Kiswire Advanced Technology Ltd.

FCC Conductor Development at KAT-Korea

2017 FCC Workshop in Berlin

30-May-2017

Jiman Kim

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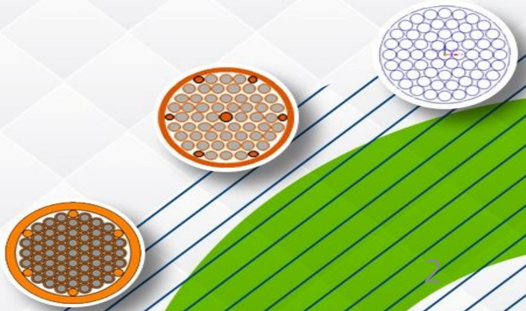


Introduction – CERN-KAT Nb_3Sn Development Program

COLLABORATION AGREEMENT
REFERENCE KE3449
(THE "AGREEMENT")

between

The European Organization
for Nuclear Research (CERN)

and

Kiswire Advanced Technology (KAT)

concerning

The development of Nb_3Sn multi-filamentary wire

- ✓ Collaboration agreement between CERN and KAT has been established
- ✓ Kick-off meeting was conducted in 21 March 2017.
- ✓ Developing period : 2017 March ~ 2021 March(4 yrs)
- ✓ Requirement :

a) A non-copper critical current density at 4.2 K and 16 T (Jc (4.2 K, 16 T)) of at least 1500 A/mm^2;
b) A wire diameter of not more than 1 mm;
c) A fraction of stabilizer to superconductor in the wire of about 1;
d) An equivalent diameter of the superconducting Nb_3Sn filaments of less than 50 μm;
e) A low electrical resistivity of the copper stabilizer of the wire, i.e. a Residual Resistivity Ratio (RRR) of the copper after wire reaction of above 150.

Introduction - Collaborations with Local Institutes

Kiswire KAT

- ☑ Strand design and manufacture
- ☑ Project management

KITECH

- ☑ Hydrostatic extrusion process

NFRI National Fusion Research Institute

- ☑ Strand design consultation

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

RIST

- ☑ 18T superconducting magnet with VTI

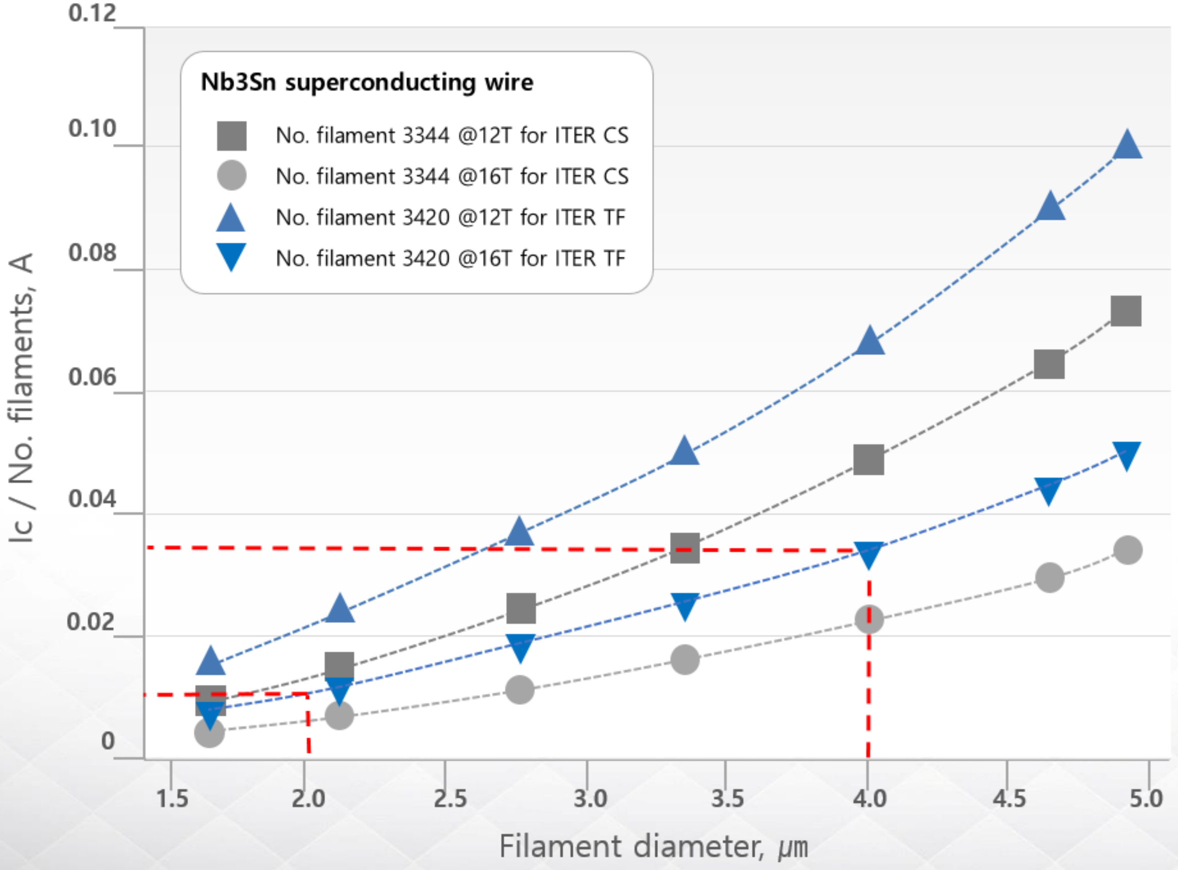
KOREA UNIVERSITY

- ☑ Strand performance test

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

Strand Design Studies for FCC Conductor

❖ How to decide the number of filaments and final diameter?



✓ Target performance
① Jc > 1500A/mm^2 @ 16T
② Diameter = 1mm
③ Cu/non-Cu = 1
④ Ic > 589A@16T

✓ Decision of final filament diameter
① ~ 4 μm : similar to ITER strand
② ~ 2 μm : to make fine grain structure of Nb

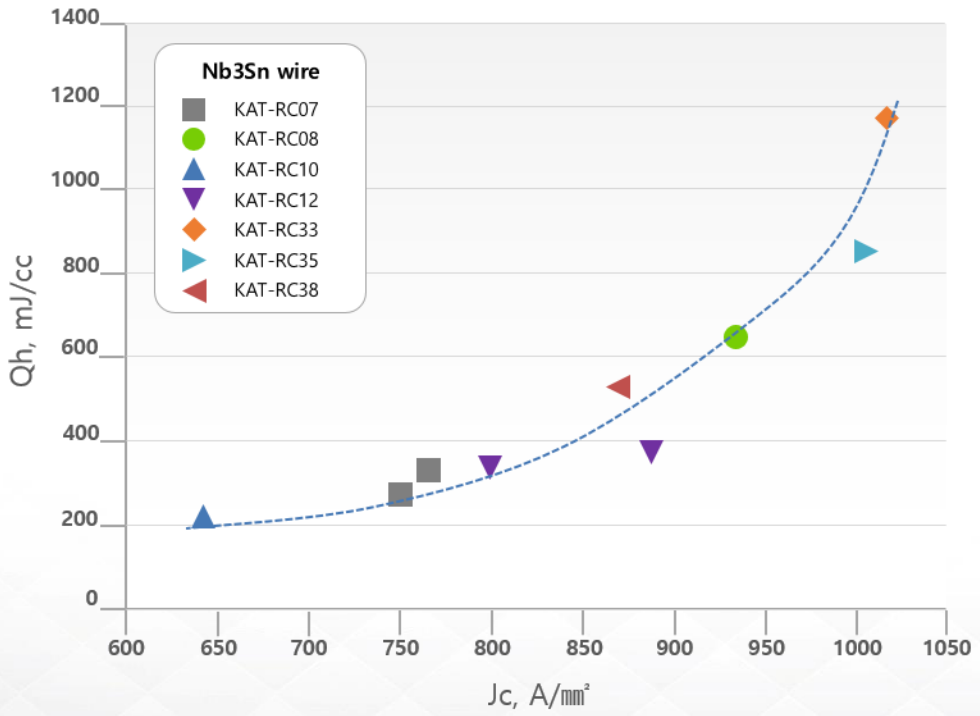
✓ Decision of required number of filament
① $\phi_{Filament}$ ~ 4 μm : 589A / 0.038 A/ea = 15,500 ea
② $\phi_{Filament}$ ~ 2 μm : 589A / 0.01 A/ea = 58,900 ea

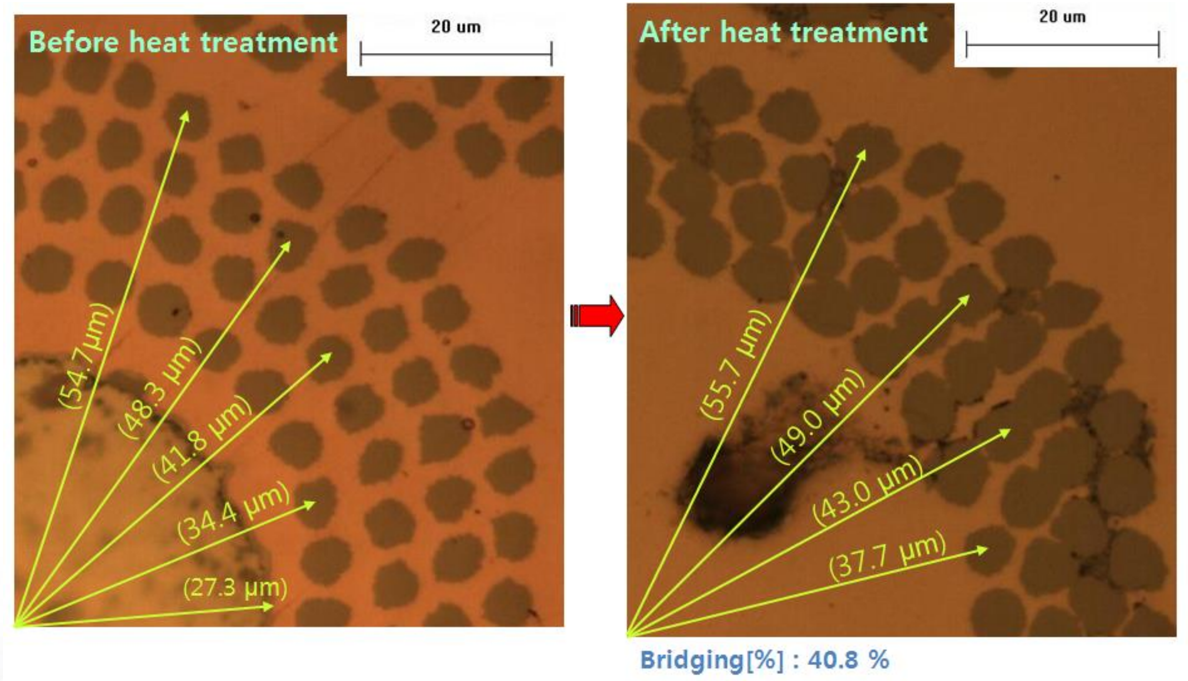
✓ According to increasing number of Nb filament, the reduction of Cu matrix is necessary to less than 15%.

Strand Design Studies for FCC Conductor

❖ How to improve the Ic performance of single filament?

✓ Increase hysteresis loss → Jc will be increased simultaneously





✓ The main reason of high hysteresis loss of multi-filamentary wire is the bridging between filaments.

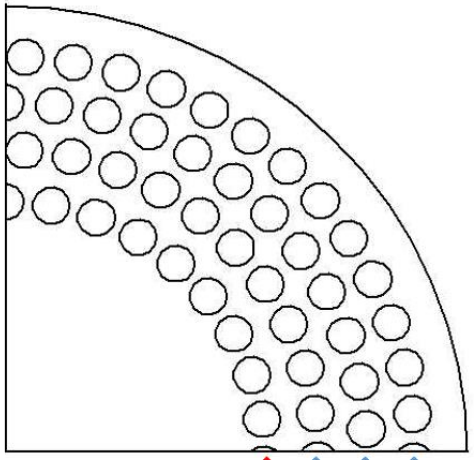
✓ Filament bridging is occurred by the movement of filaments during HT.

✓ Most bridging filaments were located on 1st and 2nd layers in ITER strand.

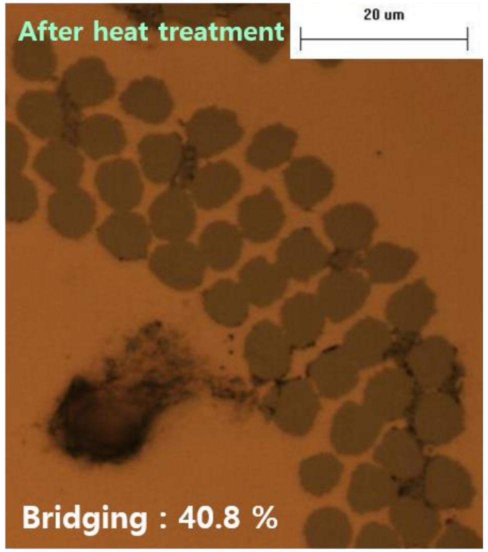
Strand Design Studies for FCC Conductor

❖ How to control bridging?

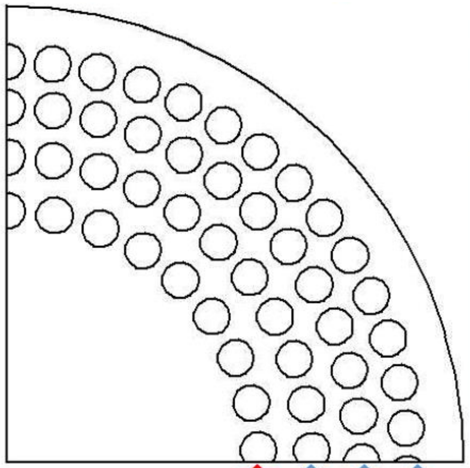
No. Nb: 175



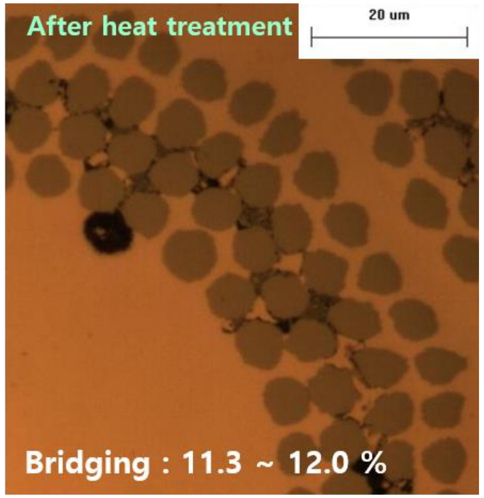
No. Nb/Layer: 35 | 41 | 46 | 53



No. Nb: 177



No. Nb/layer : 33 | 41 | 45 | 55



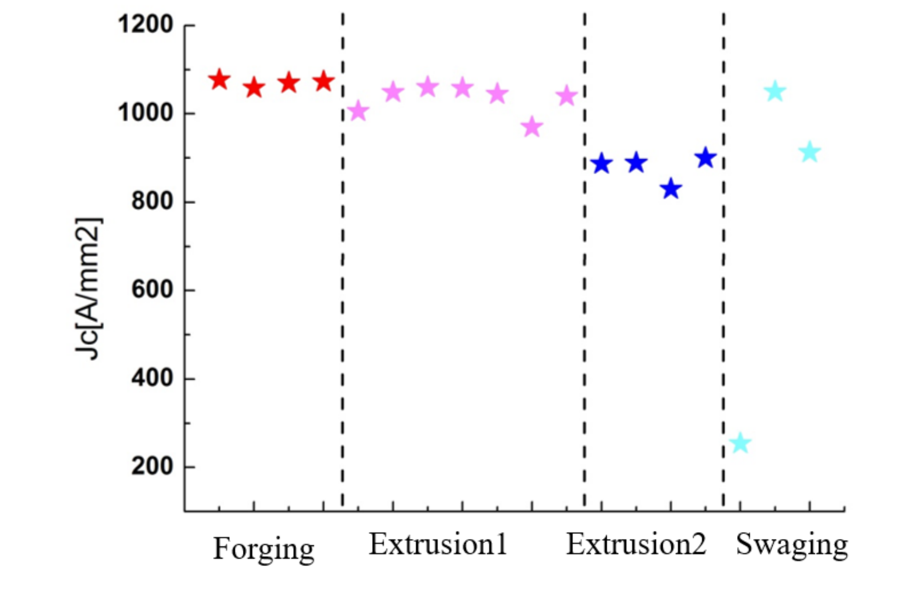
HT scenario	No. Nb	Barrel	Cu/ non Cu	Ic	Jc	n −value	Qh	RRR	
				[A]	[A/mm^2]		[mJ/cc]	Bare	Cr
ITER	19M x 175	3325	1.06	257.9	1016	37.6	1180	364	74
	19M x 177	3363	1.04	189	737	18	589		

✓ Even though 177 sample had many more filaments, it showed lower Jc and Qh due to the bridging.

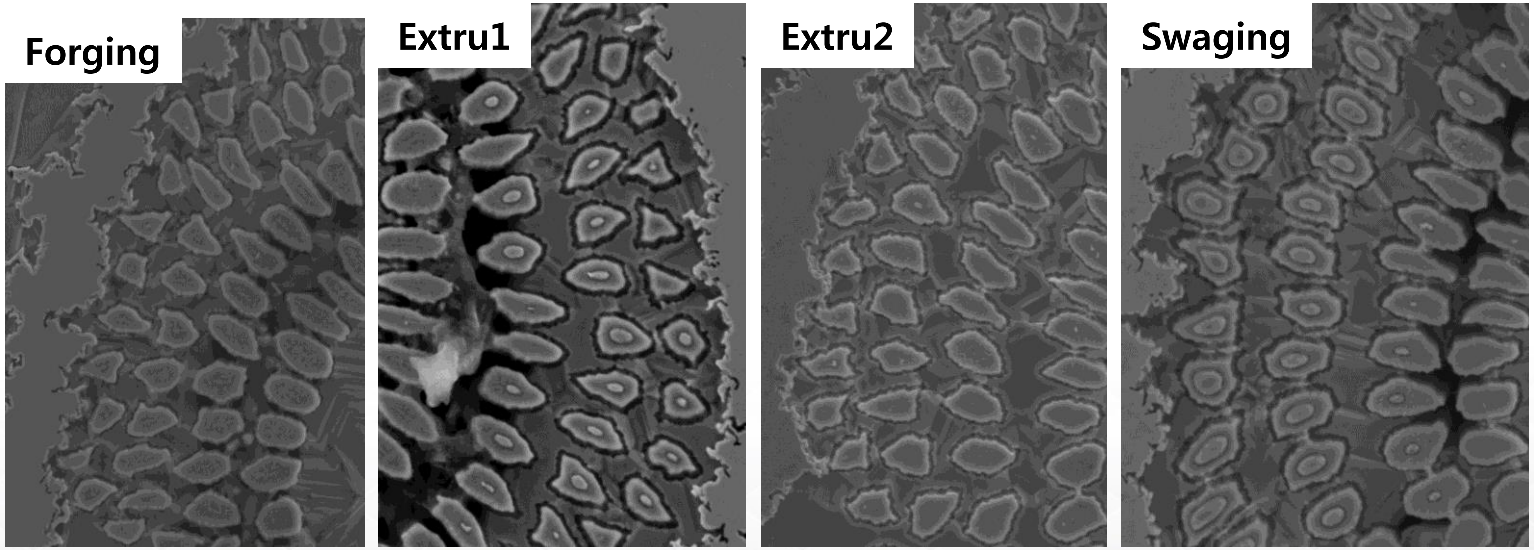
✓ Filament bridging can be an important factor to increase Jc performance.

Strand Design Studies for FCC Conductor

- How to improve the performance of the single filament?
  - ✓ Improve manufacturing process of SnTi alloy



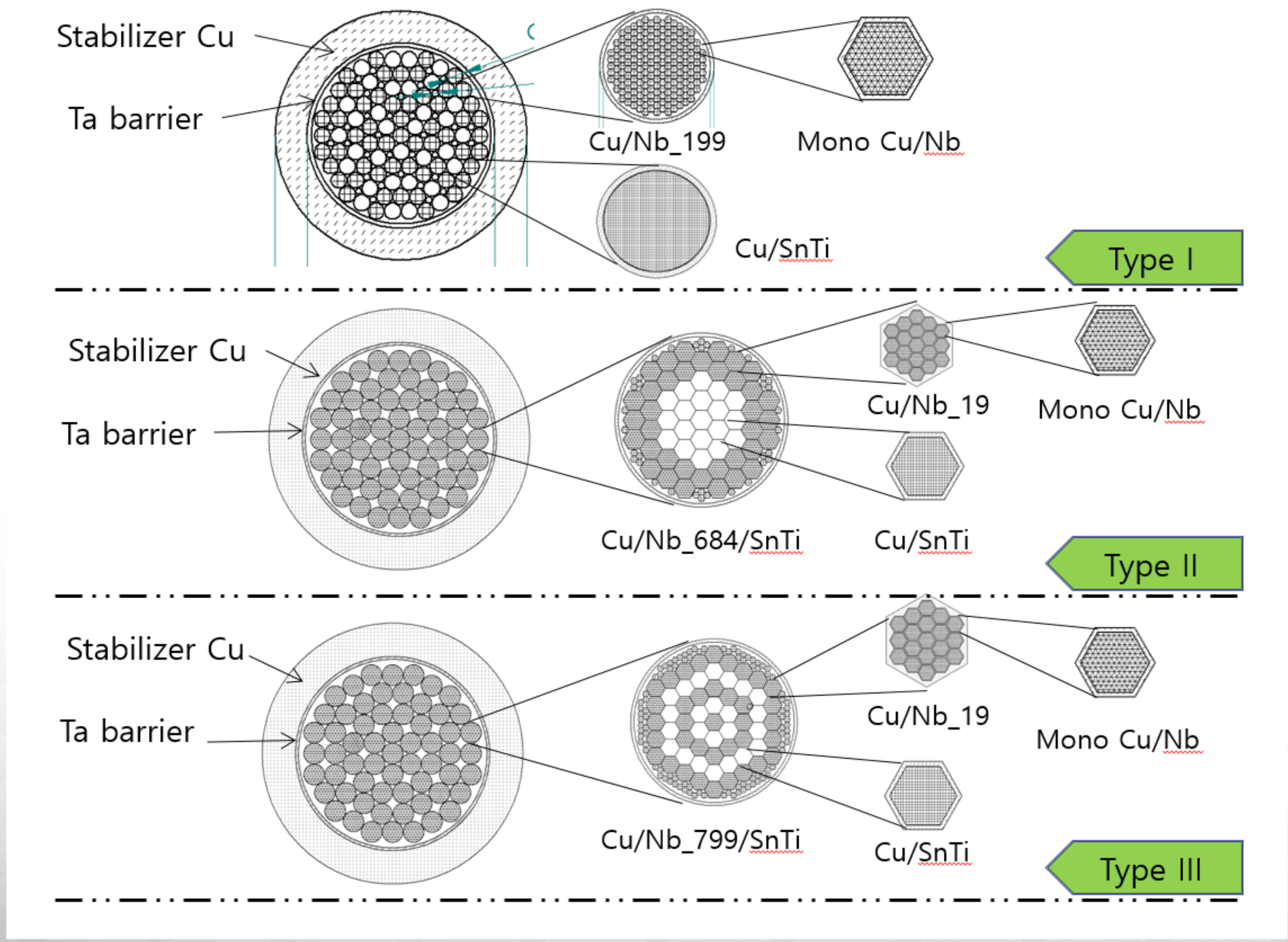
Using same extrusion billet design(176hole).
Heat treatment schedule: ITER HT schedule



- ✓ Different manufacturing process after casting can affect the wire performance.
- ✓ Different SnTi alloy shows the different diffusivity of Nb_3Sn with same heat treatment.

Strand Design Studies for FCC Conductor

❖ Trial designs of Nb_3Sn for FCC



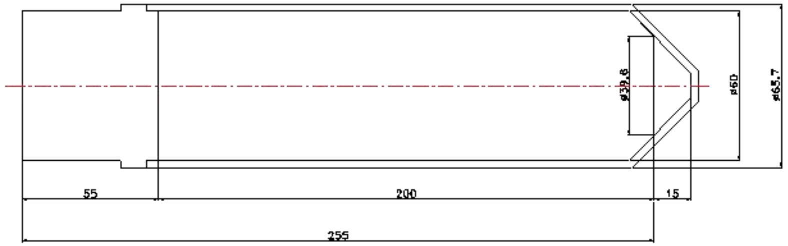
✓ Designed parameters

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

Manufacturing status

❖ Development of hydrostatic extrusion

✓ Hydrostatic Extrusion process is developing by KITECH.



Billet Design

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

Extrusion Die

Metal Seal

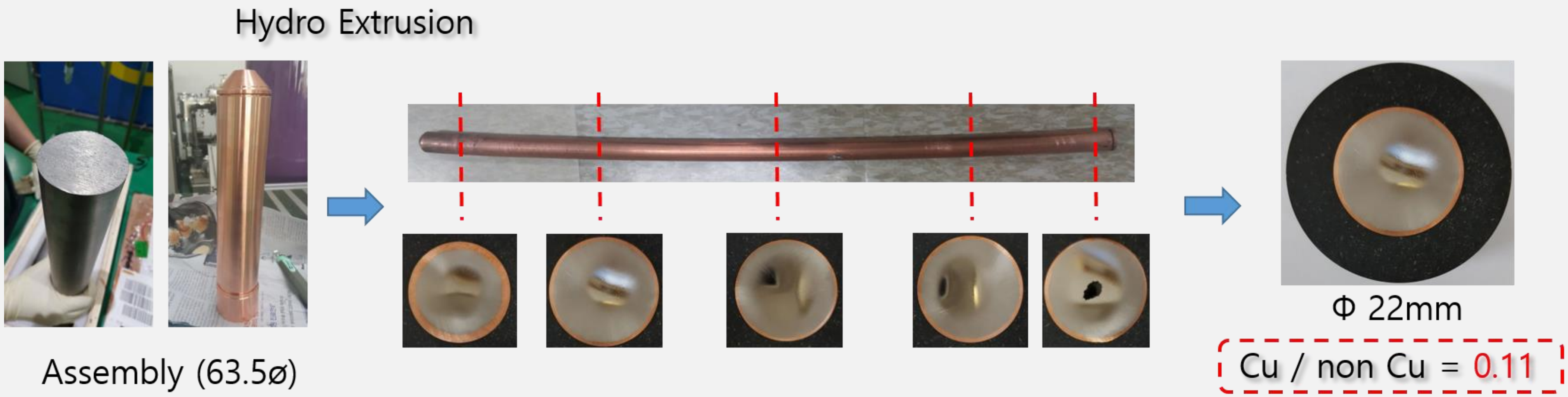
Advantages!

- Thin Cu cladded rod can be manufactured
- Uniform Cu/Non-Cu ratio

Manufacturing status

❖ Development of hydrostatic extrusion

✓ Cu-Nb mono extrusion results



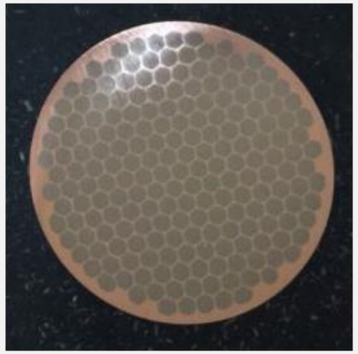
- Cu/NonCu ratio can be reduced to 0.11 by hydrostatic extrusion.
- The yield of extrusion is improved to 90%.

Manufacturing status

❖ Development of hydrostatic extrusion

✓ Results of multi Cu-Nb extrusion

Assembly (Φ45mm)
199 Cu-Nb

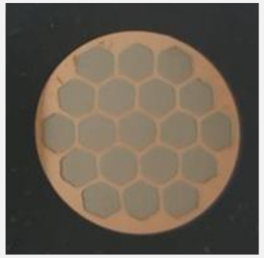


Extrusion (Φ22mm)

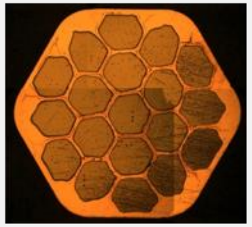
Cu / non Cu = 0.3

Assembly (Φ45mm)
19 Cu-Nb

Cu / non Cu = 0.4



Extrusion (Φ22mm)



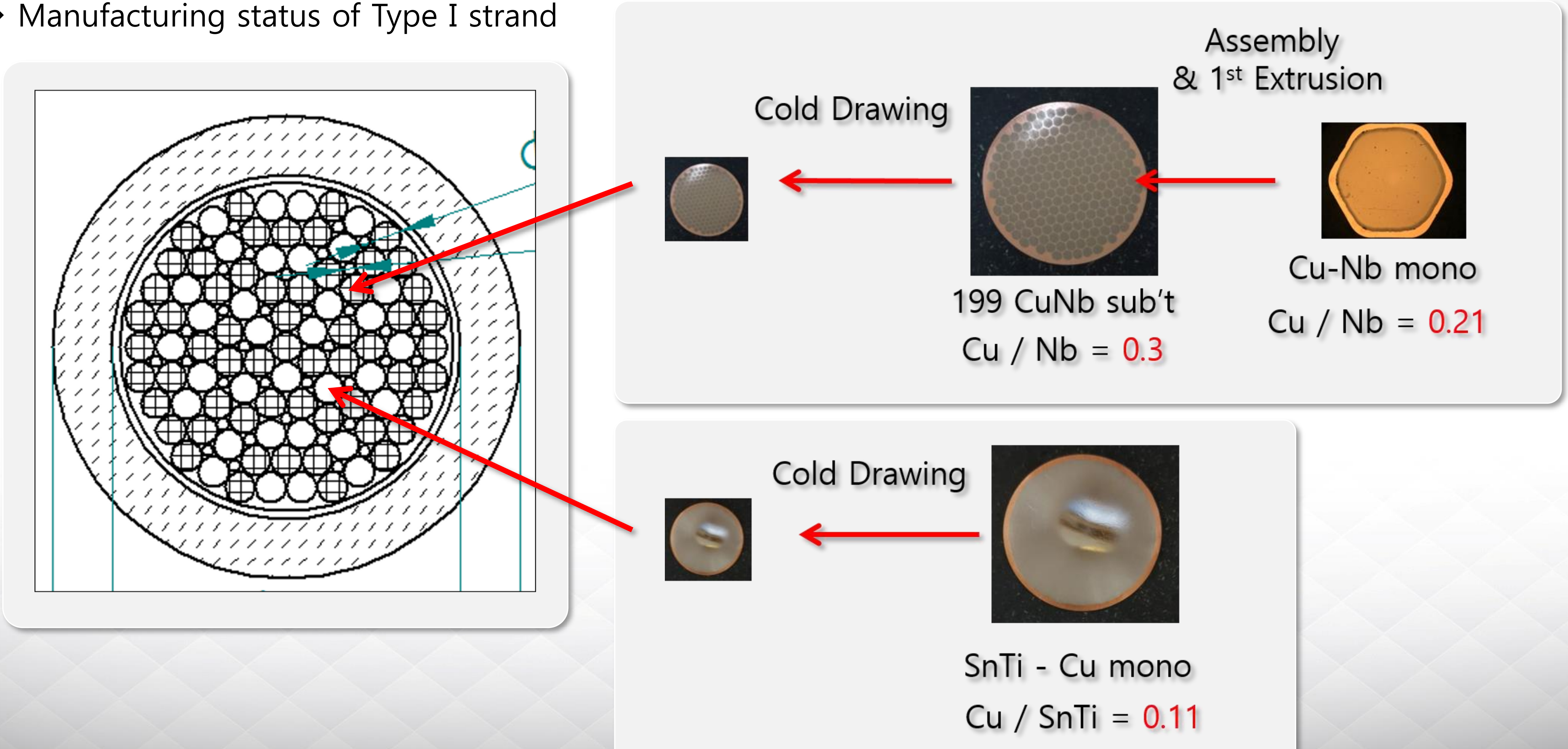
Cold drawing
(W 8mm)

✓ Multi filamentary billet was extruded successfully.

✓ Process optimization issues is still remained to increase extrusion yield.

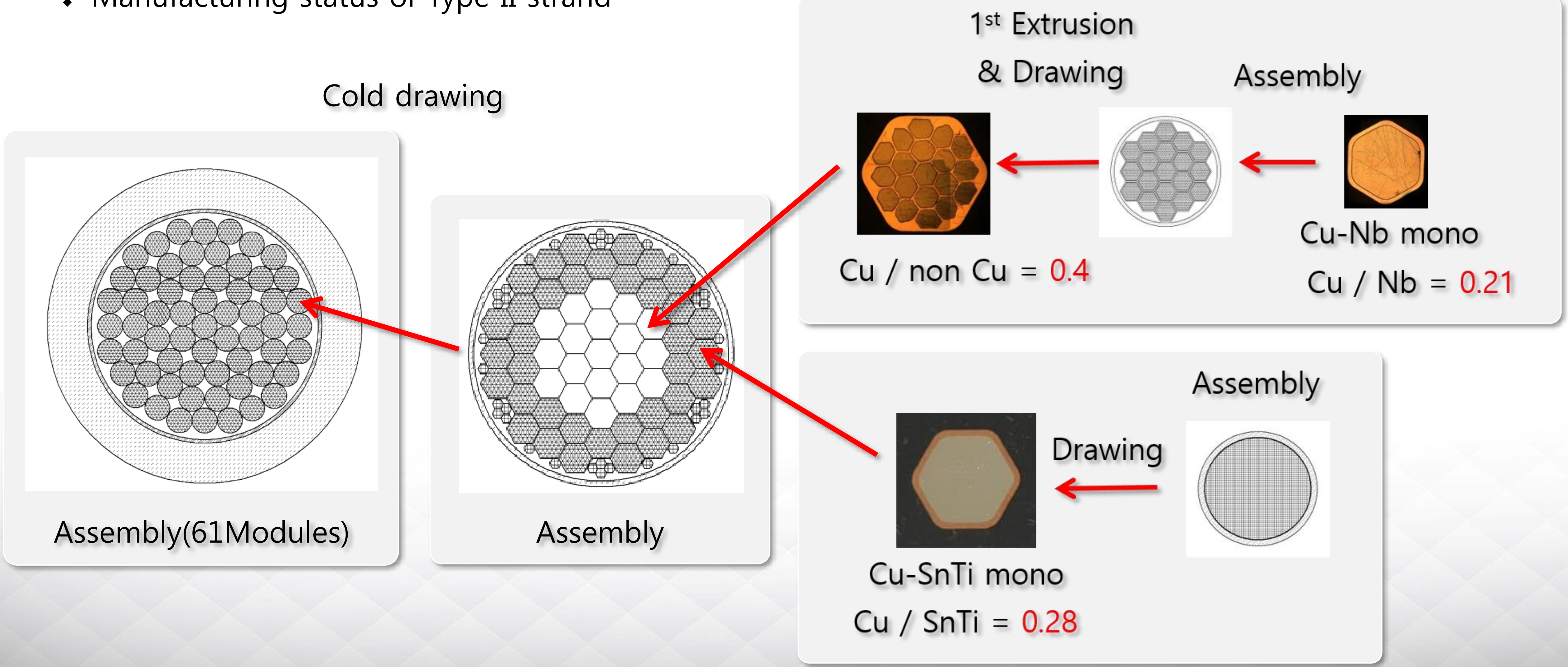
Manufacturing status

❖ Manufacturing status of Type I strand



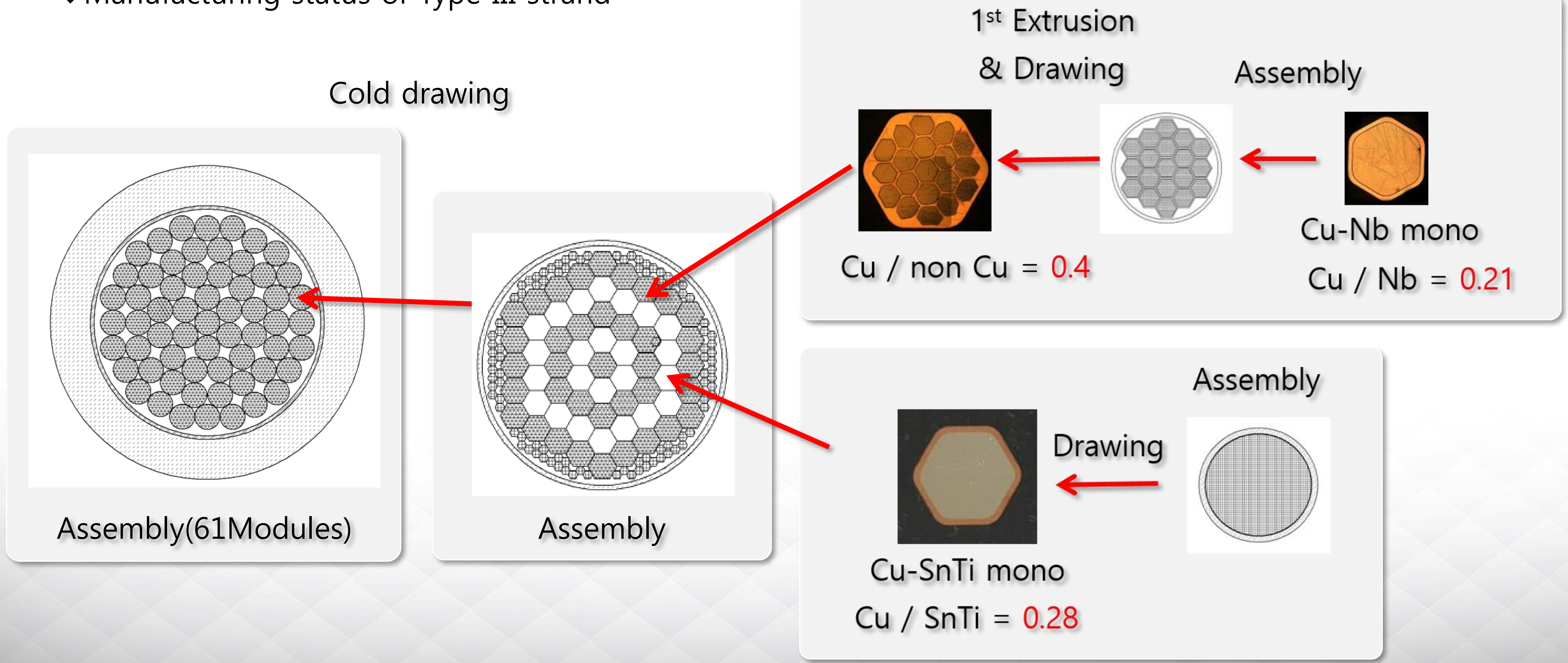
Manufacturing status

❖ Manufacturing status of Type II strand



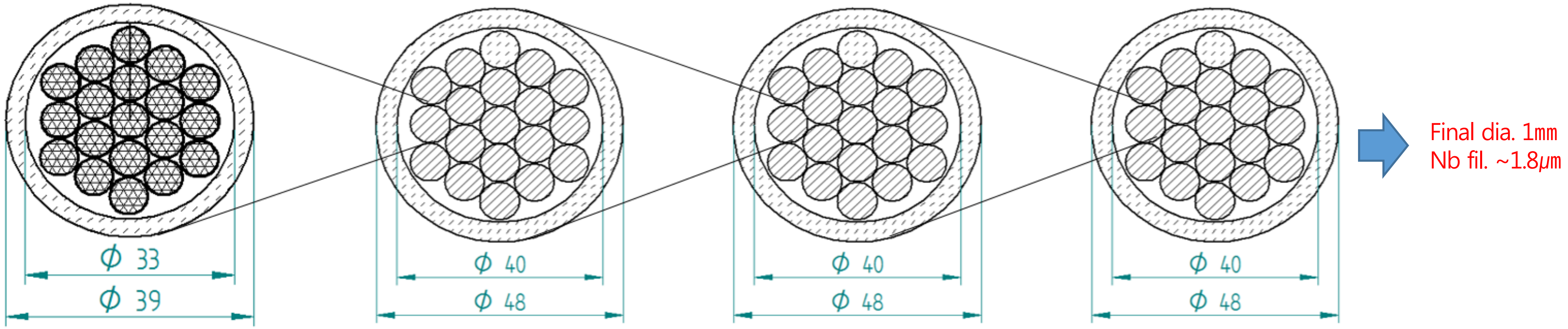
Manufacturing status

❖Manufacturing status of Type III strand

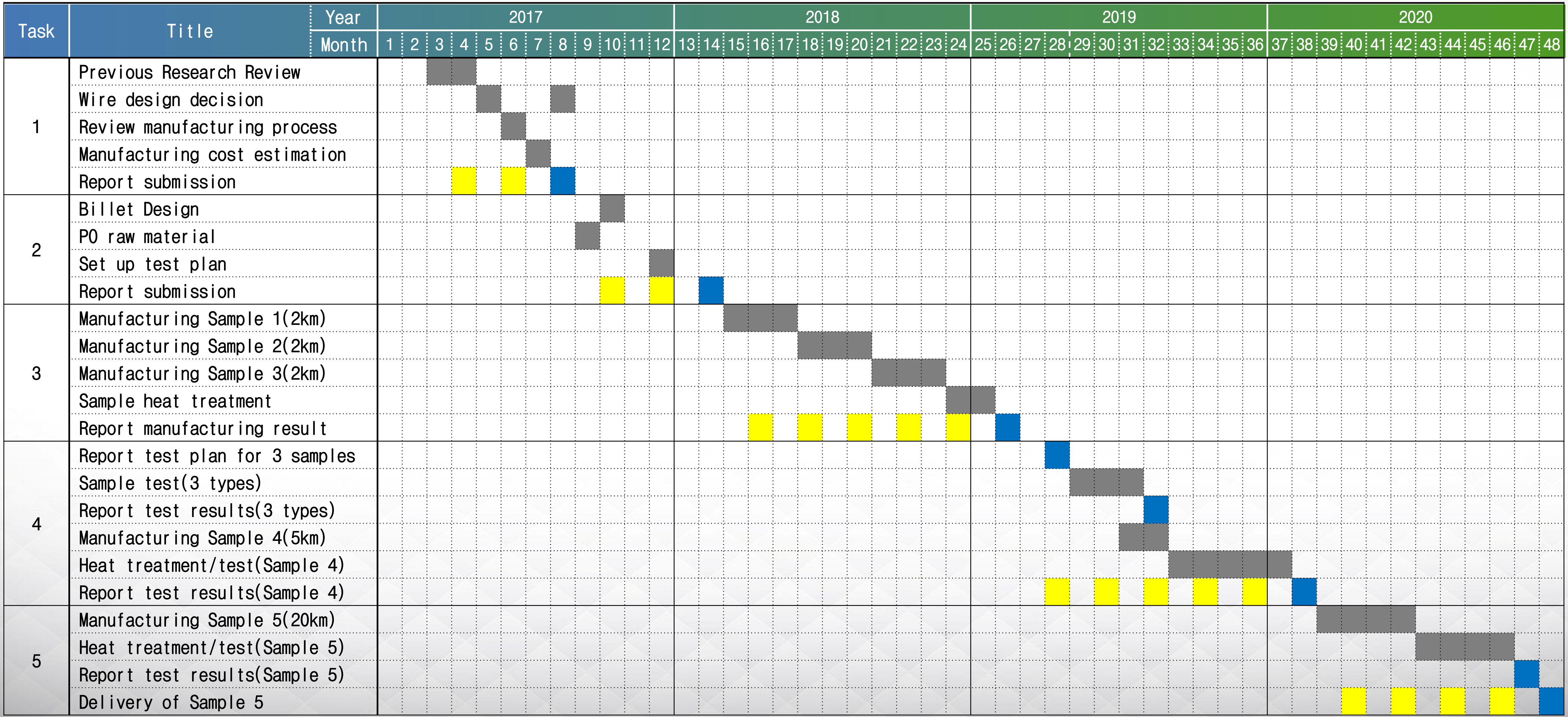


Manufacturing status

❖ Additional process validation for cold drawing

ITEM	Restacking Billet
Cross Section	 1st assy · 2nd assy · 3rd assy · 4th assy (Nb fil.~44μm)
Development Point	1. Cold drawing process (Optimization of dies design and schedule for multifilamentary wires)
Process Variables	1. Raw material : Nb rod suppliers (Firm metal, HC Starck, WC etc.) 2. Dies design and schedule : Reduction rate, Shape of reduction zone, Total drawing force (comparing simulation result) 3. Extrusion method : Direct extrusion, Indirect extrusion, Hydrostatic extrusion
Objectives (Goals)	1. Deformation behavior of Nb rod 2. Optimize cold drawing process to minimize breakage of Nb filaments 3. Control of copper to non-copper ratio

Master Plan(4 years)



Conclusions

- ❖ Nb_3Sn development program started successfully by the collaboration with CERN and local laboratories in Korea.
- ❖ Hydro-static extrusion have been adopted to make the low Cu fraction type's wire.
- ❖ 3 different designs were suggested with different final filament size and numbers.
- ❖ Cu-Nb multi-filamentary sub-element were extruded for Type II and Type III.
- ❖ Short samples for performance validation will be prepared and tested by end of 2017.

Thank you for your attention!