U.S. MAGNET DEVELOPMENT PROGRAM

High-C_p Nb_3Sn conductor development

Xingchen Xu

Fermi National Accelerator Laboratory

Xuan Peng (Hyper Tech Research Inc), Fang Wan (Fermilab), Jacob Rochester & Mike Sumption (OSU)

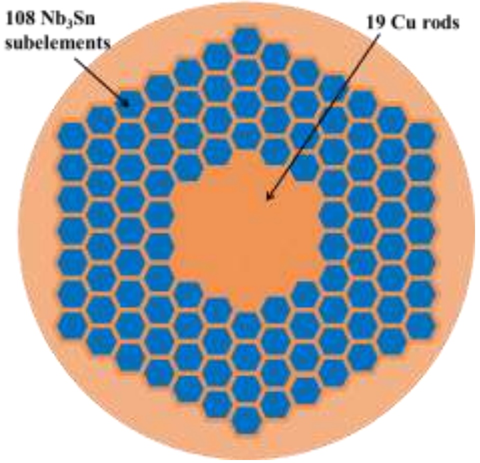
High-C_p Nb_3Sn – a brief review

- **Purpose: increase conductor energy margin: $\int_{T_{op}}^{T_{cs}} C_p dT$. May help to reduce magnet training.**
- **High-C_p idea dates from 1960s. Increase in MQE was demonstrated:** Keilin et al. Supercond. Sci. Technol. 22, 085007, 2009

A design for Nb_3Sn strands (2017):

Xu, Li, Zlobin, Peng, *Supercond. Sci. Technol.* 31, 03LT02, 2018

RRP wire for HL-LHC:

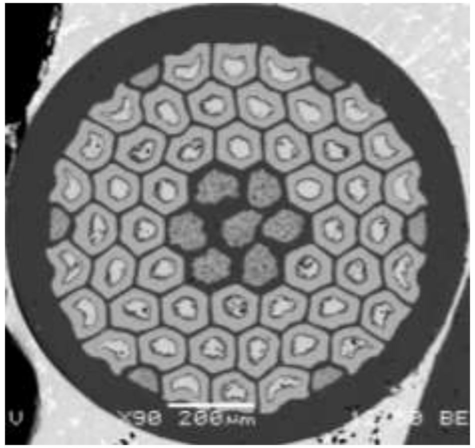


High-C_p wire:

Cu rods ➔ Cu tubes filled with high-C_p powders.

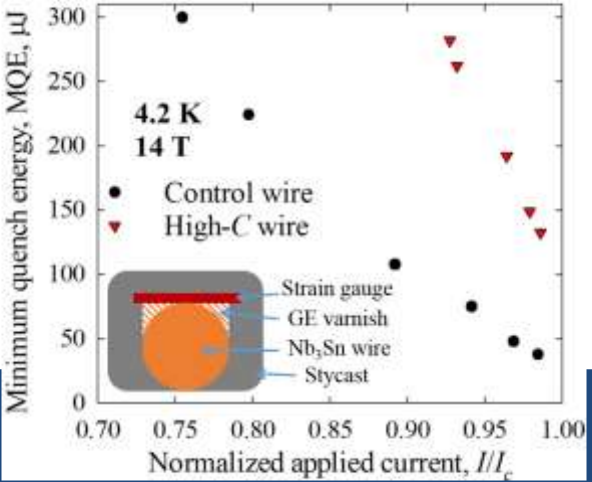
- **Compatible with standard production.**
- **Does not affect J_e**

2017: the first high-C_p wire (Hyper Tech):

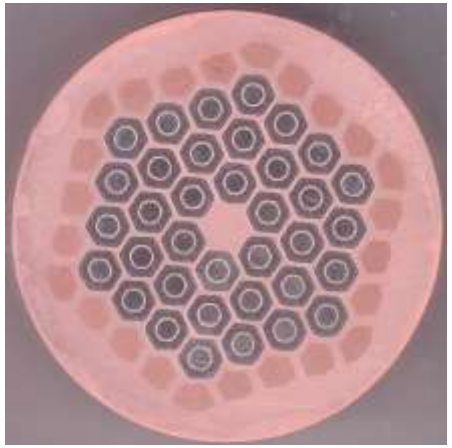


The results were encouraging:

- Drawability was good.
- MQE was tripled.



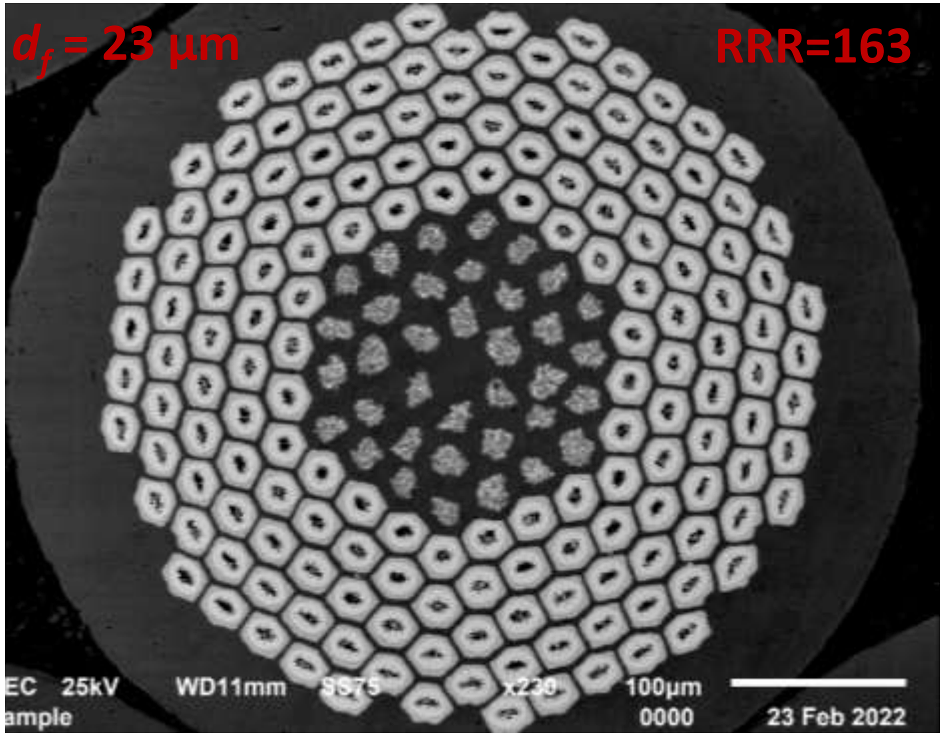
2018-19: tried to make a long high-C_p wire (Bruker):

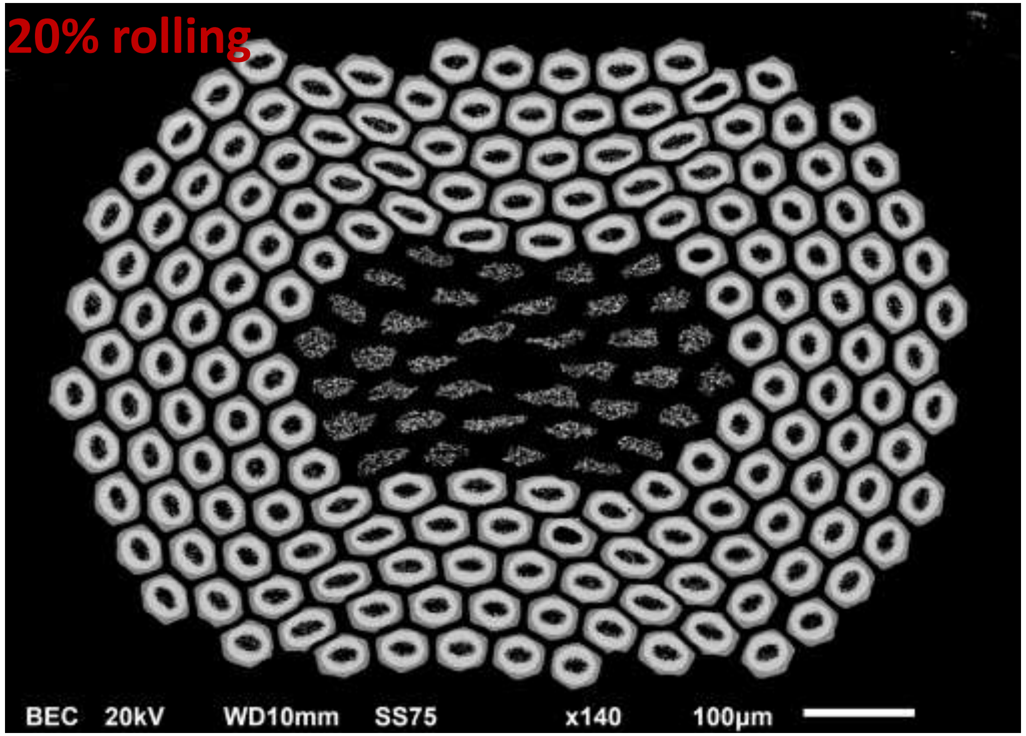


- Had drawability issue due to improper design.
- Since 2020, efforts were focused on optimizing design for drawability.

Current status of high-C_p strand development

- Made a number of small billets to optimize wire design for drawability: each Φ0.75”, 7-8”L, ➔ 50-100m long wires
- Relevant parameters for drawability: position of high-C_p filaments, Cu tube thickness, Cu/high-C_p powder ratio, etc.
- By optimizing these parameters, now the drawability issue has been solved.



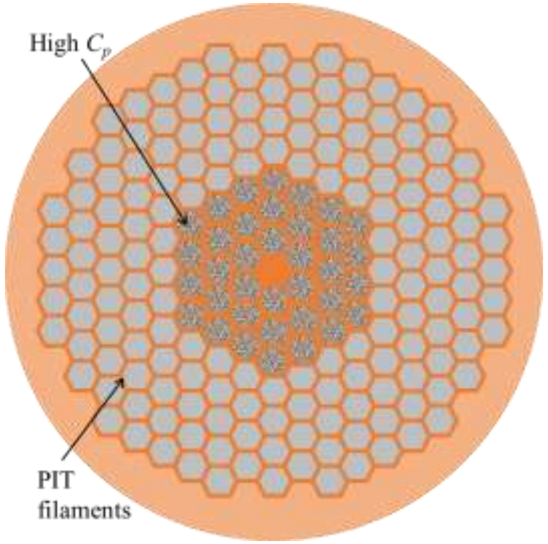


With these progresses, we think we are ready to make a big billet

Current status of producing a big billet

Billet/strand design:

- CPRD has ordered a billet from Hyper Tech, which is being fabricated.
- The billet is expected to have a diameter of 2” and a length of ~3’, weight of 12-14 kg.
- If the whole billet is drawn to 0.7 mm diameter, it can produce 2-3 km long wires.
- Nb_3Sn filaments: Sn+Cu powders into Nb-Ta tubes. High-C_p filaments: Gd_2O_2S + Cu powders into Cu tubes.



Estimated area fractions:

Components	Vol.%
Nb_3Sn filaments	42-45%
High-C_p filaments	4-4.5%
Cu matrix	50-55%

Current status:

- All of the Nb_3Sn and High-C_p filaments have been made and drawn to the stacking size, ready for stacking into the Cu can.
- But Hyper Tech has to use an outside vendor to draw large billets (> Φ1”). Currently waiting for the vendor to be ready.
- Expected delivery time: by the end of FY23.

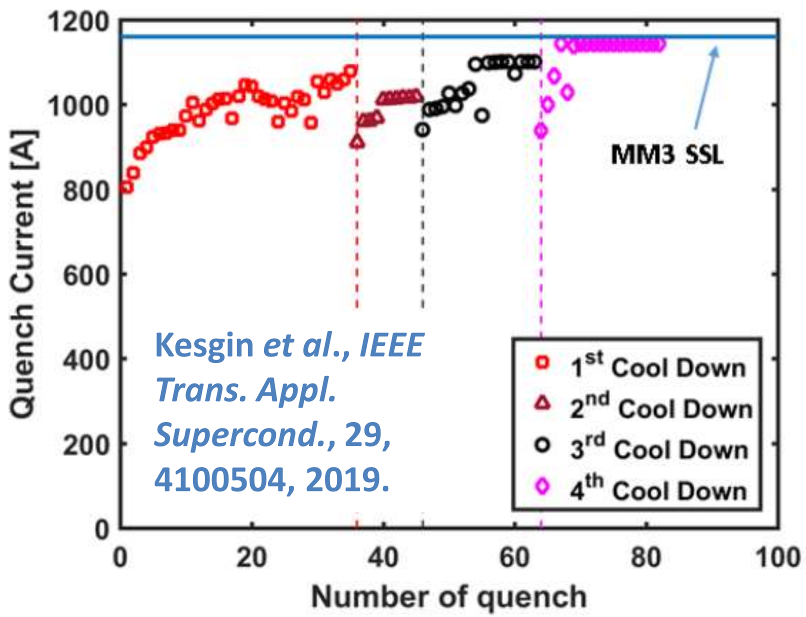
Other studies of high-C_p strands

There are two purposes for developing high-C_p strands:

1) The major purpose is to see if the increased energy margin can help to reduce magnet training.
2) A secondary purpose is to see if it can improve conductor stability. If yes, this is an extra benefit.

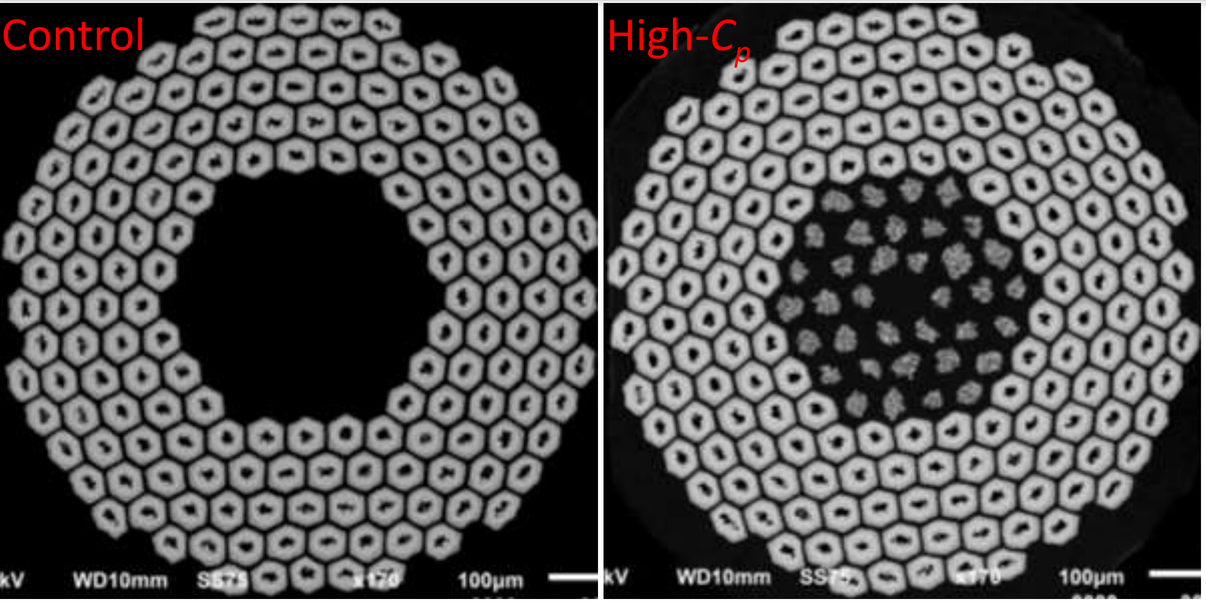
- For the impact on training, there is still a long time before a coil can be made using the long high-C_p wires.
- Is there any quicker way to judge if high C_p can impact training using our short wires?

Nb_3Sn undulators made by ANL:



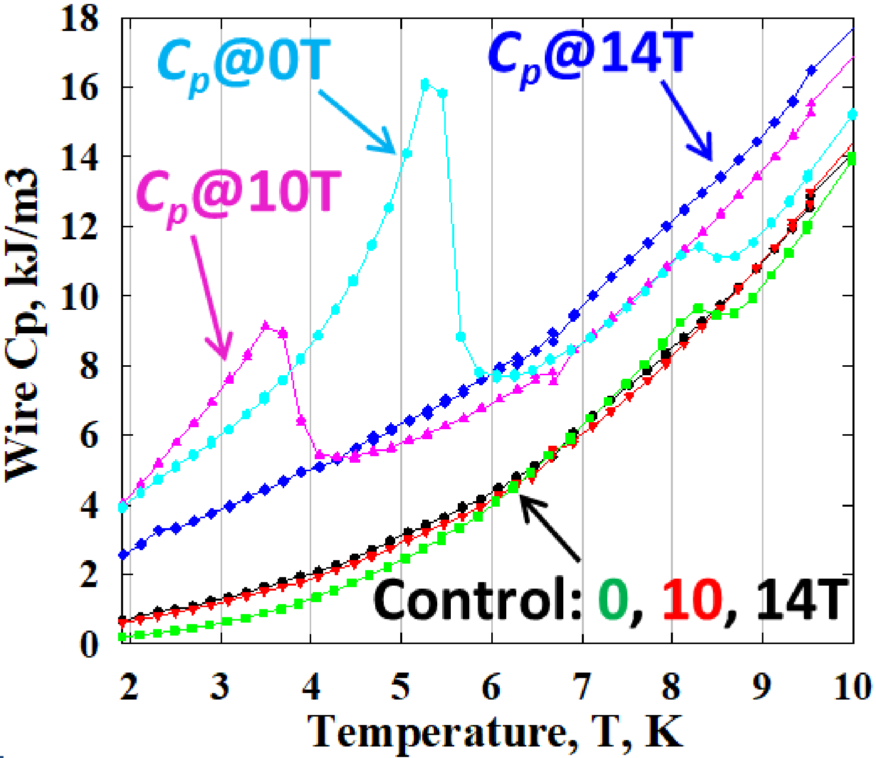
We are happy to collaborate if you have other ideas about testing the training using single high-C_p wires.

Other studies of high-C_p strands



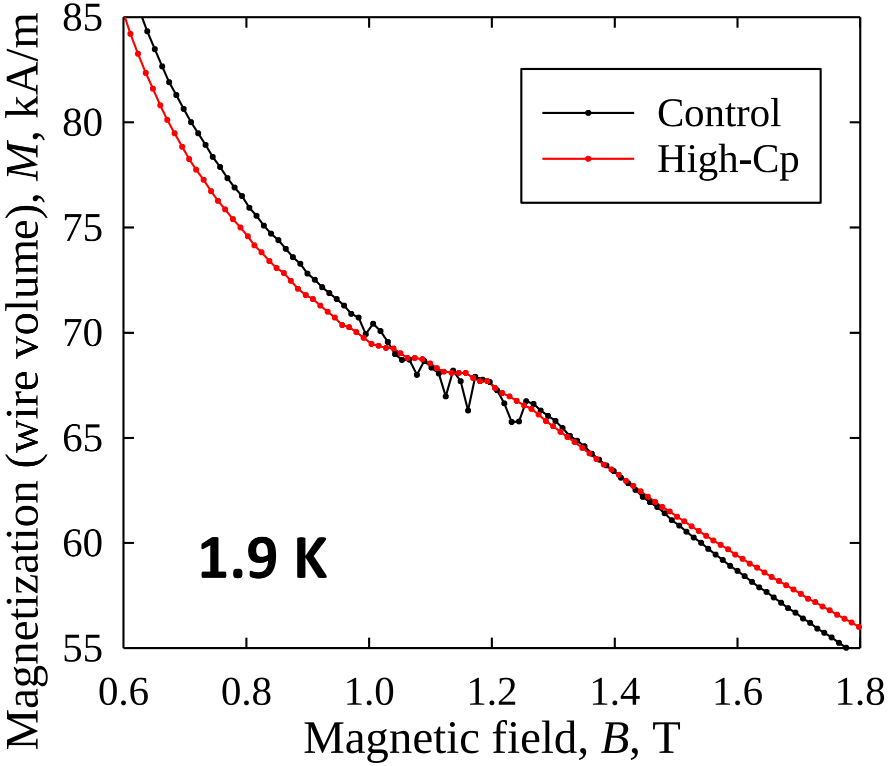
Component vol%	Control	High-C_p
Nb_3Sn filaments	46%	46%
High-C_p filaments	-	4.5%
Cu matrix	54%	50%

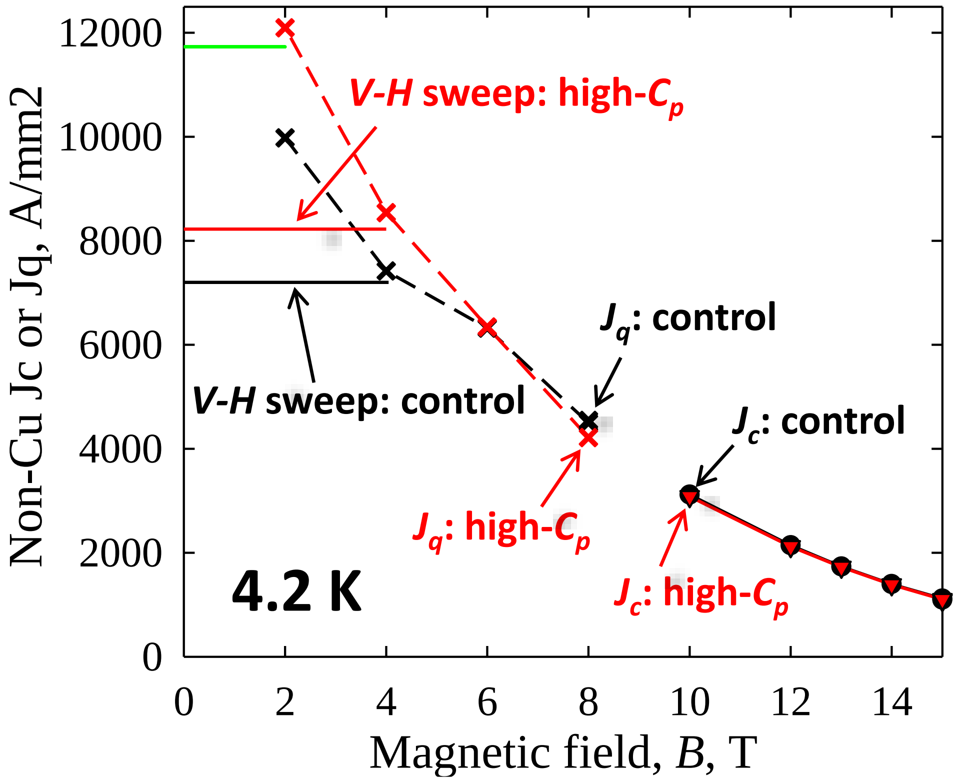
- Both strands: 0.6mm diameter, filament size 30 µm, twisted.
- Heat treatment: 650C/50h.
- RRR: 174 for the control; 144 for the high-C_p wire.

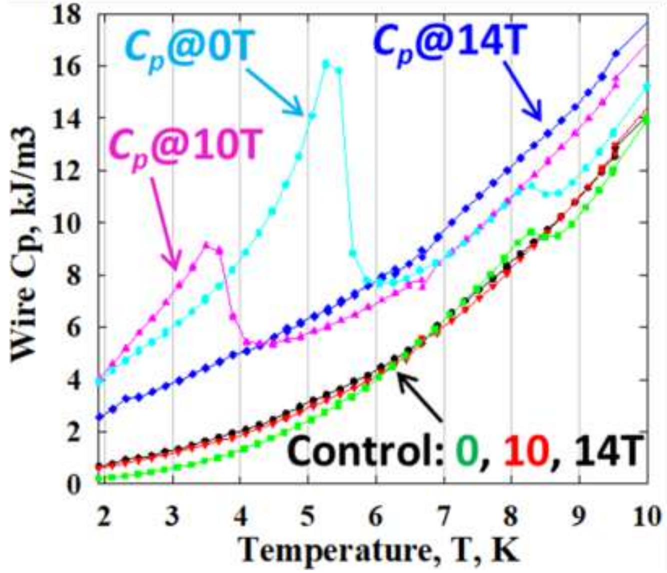


Other studies of high-C_p strands

No sample had flux jumps in 4.2 K M-H loops.

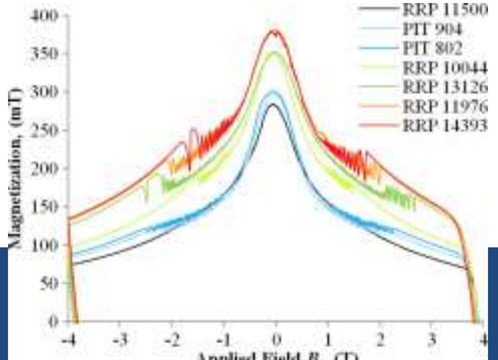






Flux jumps are common for Nb_3Sn strands at 1.9 K: e.g.,

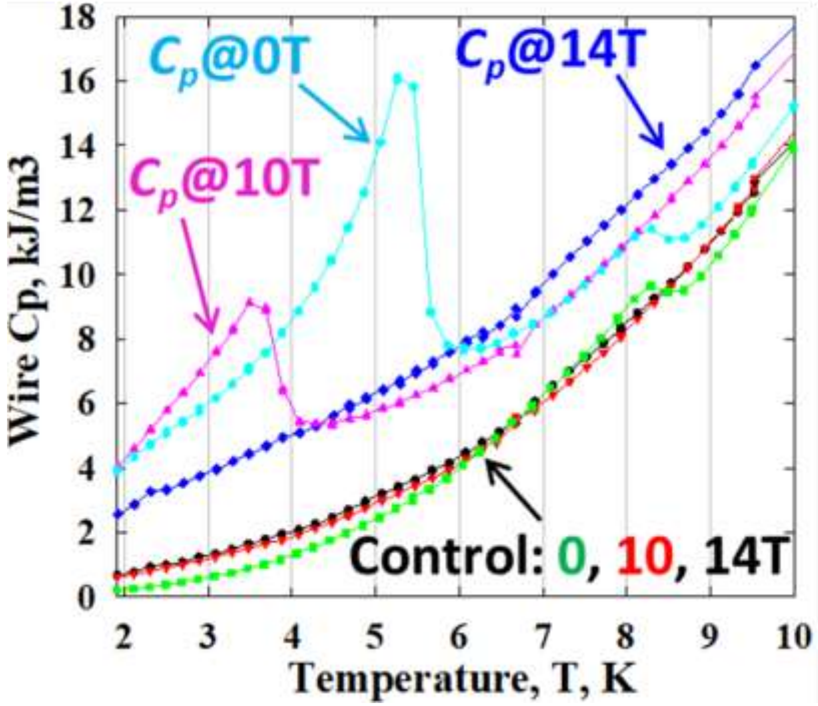
Bordini et al., IEEE Trans. Appl. Supercond., 23, 7100806, 2013.

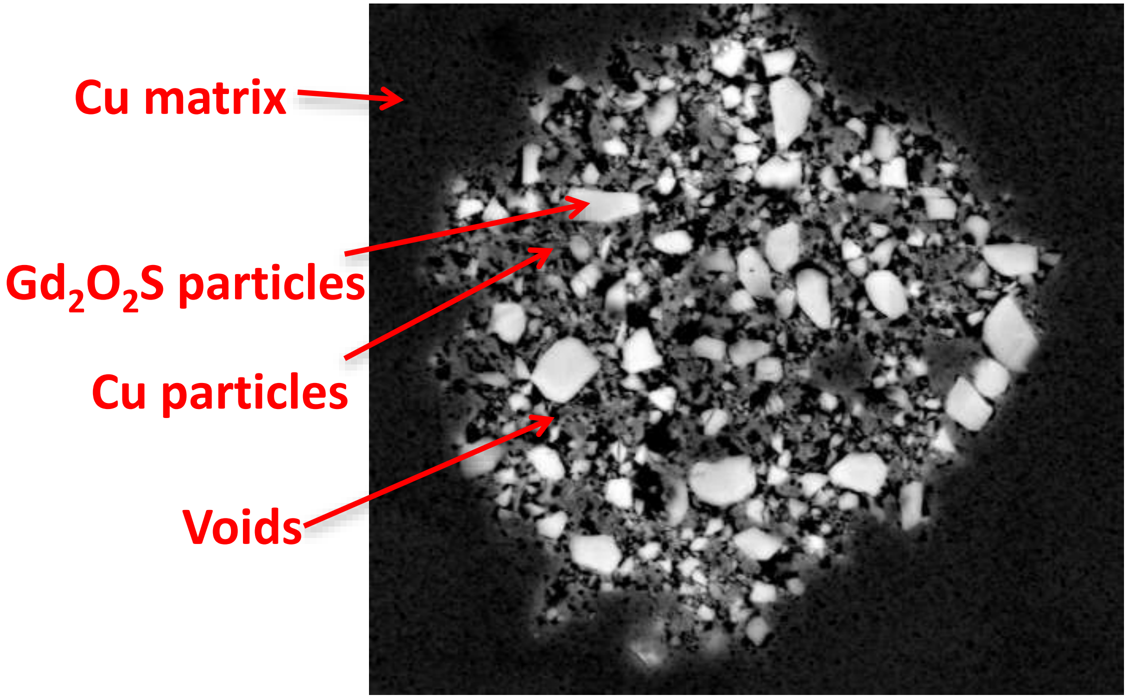


- It seems high C_p can suppress 1.9K flux jumps, but has limited effect on 4.2 K transport stability.
- Perhaps due to larger C_p increase at 1.9K than at 4.2K?
- It is interesting to do transport tests at 1.9 K.

Thermal conductivity of high-C_p filaments

- **The C_p measurement includes contribution of all high-C_p materials.**
- **But in reality, the perturbation is short, so if heat conductivity in the high-C_p filaments is low, only part of high-C_p materials can absorb heat before quench.**





We are measuring the thermal conductivity of high-C_p filaments using a thermoreflectance method.

Summary

- In the early stage of high-C_p strand development we demonstrated significant improvement of MQE in a short high-C_p strand but ran into drawability issue when trying to produce a long-length high-C_p strand.
- In the past couple of years we have been working to optimize strand design to solve the drawability issue. Now we can produce high-C_p strands with good drawability and acceptable rolling degradation.
- We are producing a big billet and some long high-C_p strands.
- We are aiming to test the training performance using single high-C_p strands with short lengths. A holder is being developed for this. Hopefully this can be a quicker way to judge if high C_p can really impact training.
- It seems high C_p can suppress 1.9K flux jump, but has limited effect on 4.2 K transport stability, perhaps due to larger C_p increase at 1.9K than at 4.2K. We will verify this by doing the transport tests at 1.9 K.

Acknowledgement

- The high-C_p R&D work is supported by the ECRP from US DOE.
- The big billet is supported by MDP CPRD.

Thank you for your attention!