

AdvSCMws 2019

Workshop on Advanced superconducting Materials and
Magnets-KEK

State of Internal Tin Nb₃Sn Strand
at WST

Bo Wu (博 武)

Western Superconducting Technologies Co., Ltd

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Outline

1

Internal Tin Nb₃Sn Strand for ITER

2

Feature of High J_c Nb₃Sn Strand

3

Problems with High J_c Nb₃Sn Strand

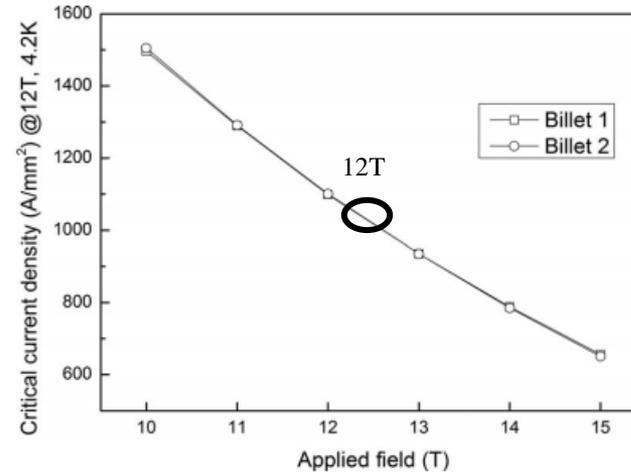
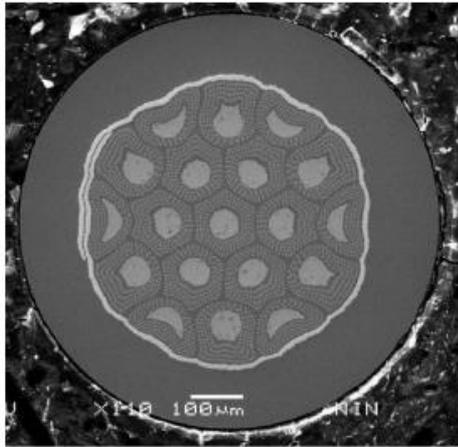
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Properties of High J_c Nb₃Sn Strand

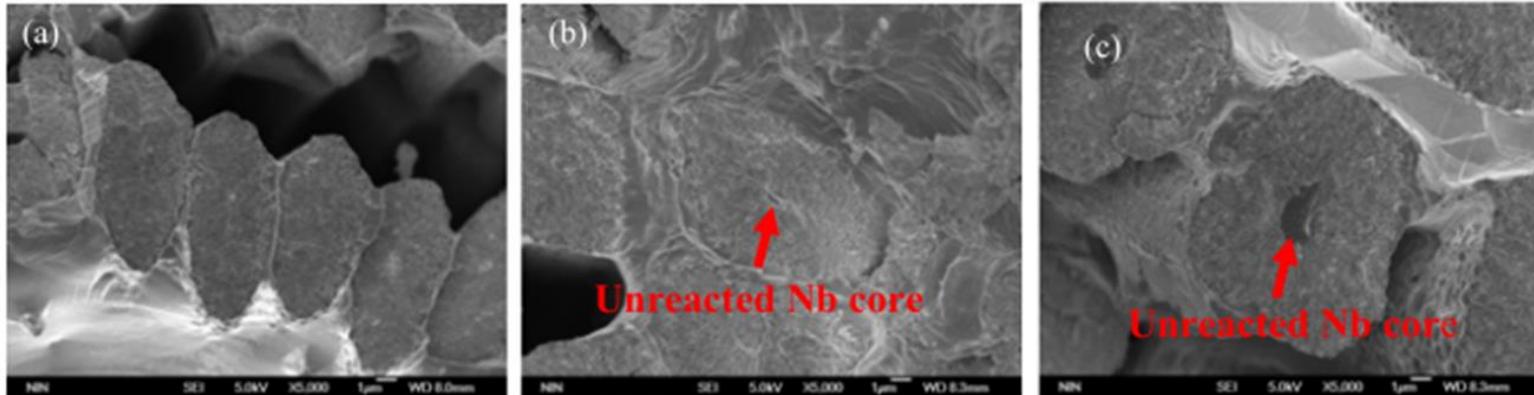
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Summary

1. Internal Tin Nb_3Sn Strand for ITER



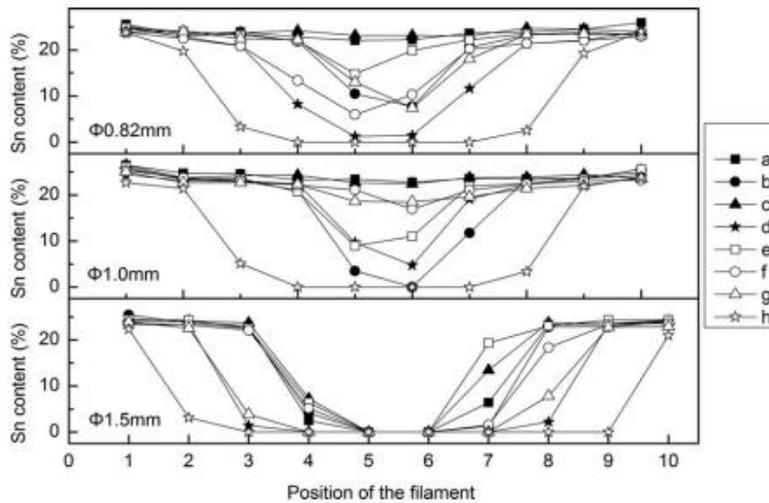
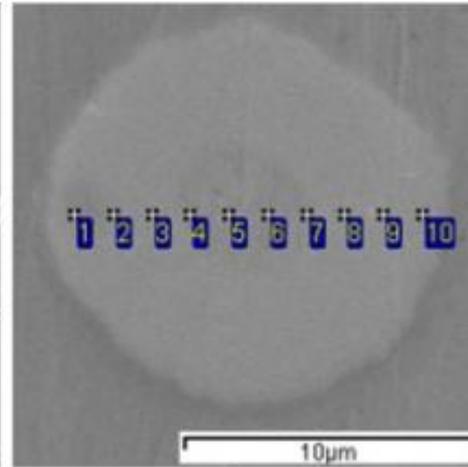
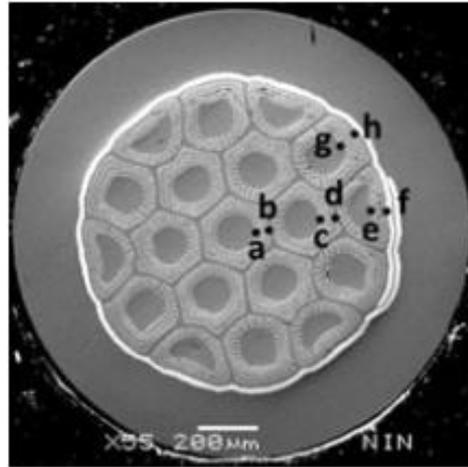
Nb_3Sn for ITER



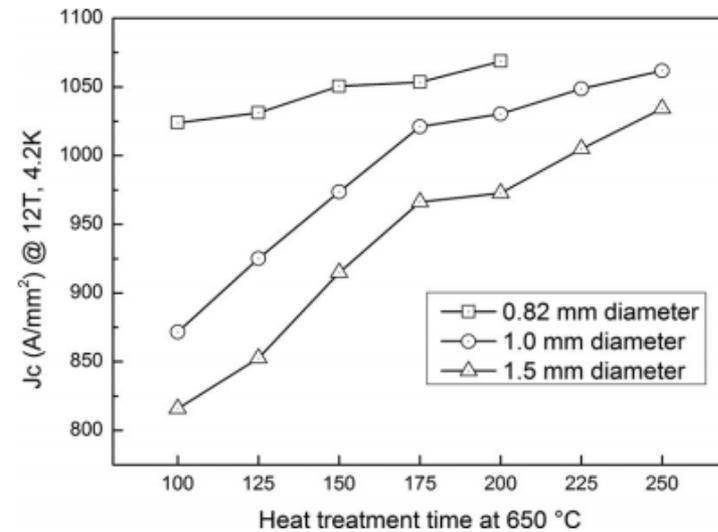
Microstructure of Nb_3Sn filaments

- With $210\text{ }^\circ\text{C} \times 50\text{ hr} + 340\text{ }^\circ\text{C} \times 25\text{ hr} + 450\text{ }^\circ\text{C} \times 25\text{ hr} + 575\text{ }^\circ\text{C} \times 100\text{ hr} + 650\text{ }^\circ\text{C} \times (100)$ hr, J_c at 12 T and 4.2 K was 1100 A/mm^2 and unreacted Nb core can be found.

1. Internal Tin Nb_3Sn Strand for ITER



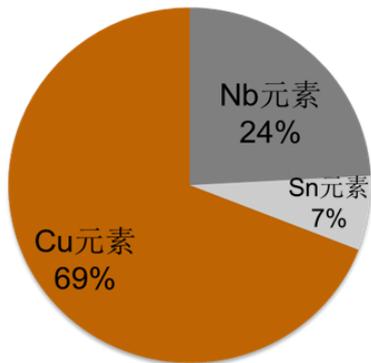
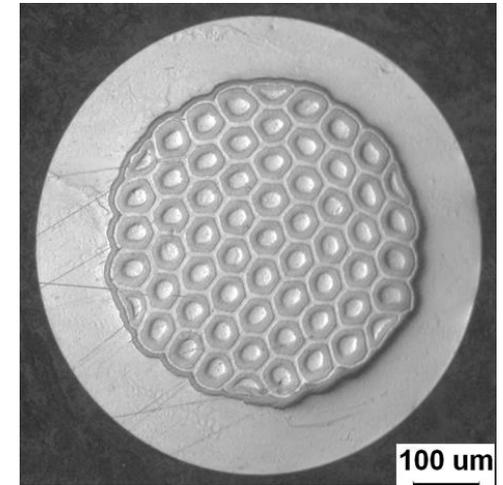
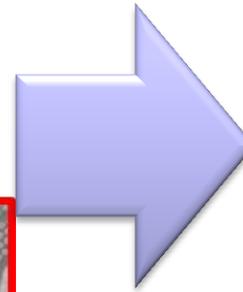
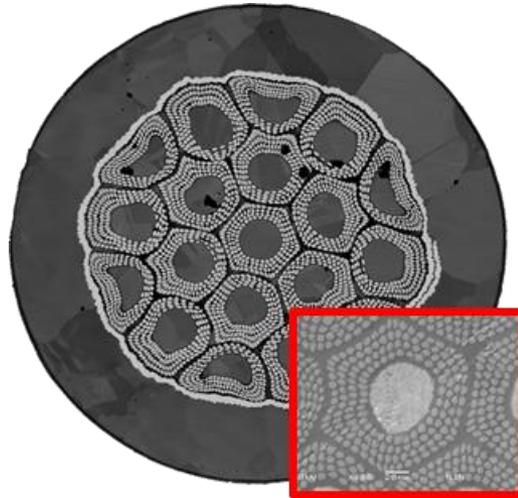
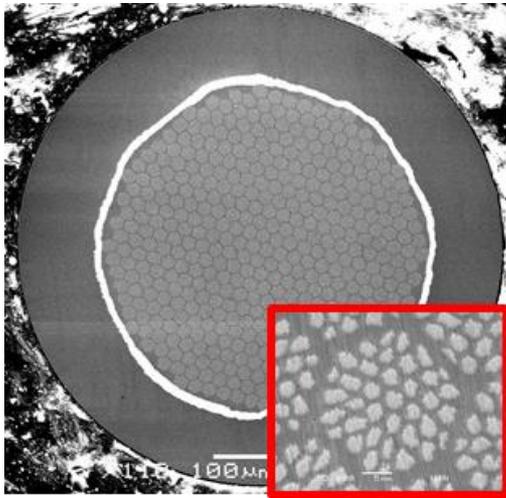
Sn content within one Nb_3Sn filament



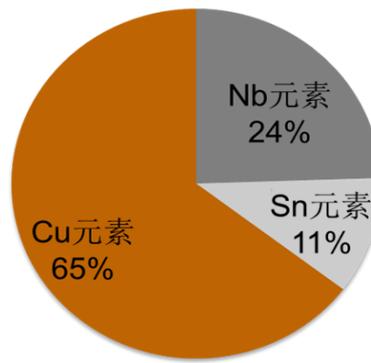
Effect of heat treatment time on J_c

- Prolonging heat treatment time is effective for strands with larger diameter filament to make a full reaction.

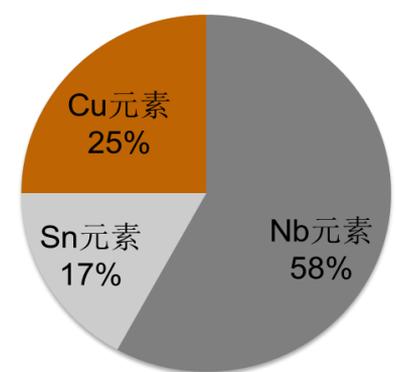
2. Feature of High J_c Nb_3Sn Strand



Bronze Nb_3Sn



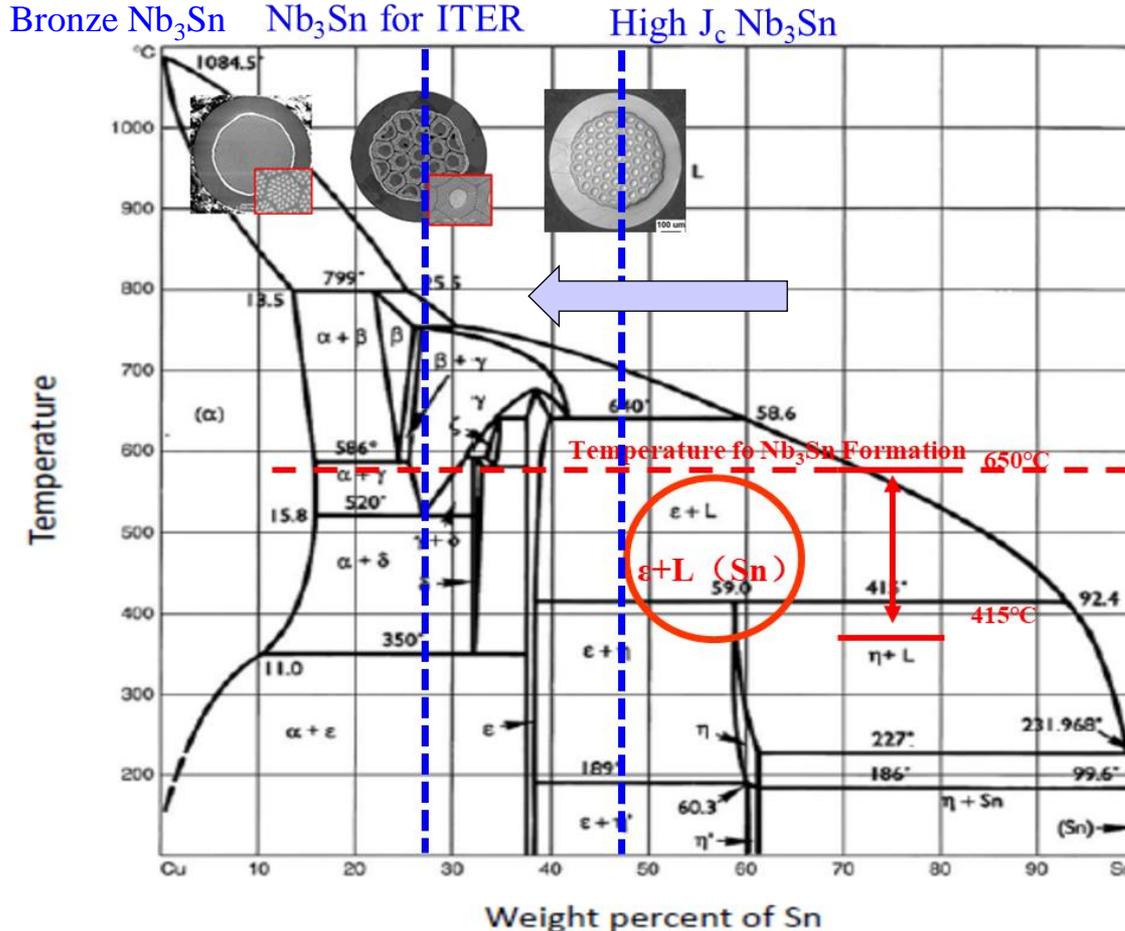
Nb_3Sn for ITER



High J_c Nb_3Sn

- Compared with ITER Nb_3Sn strand, 2~3 times of J_c should be increased for high J_c Nb_3Sn strand;
- More Nb content should be added within high J_c Nb_3Sn strand;
- Small sized Nb filament should be obtained (full reaction and short heat treatment time).

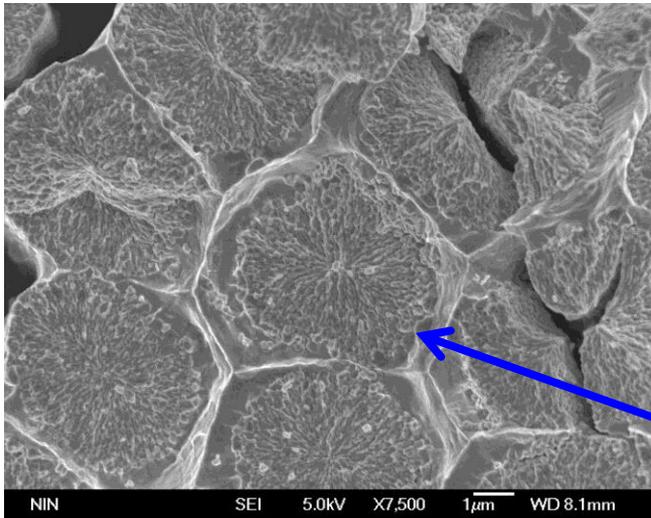
3. Problem I



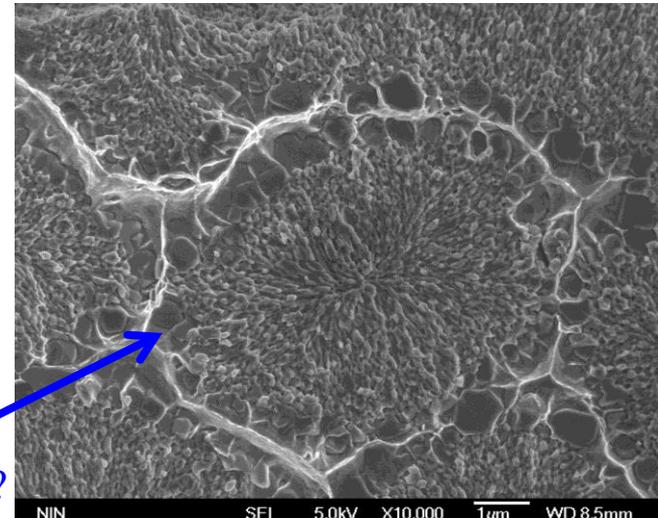
Cu-Sn phase diagram

- New phase (Cu-Nb-Sn) was induced by liquid Sn during heat treatment (above 400°C);
- Phase-balance (less Cu-Nb-Sn (nausite) produced) can be obtained through element ratio optimization.

3. Problem II



Nb₃Sn for ITER



High J_c Nb₃Sn

Same phase?

- Nano-sized (150nm) Nb₃Sn grains generated within each Nb filament;
- Same phase among each Nb filament for ITER Nb₃Sn wire and high J_c Nb₃Sn wire?

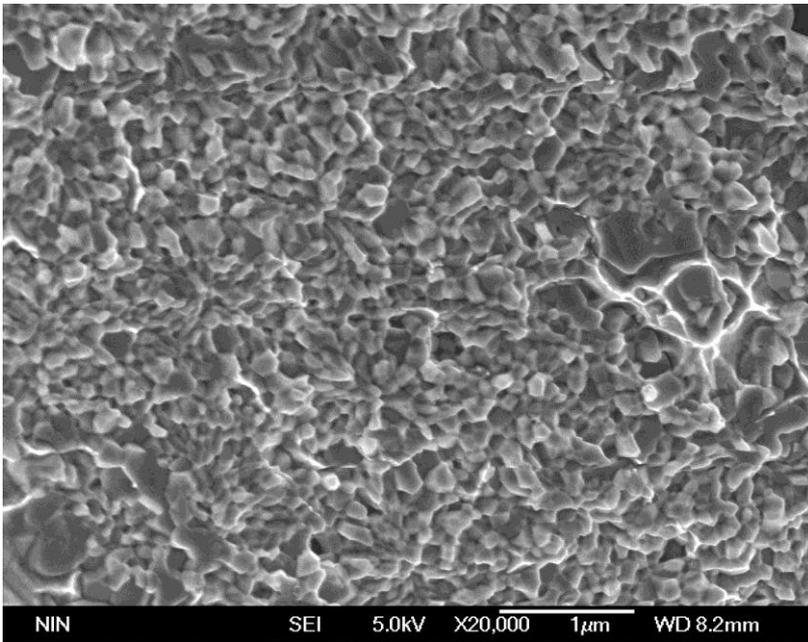
For Nb₃Sn for ITER: Cu

For High J_c Nb₃Sn: Cu and Nb₃Sn mixture

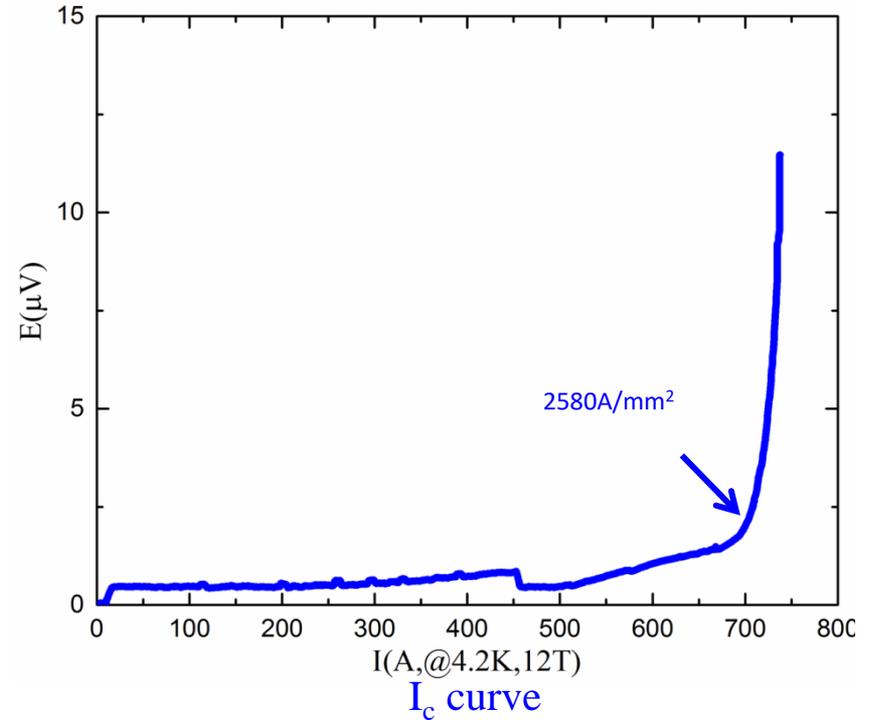


Nb₃Sn only

4. Properties of Nb₃Sn Strand

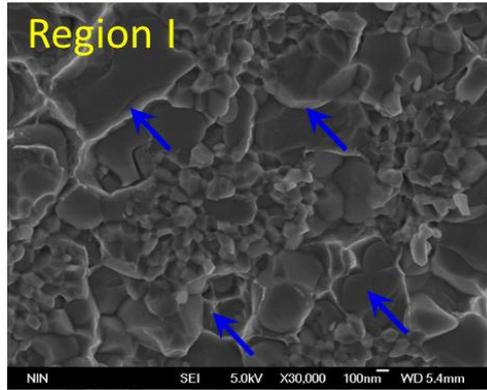
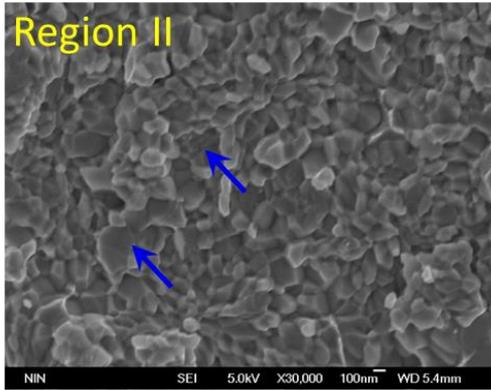


Fine grains obtained



- With nano-sized (150 nm) grains, J_c about $2580\text{A}/\text{mm}^2$ (RRR value 121, n value 47) can be obtained ($\Phi 0.86\text{mm}$ strand after $665^\circ\text{C} 60\text{h}$).

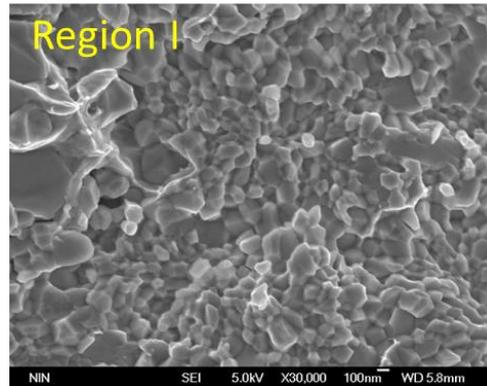
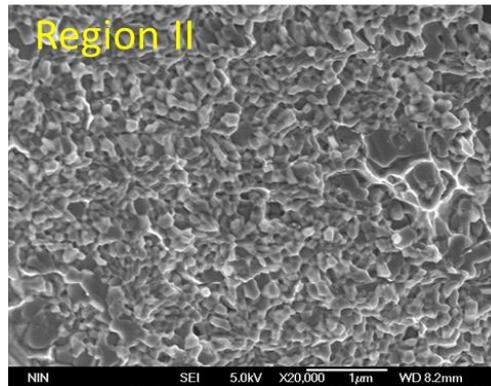
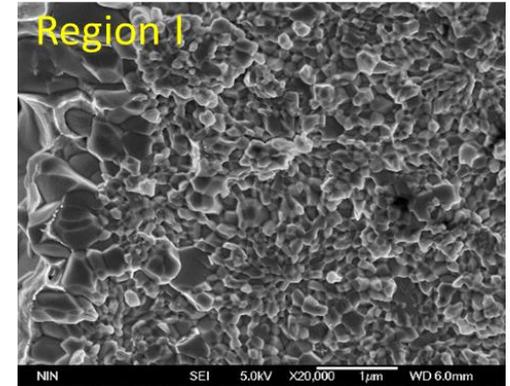
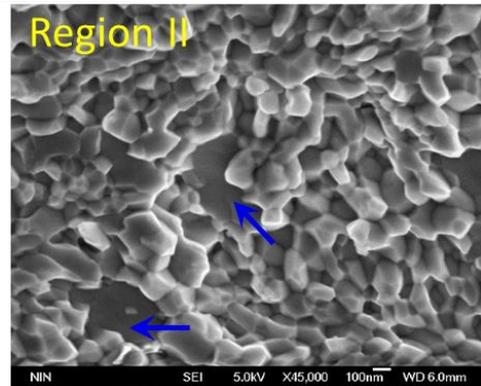
4.1 Effect of grain size of Cu/Nb₃Sn mixture



Region I : Close to Sn source
 Region II: Far away from Sn Source

~2000A/mm²
 300~1000nm sized grain found among Nb filaments

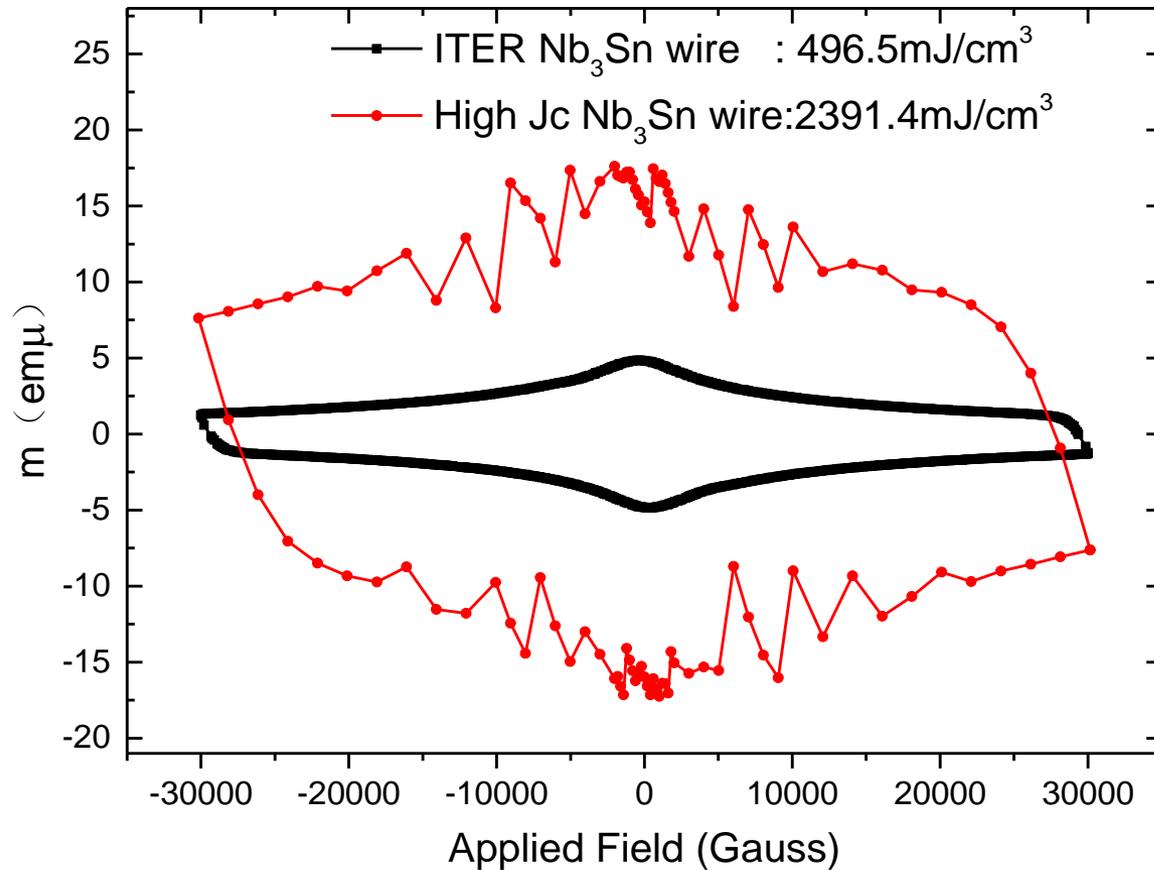
~2300A/mm²
 300~400nm sized grain found among Nb filaments



~2500A/mm²
 120~180nm sized grain and uniform distribution

Refining from 120~180nm to 80nm or even 40nm?

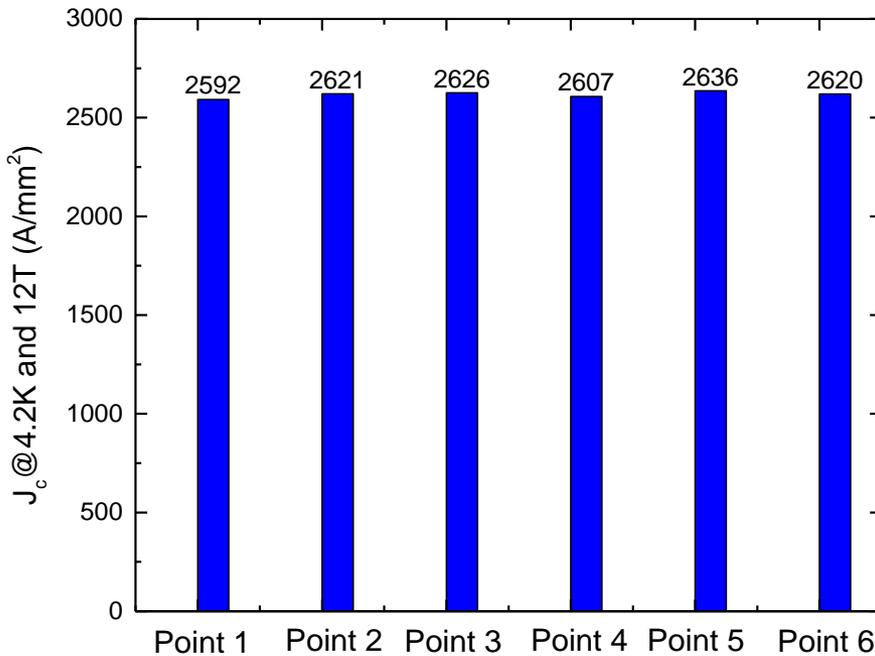
4.2 Magnetic Hysteresis Loss



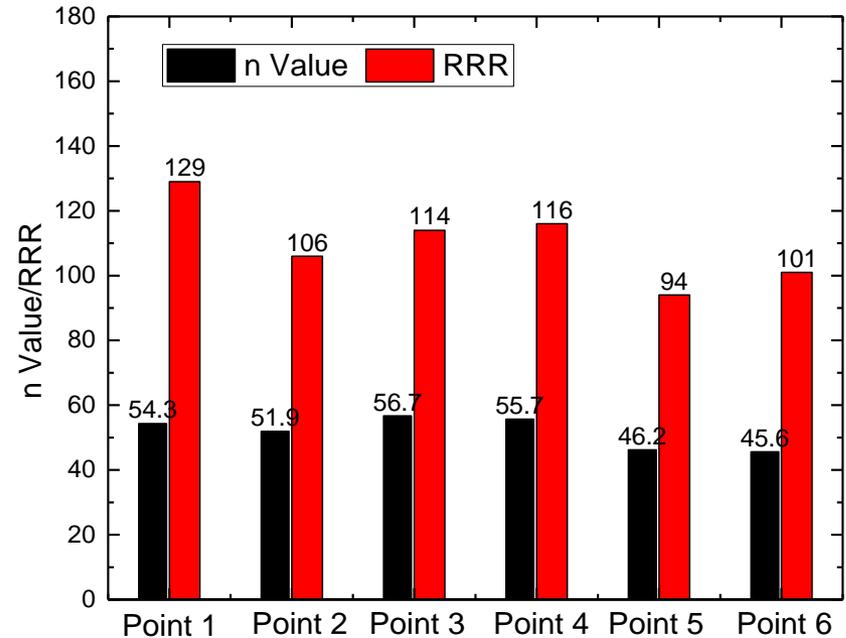
- Higher magnetic hysteresis loss about 2391 mJ/cm³ was found for high J_c Nb₃Sn strand as the reason of little Cu element among Nb₃Sn filaments. (About 130 μm for sub-element for Φ1.3mm strand with J_c 2200 A/mm² (4.2K ,12T))

4.3 Homogeneity of Nb₃Sn Strand

Six samples were picked from one piece of Nb₃Sn strand (about 1000m).



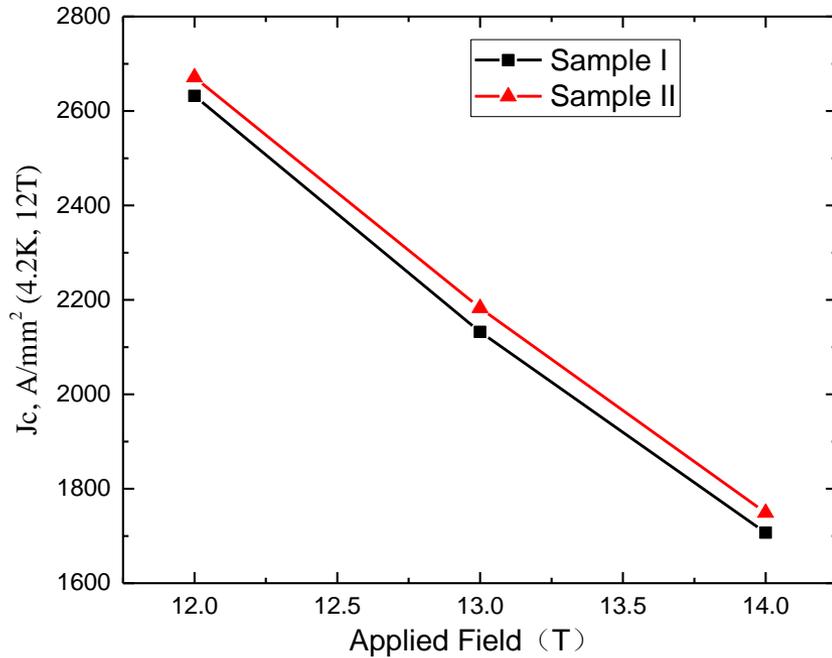
Results of J_c for six points



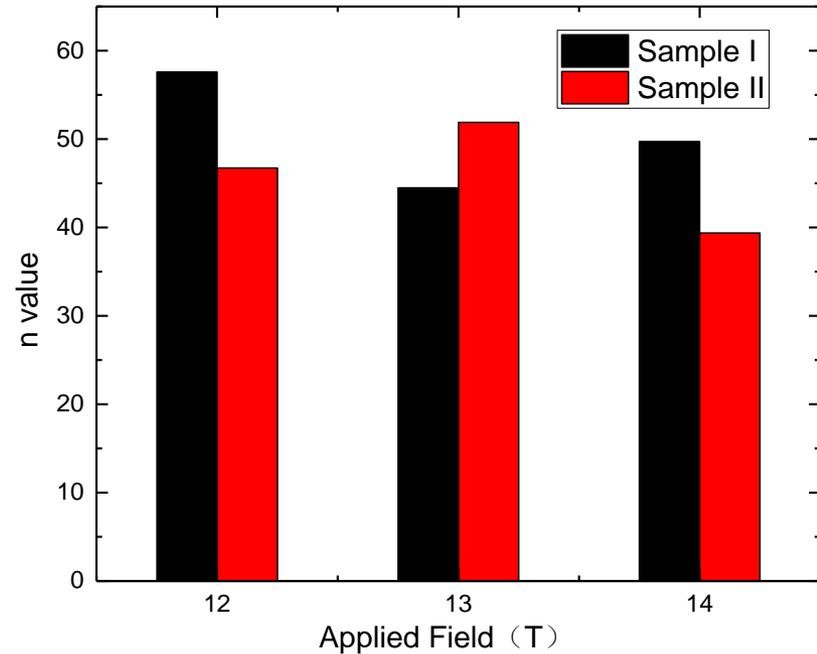
Results of n value and RRR for six points

- From J_c results, maximum 1.7% variation of one piece of Nb₃Sn strand can be found;
- Uniform Nb₃Sn strand was obtained for Φ0.818mm strand.

4.4 Effect of Applied Field



J_c (4.2K, 12T; 13T; 14T)



n value (4.2K, 12T; 13T; 14T)

- With higher magnetic field, J_c reduced from 2600 A/mm² (4.2K,12T) to 1700 A/mm²(4.2K,14T).

- ◆ Performance of ITER Nb₃Sn strand can be improved by prolonging heat treatment time for larger diameter filament .
- ◆ For high J_c Nb₃Sn strand, more Nb content can induce Cu-Nb-Sn phase and lower performance.
- ◆ Coarse grains can be refined through Cu removal by element ratio optimization.
- ◆ A big impact of Grain size of Cu/Nb₃Sn mixture on the performance of high J_c Nb₃Sn strand can be found.
- ◆ With nano-sized grains, J_c about 2600A/mm² (@4.2K, 12T) can be obtained and severe flux jumps can be found .

Thanks for your attention!

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<http://www.wstitanium.com> *(for products)*