Development of Nb_3Sn in Japan

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Summary of FCC week 2017

- Joint R&D program: CERN, KEK and Tohoku & Tokai university with Two private companies.
  - 4 years program
- 2 Manufacturer started R&D
  - JASTEC/KobeSteel:DT (Nb sub bundle)
    - Reduce conductor size to reduce diffusion length
    - Conductor is provided to KEK, CERN and Tokai University for further characterization.
    - Next step is to increase Nb volume fraction
  - Furukawa: Nb Tube
    - Just started, first trial conductor is now in production

Development of FCC wire in KSL/JASTEC

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Key factors for higher Jc Nb_3Sn

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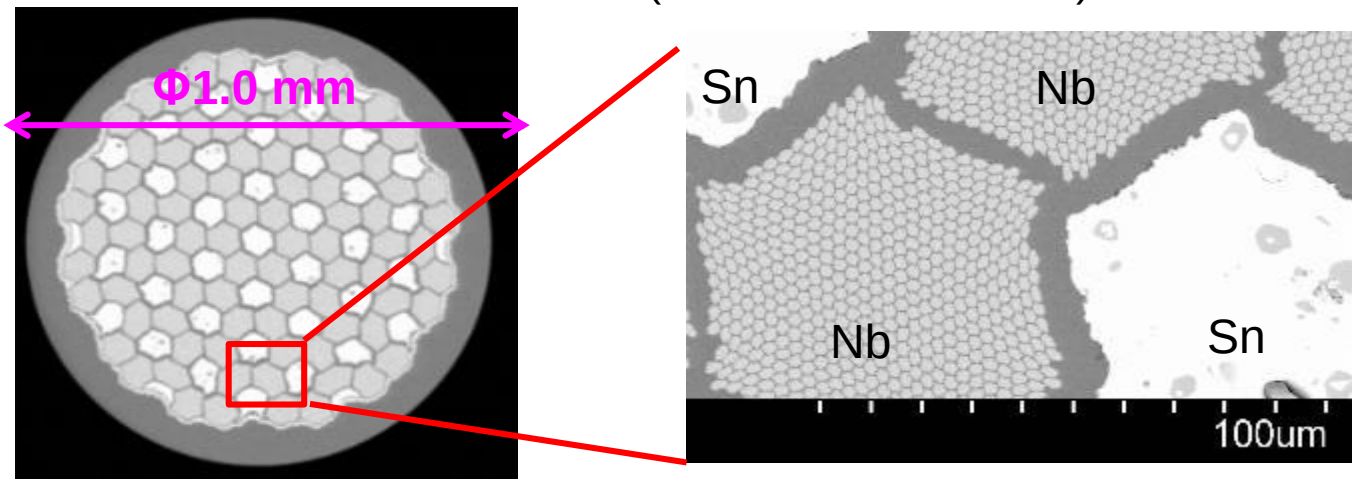
KSL/JASTEC are developing the DT process with higher Sn concentration for FCC.

Cross-section of DT wire (before Heat treatment)



For higher Jc…

(1) Improvement of Sn diffusion：Reduction of Sn diffusion distance ←*Today's topic*
(2) Increase Nb volume fraction：Reduce useless volume
(3) Ternary additive elements ：Amount and method ←*Today's topic*
(4) Optimization of heat treatment ：Stoichiometry, Refinement

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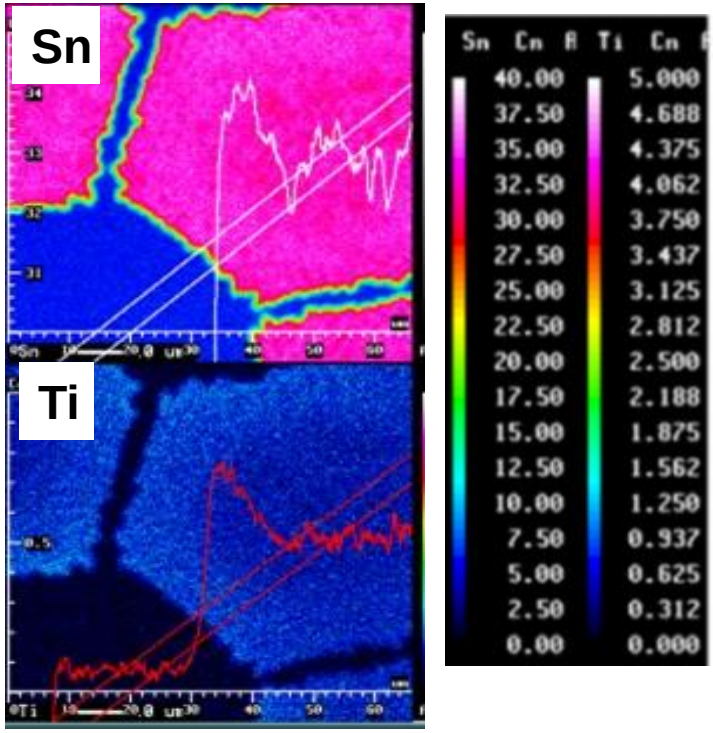
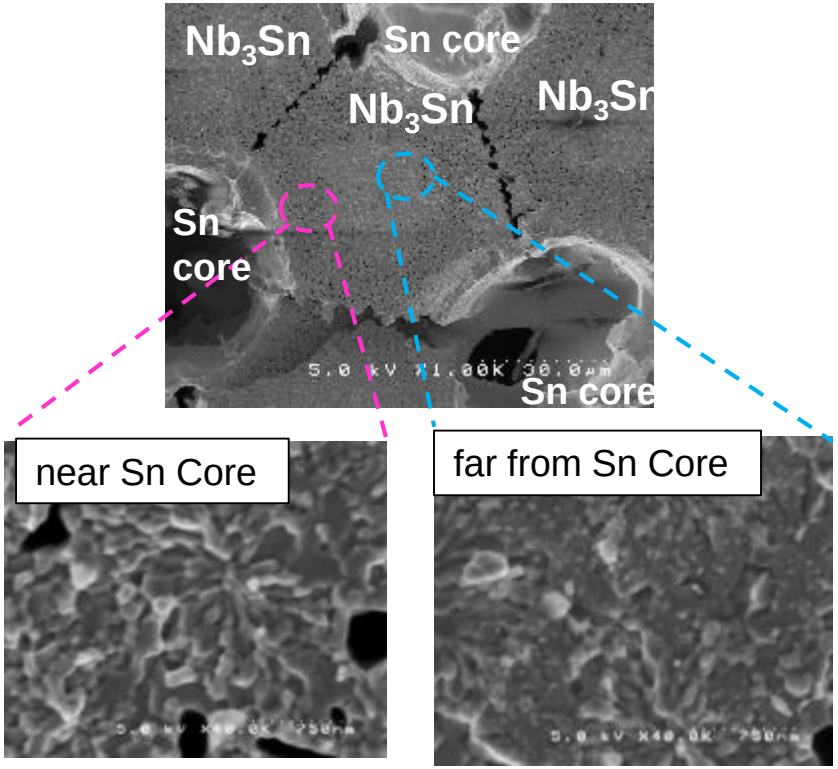
Topic 1: Sn diffusion for Jc

Sn diffusion improvement is one of key ideas to achieve higher *Jc*



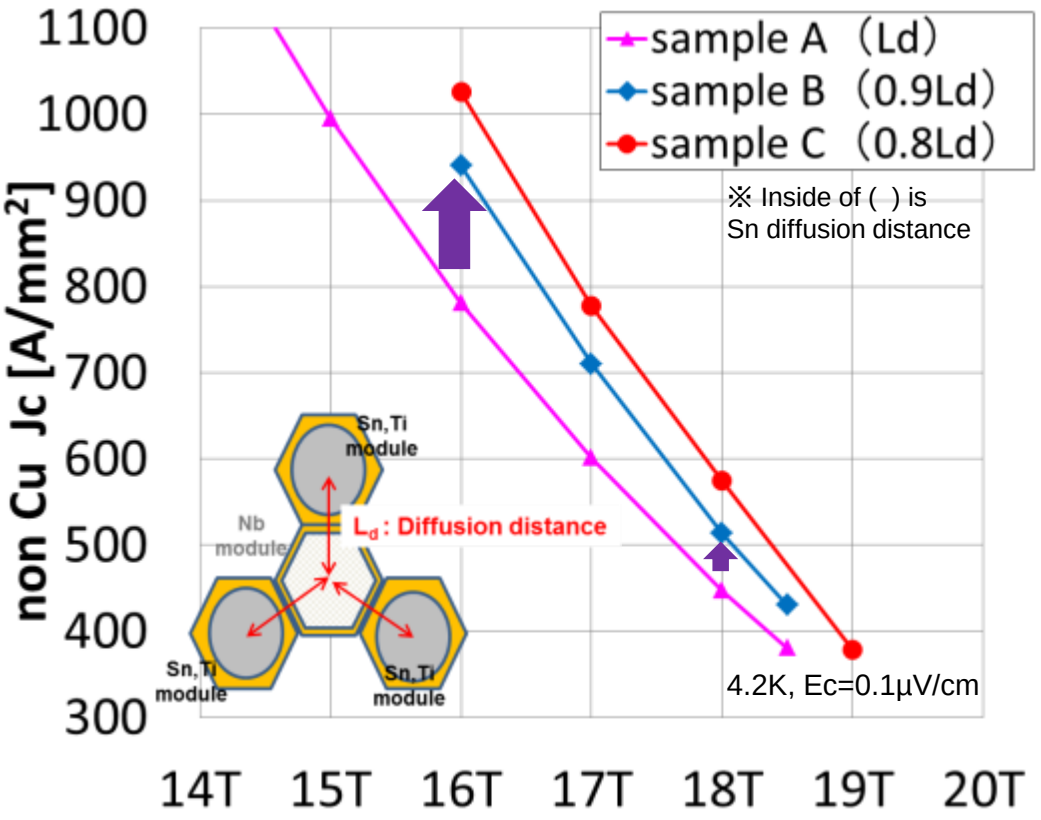
Sn and Ti EPMA map (after Heat treatment)



SEM image (after Heat treatment)

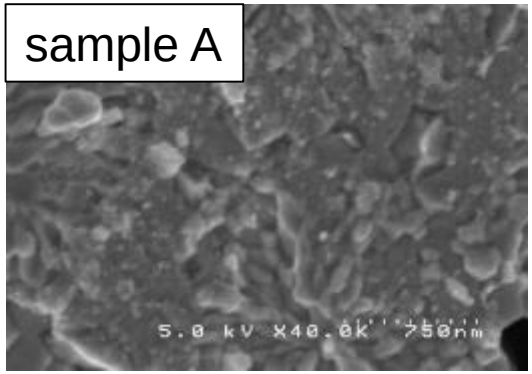
If the design of Sn diffusion distance is inappropriate,
at locations far from Sn core, Sn and Ti in Nb_3Sn is considered poor
and the Nb_3Sn grain is large.

Topic 1: Sn diffusion for Jc

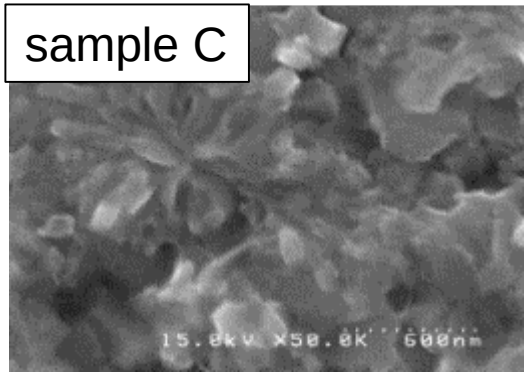


Non Cu Jc vs field curve.

Before Sn diffusion improvement



After Sn diffusion improvement



SEM image of A15 area far from Sn core before/after Sn diffusion improvement

Reducing the Sn diffusion distance improves Jc by 28%.
non Cu Jc=1025A/mm^2@16T.

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Topic 2:Ternary additive elements

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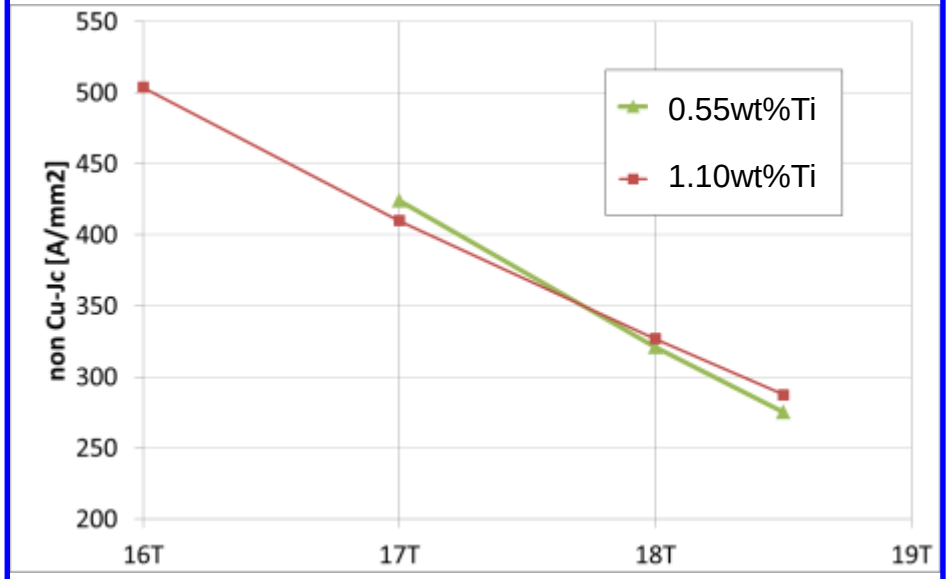
Amount



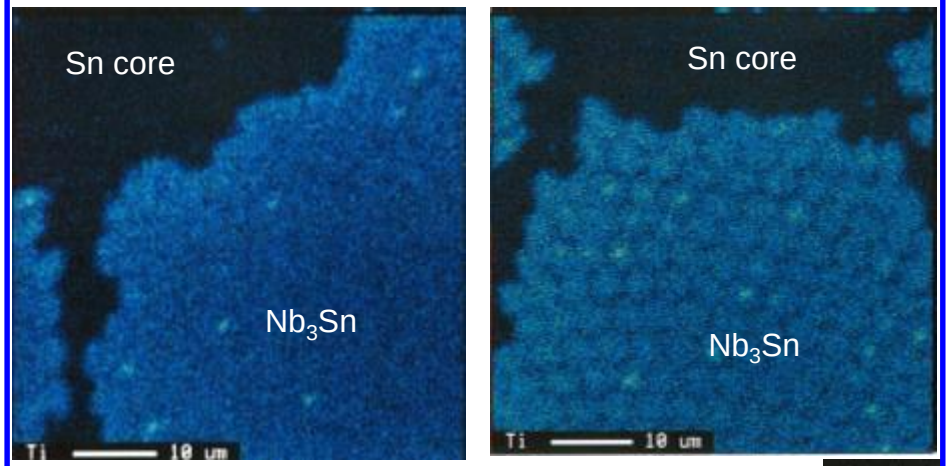
In our past developments for high magnetic field magnets, we increased Ti content and improved *Jc* under the high magnetic field (>18T).

→For FCC @16T, we decrease Ti amount. (next page)

Method

Ti to Sn core

Ti to Sn/Nb core



Ti EPMA map (after Heat treatment)

In our past developments,
When Ti was added to both Sn and Nb core, Ti diffused more uniformly.
This is applied to the current high Jc (non Cu *Jc*: 1000A/mm^2@16T)
DT method, and it is under development.

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Topic 2:Ternary additive elements

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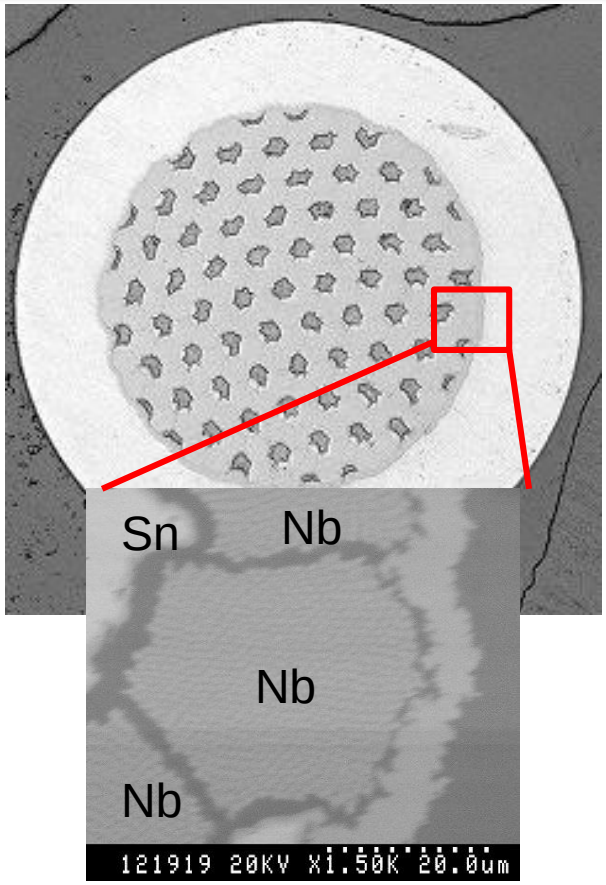
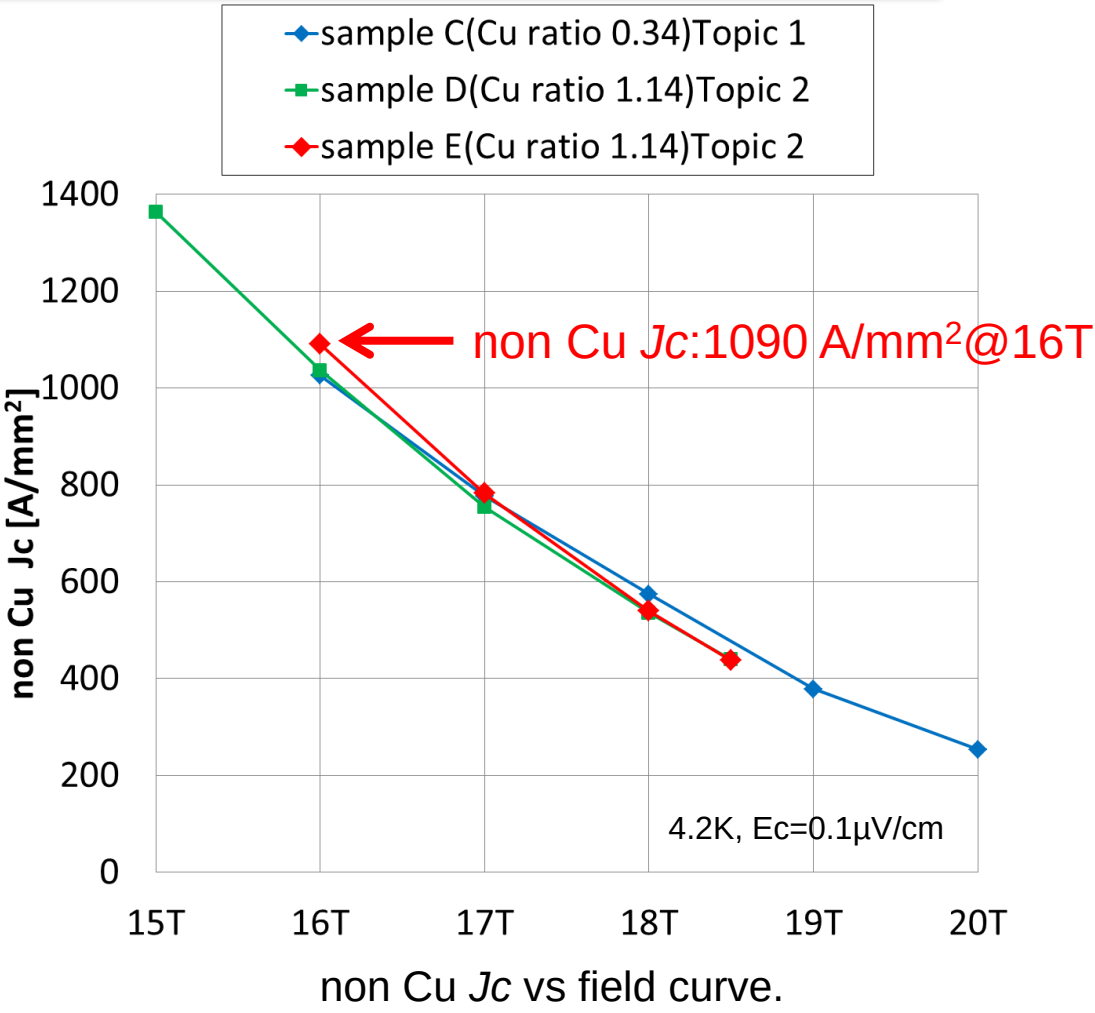


Cross-section of Topic 2 wire
(before Heat treatment)



non Cu *Jc* vs field curve.

This is new data last week. We improved *Jc* @ 16T by decreasing Ti content (In descending order of Ti amount: C > D > E).
We have produced some wires with different addition methods.

Current Results and Next steps

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- KSL/JASTEC have achieved non Cu *Jc*@16T up to 1,090A/mm^2, by improving Sn diffusion and reducing Ti content. This is approaching to the specification of 16T test dipole.

- We investigate the followings to overcome the provisional Jc target of 1,100A/mm^2:

(1) Control ternary additive element
(2) Increase Nb area ratio
(3) Further refinement of Nb_3Sn grain by controlling heat-treatment condition

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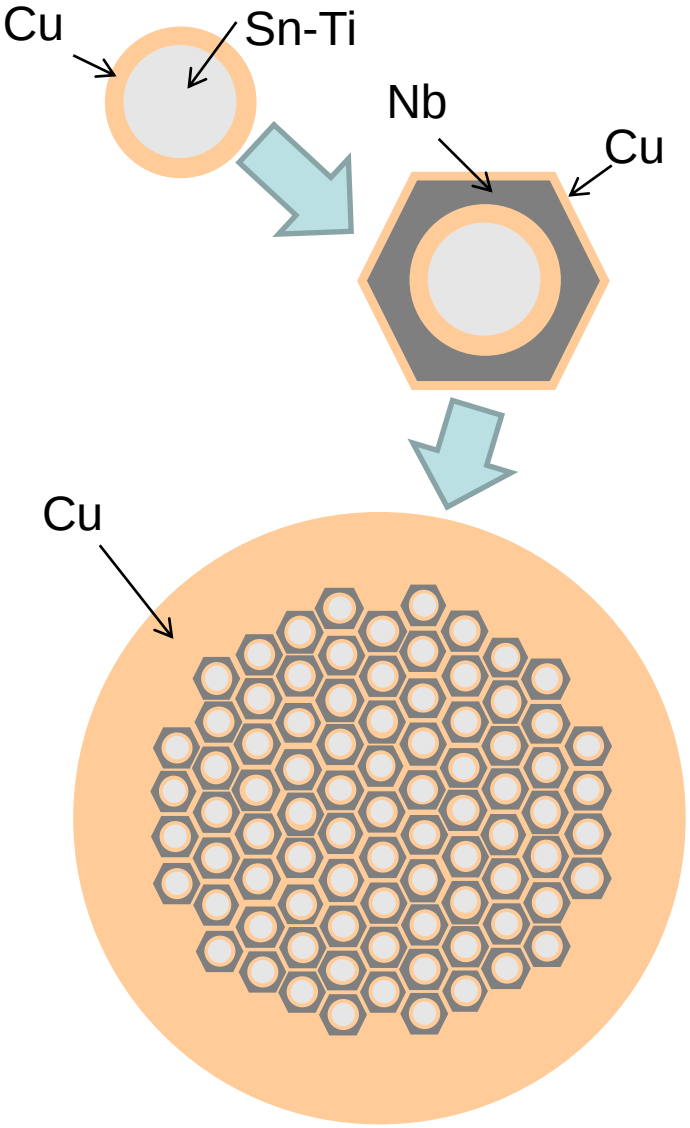
Development of FCC wire in Furukawa Electric

Wire design

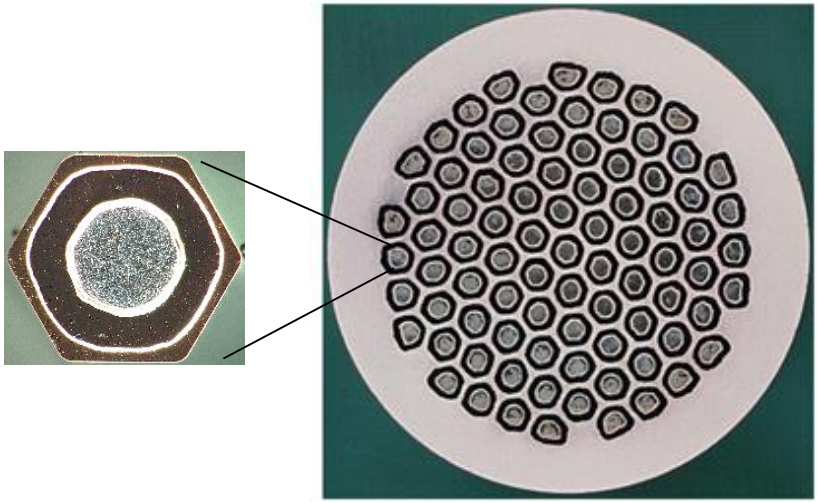


Schematic View of the Wire

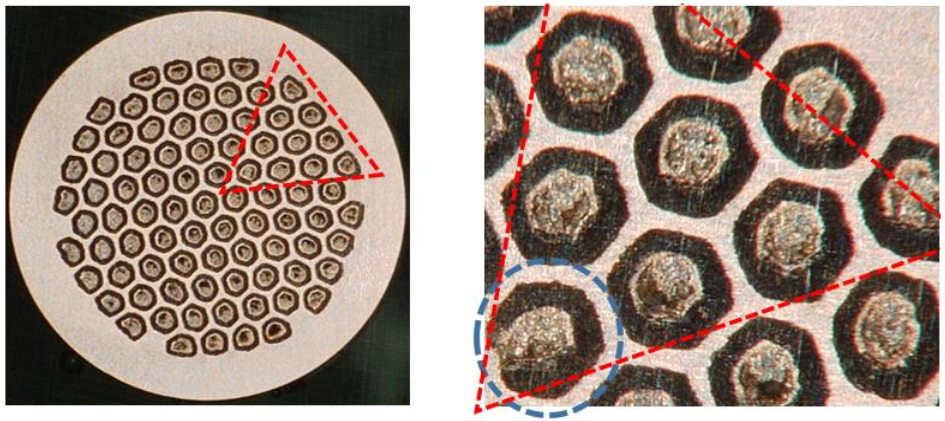
Design Parameters of the Wire

Items	
No. of Filament	85
Filament Material	Nb
Sn material	Sn-Ti
Filament Dia.	50μm at wire dia.of 0.7mm
Thickness of Nb Tube	10μm at wire dia.of 0.7mm
Cu/non-Cu ratio	1.3

Wire Processing



At 4.8 mm in dia., wire breakage was occurred.
Breakage of Nb tube was observed.

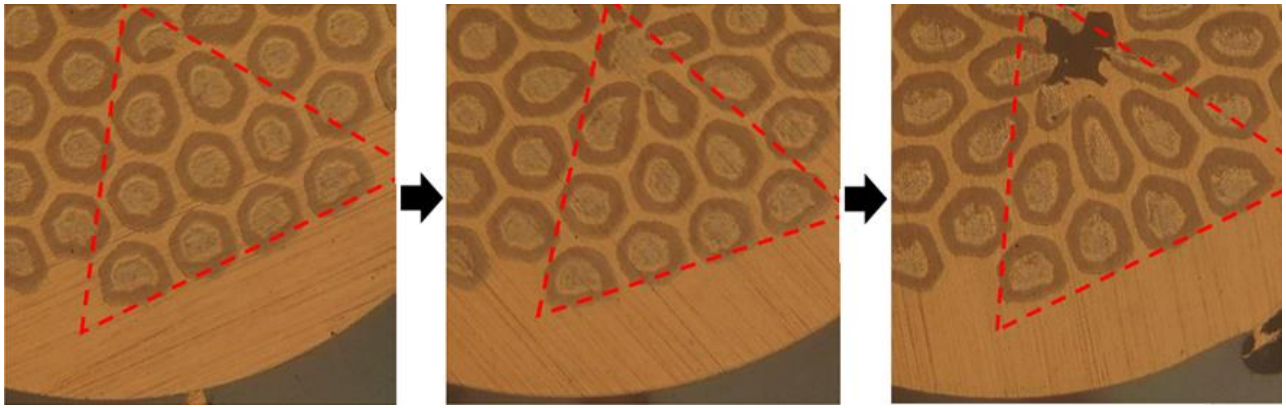


Multiple wire breakage was occurred at finer than 4.8mm in diameter.
Drawing stopped at about 3mm in diameter and investigate cause of wire breakage.

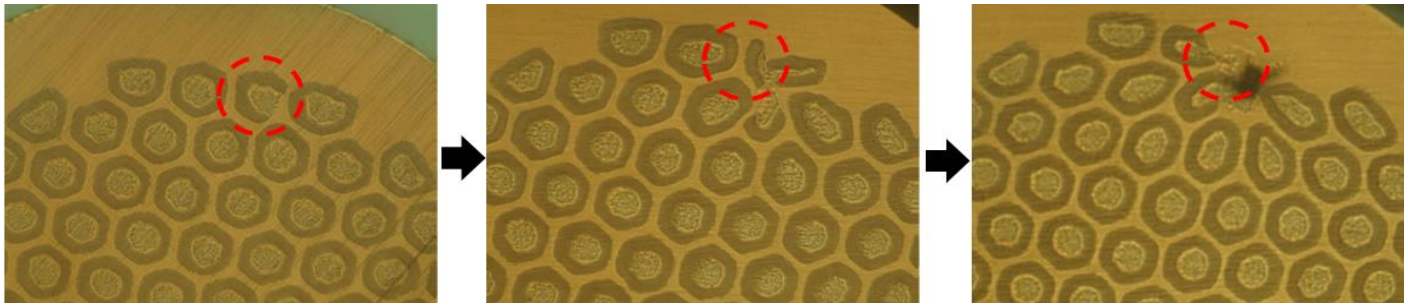
Cause of wire breakage

It found that only two of 85 filaments were broken and caused wire breakage.

One is the filament at mid position that was shown previous page.



The other is the filament at outmost.



Possible cause of Nb tube breakage

- Defect of Nb tube
- Bending stress at drawing process on outmost one

Summary

- Nb_3Sn wire with 85 Nb-tube filaments was tried.
- Multiple wire breakage was occurred at 4.8 mm in diameter or less. Those were caused by filament breakage.
- From the observation of broken sample, it found that two of 85 filaments were broken.
- One is at mid portion of filament array and the other is outmost.
- One possible cause of Nb tube breakage is defect of Nb tube material on both filaments.
- On outermost one, bending stress at drawing is another possibility.
- Retry Nb-tube Nb_3Sn with careful attention to Nb tube

Summary of FCC week 2018

- Joint R&D program: CERN, KEK and Tohoku & Tokai university with Two private companies.
- 2 Manufacturer started R&D
  - JASTEC/KobeSteel:DT (Nb sub bundle)
    - Achieve 1090 A/mm^2 at 16 T
      - Reduce diffusion length
      - Reduce Ti content in Sn
    - Next step: achieve reproducible 1100 A/mm^2 by increase Nb, optimize Ti ratio and heat treatment
  - Furukawa: Nb Tube
    - Wire breakage at 4.8 mm dia.
    - Detail analysis of breakage on going