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Microstructure and superconducting properties of Hf,Ta-added bronze-route Nb_3Sn wire

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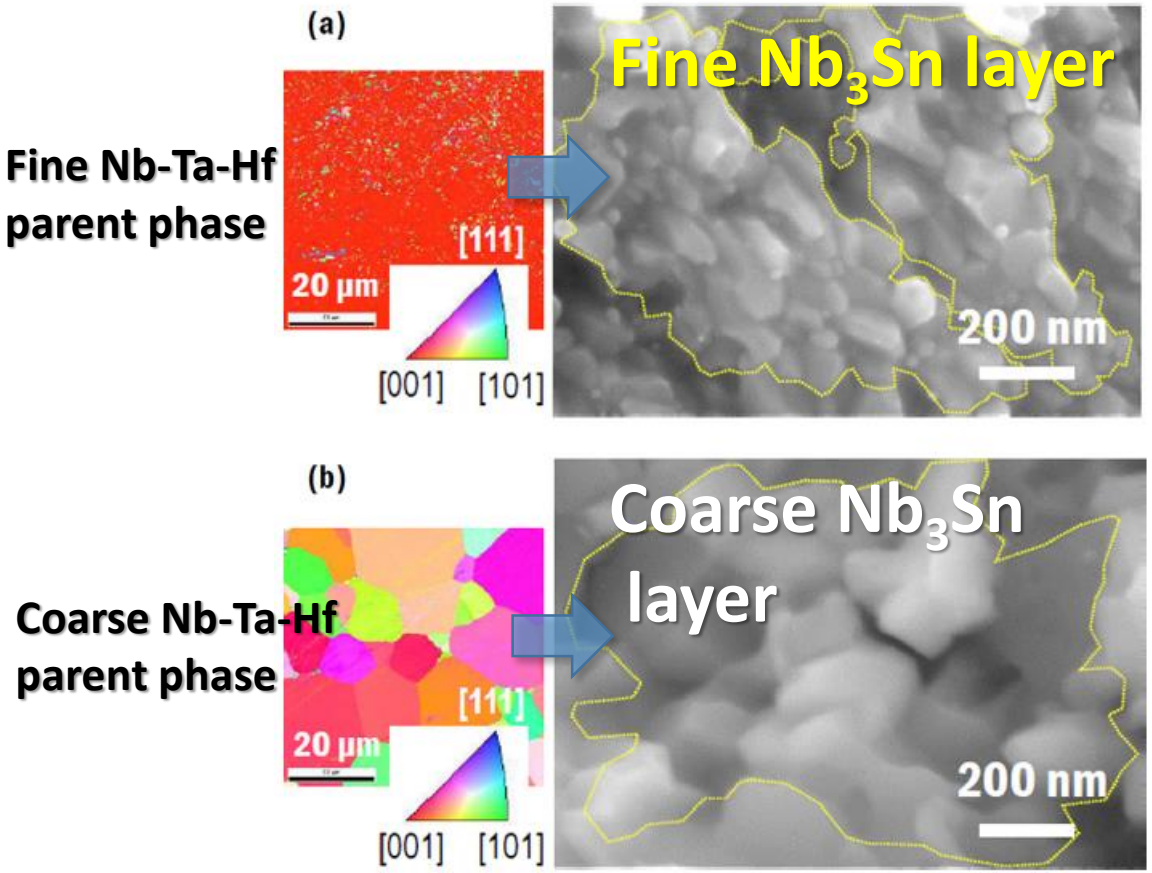
Introduction

- **Hf addition together with Ta to the Nb cores** results in significant refinement of the Nb_3Sn grain morphology, leading to large enhancement of flux pinning characteristics [1].

  That is of great interest in the field of Nb_3Sn wire development.



[2] Nobuya Banno et al."Influence of parent Nb-alloy grain morphology on the layer formation of Nb_3Sn and its flux pinning characteristics", **Scr. Matr., 199 (2021) 113822** https://doi.org/10.1016/j.scriptamat.2021.113822

[1] Shreyas Balachandran et al."Beneficial influence of Hf and Zr additions to Nb4at%Ta on the vortex pinning of Nb3Sn with and without an O source", **SUST, 32 (2019) 044006**

- This effect has been confirmed so far for the PIT [1] and the internal tin Nb_3Sn wires [2].

  However, **this effect** should be naturally **expected also for the bronze route Nb_3Sn wires**.

  ➡ **Confirm it in this work**
  (Compare the microstructure and J_c with conventional bronze-processed wires)

Interesting results have been obtained.

Contents

- Fabrication of **single-core Bronze-processed Nb_3Sn wires**

  #1: **Nb/Cu-14wt%Sn-0.2wt%Ti**: N-C14S02Ti

  #2: **Nb-0.8wt%Ti/Cu-14wt%Sn**: N08Ti-C14S

  #3: **Nb-4at%Ta-1at%Hf/Cu-14at%Sn**: N4Ta1H-C14S

  (point of #1: typical bronze-process (**Ti addition to matrix**)

  #2: typical bronze-process (**Ti addition to Nb**)

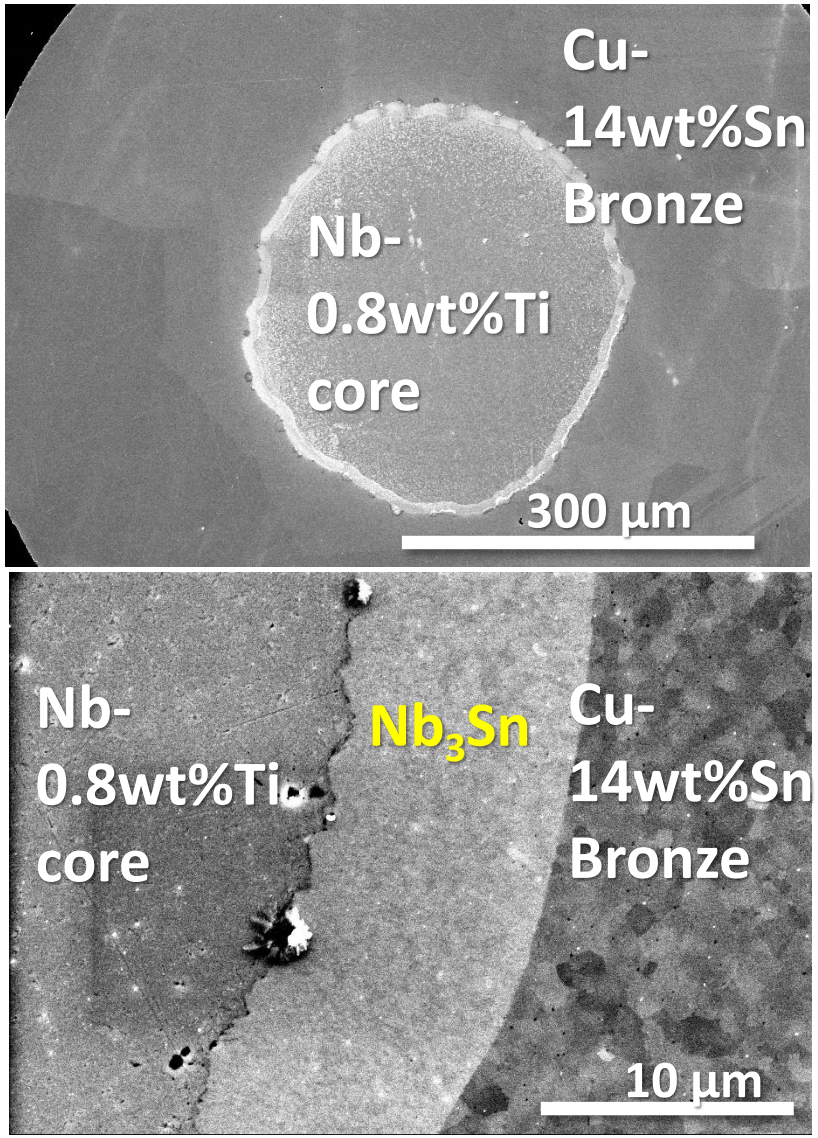
  #3: **Hf-Ta-addition to Nb** & no Ti addition)

  (Heat-treatment: 685-700°C x 100 h)

- **SEM, EDS, EBSD** microstructural observation & analysis

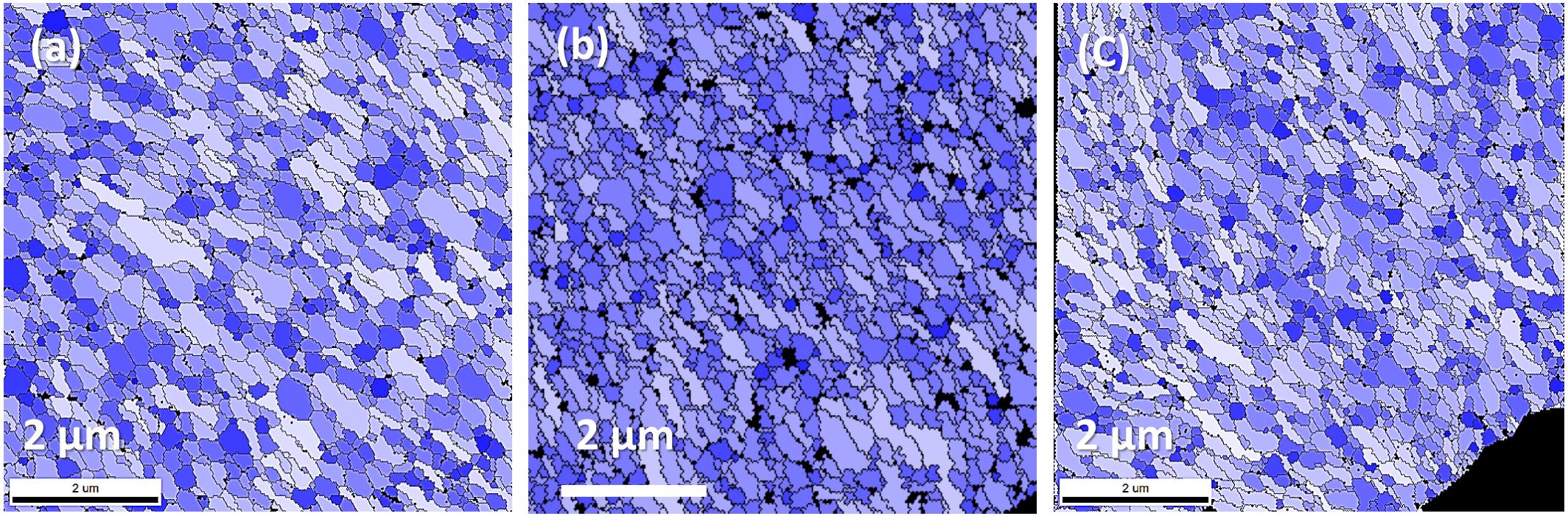
- I_c-B (**Layer J_c-B**) measurement in LHe.

Ex. of cross-section (N08Ti-C14S)



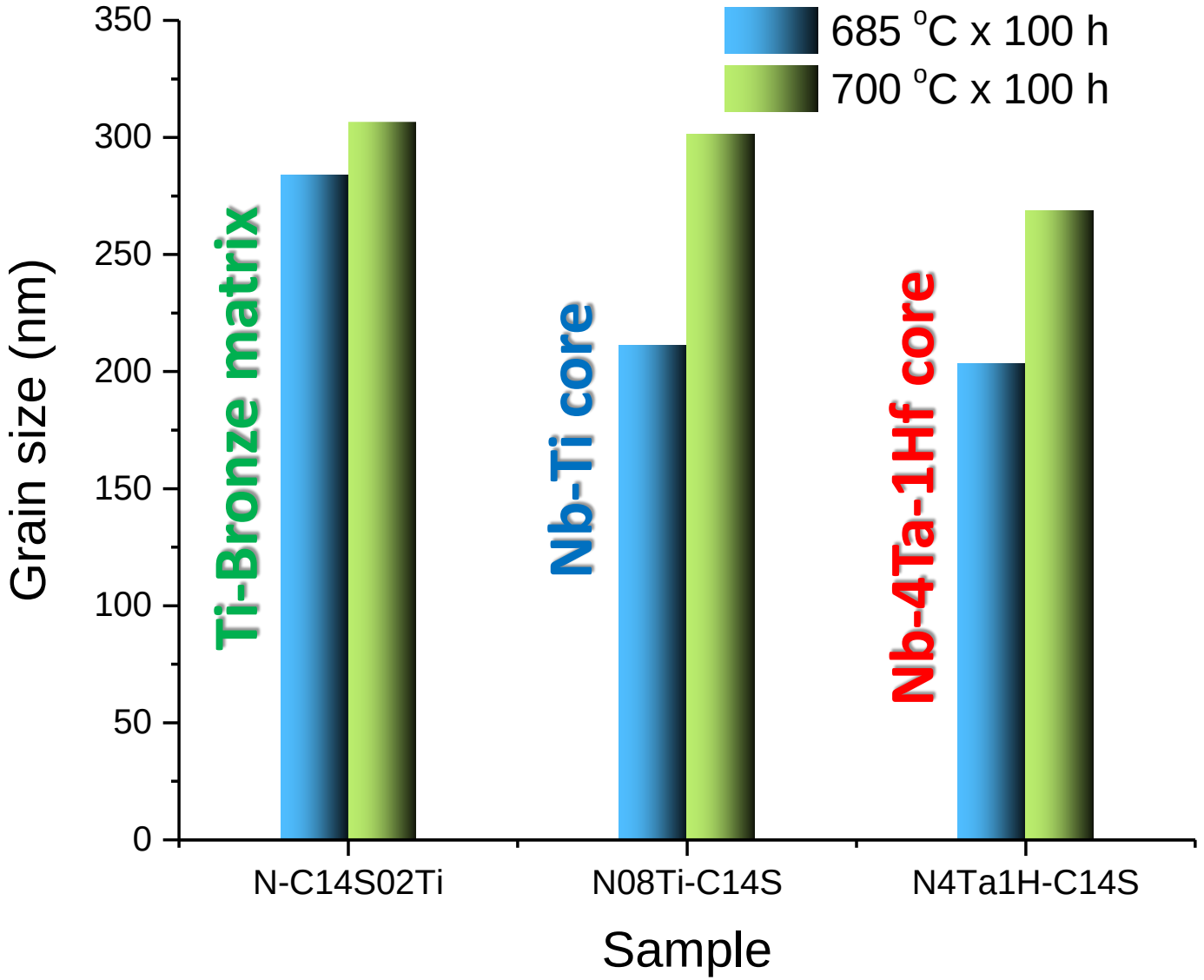
Grain size – EBSD map –

EBSD grain maps on Nb_3Sn layer after **700 °C × 100** h.
Contrast indicates aspect ratio.



N-C14S02Ti **N08Ti-C14S** **N4Ta1H-C14S**

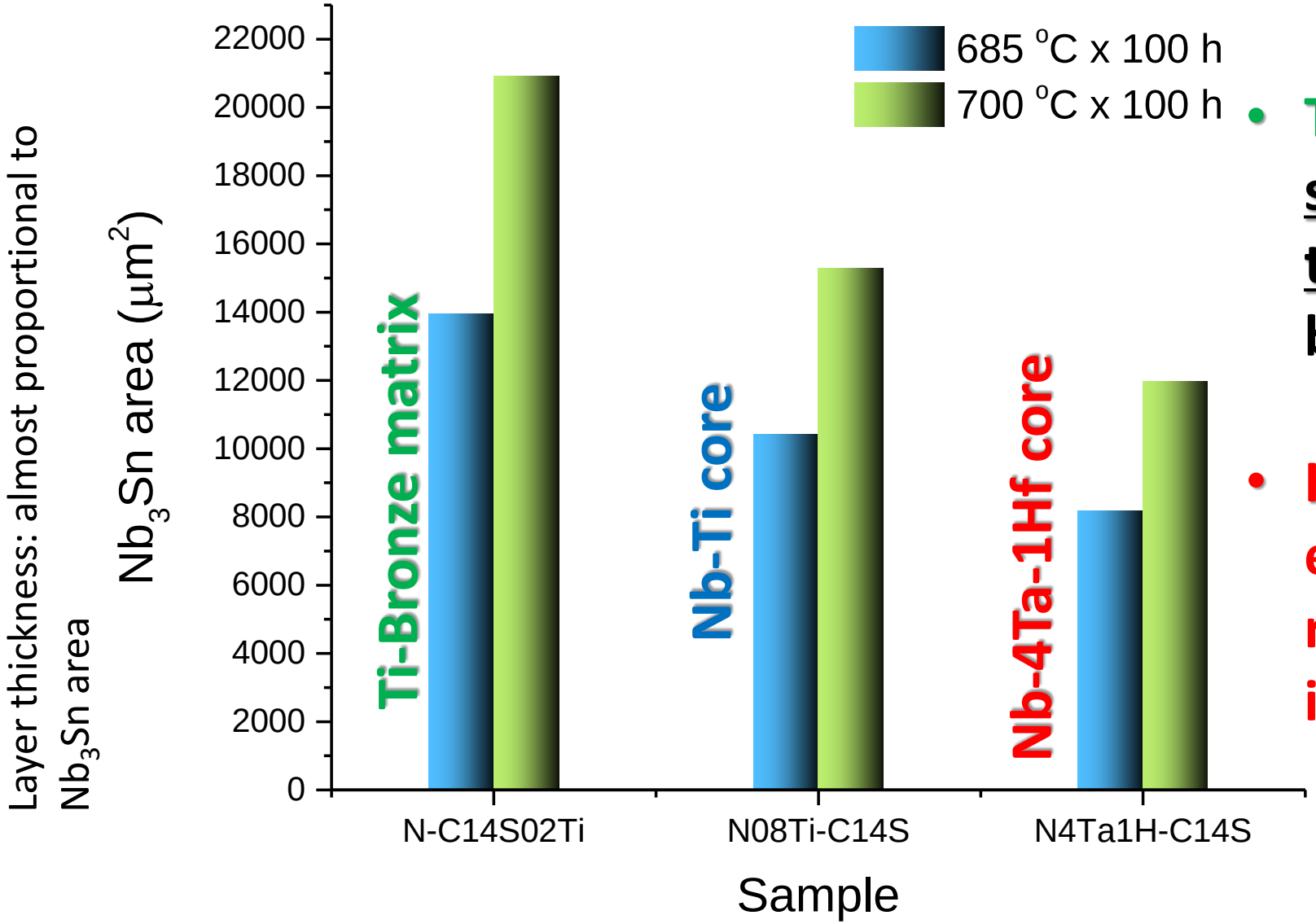
Grain size – EBSD analysis –



Summary

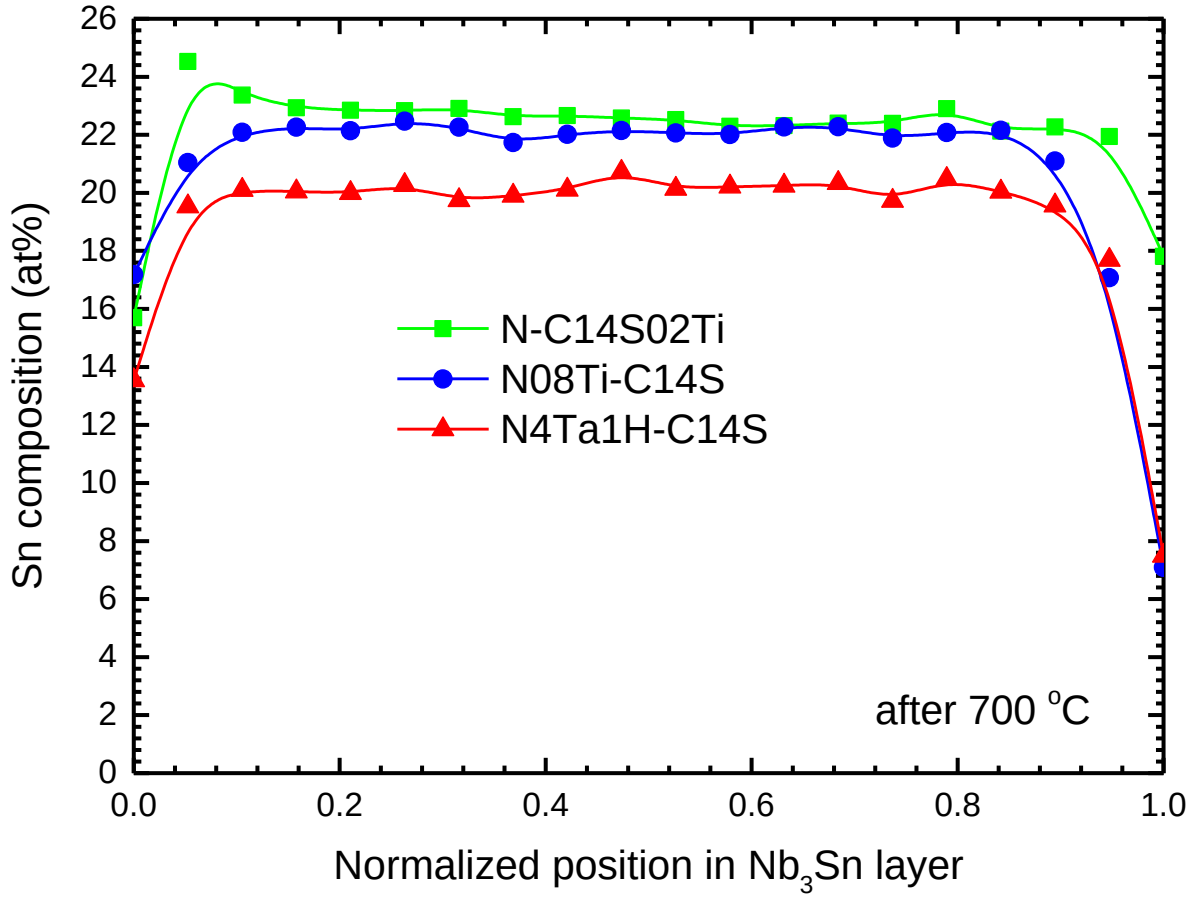
- **Small grain refinement by Hf-Ta addition**
- **However, not significant (700°)**

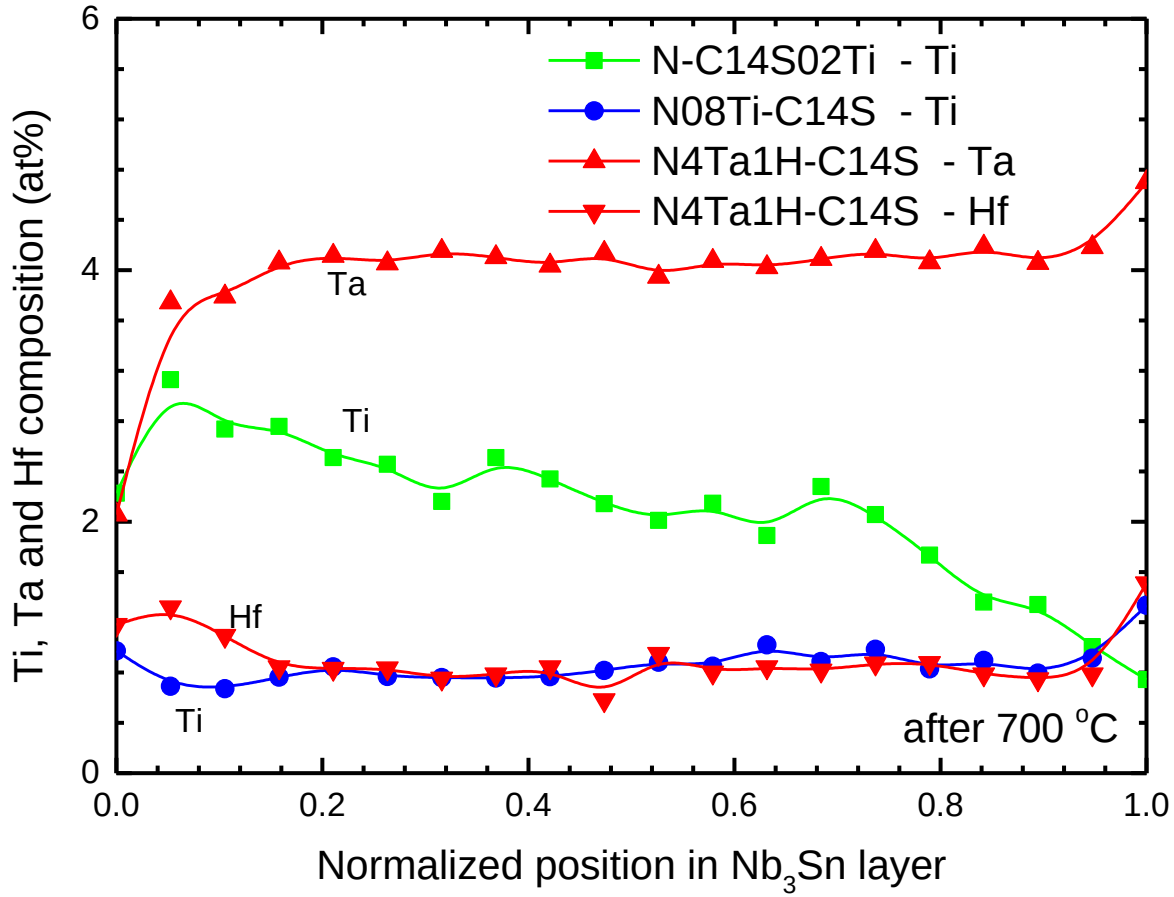
Layer thickness – EBSD analysis –



- **Ti-addition to bronze matrix <u>significantly enhanced layer thickness</u>, especially for Ti-bronze**
- **Hf-Ta addition did not enhance the layer growth rate in bronze-process**

Composition distribution – EDS analysis –

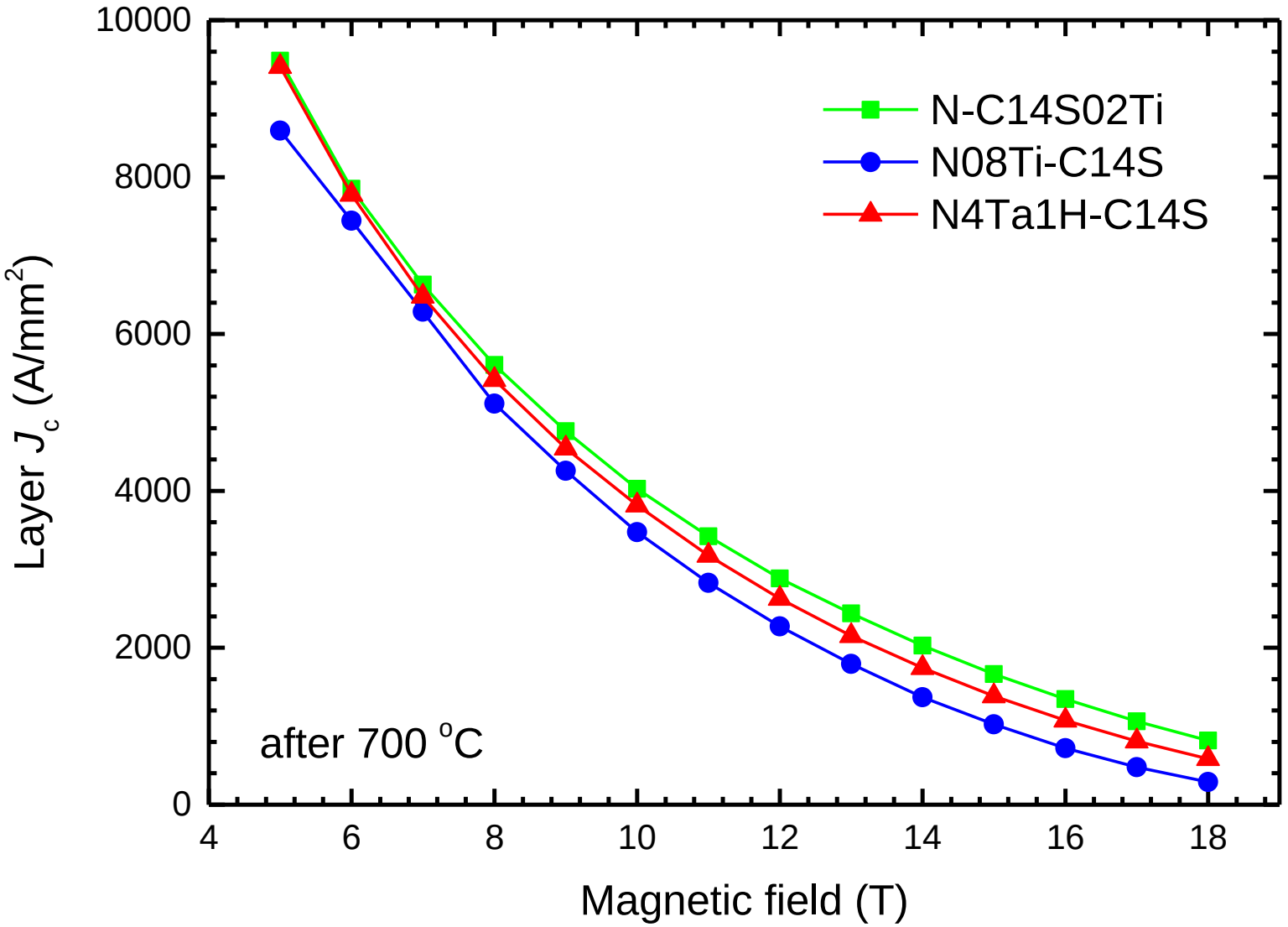




Nb-4Ta-1Hf core: **Sn** content in the Nb_3Sn layer is **small**.

Ti-Bronze matrix: **Ti** content is very **high**, which should contribute to Sn diffusion.

Layer J_c - B



- The **best** J_c property is for conventional **Ti-Bronze matrix** wires.
- **Hf-Ta addition** wire is the **second**.

Discussion

- There was **no significant effect by Hf-Ta addition on layer J_c in bronze process**, compared with conventional Bronze Nb_3Sn wires.
- **Ti-Bronze matrix wire** (N-C14S02Ti) has the **best** property.
- **WHY?**

As a simple case, we can discuss **the growth kinetics of Nb_3Sn layer formation** form the following **two viewpoints**.

1st : **Sn diffusion driving force**
2nd : **Internal strain energy (dislocation etc.)** of parent Nb phase

- **Ti addition** is significantly effective to **improve Sn diffusion driving force**, especially in case of Ti addition to bronze matrix.

→ That accounts for **significant layer growth** and **better Sn composition** of **Ti-Bronze matrix wire** (N-C14S02Ti).

→ Furthermore, high Sn driving force **promotes Nb_3Sn nucleation** of **Ti-Bronze matrix wire** (N-C14S02Ti), which contributes to Nb_3Sn grain refinement.

- **Hf addition to Nb** (N4Ta1H-C14S) is effective to **improve the internal strain energy**, which can contribute to **promotion of nucleation**, **but not enhanced Sn diffusion so much**, compared with **Ti-Bronze matrix wire** (N-C14S02Ti), in a condition of similar grain size.

→ Consequently,
the **grain size** of all wires is **comparable** each other,
the **Nb_3Sn layer thickness** of **Ti-Bronze matrix wire** (N-C14S02Ti) is **much larger** than in **Hf-Ta-added wire** (N4Ta1H-C14S), and
the **Sn composition** of **Ti-Bronze matrix wire** (N-C14S02Ti) is **good** .
→ **Ti-Bronze matrix wire** (N-C14S02Ti) showed **the best J_c performance**.

Conclusions

- **In bronze process, the effect of Hf-Ta addition is not so large, compared with conventional Ti-bronze Nb_3Sn wire.**

- **This is thought to be because Ti-addition to bronze matrix has a significant effect on improvement of Sn diffusion driving force, which contributes to not only enhancement of layer growth rate but also Nb_3Sn grain refinement.**

- **Effect of Hf-addition seems to be additional to Ti-addition.**
  Therefore, if we combine the Ti-addition to the bronze matrix and Hf-addition to the Nb core, we might obtain synergic effect by both method.