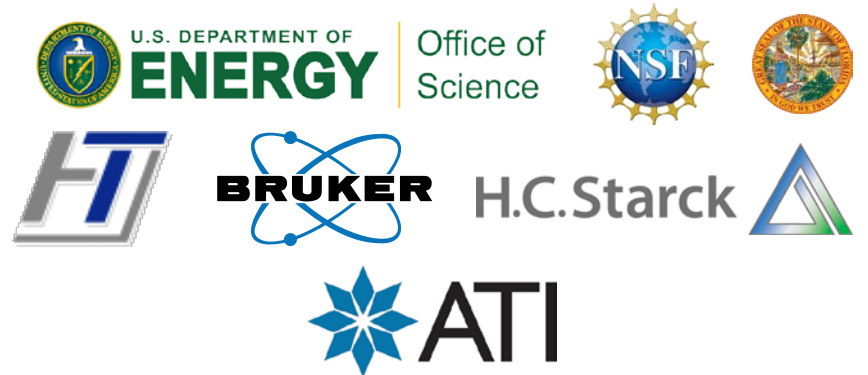


60 years on- A new alloy for better Nb₃Sn

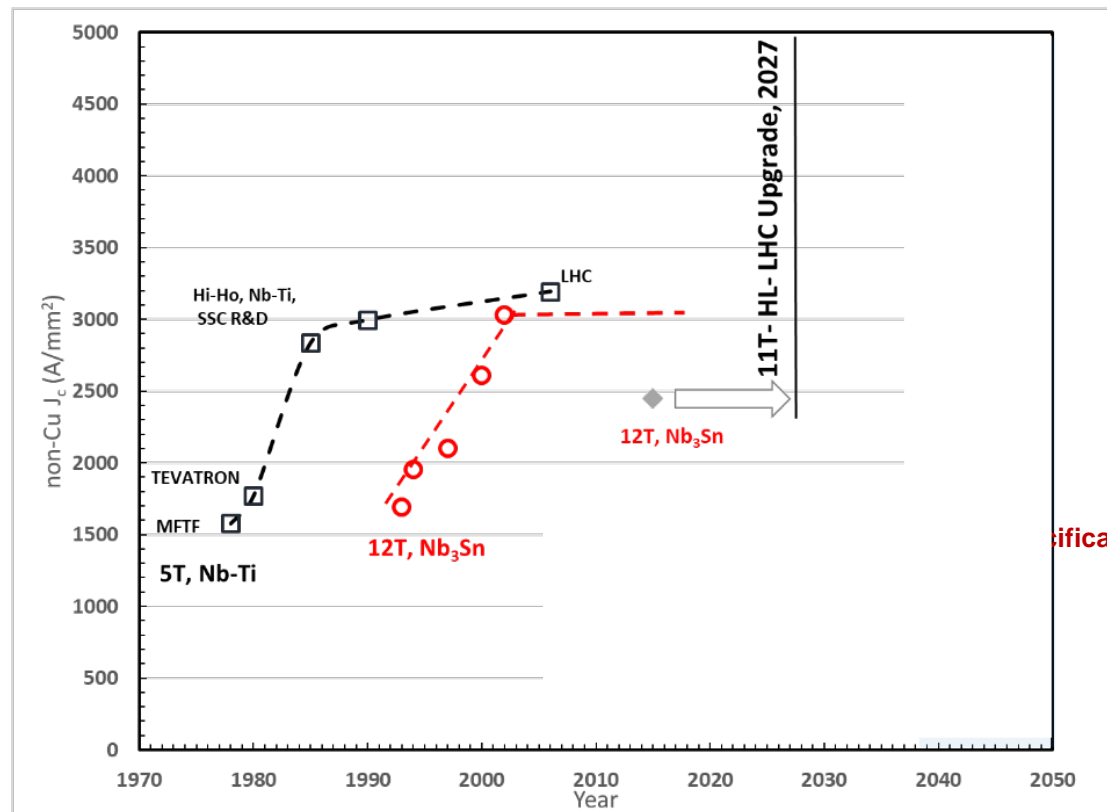
Shreyas Balachandran

Chiara Tarantini, William L. Starch, Nawaraj Paudel, Peter J. Lee, David C. Larbalestier.
Applied Superconductivity Center, NHMFL, FSU, Tallahassee, FL 32310, USA

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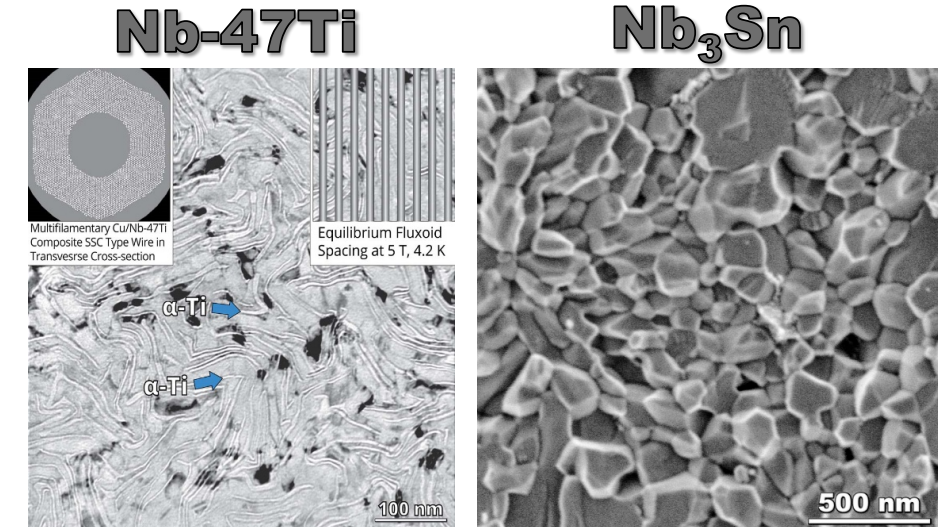
Commercial Nb₃Sn round wire J_c (4.2K, non-stabilizer) can reach up to 1100 A/mm² (16T, 4.2K), still below FCC specification of 1500 A/mm²(16T, 4.2K)



Nb₃Sn data from Parrell *et al.* 2004 <http://dx.doi.org/10.1063/1.1774590>,

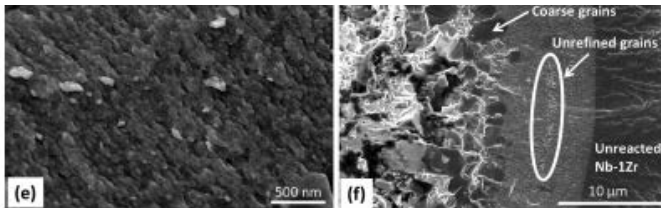
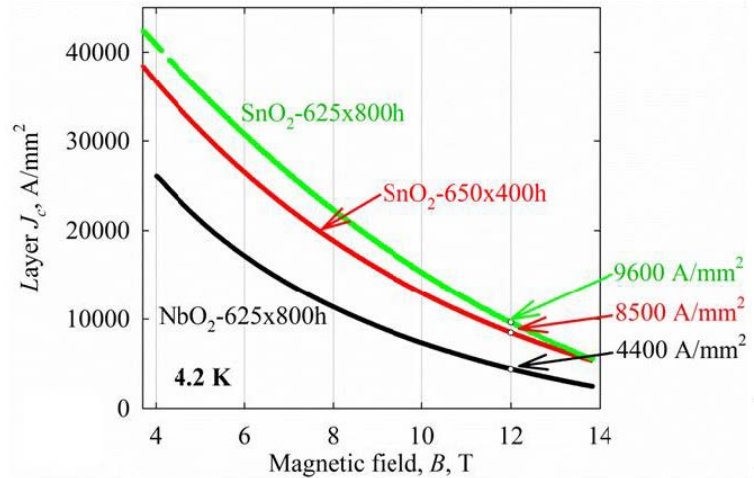
Sanabria *et al.* 2018 doi.org/10.1088/1361-6668/aab8dd

Plot from Peter Lee, ASC, NHMFL



- Grain boundary pinning in Nb₃Sn is neither as efficient nor as dense as α-Ti pinning in Nb-47Ti.
- Decreasing grain size would boost Nb₃Sn, and addition of insulating pins increases J_c.

Nb₃Sn grains nucleate small but grow reaction heat treatment: Can we prevent this?

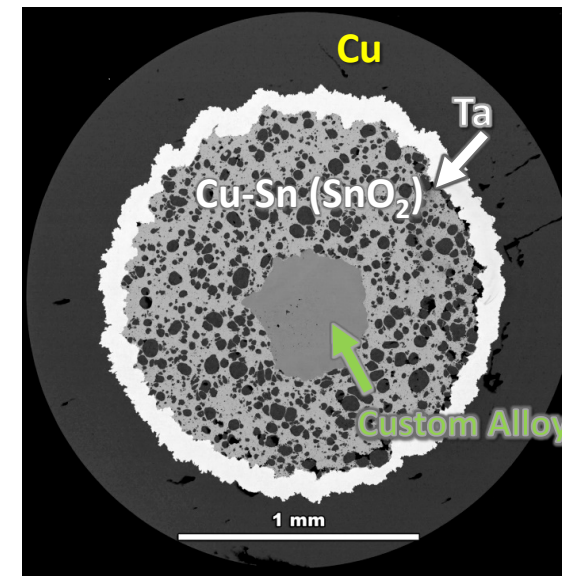


X. Xu, et al. *Adv. Mater.* 2015, 27, 1346–1350

Nb1Zr with internal oxide source resulted in improved J_c , ZrO_2 precipitates, and finer Nb_3Sn grains (30-50nm).

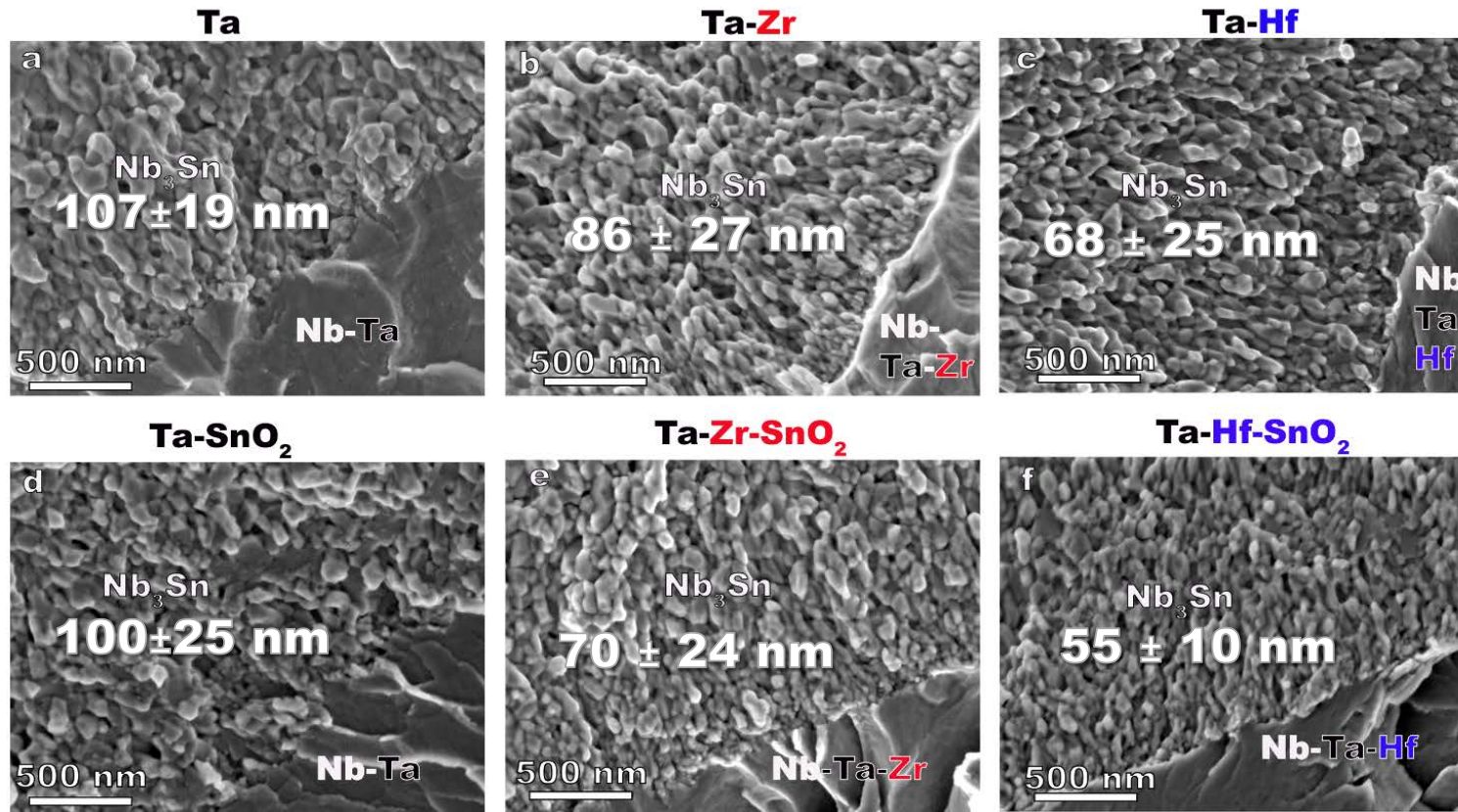
A more general question-

- Initial A15 nucleation occurs in the Nb alloy grain boundaries.
- Avoiding alloy grain growth during the Nb_3Sn reaction heat treatment could be very beneficial.

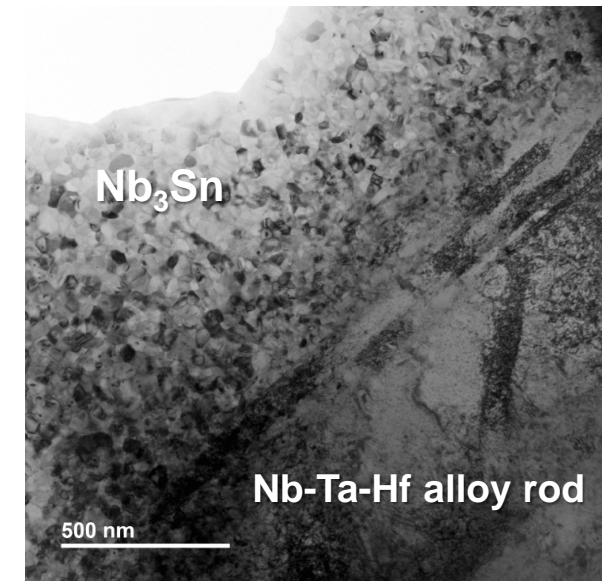


S. Balachandran et al., *Supercond. Sci. Technol.* 32 (2019) 044006

Nb₃Sn grain size formed from Hf and Zr based Nb4Ta alloys are reduced to 50-60nm, because neither alloy recrystallizes during the 550°C/100h + 670°C/100h.



Wk2MOr3A-01 -Nb₃Sn: Grain Refinement and Artificial Pinning Centers
 Wednesday, November 4th, 4:45pm-5:45pm

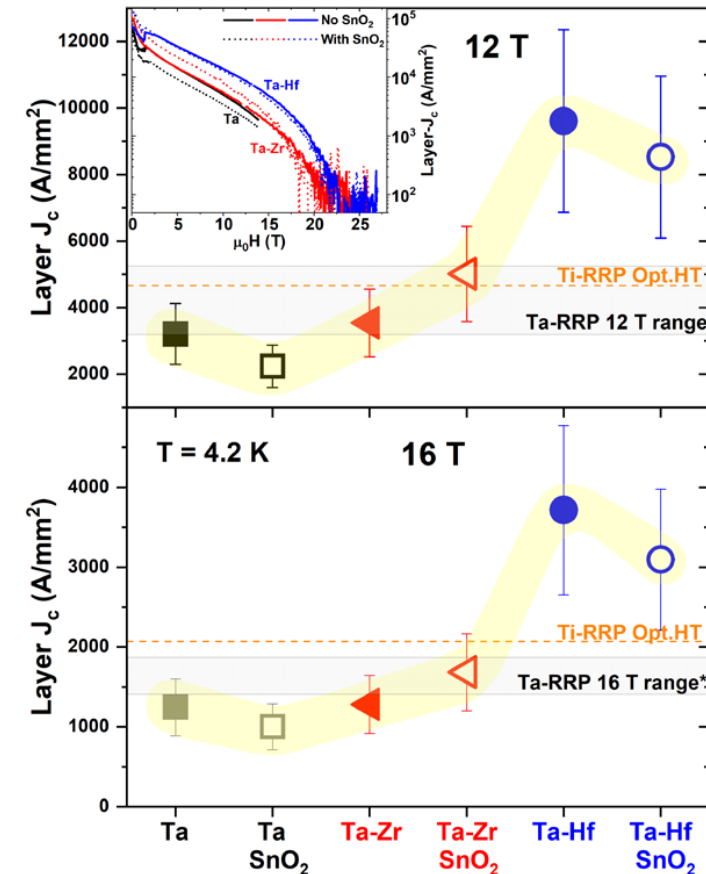
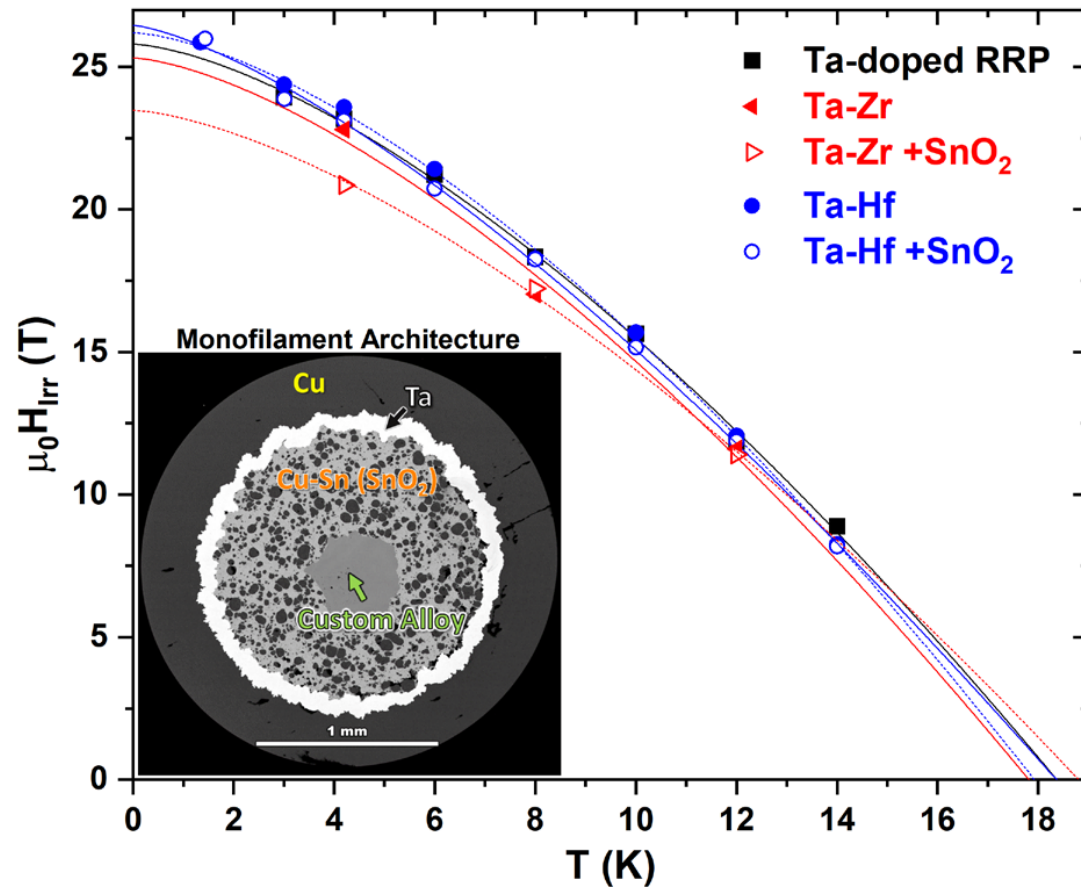


Nb-Ta-Hf -Nb₃Sn interface

S. Balachandran *et al.*, *Supercond. Sci. Technol.*
 32 (2019) 044006

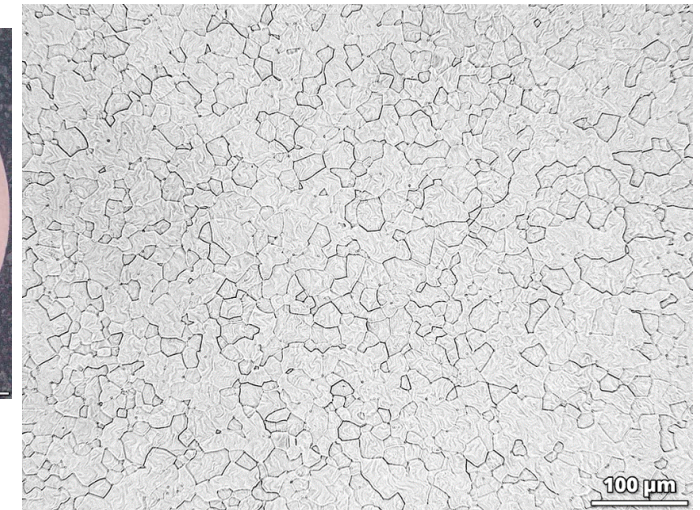
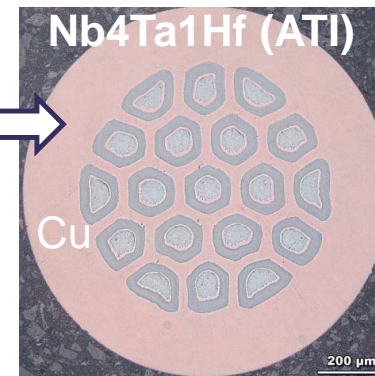
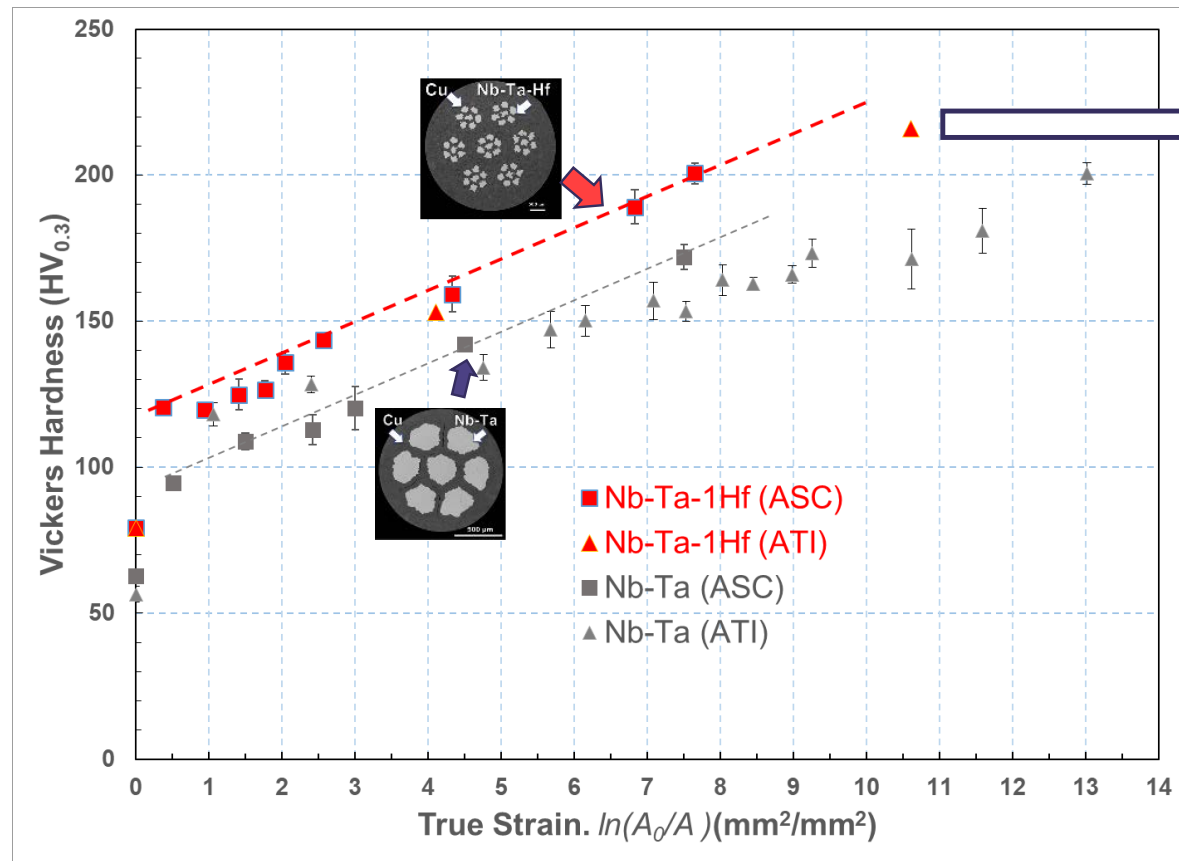
- The smaller the grain size in the alloy rod, smaller is the A15 grain size.
- Finer alloy rod grain size promotes faster Sn diffusion along GBs.

These ternary alloys Nb₄Ta₁Hf and Nb₄Ta₁Zr slightly increase the irreversibility field. Nb₄Ta₁Hf provided the highest pinning force magnitude.



Enhanced irreversibility field was separately confirmed by X. Xu et. al in Nb₄Ta₁Zr with SnO₂

Industry has been able to fabricate the Nb₄Ta₁Hf alloy.



- ATI Metals have fabricated a 1200lb ingot.
- ASC-NHMFL received the rods and tubes September 10th.
- HC Starck has fabricated a small scale 20lb ingot and are able to scale up to greater than 100lb ingots

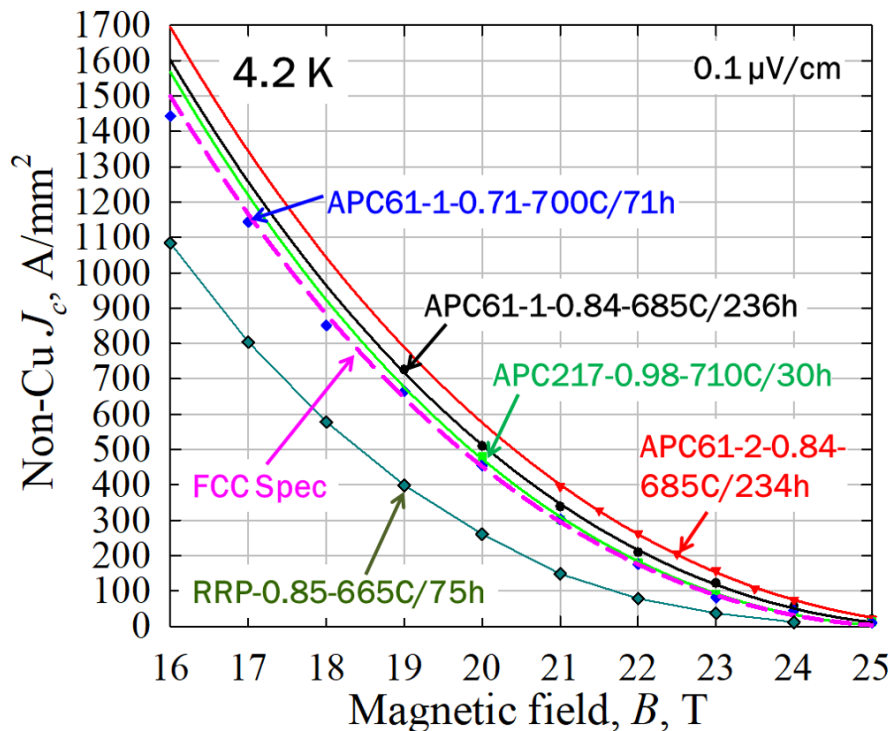
Drawing of a multi-filament is not an issue in the strain space explored

Wk2MOr3A-01 - [Invited] Progress on Nb-Ta-Hf multi-filamentary Nb₃Sn conductors.
Wednesday, November 4th, 4:45pm-5:45pm

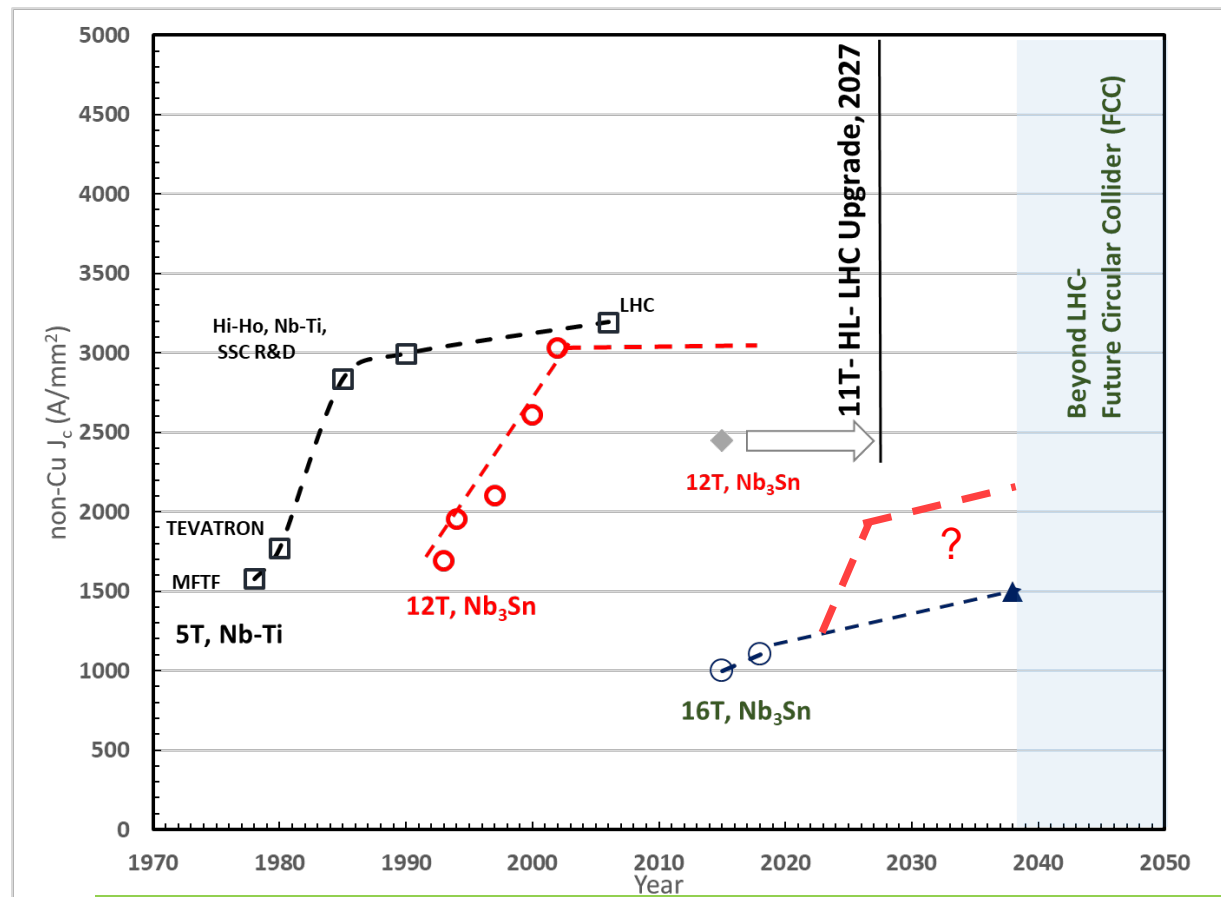
Main takeaways

- Grain refinement of Nb₃Sn below the current grain size of 100nm is essential for increasing the high field pinning force, especially at 16T, 4.2K.
 - Nb alloy fine grain size that is stable during the reaction heat treatment refines Nb₃Sn grain size by increasing Sn diffusion and heterogeneous nucleation density.
- Ternary doping remains important for next generation Nb₃Sn wires. Additions of Hf and Zr to Nb₄Ta produce modestly enhanced Nb₃Sn properties.
 - Hf additions perform better than Zr additions.
 - Internal oxidation may provide J_c enhancements by the formation of insulating oxide pinning centers.
- Industry has been able to fabricate a Nb₄Ta₁Hf alloy with average grain size less than 50μm.
 - We have found no issues in drawability of the Nb₄Ta₁Hf up to a strain of 10.

R&D development of next generation Nb₃Sn conductors to meet FCC targets and beyond are progressing well.



Congratulations to FNAL-OSU-Hypertech collaboration on reaching the FCC milestone



Wk2MOr3A-01 -Nb₃Sn: Grain Refinement and Artificial Pinning Centers
 Wednesday, November 4th, 4:45pm-5:45pm