Development progress in KAT

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Outline

- Introduction
- Development progress of Nb_3Sn strand for FCC
- Plan for performance improvement
- Conclusion

Introduction

Conductor development program between CERN and KAT

Mar-2017	Sep-2017	Mar-2018	Mar-2019	Mar-2020	Mar-2021
Contract	Task 1	Task 2	Task 3	Task 4	Task 5

Task 1	Task 2	Task 3	Task 4	Task 5
R&D Design	Billet design Manufacturing plan	Sample supplement (2km – 3 Types)	Sample supplement (5km – 1 Type)	Sample supplement (20km – 1 Type)
Cost estimation	Cost estimation	Cost estimation	Cost estimation	Cost estimation
Bimonthly report Task report	Bimonthly report Task report	Bimonthly report Task report	Bimonthly report Task report	Bimonthly report Task report

Final target

- ✓ Diameter : < 1mm
- ✓ Cu/NCu : ~ 1
- ✓ Deff : < 50 ㎛
- ✓ RRR ≥ 150
- ✓ Jc ≥ 1,500 A/㎟

- Collaboration agreement between CERN and KAT was established in Mar-2017.
- Kick-off meeting was conducted in 21 Mar-2017.
- The purpose of this program is to achieve Jc target.

Introduction

Local collaboration for Nb_3Sn development

KISWIRE KAT

- Strand design and manufacture
- Project management

KITECH

- Hydrostatic extrusion process

Item	Specification
Extrusion load	6 MN
Working extrusion pressure	1 GPa
Container bore diameter	90 mm
Container type	Wire-wound
Maximum billet diameter	80 mm
Maximum billet length	350 mm
Maximum stem speed	50 mm/sec
Main hydraulic power	345 kW

NFRI National Fusion Research Institute

- Wire design consultation

RIST

- Low temperature test at 16T, 4.2K

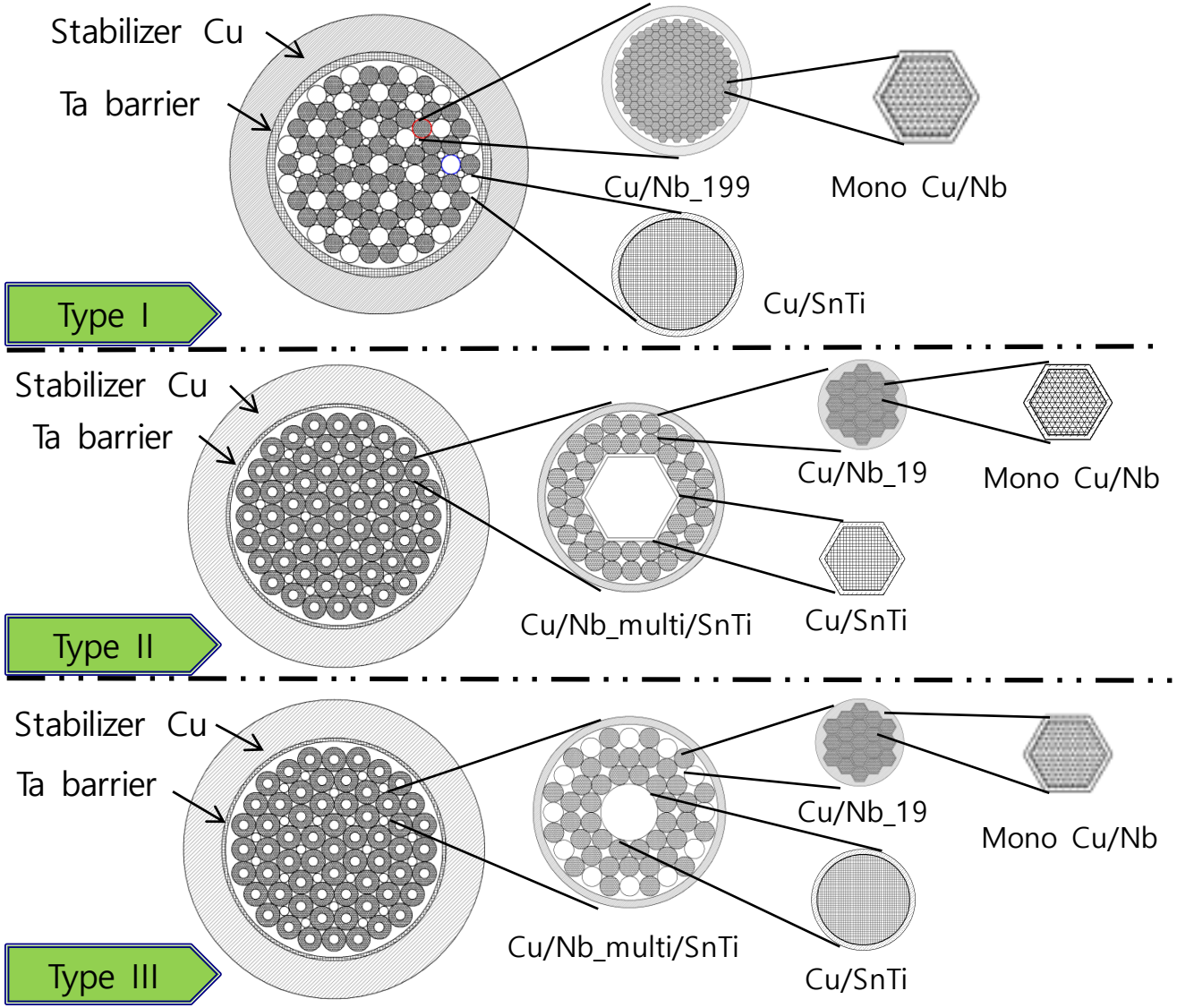
Item	Specification
Maximum field	18 Tesla
Temperature range	1.7 ~ 300K
Magnet bore size	52 mm
Sample space	37mm
Field center(from top flange)	1496mm

KOREA UNIVERSITY

- Strand performance test

Development progress

Design summary for FCC target



✓ Designed parameters

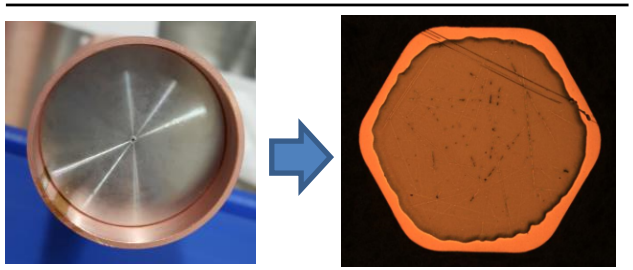
Parameter	Unit	Type I	Type II,III
Diameter	mm	1.0	1.0
Cu/N-Cu		1.0	1.0
No. Filaments	ea	11,940	48,678
Dia. Filament	μm	4.1	2.2
Dia. Sub't	μm	70	85
Cu fraction	%	15.7	14.8

✓ Estimation of performance

Parameter	Unit	Type I	Type II,III
Mono Ic	A	0.036	0.0127
Ic	A	430	618
Jc	A/㎟	1,100	1,574

Development progress

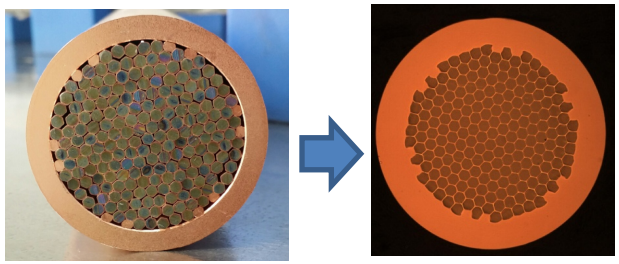
Manufacturing process of Type I



Cu/Nb mono-rod

H. Extrusion + Cold drawing

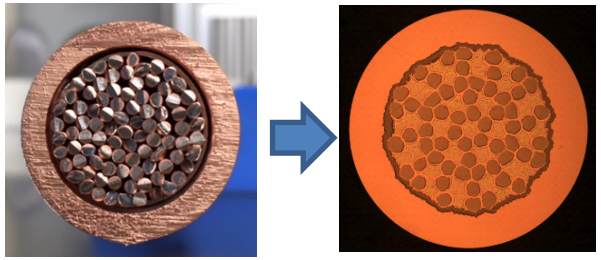
Size cutting + Assembly



Cu/Nb multi-rod(199M)

H. Extrusion + Cold drawing

Size cutting + Assembly



Restacking billet

Cold drawing

Manufacturing process for Type I strands

[Advantage]

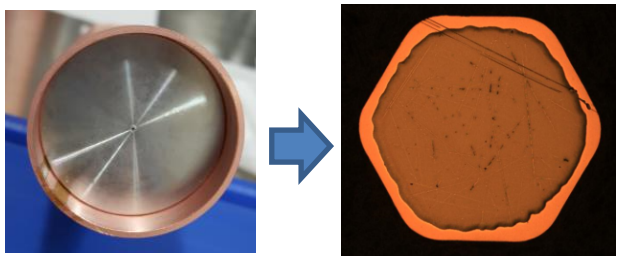
- ✓ Relatively simple process
- ✓ Low manufacturing cost

[Disadvantage]

- ✓ Non-uniform diffusion of Sn and Ti
- ✓ Optimization of heat treatment

Development progress

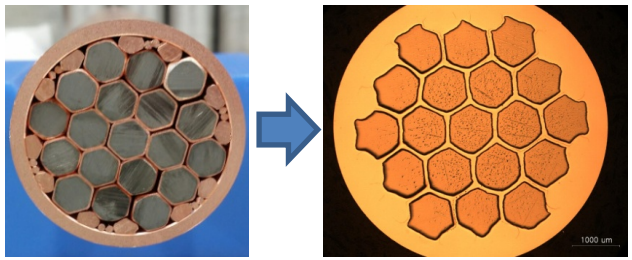
Manufacturing process of Type II and III



Cu/Nb mono-rod

H. Extrusion + Cold drawing

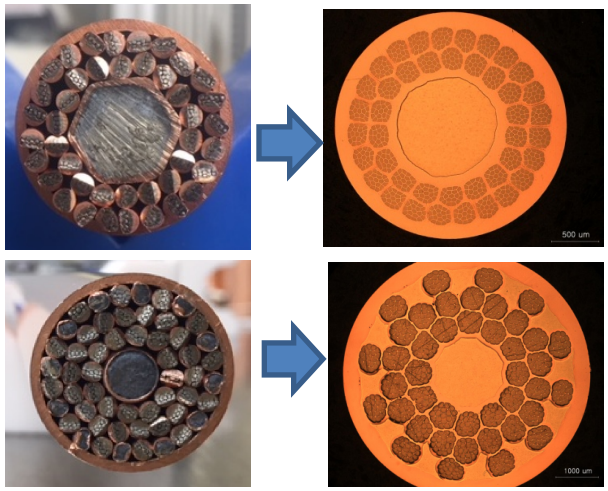
Size cutting + Assembly



Cu/Nb multi-rod(19M)

H. Extrusion + Cold drawing

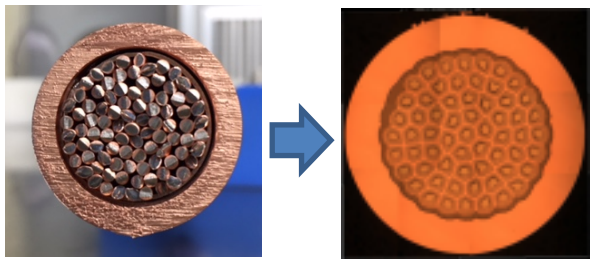
Size cutting + Assembly



Sub element

Cold drawing

Size cutting + Assembly



Restacking billet

Cold drawing

Manufacturing process of Type II & III

[Advantage]

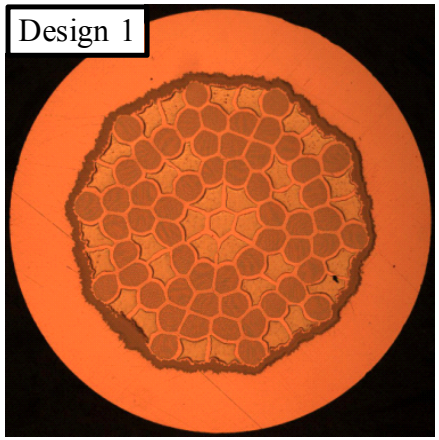
- ✓ Uniform performance
- ✓ Easy to optimize HT
- ✓ Smaller Nb filaments

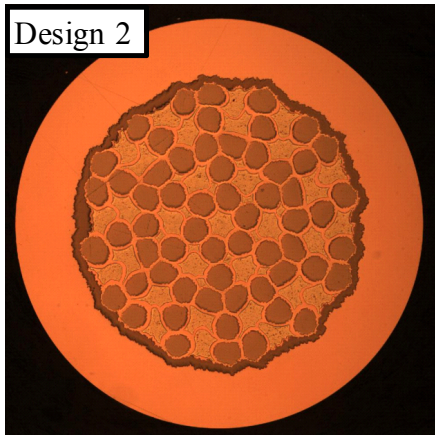
[Disadvantage]

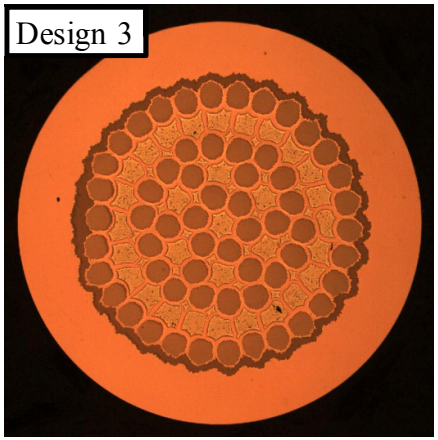
- ✓ Complicate process
- ✓ High Cu fraction in matrix
- ✓ Wire breakage

Development progress

Manufacturing results of Type I samples





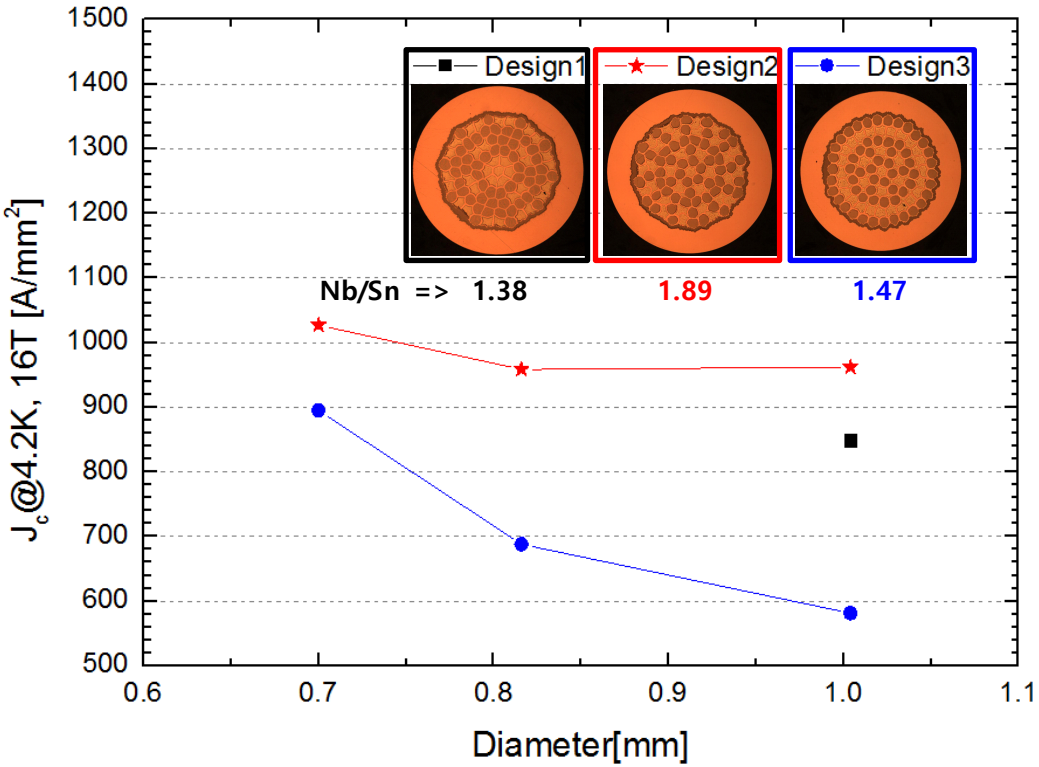


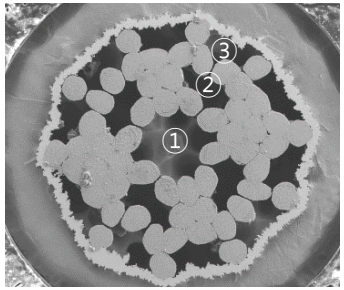
Diameter[mm]	1.00	1.00, 0.816, 0.7	1.00, 0.816, 0.7
Cu/Non-Cu	0.92	0.93	0.83
Nb/Sn	1.38	1.89	1.47
A_{mat_Cu}	15.3%	15%	19.5%
No. Nb module	56 EA	60 EA	60 EA

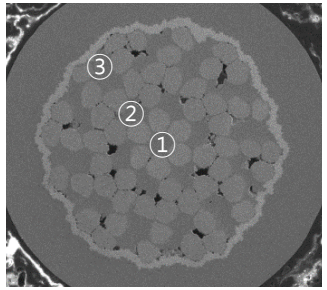
- Three samples which differ from Nb/Sn ratio and module arrangement were manufactured.
- All samples have similar final filament diameter but Design 1 has more less number of filaments.
- Heat treatment schedule : 225℃-50hr + 410℃-50hr + 650℃-250hr (Ramping rate: 5℃/hr)
- Ta tube were applied for the common diffusion barrier.

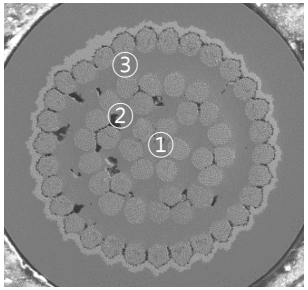
Development progress

Test results of wire performance







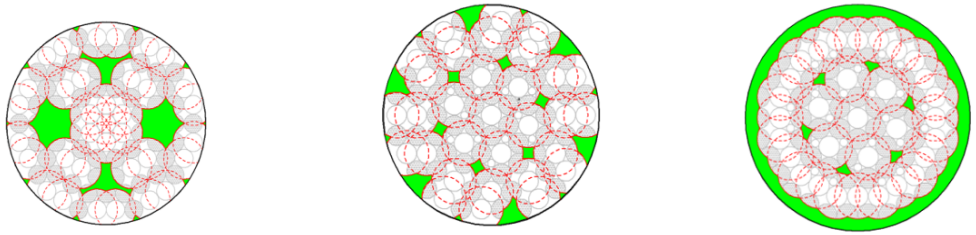


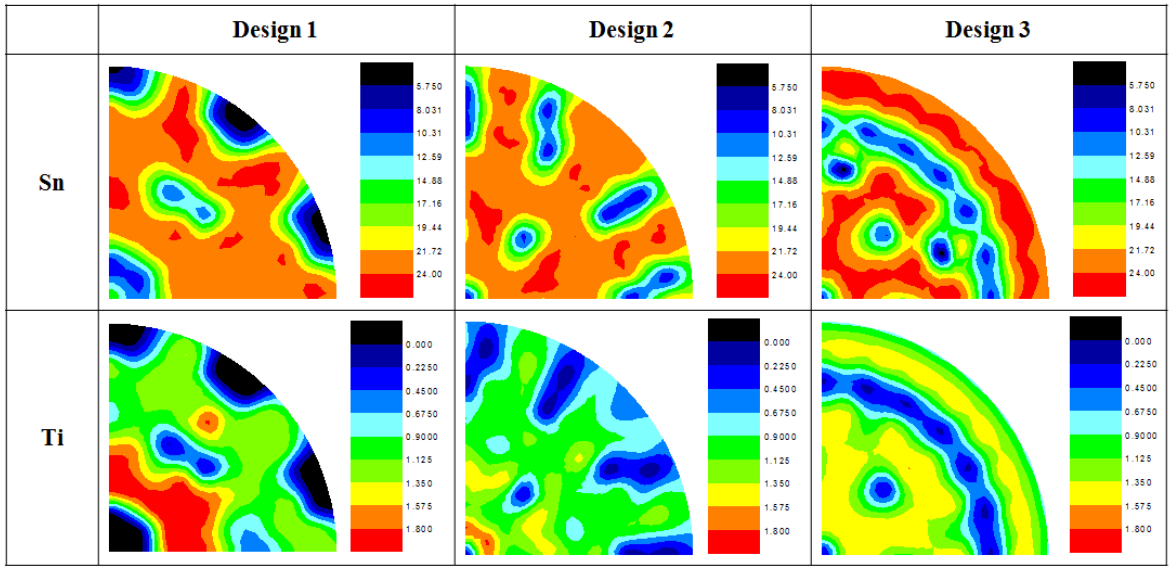
Model	Diameter	Sn at.%			Ti at.%
		Matrix ①	Matrix ②	Matrix ③	Filaments
Design 1	1.00mm	11.90	6.80	8.10	1.33
Design 2	1.00mm	6.52	6.35	6.21	1.23
	0.70mm	5.80	5.80	6.30	1.21
Design 3	1.00mm	8.20	8.40	7.80	1.40
	0.70mm	8.30	8.70	8.50	1.36

- Jc measurement was conducted at 16T and 4.2K.
- Jc has increased with decreasing diameter, highest Jc, 1,027A/mm2, was measured at Design 2 strand.
- Remained Sn after reaction is one of the effective parameter that reflects wire performance.
- Estimated Ti content in Nb_3Sn filaments is relatively lower than ITER strand(Ti 1.8 at.%).

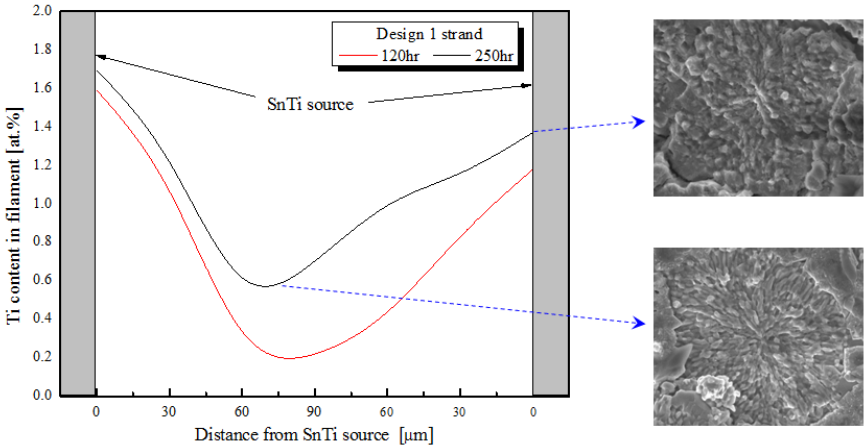
Development progress

Design dependence on diffusion





Sn and Ti contents in Nb_3Sn filaments after heat treatment were analyzed by FE-SEM and EDS.



Poster 2AMSP75

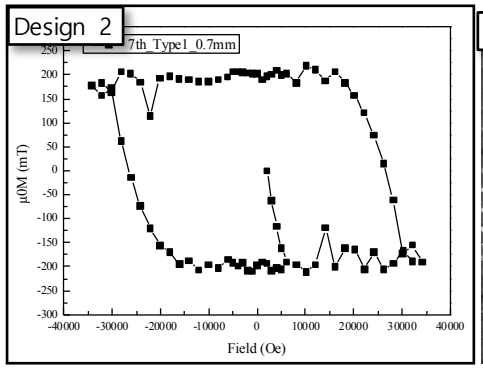
Study on tin and titanium diffusion characteristics for Nb_3Sn strand for FCC conductor

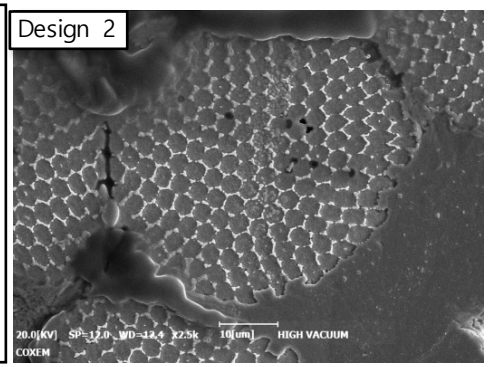
- An intuitive interpretation of the R-billet design was performed to estimate the diffusion behavior.
- Non-uniform distribution of Ti is higher than that of Sn.
- To overcome the limitation of performance, homogeneous Ti diffusion is required.
- Optimization of heat treatment are ongoing to control Ti diffusion.

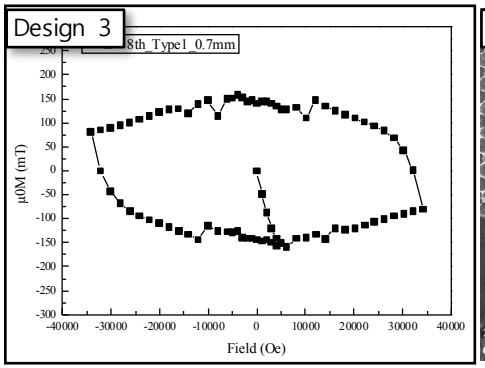
Development progress

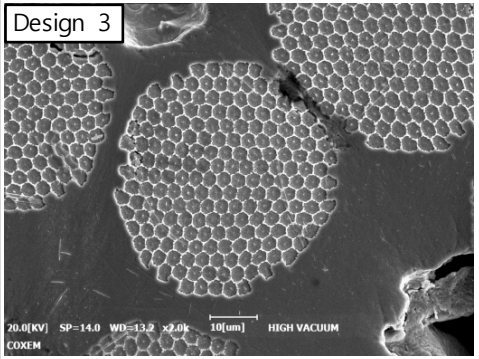
Magnetization & RRR measurement results

Wire type	Diameter [㎜]	Cu/ nonCu	μ0ΔM@1T [mT]	D_{eff} [㎛]	Sub't diameter[㎛]	Distance b/w sub't[㎛]	RRR
Design 2	0.70	0.92	398.3	155.3	44.2	3.3	197
Design 3	0.70	0.83	271.6	97.0	42.8	5.2	174
ITER	0.82	0.98	80.0	79.8	119.6	5.8	120





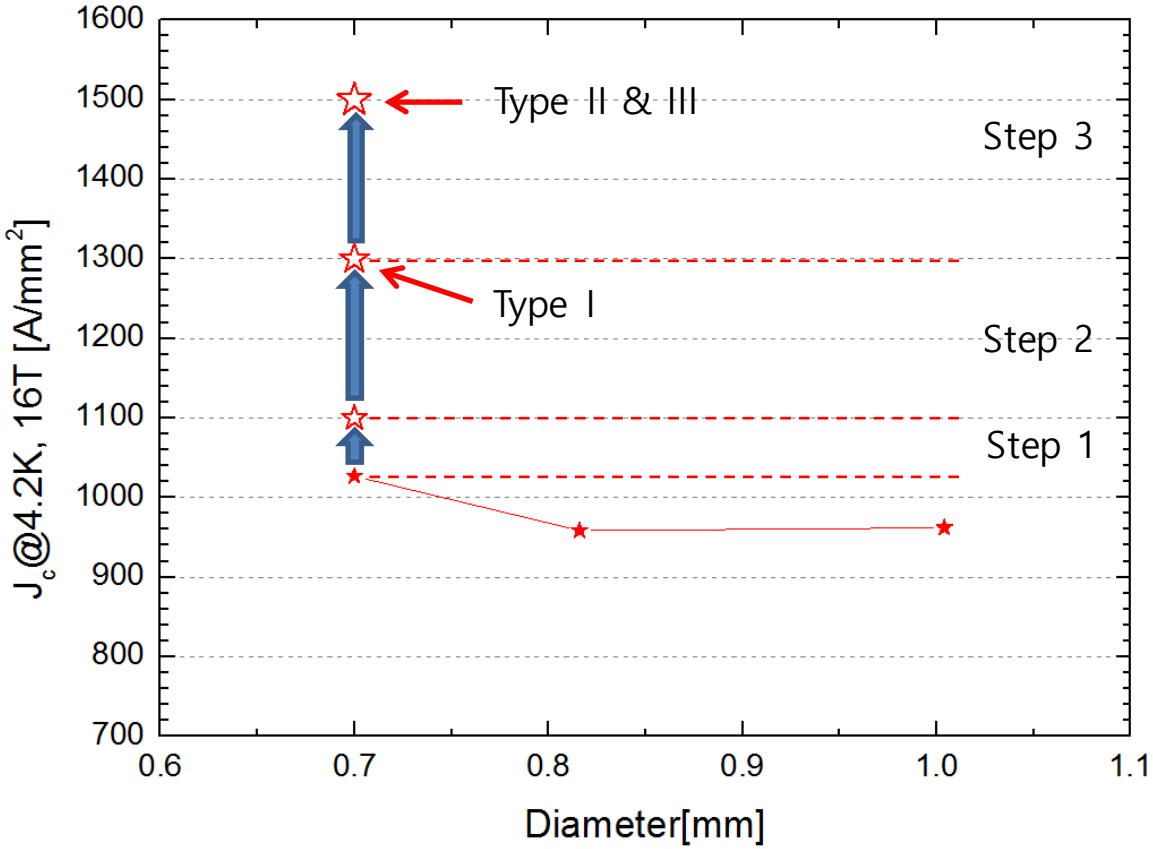




- **RRR values of developed strands show higher values compared to ITER strands.**
  → RRR degradation of ITER strand is associated with the diffusion of Cr plating.
- **Design 2 strand have larger magnetization than Design 3 because of smaller distance between sub-elements. → Distance between sub'ts should be increased to reduce the effective diameter.**

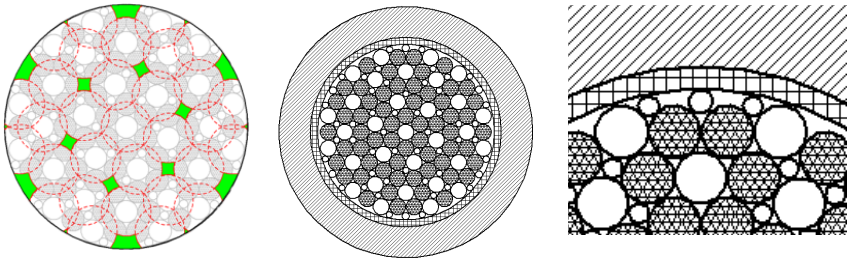
Plan for performance improvement

Strategy to approach Jc target of FCC



Step 1. Improve Jc with current design

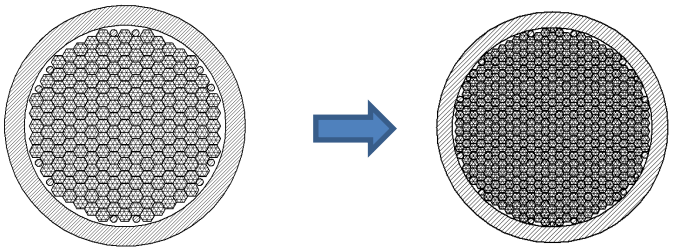
1) Optimization of SnTi arrangement
(Allocate SnTi spacers on weak diffusion area)



2) Increase Ti contents in SnTi alloy
3) Optimization of heat treatment
4) Opportunity: quality issue of SnTi alloy

Step 2. Design change of Type I

1) Increase number of Nb in the multi-rod



2) Increase number of modules in R-billet
3) Opportunities: Homogeneous distribution of Sn and Ti, Increasing wire breakage

Conclusions

Current status of development

- Achieved Jc with Type I strand - 1,027 A/mm^2@16T, 4.2K
- Exist more room to increase Jc maintaining current design
  : increase Ti content, Apply SnTi spacers → Expected Jc ~ 1,100 A/mm^2
- Type II and III are faced on drawing issues
- Ta barrier can maintain good RRR performance.
- Effective diameter larger than requirement. → Need to consider increasing modules in R-billet

For the next steps..

- Need to consider design change of multi assembly and restacking billet to achieve FCC target.
- Proceed manufacturing Type II and III with improved process
  (HIP + Extrusion → Deep hole for SnTi insertion)
- Optimization of heat treatment schedule

Thank you!