Fermilab

Update on the APC Nb_3Sn project

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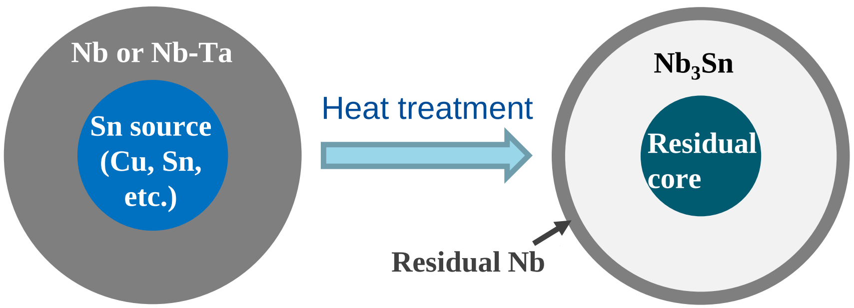
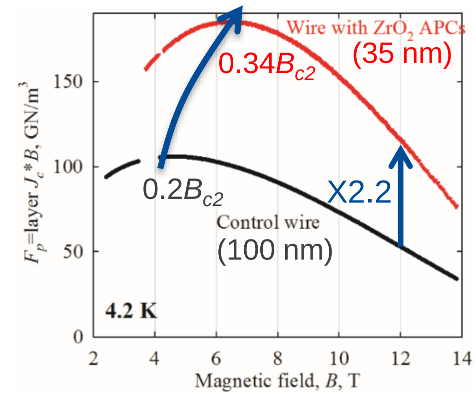
Goal: develop an APC technique to improve J_c of Nb_3Sn

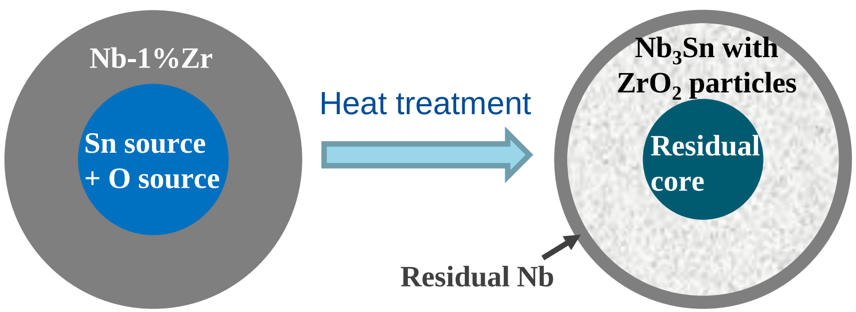
A present-day Nb_3Sn subelement:



ZrO_2 particles (3-15 nm)
→ refined grain size *d* (100-150 nm to 35-50 nm)
→ improved J_c ($J_c \propto 1/d$)



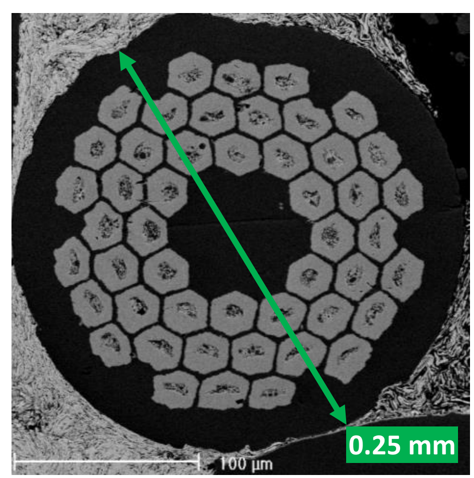
A modified Nb_3Sn subelement:



First we will focus on the PIT wires.

Baseline design: Sn+Cu+SnO_2 powders in Nb-1%Zr tube.

Such wires were drawn to 25 µm D_s with no issues:



Need to optimize the recipe:

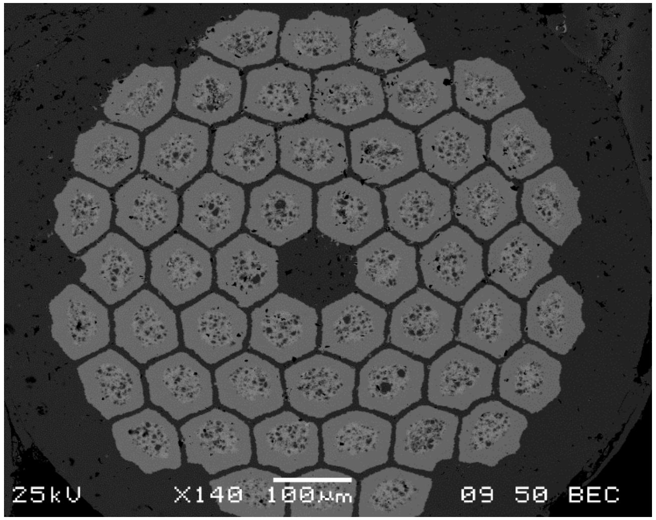
- SnO_2 amount
- Sn and Cu amounts
- I.D./O.D. of Nb-Zr tube
- Powder packing density
- Method to mix powders
- Method to fill powders

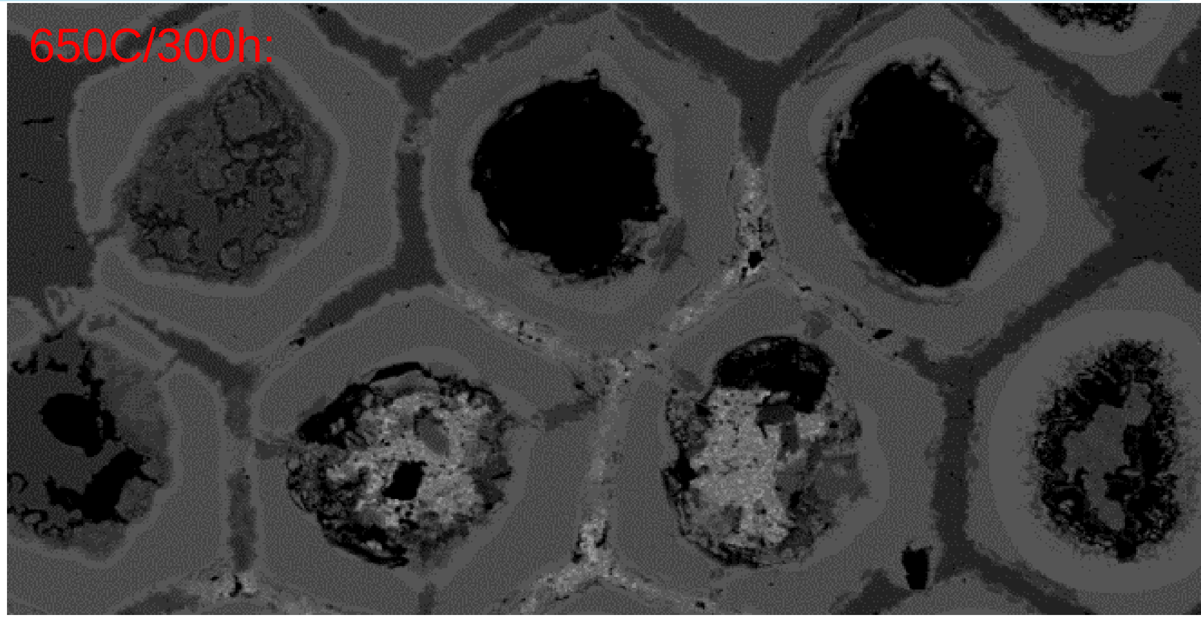
What needs to be done:

Task 1. Maximize Nb_3Sn fraction: requires optimizing recipe:

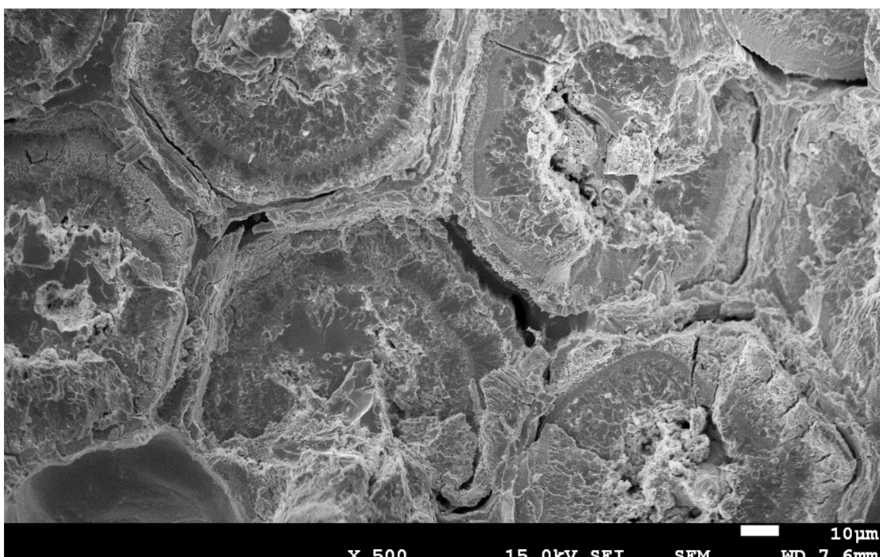
Task 2. Add doping to improve B_{c2}.

The result shown in LTSW 2017:





Non-Cu J_c (12 T) = 1100 A/mm^2



Most filaments have very low Nb_3Sn fraction, perhaps because Sn leaks out, or even filaments are broken.

- The major problem to tackle for this APC project
- Will be a big jump in non-Cu J_c after solving it

Possible causes:

1. Improper powder mixing or filling methods
2. Bad recipe
   - Too much SnO_2
   - Too large core (too high packing density)

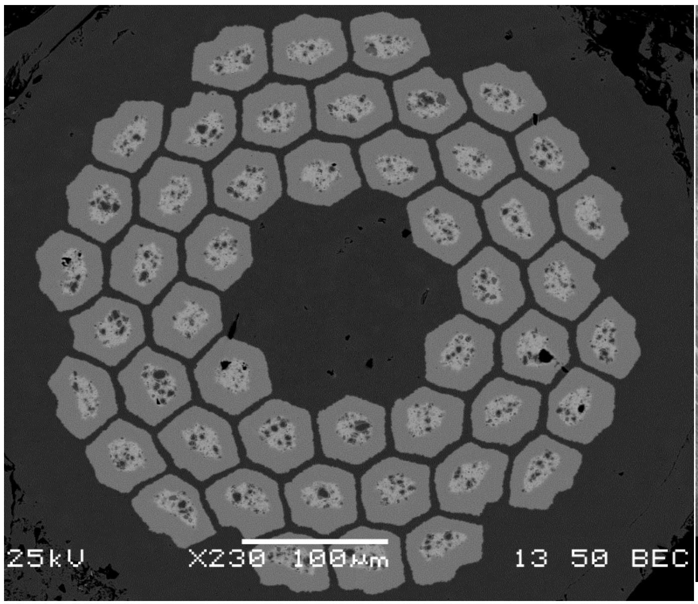
What has been done since LTSW 2017 – I

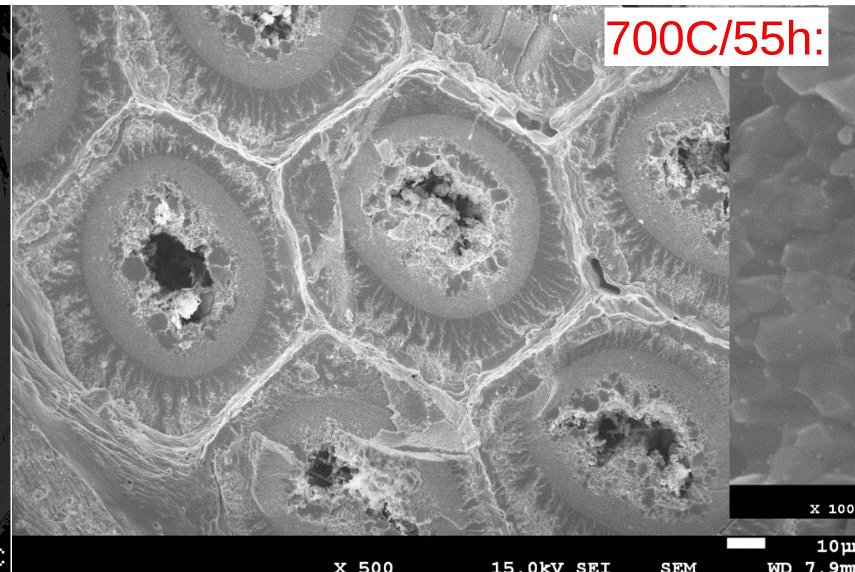
First, a lot of time was spent on learning how to fabricate wires with powders, e.g.:

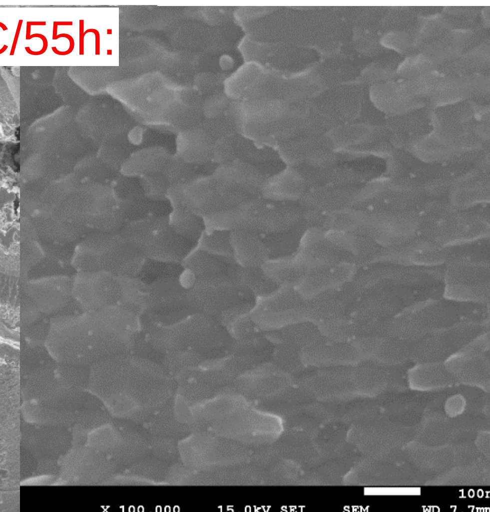
- mixing powders evenly (e.g., regular mixing, planetary milling, etc.),
- filling powders (e.g., stamping with a certain force to reach certain packing density)
- other powder handling

A few multifilamentary wires were made based on these different powder mixing/filling methods.

The most recent methods turn out to have greatly improved the quality of wires.







Grain size refined.

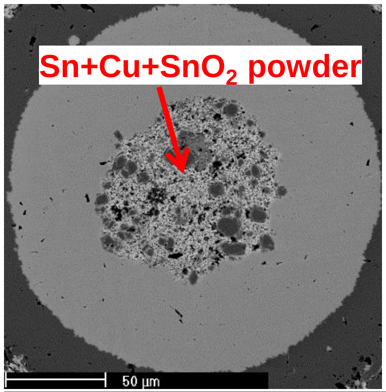
Heat treatments at 650 and 625 C are ongoing. J_c results will be reported next time.

The recipe is not optimized: Nb/Sn ratio too high. Next, use the same powder mixing/filling methods and try modified recipes.

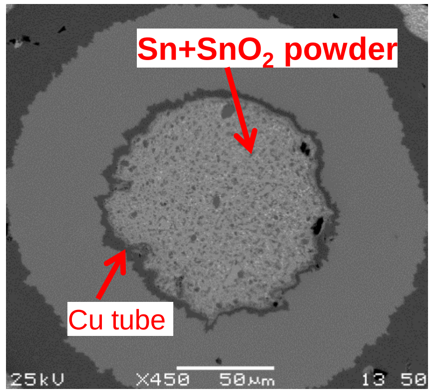
What has been done since LTSW 2017 – II

Searching for a better design: mixing two powders instead of three

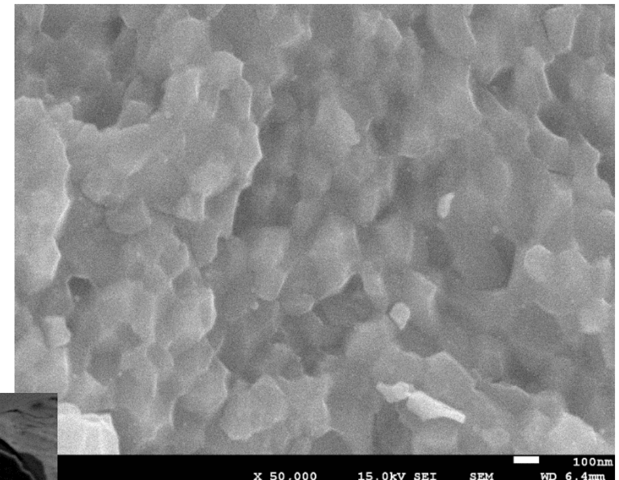
Baseline design:



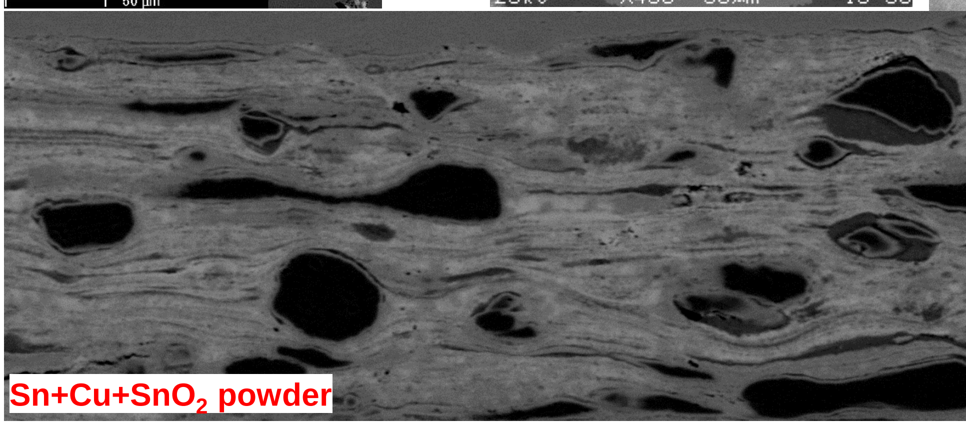
New design:

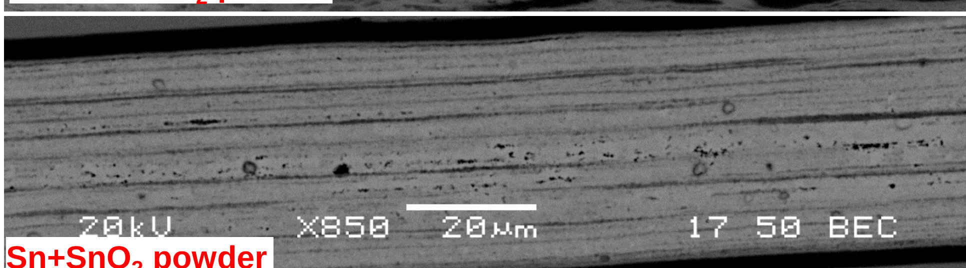


Grain size not refined:

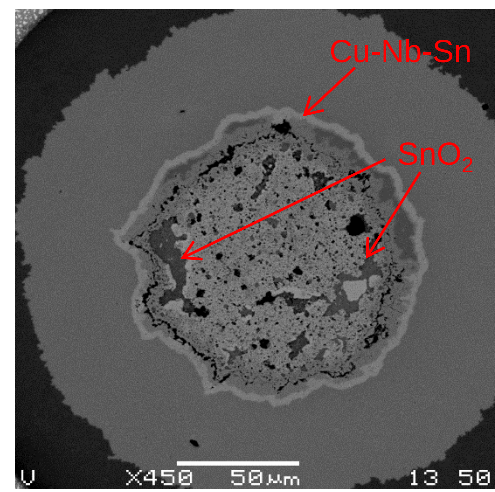


Oxygen does not transfer from SnO_2 to Nb-Zr: Very likely because the Cu-Nb-Sn ternary phase blocks O transfer.





Maybe new heat treatment can solve this issue.



Two advantages:
1. Uniformity is better.
2. Smoother.

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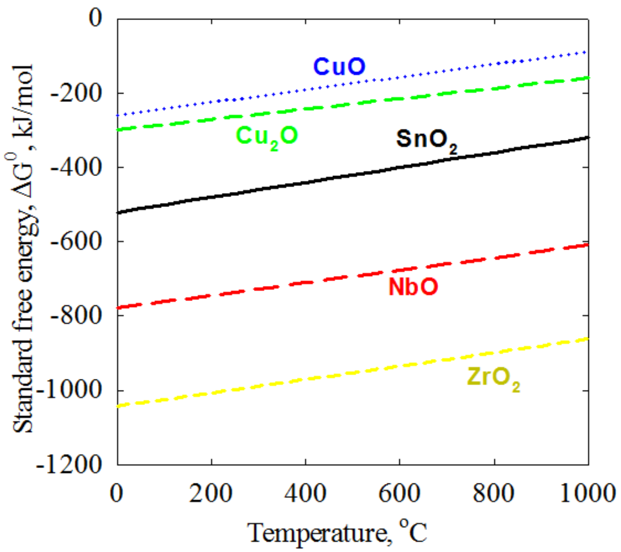
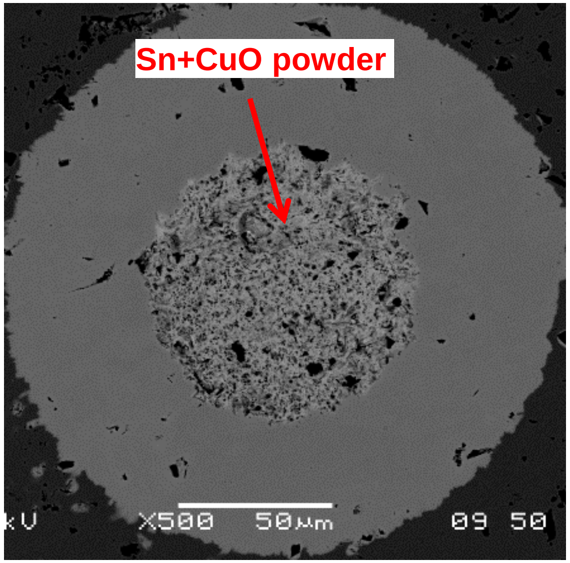
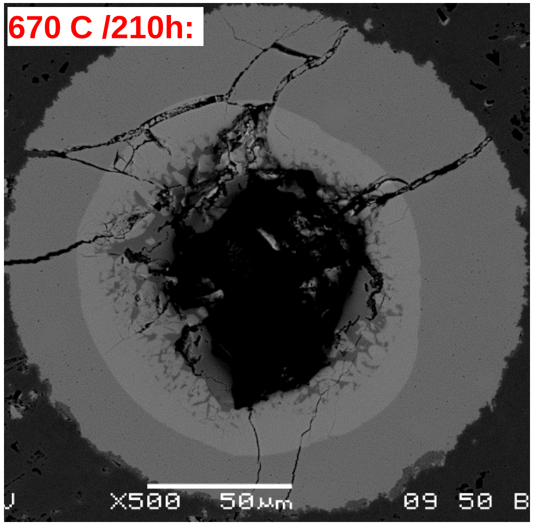
What has been done since LTSW 2017 – III

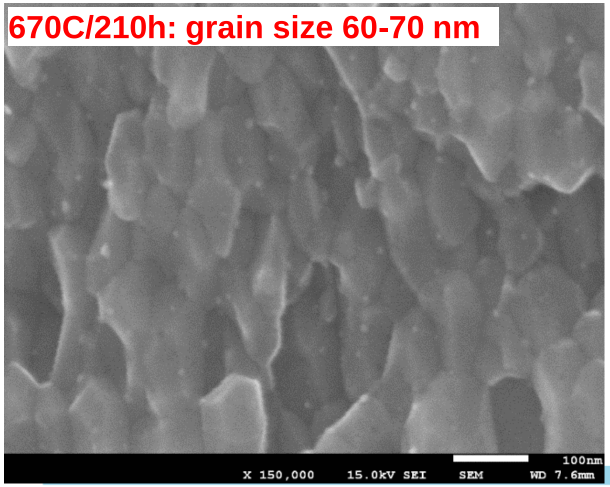
Searching for a better design: mixing two powders instead of three



A new design:







We could also use Cu_2O powder instead of CuO if we want more Cu.

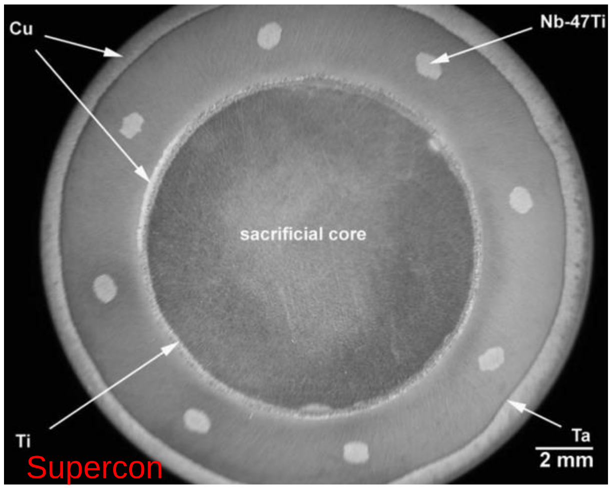
A multifilamentary wire with Sn+Cu_2O powders is being fabricated.

What has been done since LTSW 2017 – IV

Adding Ti doping

Adding Ti to the core does not work, because Ti reacts with O to form TiO_2.
Ti must be added to the Nb alloy tube.

How?



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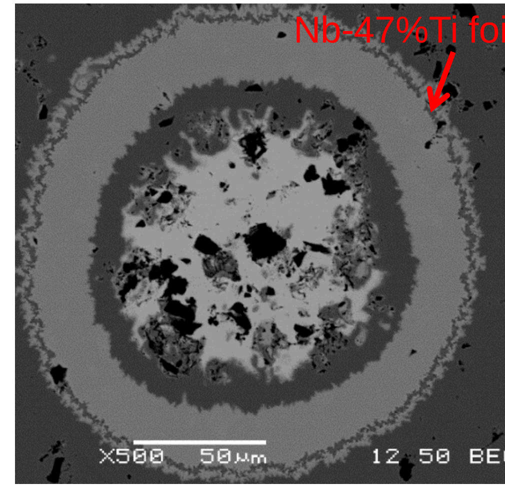
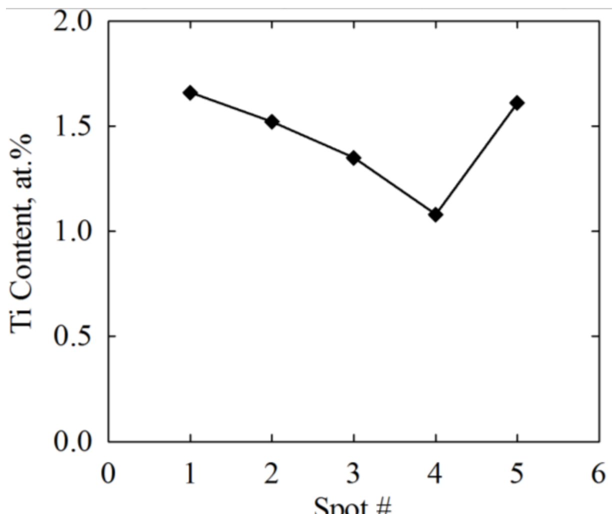
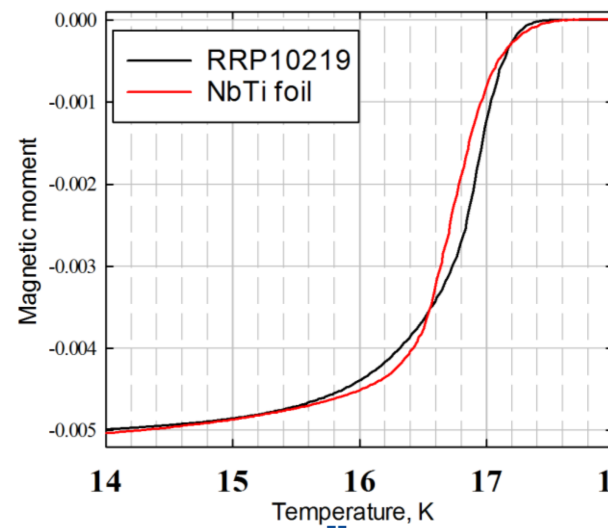
This scheme is suitable for introducing Ti to PIT wires. However, drilling holes is not good for large-scale production.

We came up with a new scheme, and first fabricated a normal tube type wire to see if Ti doping can be realized:



EDS results show we got desired Ti level:





What has been done since LTSW 2017:

1. A lot of time was spent on learning how to properly mix powders and fill powders to reach certain packing density. This is critical to avoid bad filaments.
2. Through these studies we have acquired the proper techniques and have fabricated good-quality wires. Still need to optimize recipe.
3. Extensive work to search for a better design has been done (and is still ongoing). A scheme using Sn+CuO (Cu_2O) is very promising. If successful, the new design should lead to much better wire quality than the present baseline design.
4. Work on Ti doping using NbTi foil shows very promising results.

Work next:

1. Finalize the subelement design: if the Sn+Cu_2O scheme is good, it will be the new standard design.
2. Continue optimizing the recipe, which should lead to Nb_3Sn fraction similar to present PIT wires.
3. Continue studying Ti doping, and fabricate ternary APC wires soon.