Status of A15 Superconductor Developments in Asia

Toru OGITSU

KEK

Acknowledgement

- JASTEC: S. Kawashima, K. Saito, Y. Fukumoto
- Furukawa Electric: M. Sakamoto, H. Shimizu
- NIMS: A. Kikuchi
- Tohoku Univ.: S. Awaji
- KEK: T. Nakamoto, M. Sugano
- CERN: A. Ballarino
- KAT: J. Kim
- WST: J. Liu

Contents

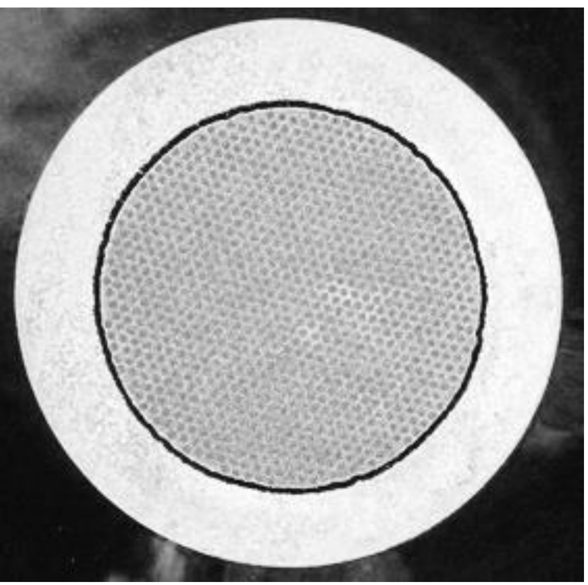
- **Activities in Japan**
  - Nb_3Sn Manufacturers in Japan
    - JASTEC/KOBELCO
    - Furukawa electric.
  - Activity at NIMS for Nb_3Al
  - Stress/Strain Studies
- **Other Asian Activities**
  - Korea KAT: FCC week 2017, KAT Introduction & Products 2015
  - China WST: MT25

JASTEC
SUPERCONDUCTOR

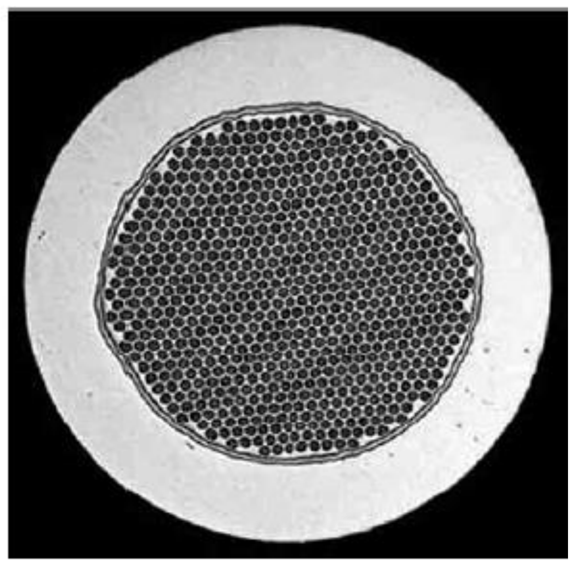
KOBELCO
KOBE STEEL GROUP

JASTEC Bronze Nb_3Sn Wire

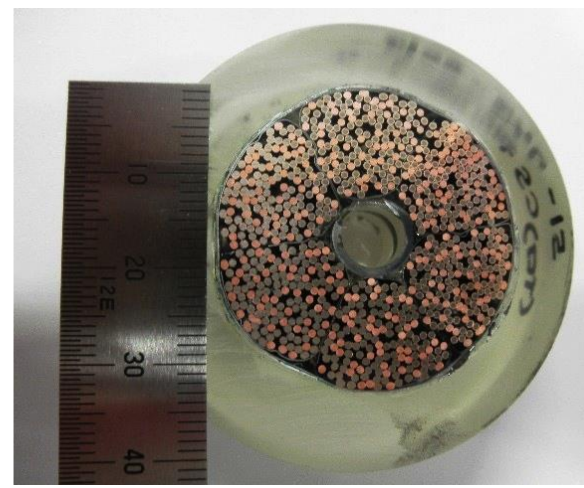
- **JASTEC is a world primary wire manufacturers, especially for Nb_3Sn.**
  - **For NMR: ~10 tons every year**
  - **For ITER: 100 tons in total**
- **JASTEC supplied TF & CS (Nb_3Sn) wires for ITER.**
  - **- 40 tons for TF conductor (40% of JAPAN contribution)**
  - **- 60 tons for CS conductor (43% of total procurement**



Strand (TF)



Strand (CS)



Cable (CS)

KOBELCO
KOBE STEEL GROUP

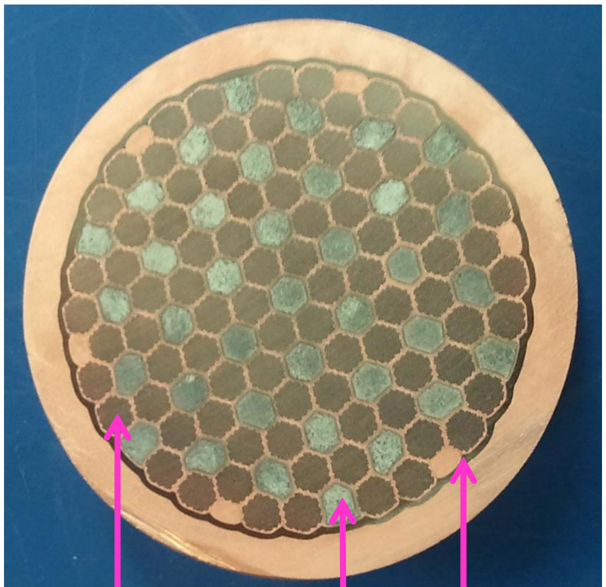
High-Jc Bronze strand/cable for ITER

JASTEC SUPERCONDUCTOR

Distributed Tin(DT) Nb_3Sn Wire

We are developing the DT process, with **higher <u>Sn concentration</u>** .

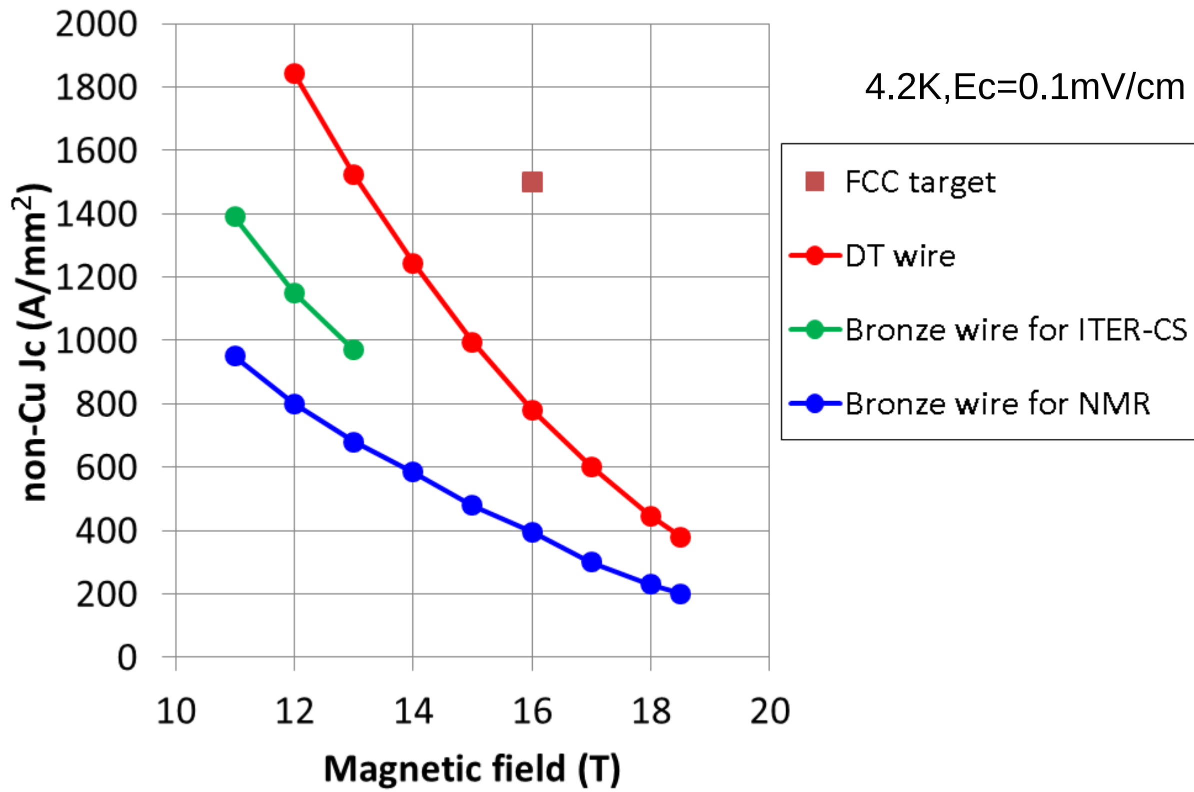
⇒Bronze process : < 16 wt %Sn, **DT process : 37.3 wt %Sn**



Nb barrier

Cu/Nb module

Cu/Sn module



KOBELCO KOBE STEEL GROUP

JASTEC SUPERCONDUCTOR

Development plan for FCC

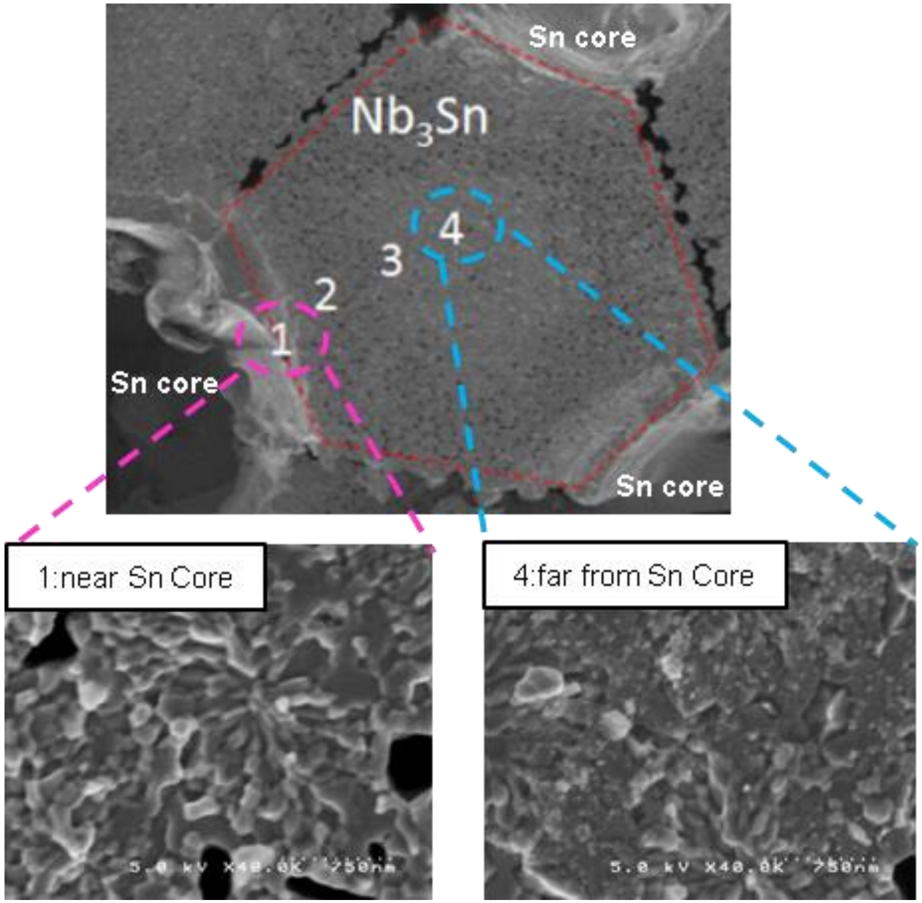
Confidential

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

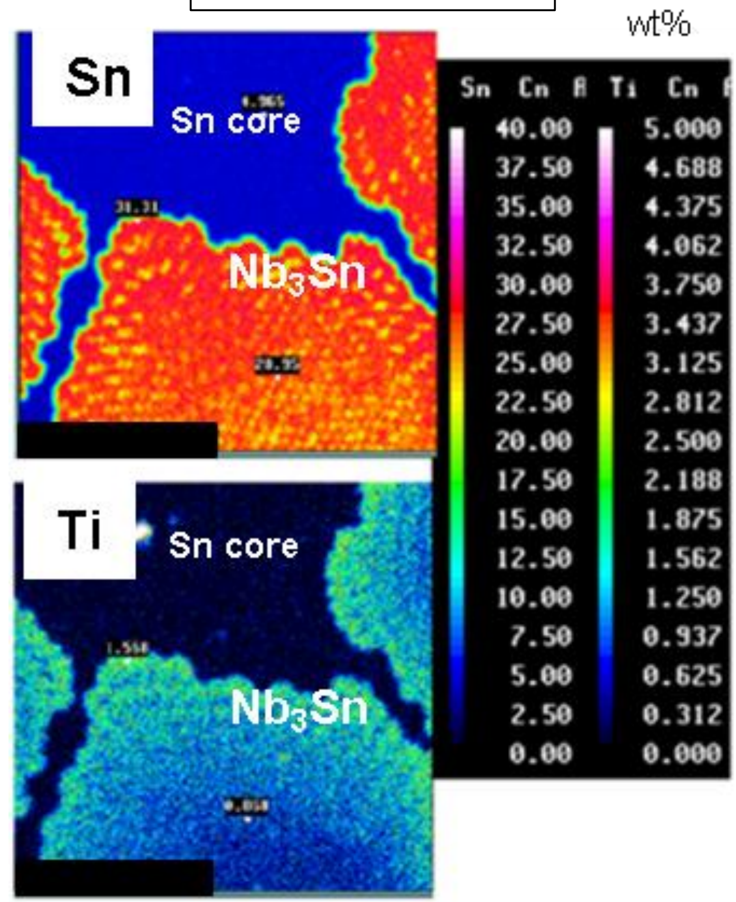
Property	Units	FCC requirements	Current status
Strand diameter	(mm)	0.5-1.0	0.8-1.5
non Copper J_c (4.2 K, 16 T)	(A/mm^2)	$\geq$ 1500	800
$\mu_o M$ (1 T, 4.2 K)	(mT)	$\leq$ 150	～200
$\sigma(\mu_o M)$(1 T, 4.2 K)	(%)	$\leq$ 4.5	------
D_{eff}	(μm)	$\leq$ 20	3(nominal)
RRR		$\geq$ 150	150-170
Unit Length	(m)	$\geq$ 5000	～7000

Analysis of present DT after HT

DT-SEM image

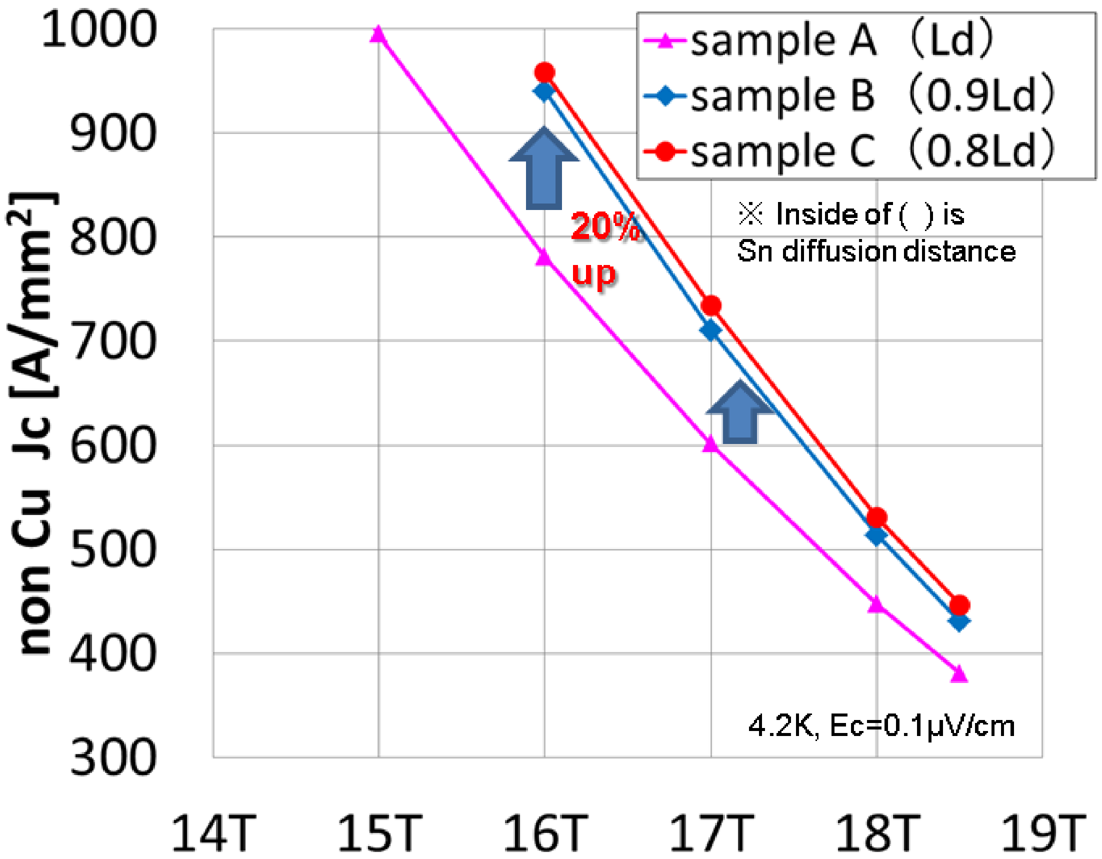


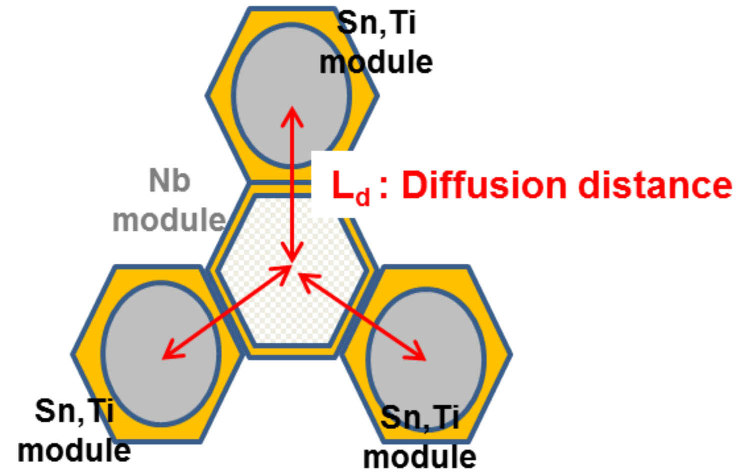
DT-EPMA map

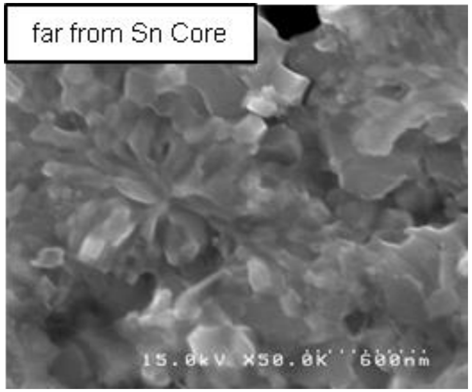


Near the center of Nb module, the number of fine crystal grains decrease. Also the distribution of Ti and Sn seems poor.

Improvement of Sn diffusion







By Reducing Sn diffusion distance,
Jc improved by 20% to improve Sn diffusion.

KOBELCO
KOBE STEEL GROUP

JASTEC SUPERCONDUCTOR

Conclusion and Next steps

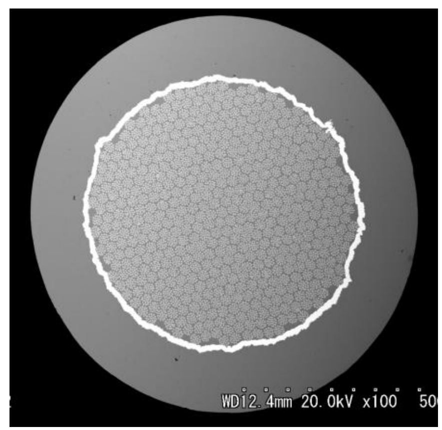
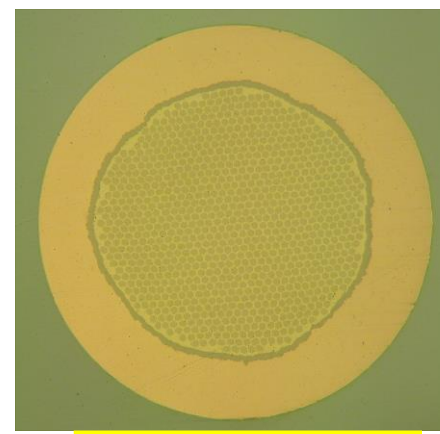
- **Conclusion**
  - **DT wire as a high Jc Nb_3Sn wire for FCC.**
  - **By improving Sn diffusion, non Cu Jc@16T is almost 1000A/mm^2.**

- **Next steps**
  - **By increasing Nb volume fraction ,**
    non Cu Jc>1100A/mm^2 @16T was a prospect.
  - **Furthermore, we will perform optimization of ternary additive elements and refinement of Nb_3Sn grain size etc., Our goal is 1500 A/mm^2 @16T.**

FURUKAWA
ELECTRIC

ITER-CS Wire -Design for higher Jc & lower Ph-

FURUKAWA ELECTRIC

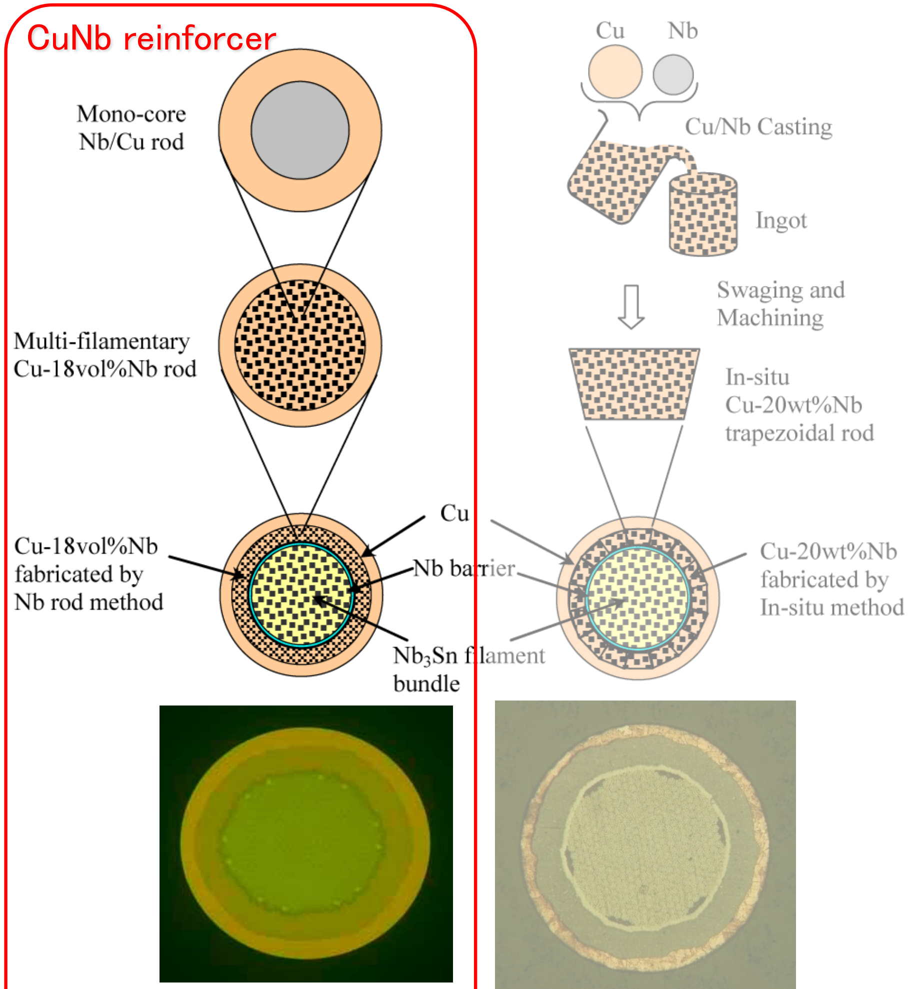
Items	2008 design	2012 design
Strand final diameter (mm)	0.83±0.005	0.83±0.005
Cr-plating thickness (μm)	$2^{+1/-0}$	$2^{+0/-1}$
Cu/Non-Cu ratio	1.0 ±0.1	1.0 ±0.1
Twist pitch (mm), direction	15 ± 2 (R.H.H)	15± 2 (R.H.H)
Diffusion Barrier	Ta	Ta
Bronze composition (wt%)	16Sn-0.3Ti	15.7Sn-0.3Ti
Filament dia. (μm)	3.3 (nominal)	2.3 (nominal)
Cross-section		

Optimized for ITER-CS

Mechanical Reinforcement

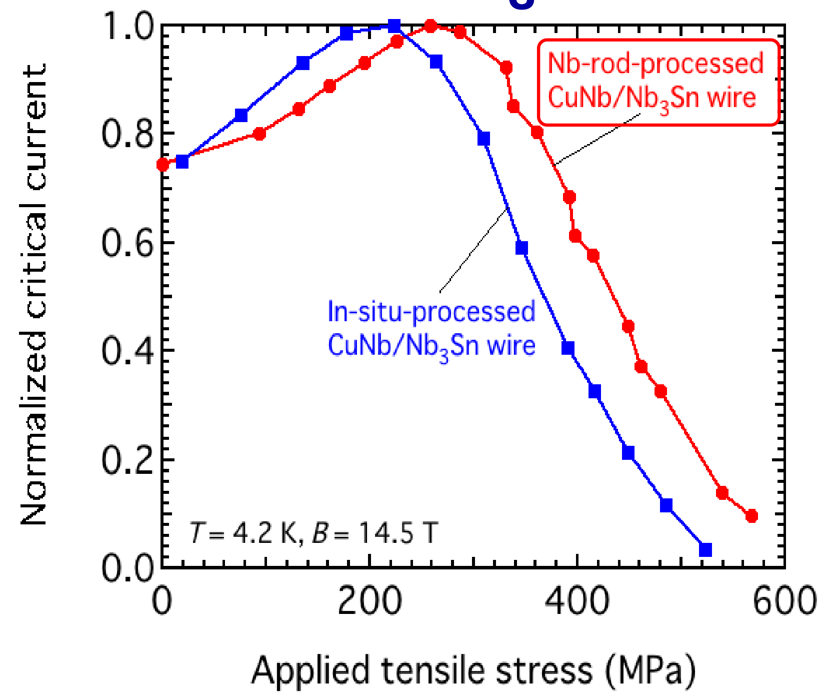
FURUKAWA ELECTRIC

Nb-rod-method CuNb reinforced Nb_3Sn



(a) Nb-rod (b) In-situ

Strand cress section



Feature of Nb-rod-method

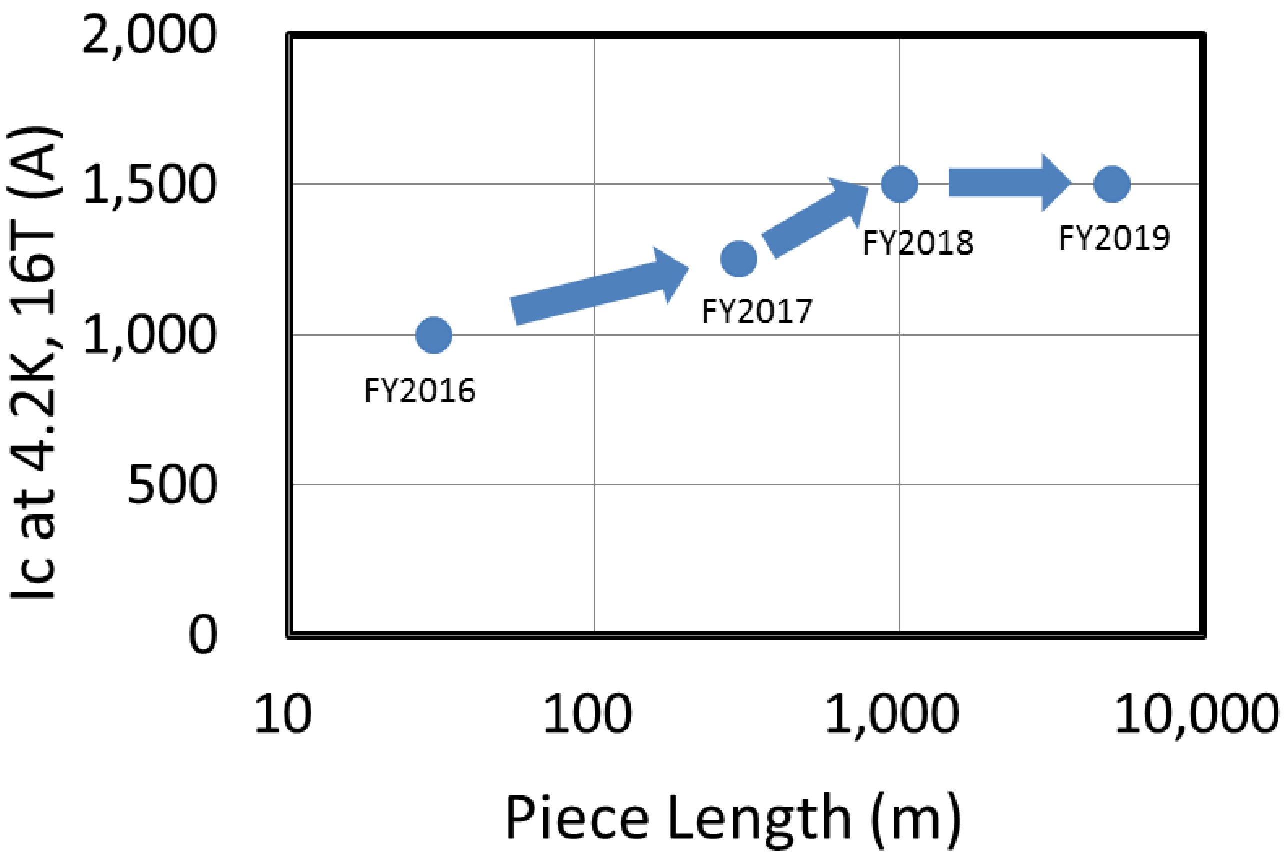
- Excellent Ic vs stress performance
- Useful RRR larger than 100: **count as stabilizer!!**
- **Suitable for mass-production**

This work was performed under collaboration with HFLSM, IMR, Tohoku University.

TOHOKU UNIVERSITY

Wire Development at Furukawa Electric(FEC)

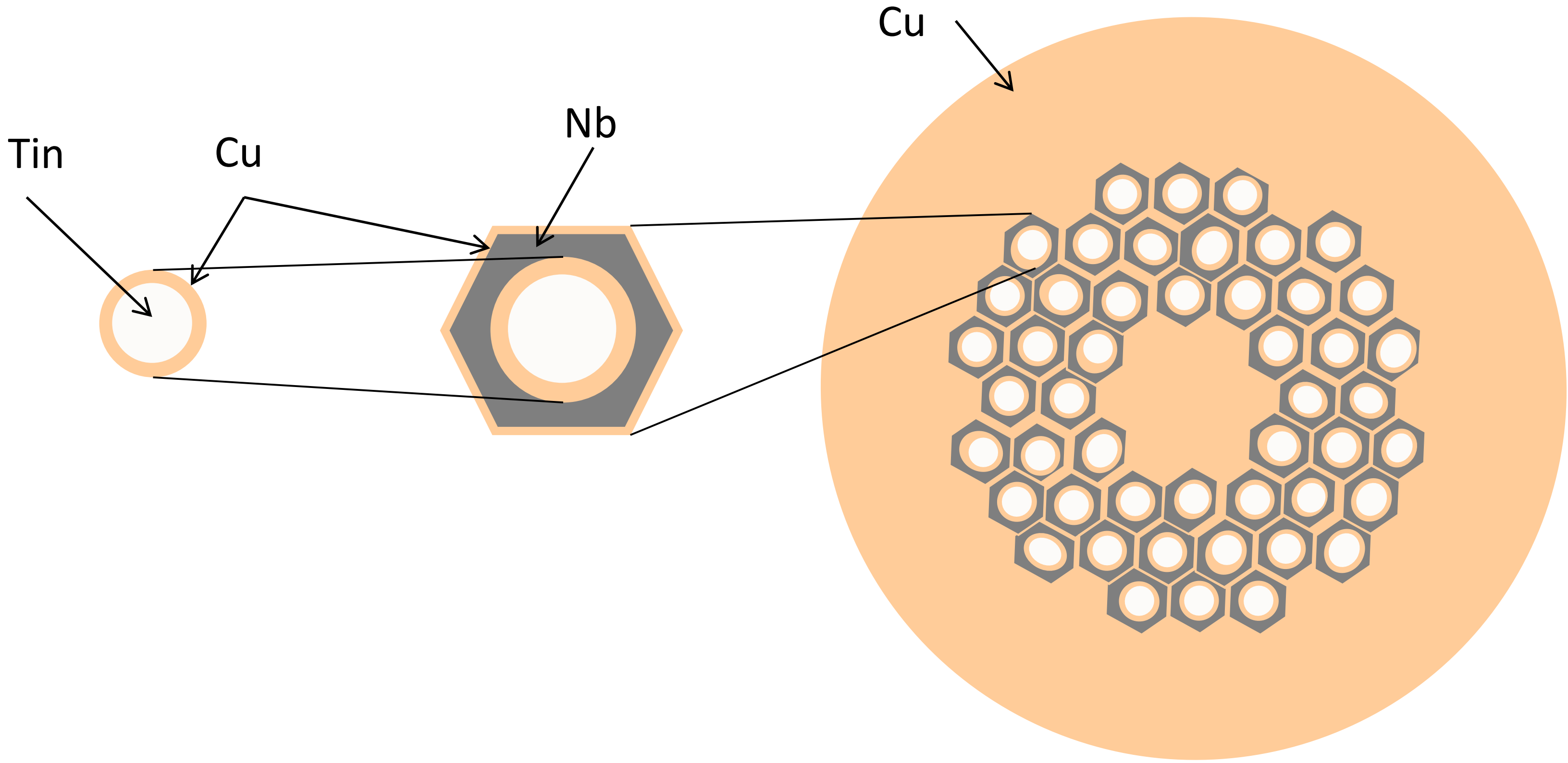
- FEC started to develop high Jc type Nb_3Sn Wire in FY2016.
- Wire will be processed through high-tin content method.



Milestone of wire development

Strand Design

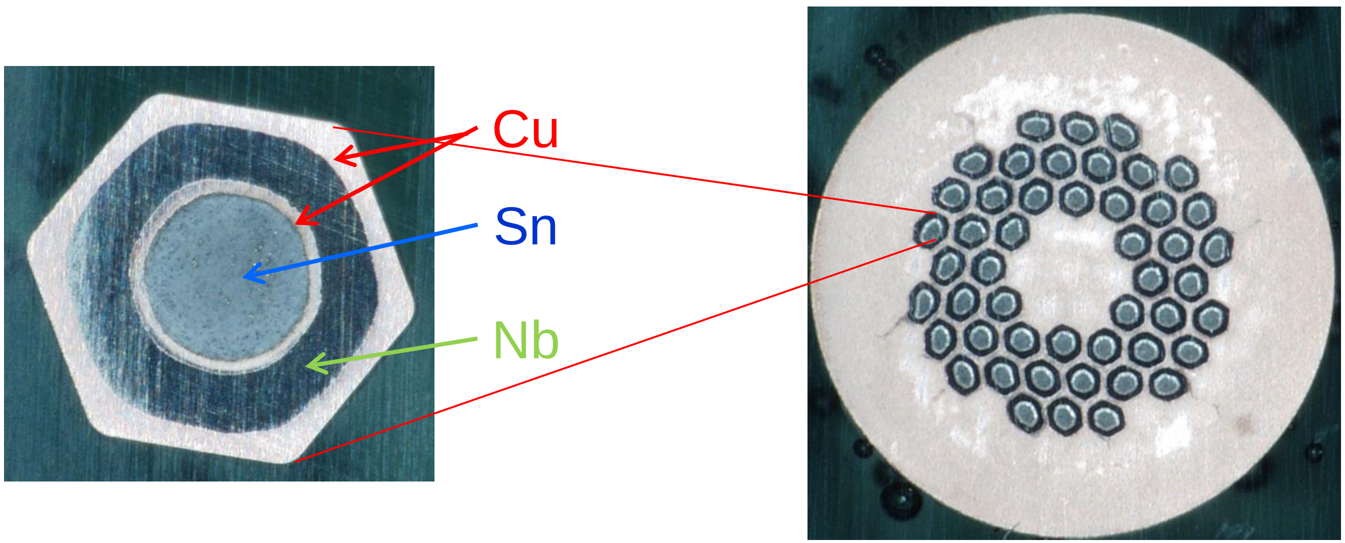
Nb Tube Method



Schematic View of Strand Design

Status of Development

- 1st trial is finished.
- Issue on fabrication is identified.



Sub element

Strand at 1st trial

- The 2nd trial is now on going

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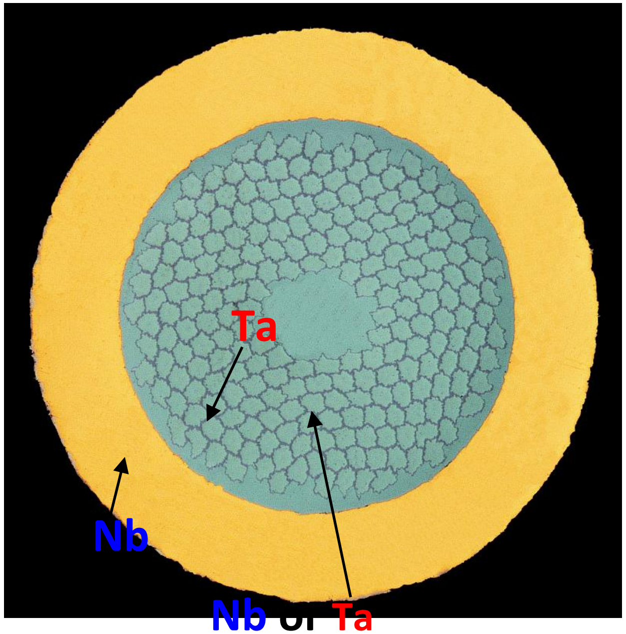
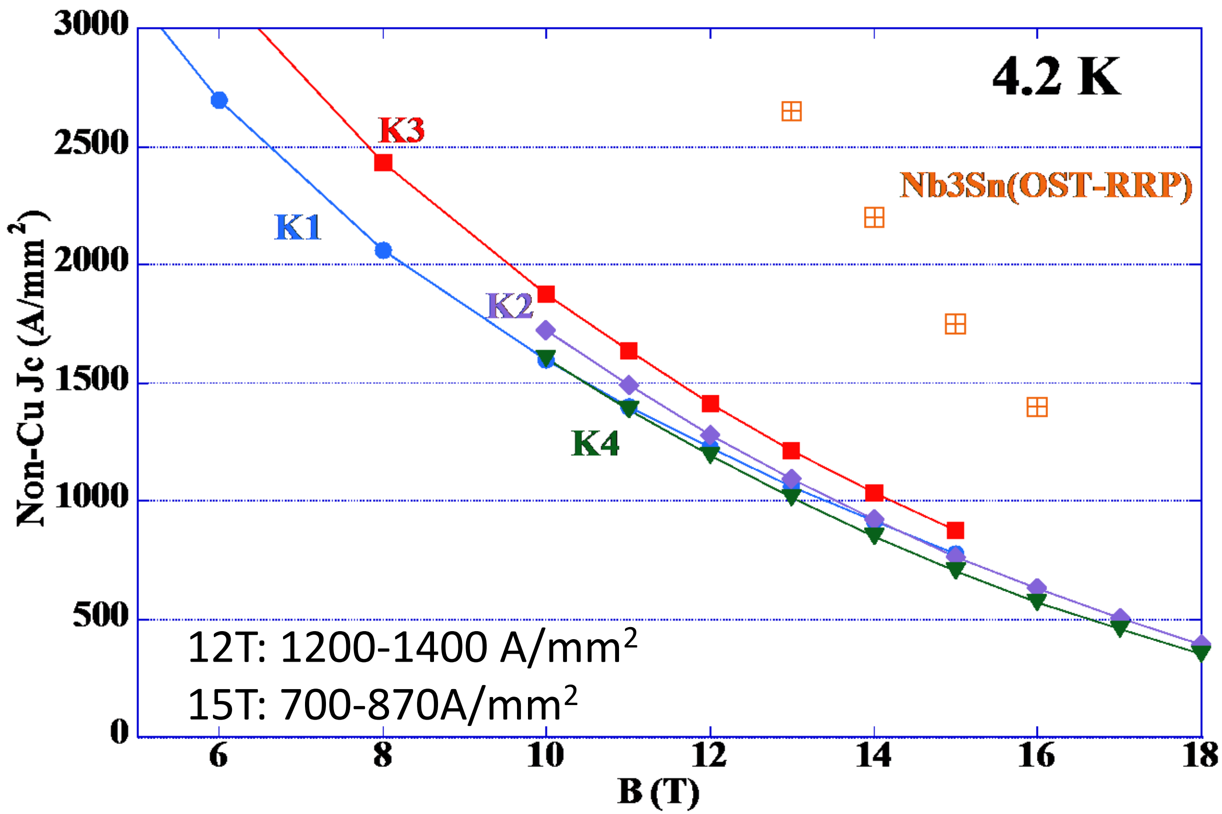
RHQ-Nb_3Al w/ Ta Barrier

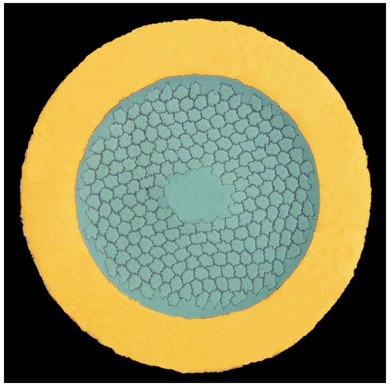


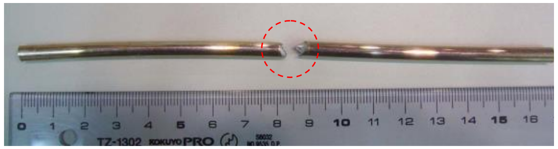


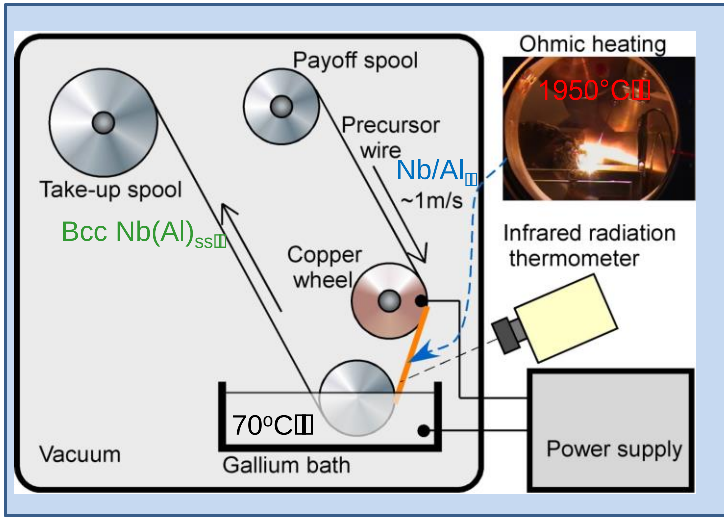
- Collaborative work between NIMS and KEK with a support from CERN (~2011)
- Development for high field accelerator magnet
- B_{c2}(4.2K): 19- 30 T+Good strain tolerance=Good for High Field

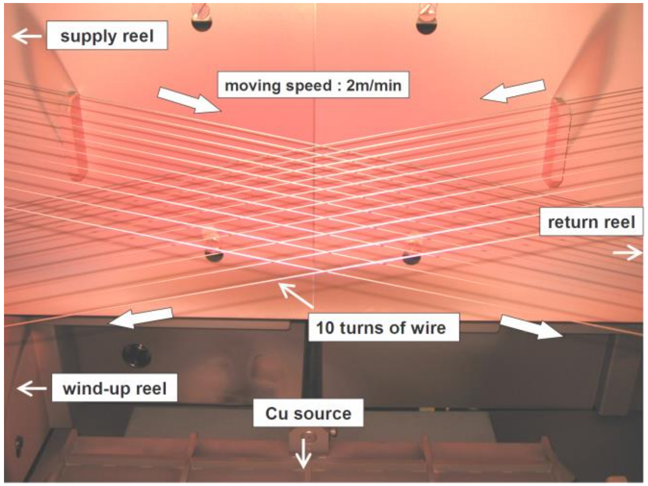
Issues for RHQ-Nb_3Al

- Many wire breakings with Ta matrix.
- RHQ process using Ga bath
  – Removal of Ga to clean wire surface
- Copper stabilization
  – Ion-plating
  – Copper electroplating









Issues for RHQ-Nb_3Al : Efforts for Improvement

- Many wire breakings with Ta matrix.

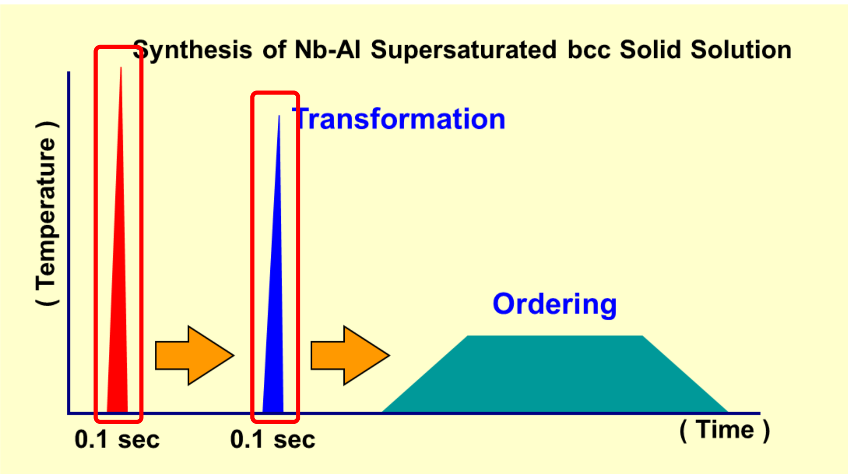
  >> Nb alloy matrix w/ good drawability

- RHQ process using Ga bath >> Gas quenching
  - ~~Removal of Ga to clean wire surface~~
- Copper stabilization
  - ~~Ion-plating~~
  - Copper electroplating >> speed-up

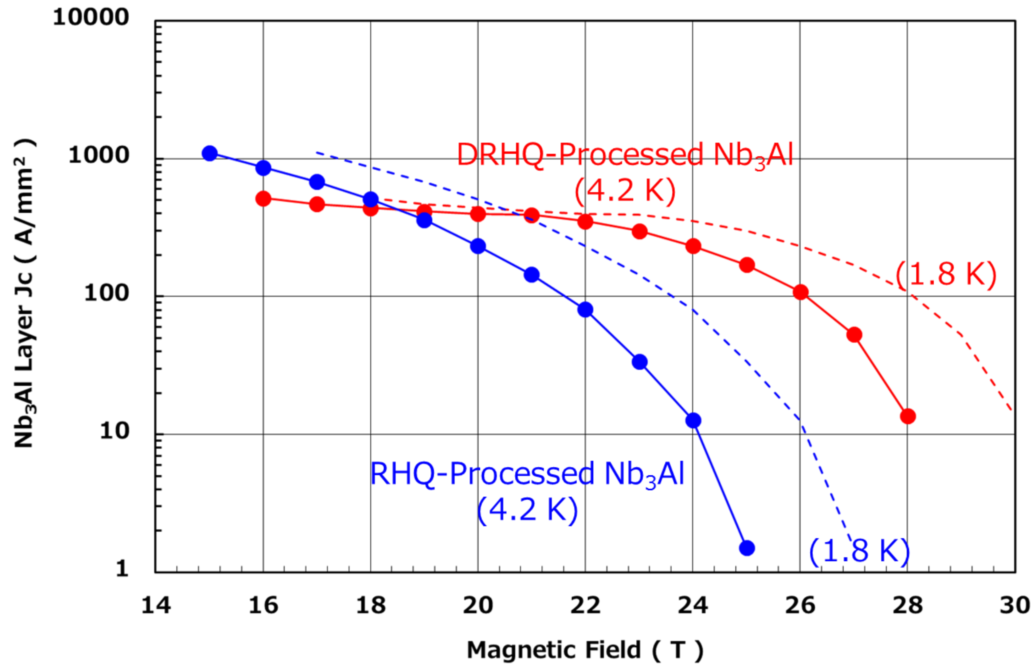
Double RHQ Processed Nb_3Al Conductor

DRHQ Process

(Double Rapidly-Heating/Quenching)



High Temperature Phase Transformation from bcc to A15



Higher Bc2

- Significant improvement of Jc beyond 20 T by DRHQ process
- Great potential for Inner coil of >20 T magnet
  - Coil winding would be challenging…

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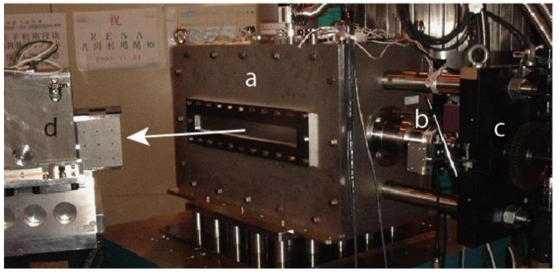
Various Load Frames for Q-beams

Load frames at Takumi@J-PARC (**Neutron**)

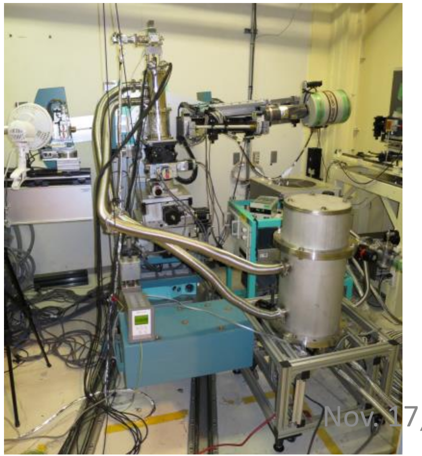
Flight time dispersion measurements.
Tensile load up to 50 kN at RT, HT(furnace) and LT (6K).
Compressive load jig also available.

Cryogenic load frame at RESA @JAEA (**Neutron**)



Angle dispersion measurements.
Tensile load up to 50kN at LT.

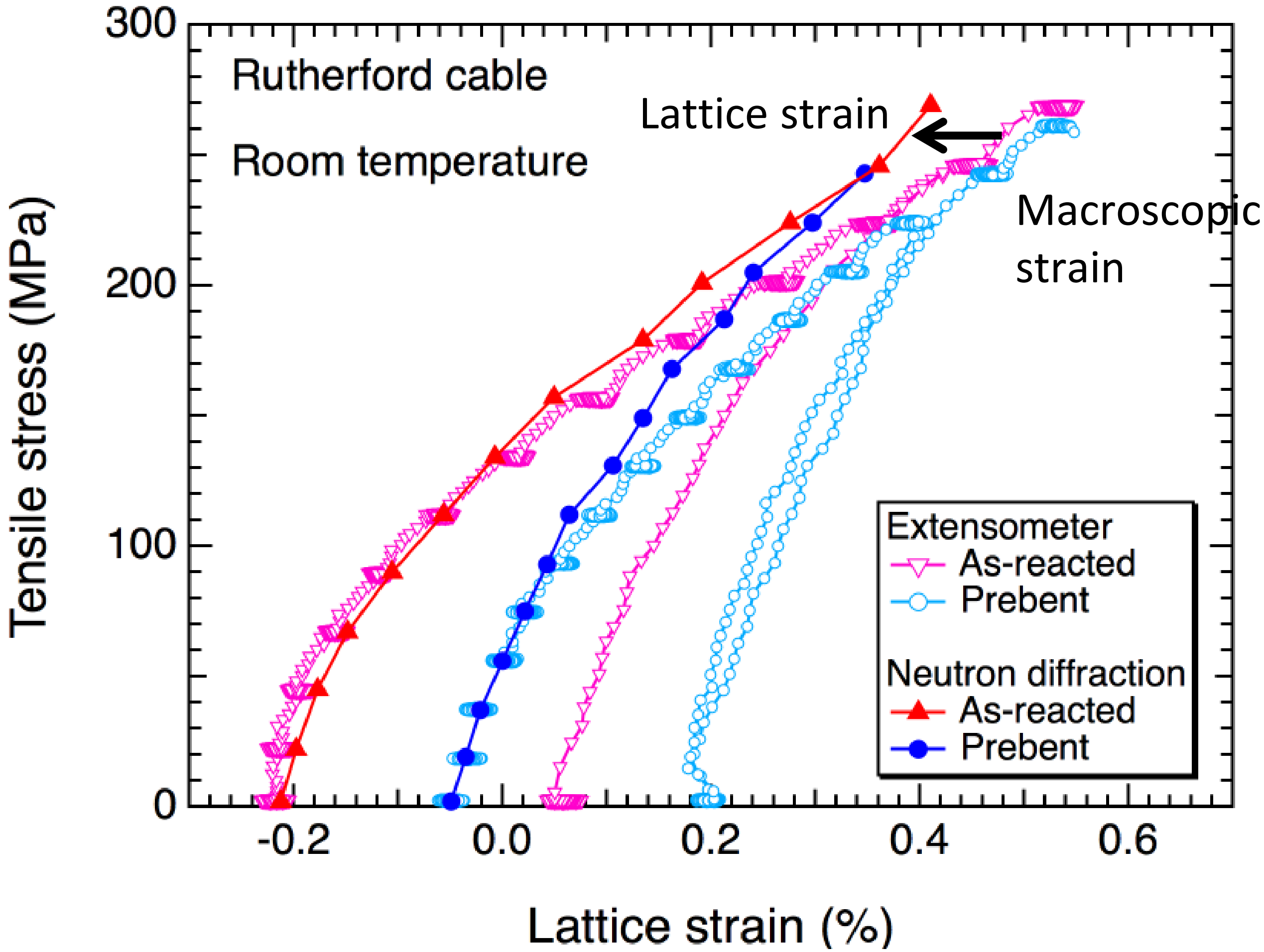
Load frame at SPring 8 (**X-ray**)

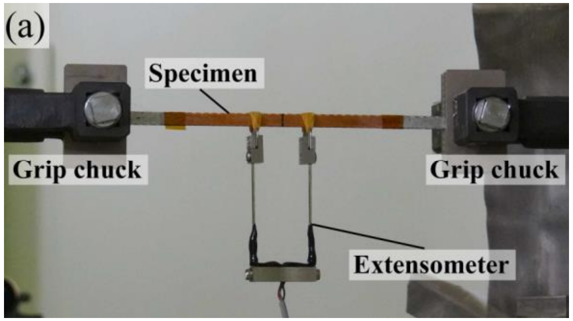


Angle dispersion measurements.
Tensile load up to 2kN at RT and LT (~25 K).

Lattice Strain & External Strain in CuNb/Nb_3Sn Rutherford cable

Measured by Neutron diffraction at the J-PARC, Japan





The strain in the strands is smaller than the macroscopic strain of cable.

Takahashi *et al.* IEEE TAS 25 (2015) 8400104

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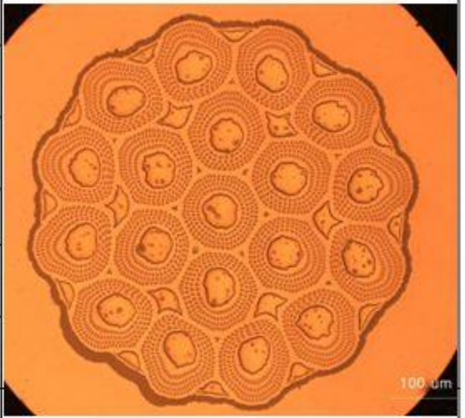
Kiswire Advanced Technology Ltd. — KAT Introduction & Products May 2015

History

- 1998 — Started R&D for SC wire by internal tin process at Kiswire R&D Center
- 2004 — Found specialized company of superconducting wire at Deajeon
- 2006 — Supplied Nb3Sn SC wire of 2 tons for PF coil to KSTAR Project
- 2008 — Certificated the first supplier of TF Nb3Sn wire to pass CPQS test by ITER in the world
- 2009 — Contracted total Korean quantity of 93 tons of TF Nb3Sn wire
- 2013 — KAT have supplied 93 tons of TF SC wire that is ATPP cleared (2013.11)
- 2015 — KAT is now supplying the Nb3Sn wire for CS Conductors (CS1U, CS2U)

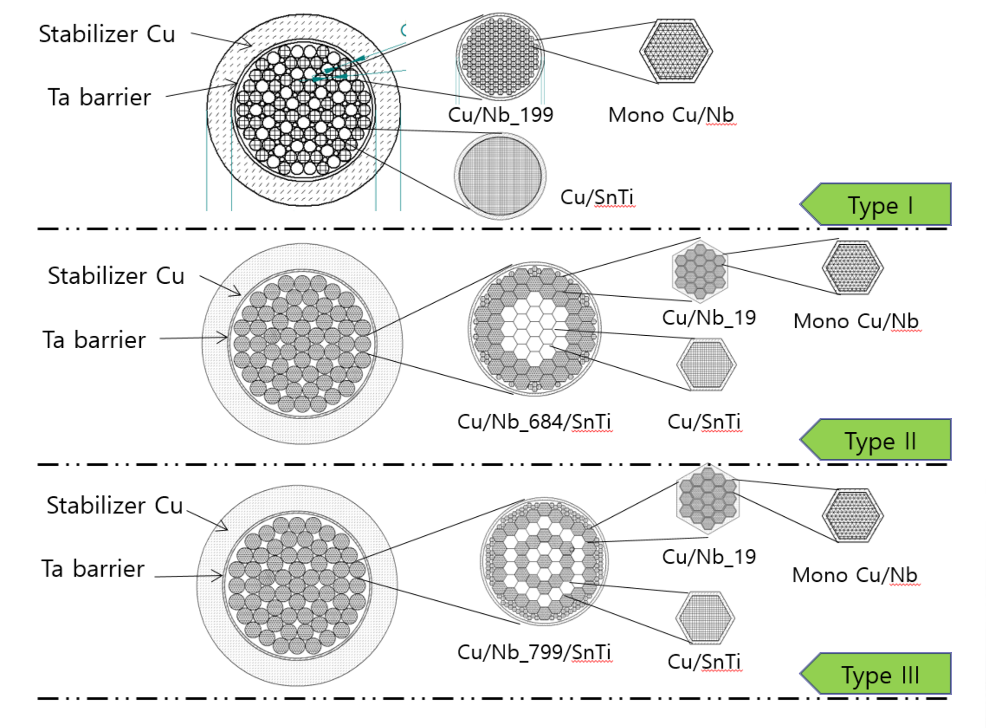
4/26

Nb_3Sn Wire Specification

ITEM	TF Strand	CS Strand	Comment
Superconductor Type	Nb_3Sn	Nb_3Sn	
Minimum Piece Length	1,000m	1,000m	
Cr-plated Strand Dia	0.82 ± 0.005mm	0.82 ± 0.005mm	
Twist Pitch	15 ± 2mm	15 ± 2mm	
Twist Direction	Right Hand Twist	Right Hand Twist	
Cr Plating Thickness	2.0 +0/-1㎛	2.0 +0/-1㎛	
Cu/Non Cu Ratio	1.0 ± 0.1	1.0 ± 0.1	
RRR	> 100	> 100	Between 273 and 20K, after HT
Minimum Critical Current	Ic ≥ 250A	Ic ≥ 250A	at 4.22K and 12T
n-value	> 20	> 20	at 4.22K and 12T in 0.1~1㎶/cm
Maximum Hysteresis Loss	< 600 mJ/cc	< 500 mJ/cc	at 4.22K over a ± 3T cycle

Strand Design Studies for FCC Conductor

❖ Trial designs of Nb_3Sn for FCC



✓ Designed parameters

Parameters	Unit	Type I	Type II	Type III
Diameter	mm	1	1	1
Cu/N-Cu		0.99	1.02	0.98
No. Filaments	ea	11,542	41,724	48,739
Effective dia.	μm	68.82	85.71	85.71
Filament dia.	μm	4.04	2.13	1.93
Cu fraction	%	15.11	15.26	15.77
Ic_Filament@16T	A	0.035	0.012	0.010
Ic@16T	A	409	489	489
NonCu Jc@16T	A/mm^2	1037	1260	1260
At % 3Sn/Nb		0.99	0.85	0.92

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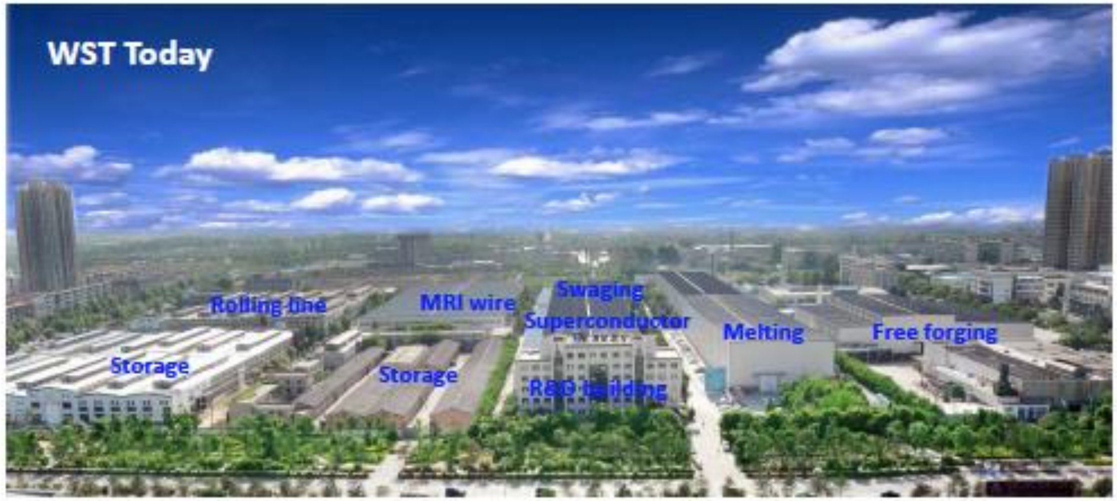
Milestones of WST



Superconductivity Discovery
NbTi Superconductivity
NIN Founded
Jc Record of NbTi strand
WST Founded
NbTi Qualification for ITER
Nb_3Sn Qualification for ITER
Nb_3Sn Delivery for ITER
WIC Qualified by GE
NbTi Delivery for ITER

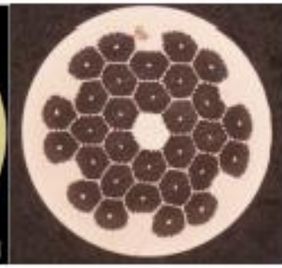
1911 1957 1965 1984 2003 2009 2010 2015 2017

J. Liu MT25

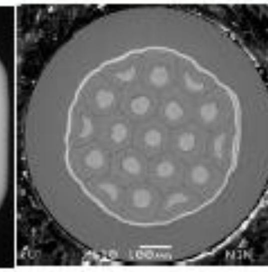
Superconductor Family of WST

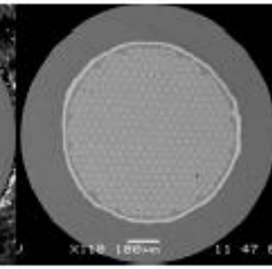
LTS

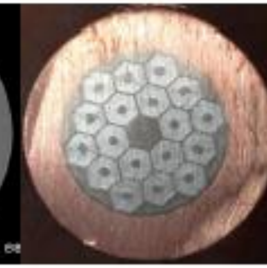

NbTi


NbTi/CuNi

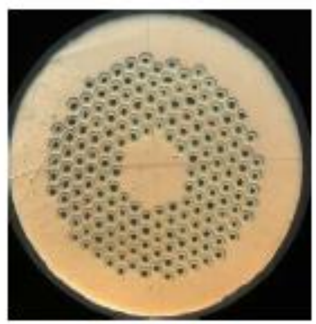

WIC

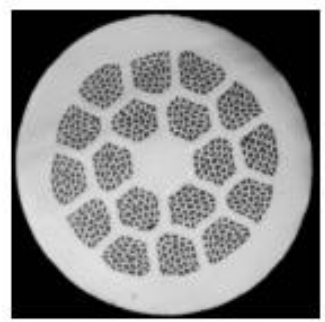

IT Nb_3Sn


Bronze Nb_3Sn


Nb_3Al

HTS


MgB_2


Bi-2212

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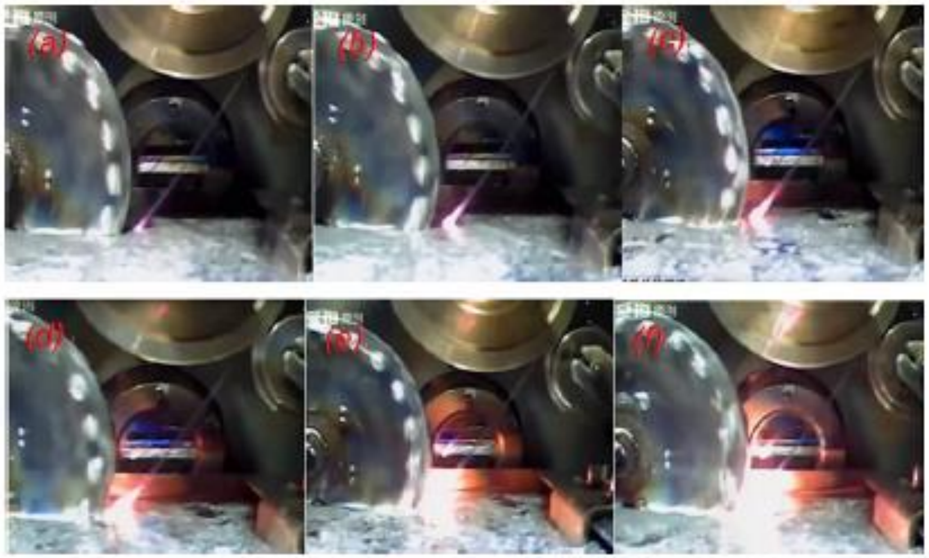
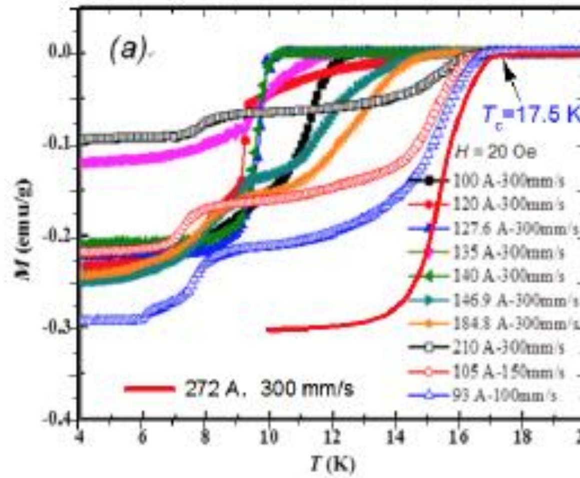
Nb_3Al wire

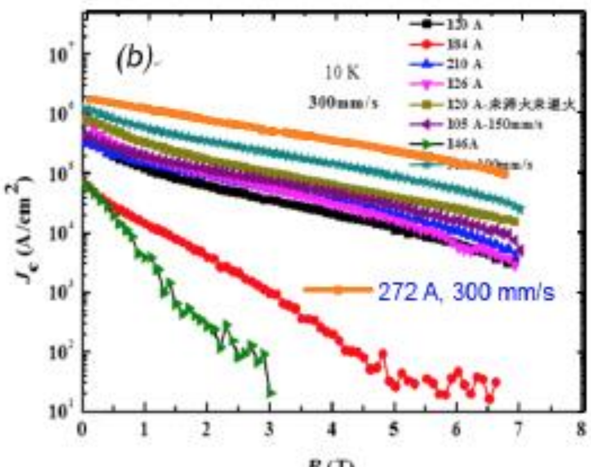
Rapid heating and quenching (RHQ) heat-treatment

◆**RHQ heat-treatment process of reel-to-reel Nb_3Al wires with a continuous increasing sintering current.**



◆**Our aim is to develop the practical high performance Nb_3Al superconducting wires, many efforts are still being ongoing.**





J. Liu MT25

Summary

- Various A15 activities in Asia
- Japan
  - Distributed tin Nb_3Sn by JASTEC/Kobelco
  - Nb tube Nb_3Sn by Furukawa electric
  - RHQ Nb_3Al by NIMs
  - Stress strain studies using quantum beams
- Korea
  - Internal tin Nb_3Sn by KAT (FCC week 2017)
- China
  - Various activities in WST including RHQ Nb_3Al (MT25)