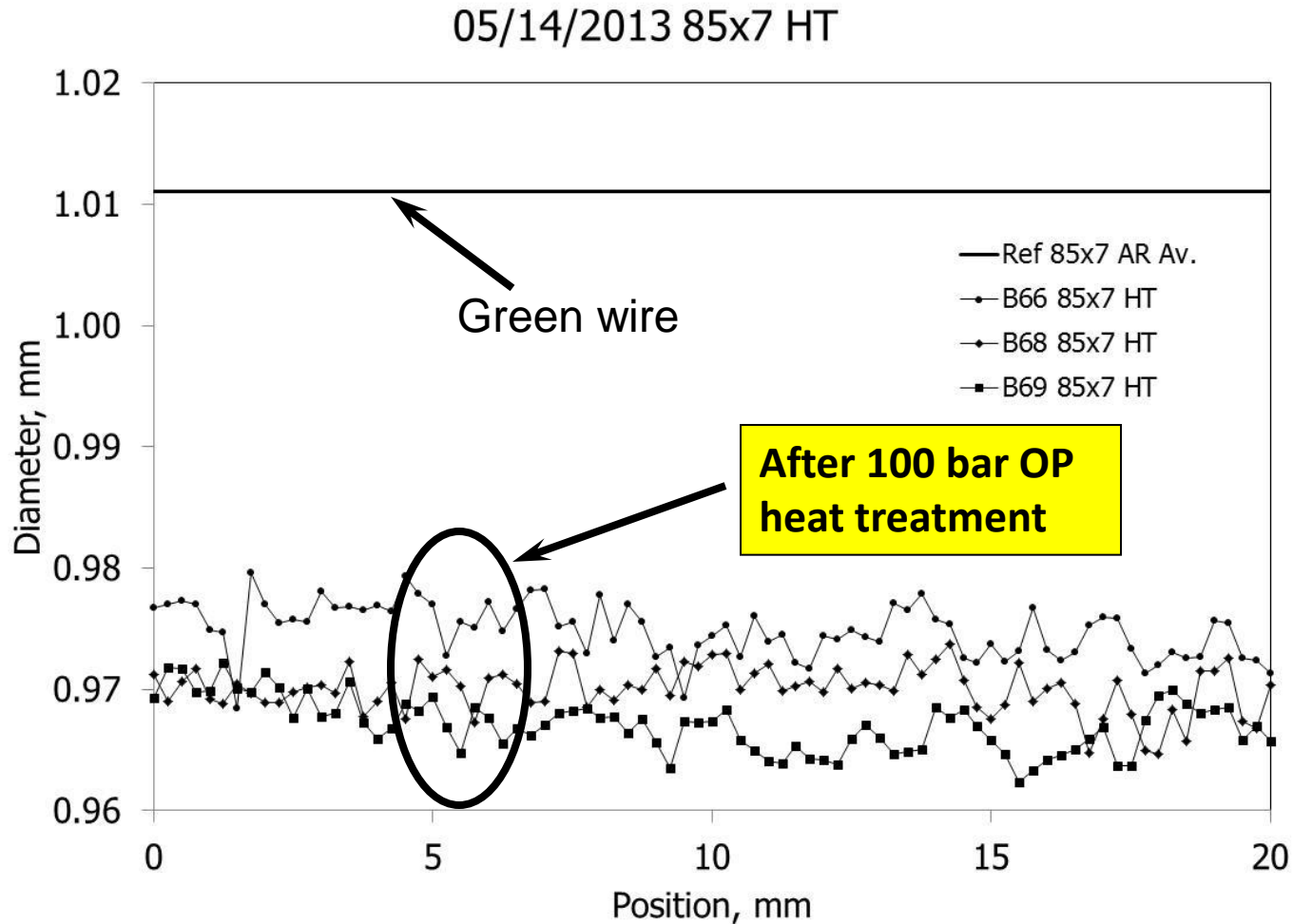
Hot zone

- 50 cm high
- 16 cm diam



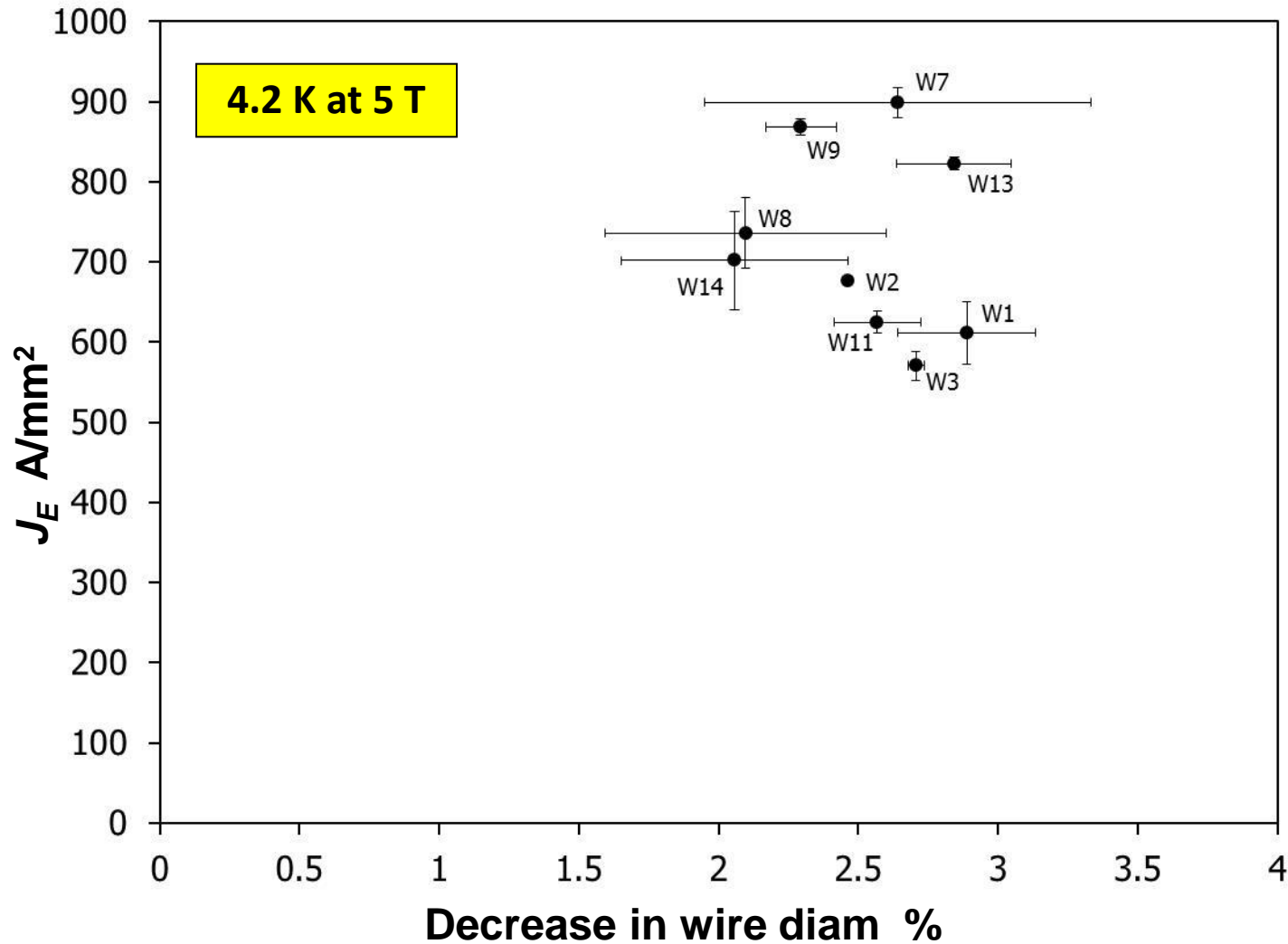


Wire diameter is relatively uniform after OP processing



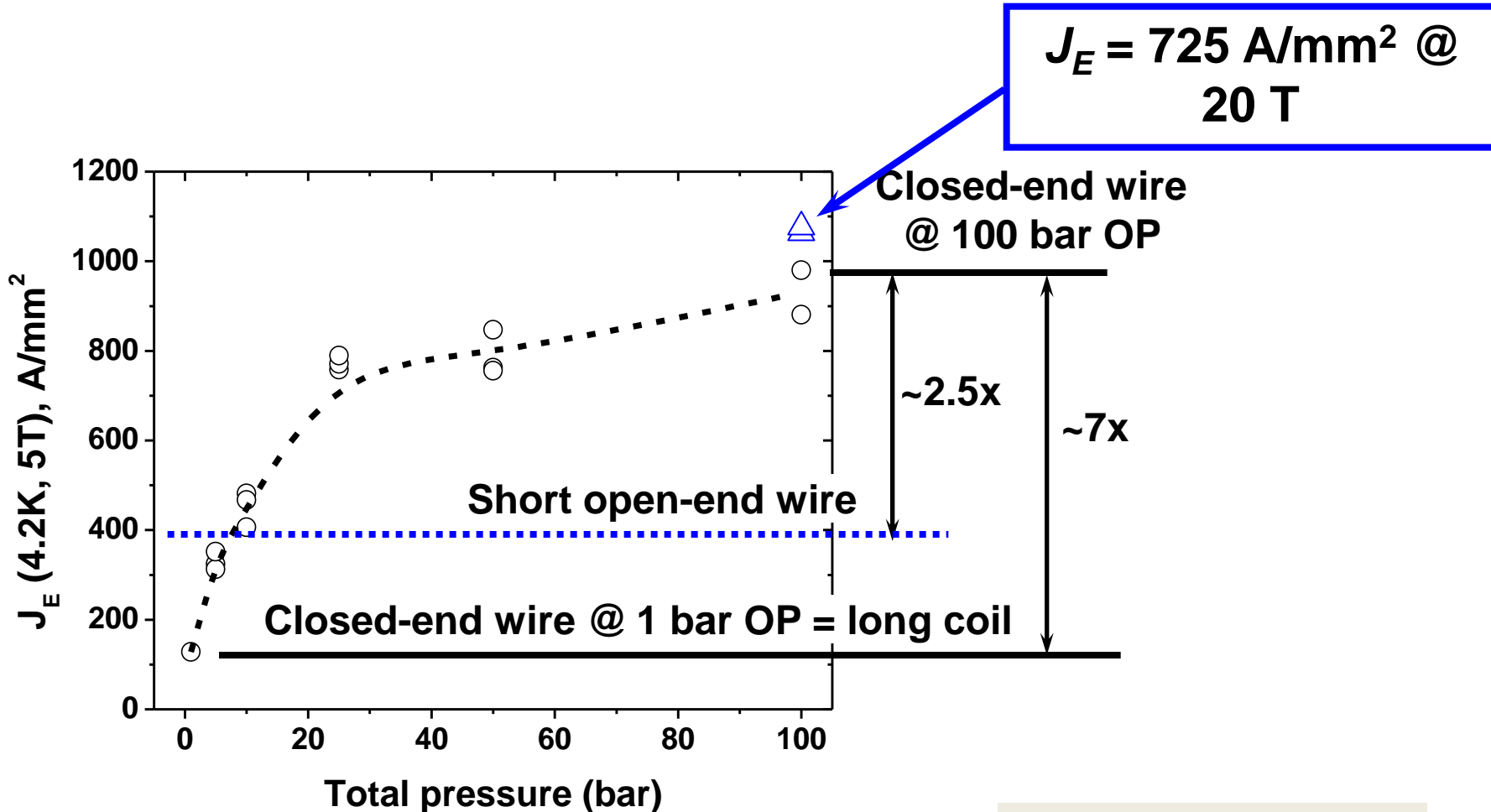


J_E is relatively constant for each wire after 100 bar OP processing





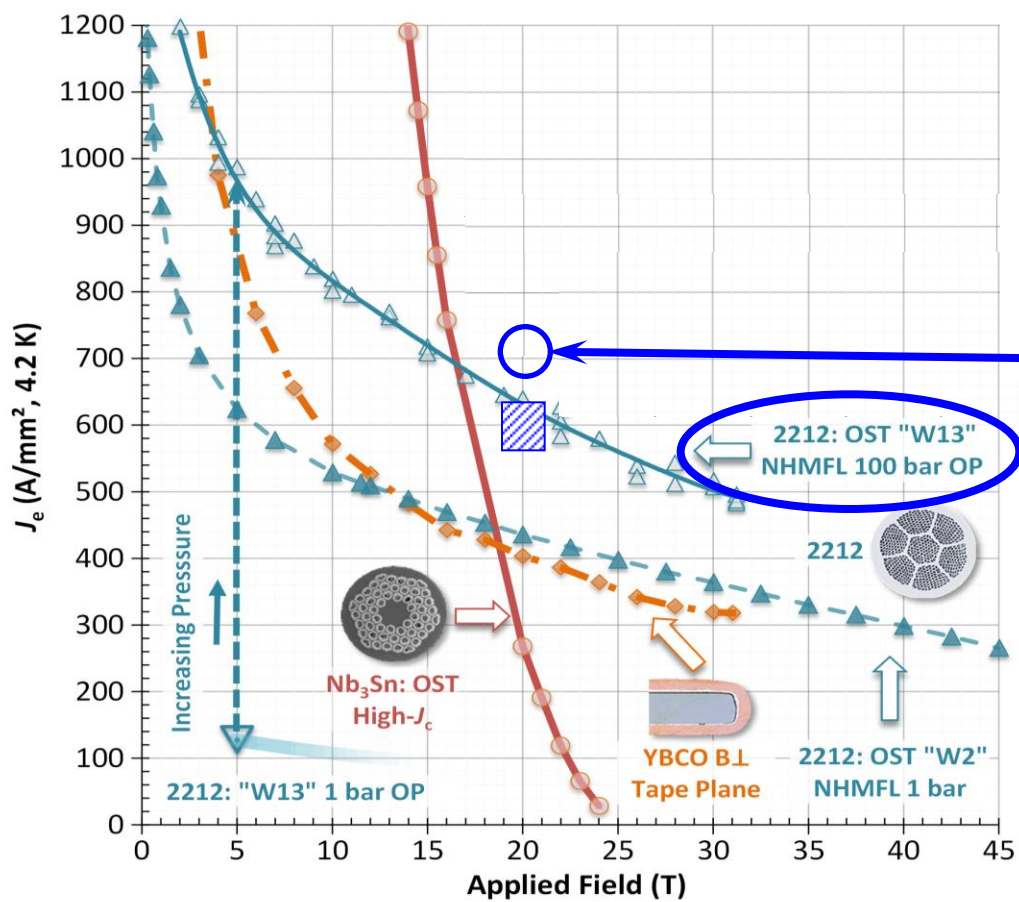
OP processing more than doubled J_E





High J_c and J_E in OP wire (4.2 K, 20 T)

$$J_E = 640 \text{ A/mm}^2 \quad J_c = 2500 \text{ A/mm}^2$$



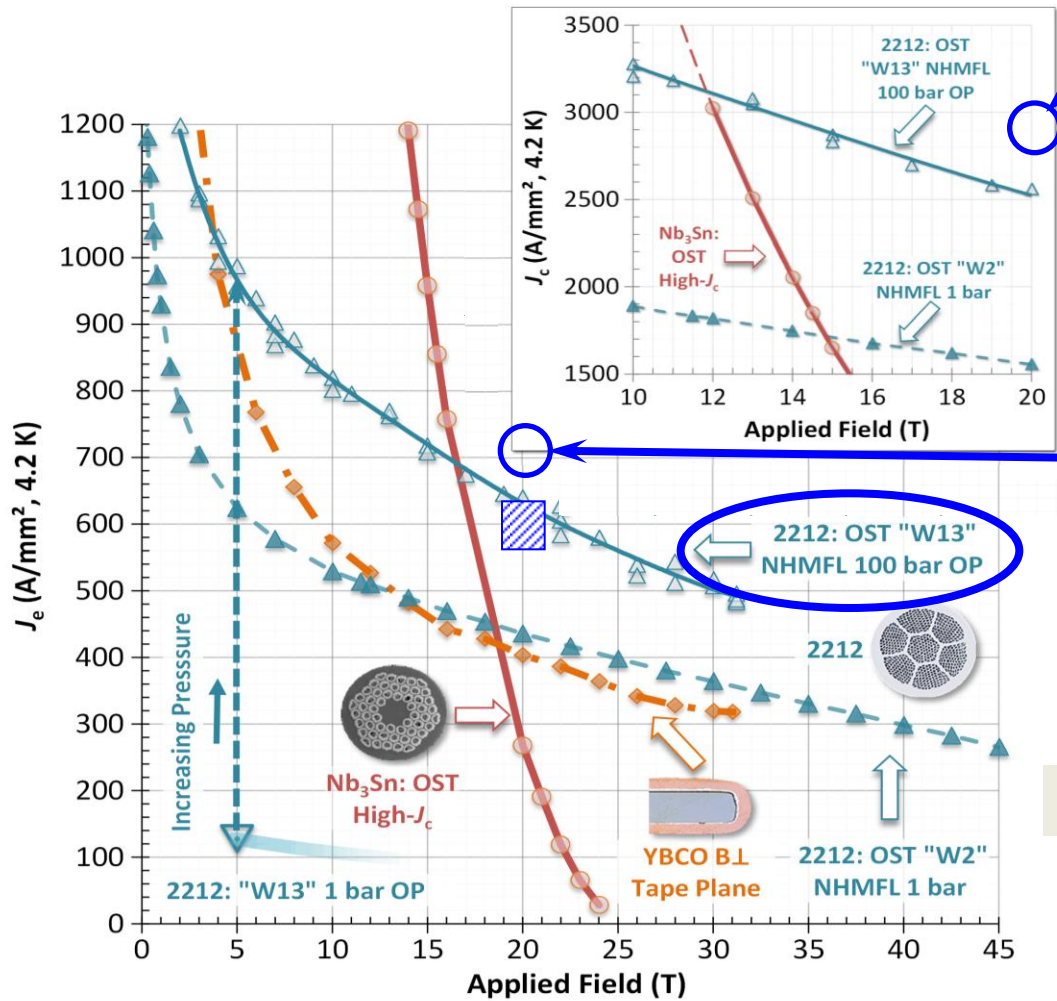
$J_E = 725 \text{ A/mm}^2$

Lee and Dalban-Canassy



High J_c and J_E in OP wire (4.2 K, 20 T)

$J_E = 640 \text{ A/mm}^2$ $J_c = 2500 \text{ A/mm}^2$



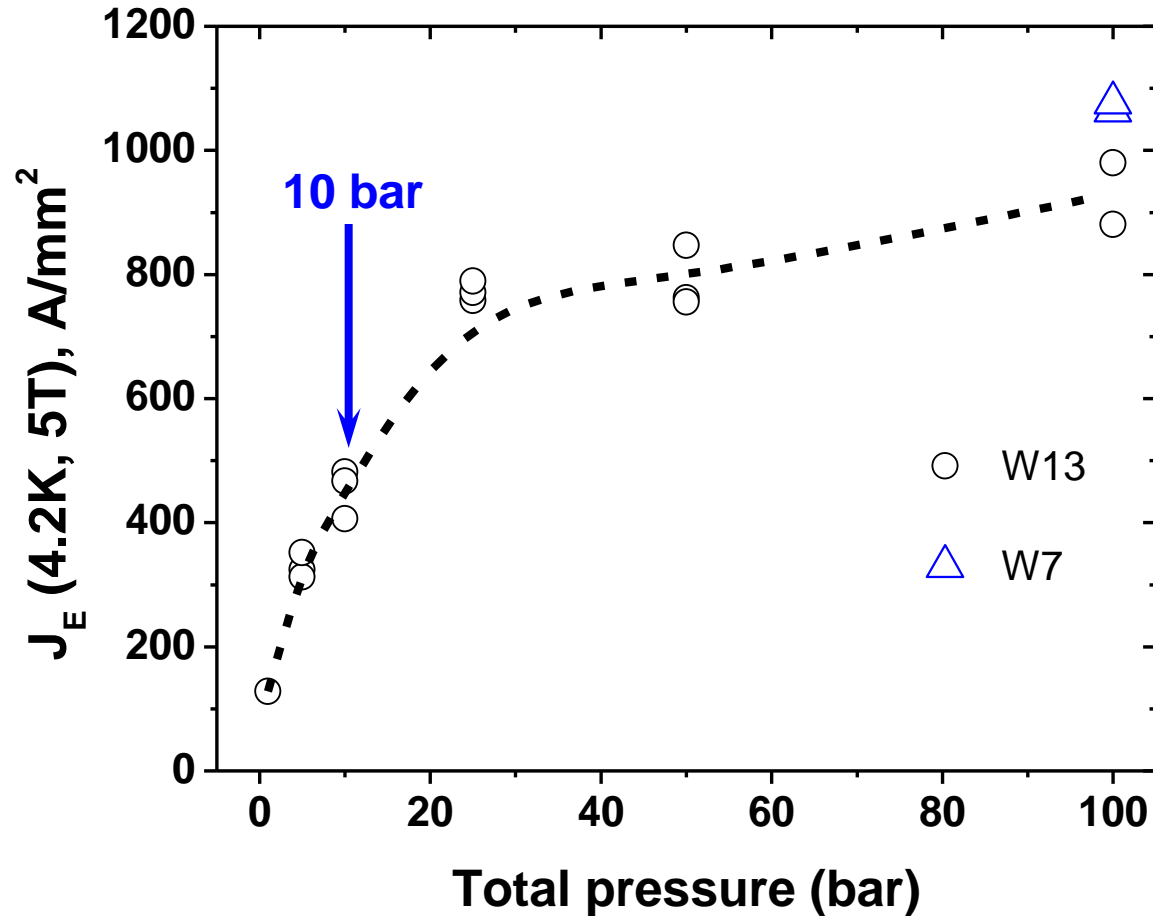
$J_c = 2900 \text{ A/mm}^2$

$J_E = 725 \text{ A/mm}^2$

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OP processed coil at 10 bar – only prevented dedensification



Matras, Jiang, Craig

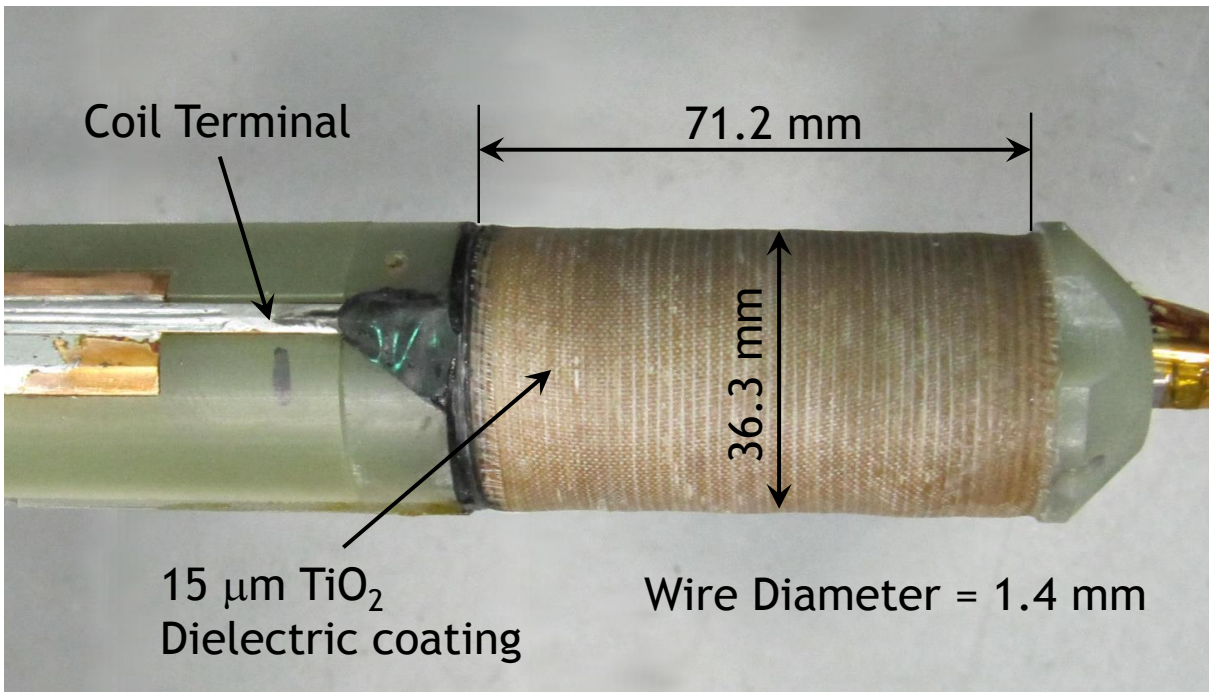


OPed 2212 coil at 10 bar - generated 2.6 T in 31.2 T background = 33.8 T

10 bar OP processing

- Pressure was only high enough to prevent wire from expanding
- Did not compress Ag sheath and remove bubbles

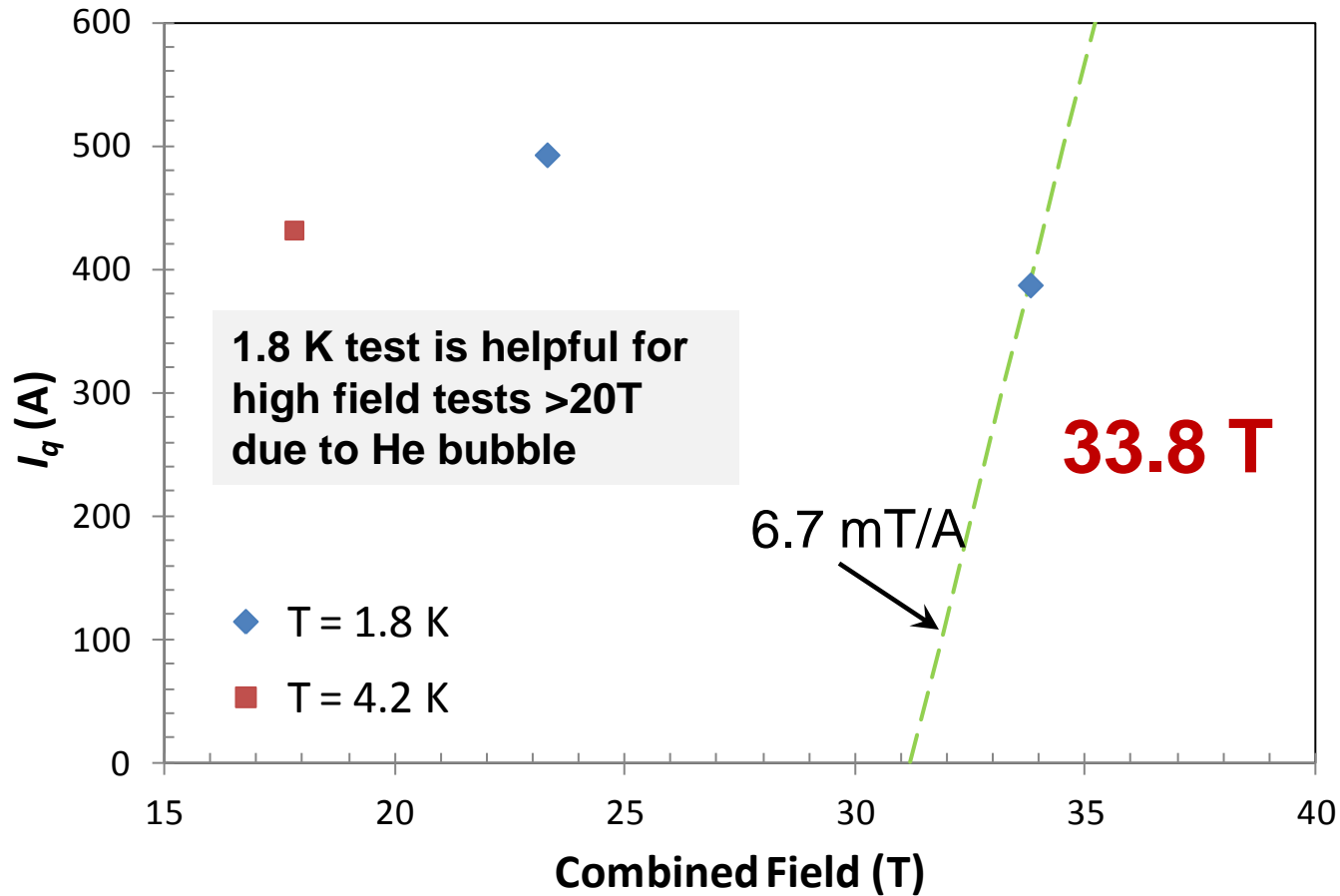
Insulation - $\sim 15 \mu\text{m}$ thick TiO_2



Wire dia. (mm):	1.40
nGimat Insulation (mm):	0.015
Turn-turn non-tightness (mm):	0.085
layer-layer tightness (mm):	-0.065
Inner Radius (a1) (mm):	7.25
Outer Radius (a2) (mm):	18.17
Height (2b) (mm):	71.21
Radial Layers (-):	8
Turnss/Layer (-):	47
Total turns (-):	376
Conductor Length (m):	30.03



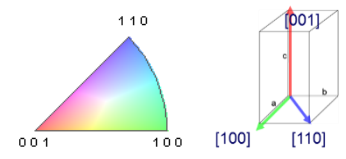
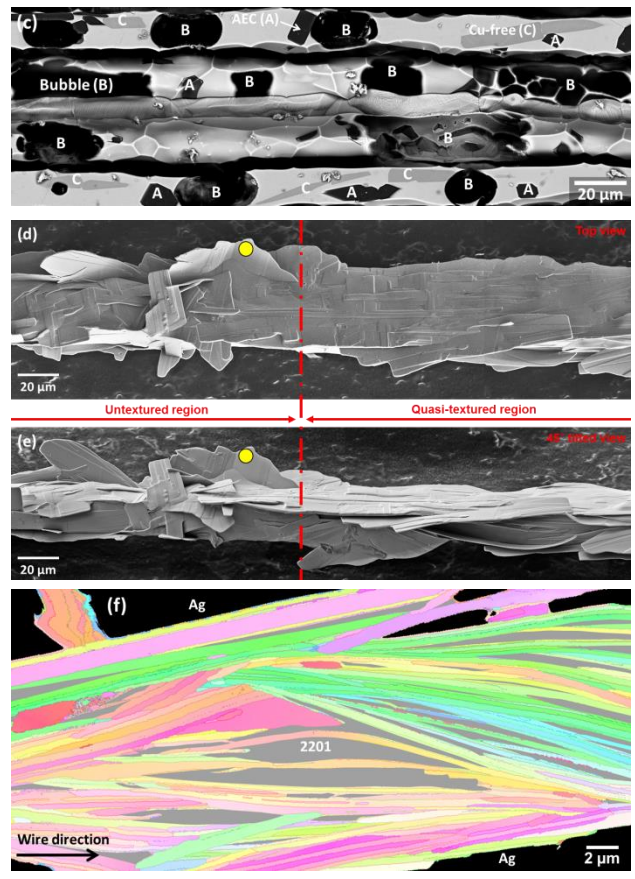
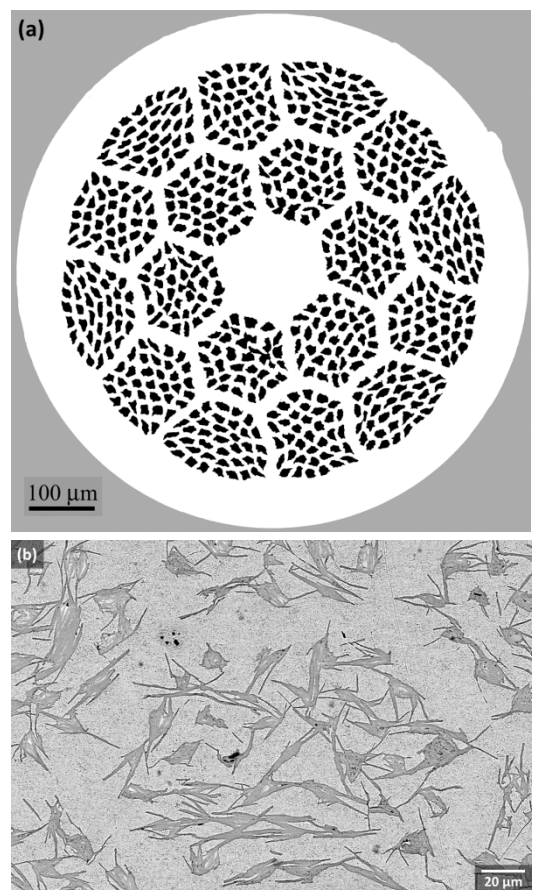
Field Generation and Coil Load Line



- 2.6 T Field increment achieved in 31.2 T background field ($I_q = 388$ A, $J_w = 187$ A/mm²)
- Slight degradation on inner terminal after a total of about 20 in-field 4.2 K runs at ramp rates varying from 2.5 – 50 A/s



2212 filaments contain many high-angles grain boundaries – and have high J_c when they do not contain bubbles



- Polished sections of filaments in their surrounding Ag
- Exposed filaments show their plate-like nature and frequent strong misalignments.
- EBSD images show some local texture and significant 2nd phase content within filaments
- **The filaments cannot be fully connected – yet do have high J_c**

Kametani and Jiang - see DCL arXiv 1305.1269



Questions driving 2212 research

1. How uniform along the length does OP leave the samples?
2. Do cleaner billets require less OP pressure?
3. What really is the optimum filament diameter (d_f) for optimum J_c ?
4. Can we do a better oxide dispersion strengthening on both Ag/Mg and Ag/Al sheath than we are doing at present?
5. How do we measure powder quality?
6. How do filaments couple and is there any change as filaments become closer and smaller?
7. Can we simplify the heat treatment?



Outlook is very positive

- OP removes bubbles in filaments – 100 bar appears to be adequate
- OP increases J_E
- OP used for 30 m long coil – generated 33.8 T total field
- Investigating how current crosses high-angle grain boundaries