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Update of the high-C_p project

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MDP collaboration meeting, 08/15/2018

Outline

Part I. Follow-up studies on the high-C_p wire fabricated by Hyper Tech

- NZPV measurements
- V-I and V-H stability tests

Part II. Current status of optimization and industrialization with Bruker

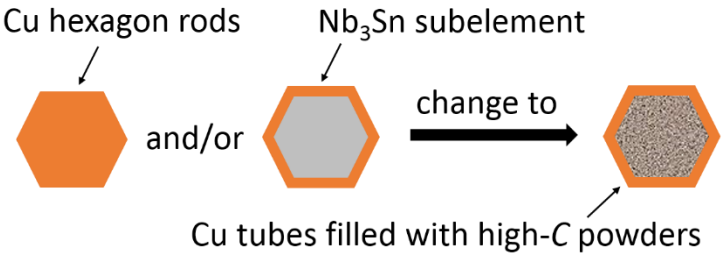
- Plan and current status
- The first two high-C_p rods
- C_p measurements

Goals and approaches

Goal: to reduce Nb_3Sn magnet training by improving energy margin of conductors. If energy margin > perturbation energy, quenches can be avoided.

Approach: improve specific heat of conductors by adding high-C_p materials in proper design.

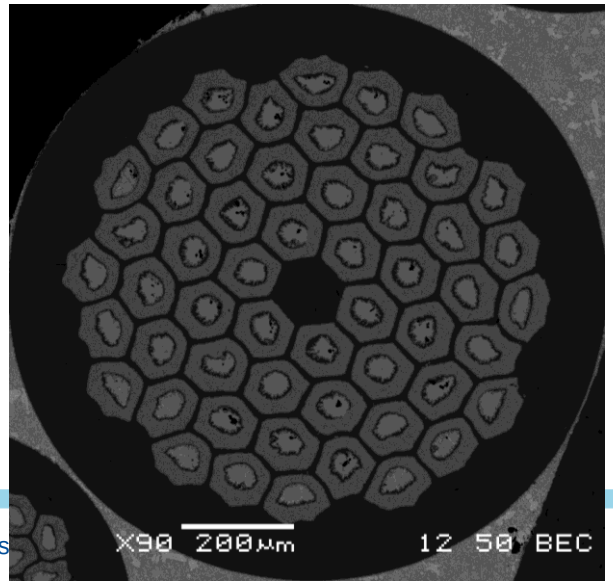
Our scheme:



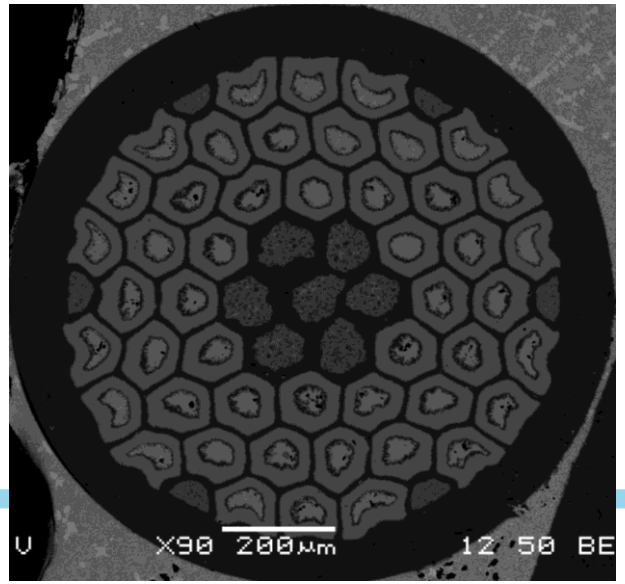
Another modification: blend Cu powder into high-C_p powder:
(1) Enhance thermal conduction
(2) Draw better

The first high-C_p wire made by Hyper Tech:

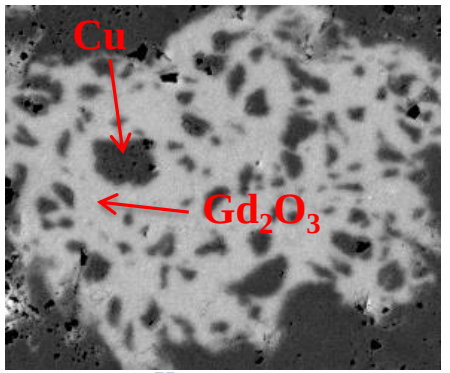
The control wire:



The wire with Gd_2O_3 (Cu/Gd_2O_3 = 0.5):



Gd_2O_3 thermal diffusivity low: time constant is big.



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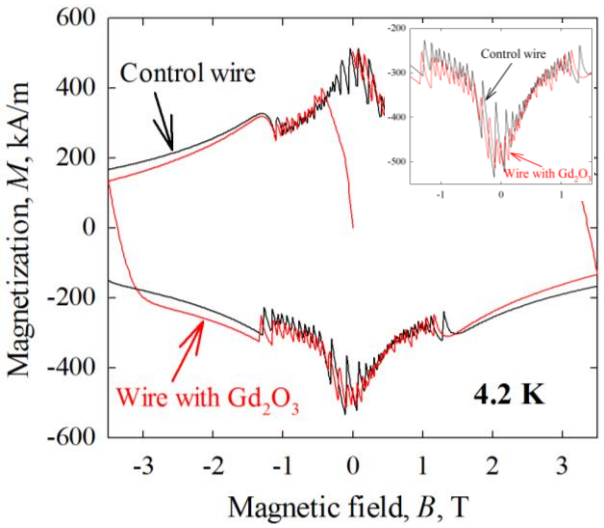
Follow-up tests on high-C_p wire from HyperTech

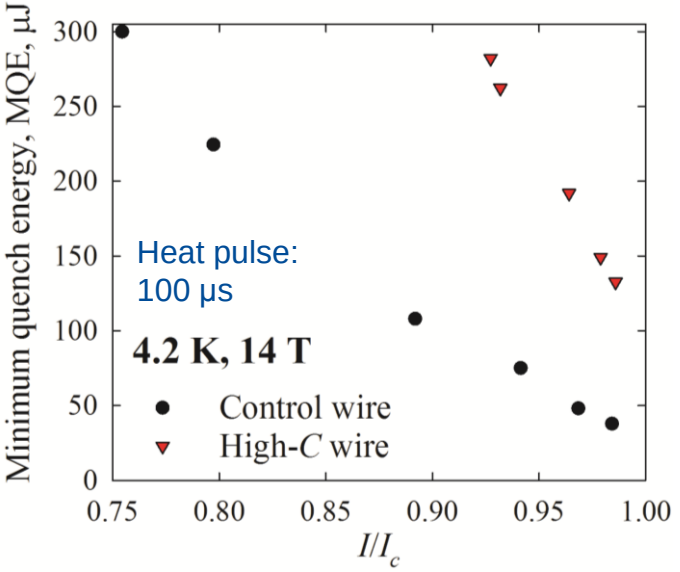
Previous results:

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

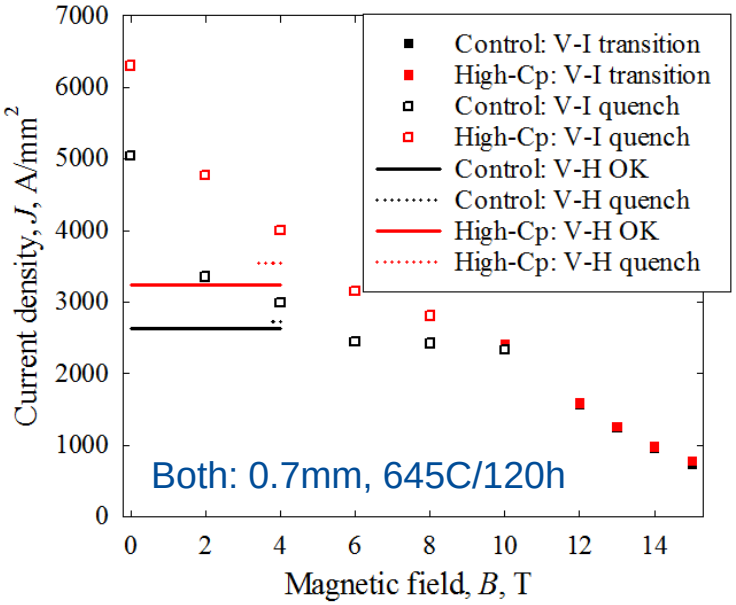
- Slight decrease of flux jump amplitude.
- Need further confirmation, especially with better Cu/Gd_2O_3.



Tripling of MQE:

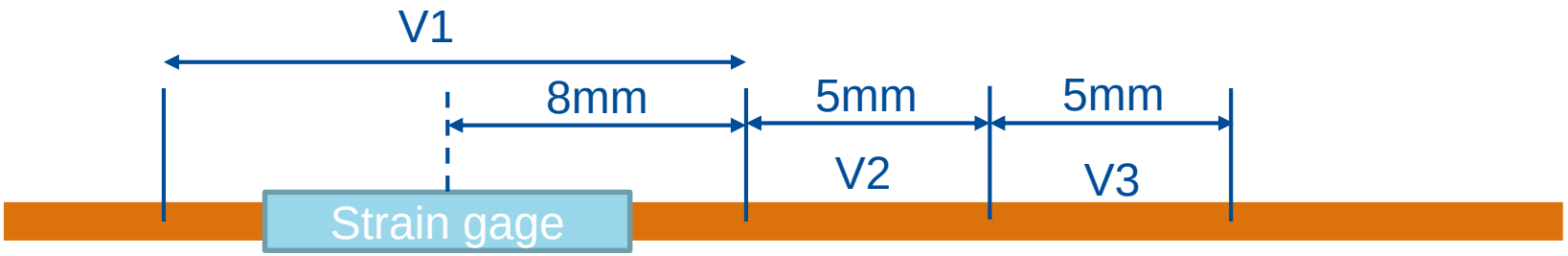


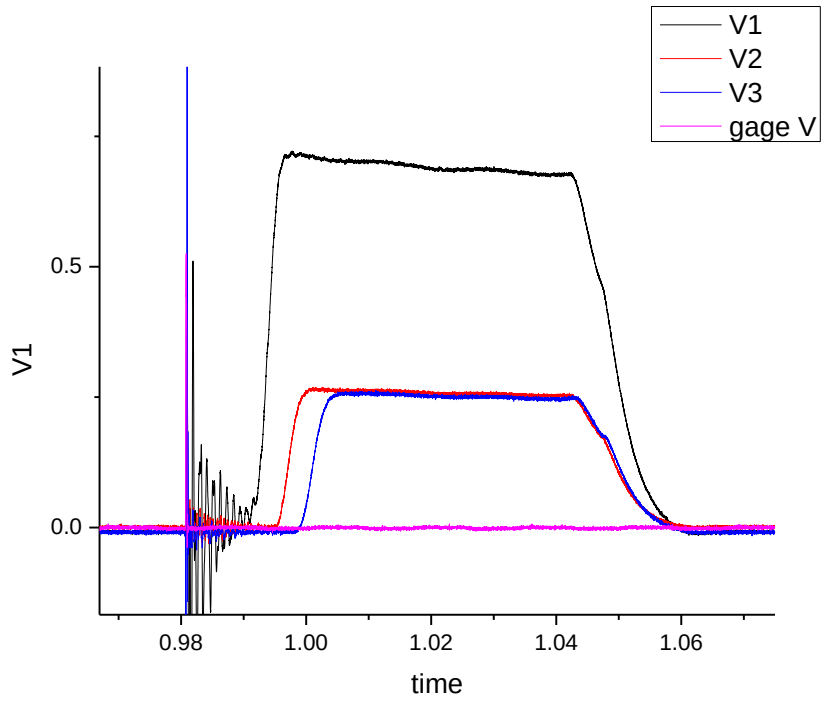
New tests:

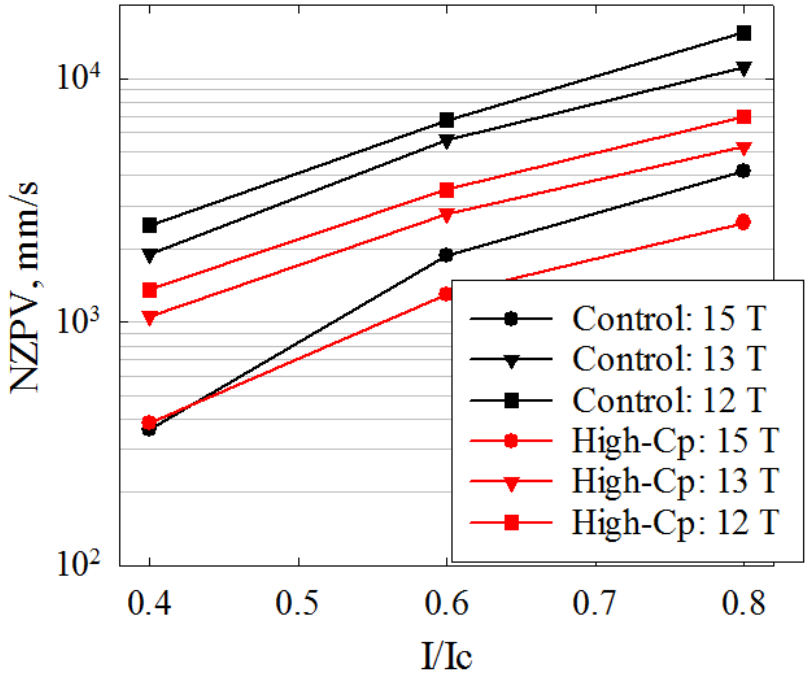


- Control wire starts to quench at 10 T.
- High-C_p wire starts to quench at 8 T.
- High-C_p wire has higher quench currents at low fields.
- Need further confirmation.
- The high-C_p filaments have large time constant, not good for intrinsic stabilization (short perturbations). Need better Cu/Gd_2O_3 mixture.

NZPV tests (set up and measured by Pei Li)





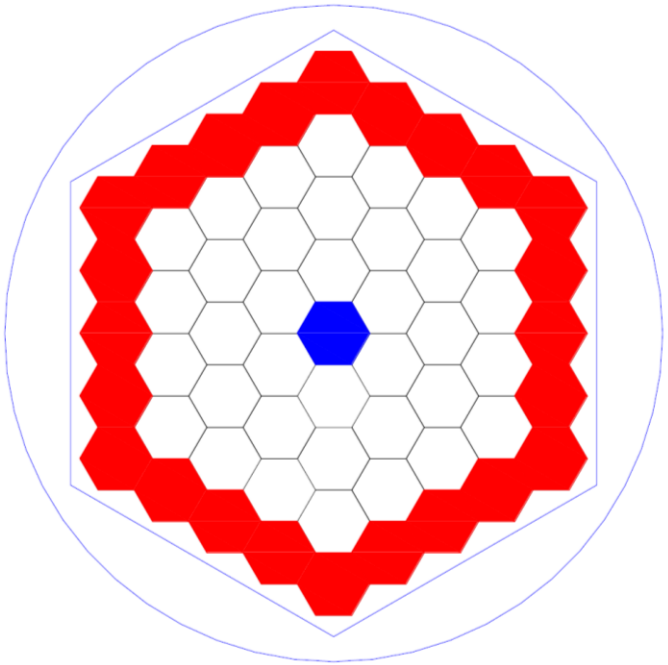


High C_p: NZPV is reduced by half or less.

Further optimization and industrialization

Plans for industrialization of high-C_p wires with Bruker:

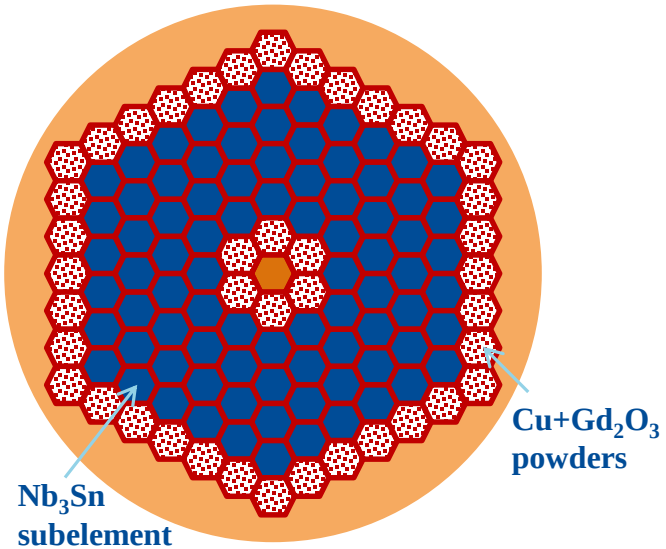
- First, optimization of high-C_p rods, including:
  - The ratio of Cu/Gd_2O_3 powders
  - The powder packing density
  - Mixing procedures
  - The size of Cu tube
- Second, shipping the optimized high-C_p rods to Bruker-OST and making RRP wires.



Original plan: 61-Re design: 24 high-C_p + 36 Nb_3Sn + 1 Cu.

In consideration: may change to 127-Re design: 42 high-C_p + 84 Nb_3Sn + 1 Cu.

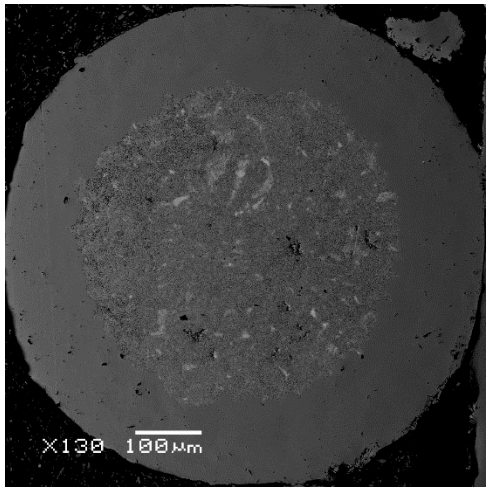
Eventually, adjust Cu/non-Cu ratio to get high Nb_3Sn%.

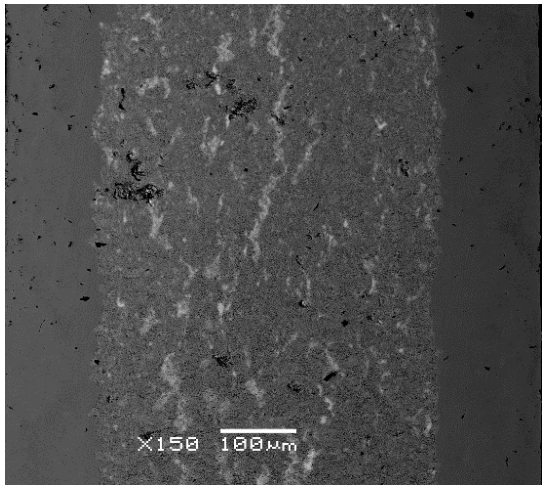


New high-C_p rods made by Bruker-EAS

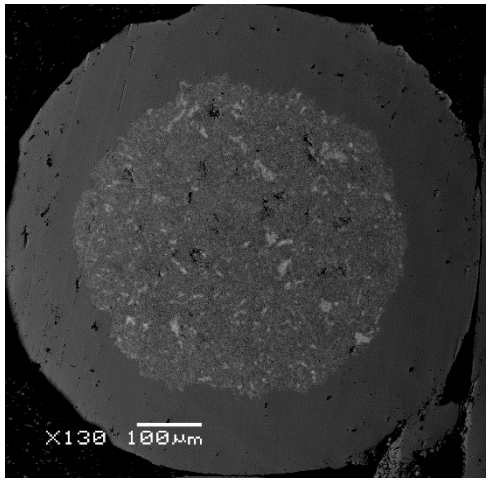
Current status: two high-C_p rods have been made, drawn to 4.6 mm and 0.74 mm.

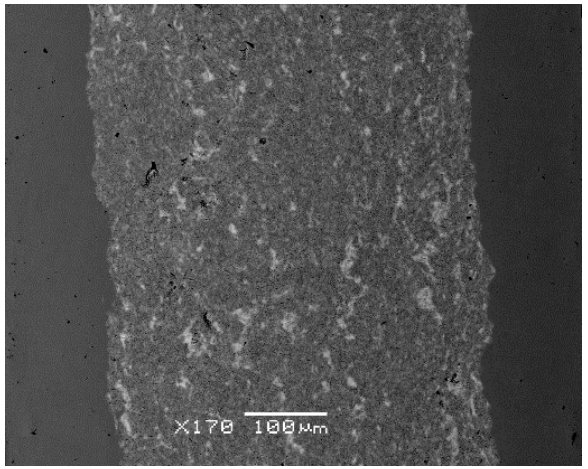
Cu/Gd_2O_3 = 8:2





Cu/Gd_2O_3 = 7:3





These have been much better than the previous one. But need to further optimize.

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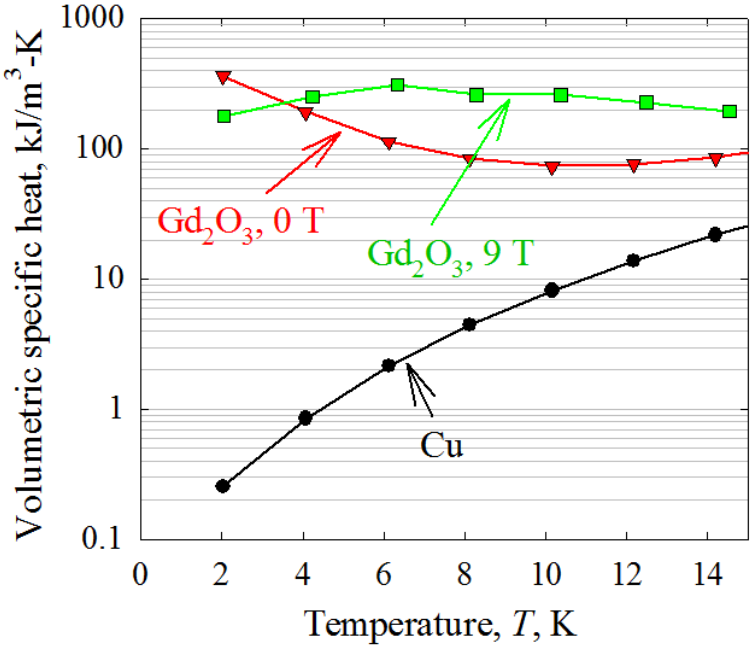
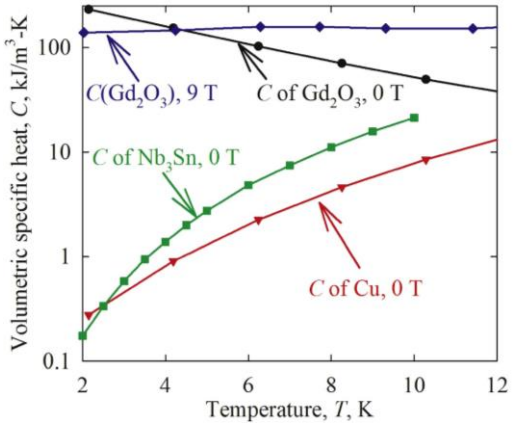
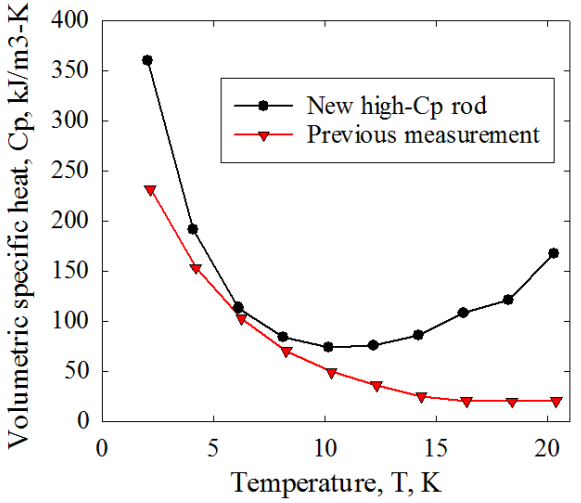
C_p measurements on the new high-C_p rods



Correction:



X. Xu *et al.*, *Supercond. Sci. Technol.* 31, 03LT02, 2018



$C_p(Gd_2O_3)/C_p(Cu)$	2 K	4 K	6 K
0 T	1400	230	60
9 T	700	300	150

Energy margin = $\int C_p dT$ from 2 K to T_{cs} (6-8 K).
May boost by >5 times by adding 2 vol.% Gd_2O_3.

It would be interesting to measure C_p at higher field, e.g., in 14 T or 16 T PPMS.

Old:

Sample Temp (Kelvin)	Samp HC (μJ/K)	Samp HC Err (μJ/K)
6.0019992	249.5877	25.22
6.001623	159.4678	10.75
6.0026711	193.2876	10.04
3.9978946	155.242	17.64
3.998003	53.09301	5.169
3.9975743	110.7092	10.46
2.0025718	82.60816	17.07
2.002424	30.01866	4.152
2.0024184	51.86808	8.638

New:

Sample Temp (Kelvin)	Samp HC (μJ/K)	Samp HC Err (μJ/K)
6.1185369	10.134208	0.09378
6.1167712	10.203325	0.04633
6.1186677	10.057748	0.05484
4.0576472	14.035768	0.09432
4.0679459	14.312299	0.09531
4.074329	14.118822	0.05416
2.0333981	25.144407	0.02311
2.0339328	25.135253	0.01162
2.0339405	25.151921	0.01203

Summary

Measurements on the high-C_p wire made by Hyper Tech show:

- Some signs of reduced flux jump amplitude
- Tripling of MQE
- Some signs of improved V-I and V-H stability
- Reduction of NZPV by half or less

For this wire, time constant for the high-C_p filaments to absorb heat is too large, not good for intrinsic stabilization. Need better Gd_2O_3/Cu mixture.

Industrialization of high-C_p wires with Bruker starts with optimization of high-C_p rods. Two have been made. More will be tried to find optimal recipe.