FCC Week 2015
Washington DC

Industry Response to FCC Specifications (SH Copper Products co., Ltd.)

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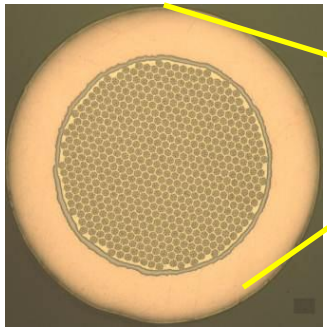
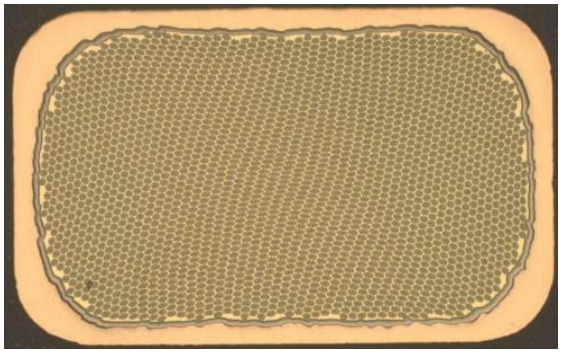
Bronze route Nb_3Sn wire

Since 1970's , SH copper manufactured Bz route Nb_3Sn wires and cables for nuclear fusion, high field magnet, NMR et. al. More than 70 ton Nb_3Sn wires were manufactured for ITER project from 2009 to 2013.

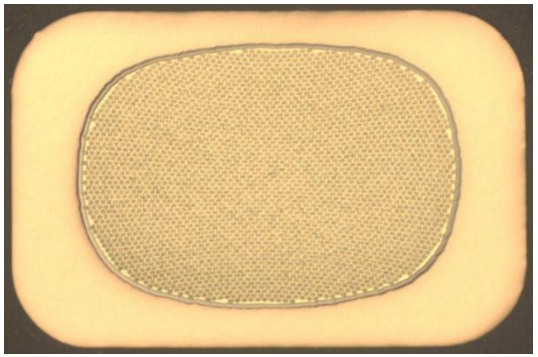


ITER Nb_3Sn wire
ϕ0.82mm Cu ratio ;1

ITER conductor



Cu ratio ;0.3



Cu ratio ;0.9

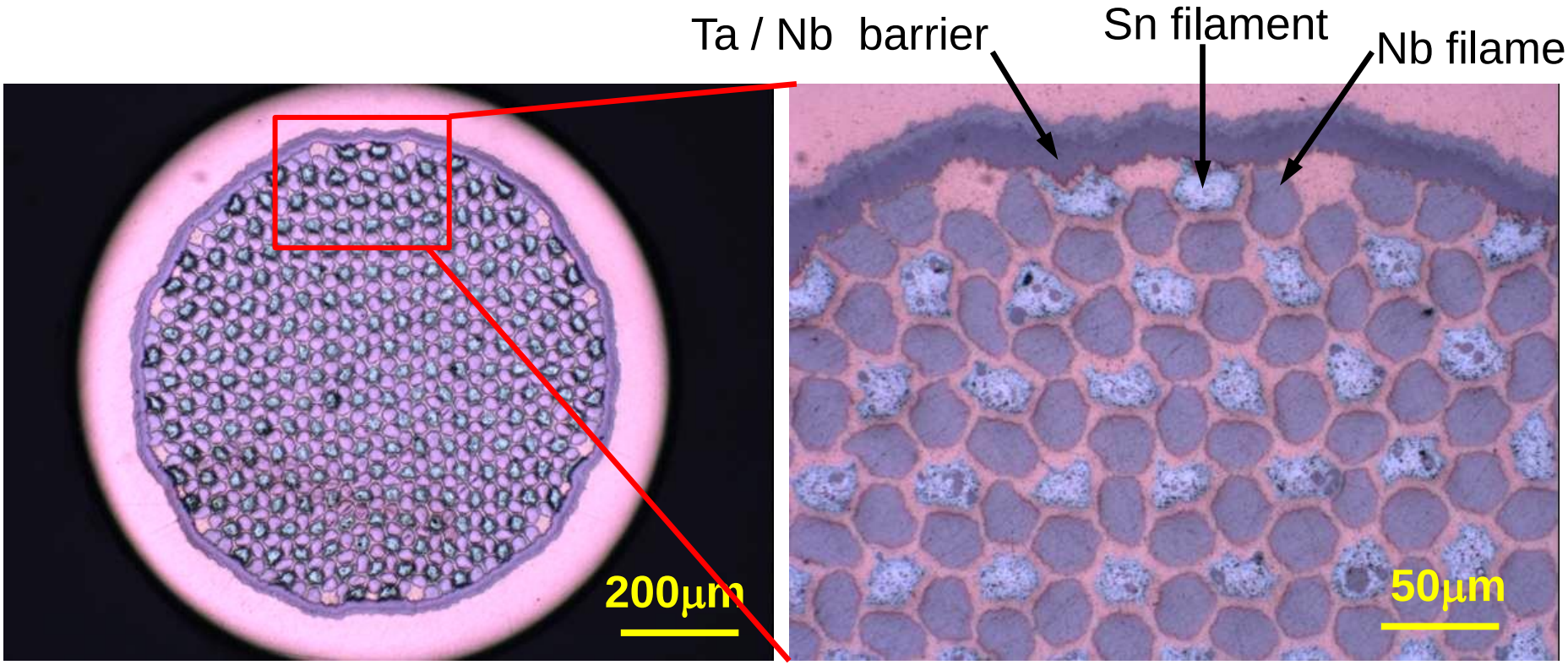
For High field magnet

High Jc ⇒ High tin (Sn) bronze

However, because of solution limit (15.8%Sn) of tin in copper, it is very difficult to draw bronze route Nb_3Sn wire with more than Cu-16wt%Sn bronze.

Internal Tin Nb_3Sn wire in SH Copper

For high field magnet application, since 2009, we started to develop new type internal tin wire

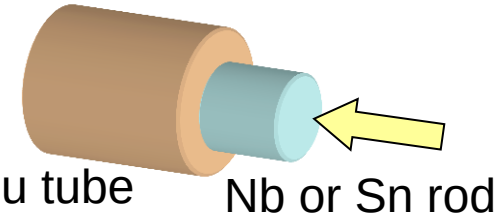


Sn Filament size is almost equal to Nb filament size.
Simple structure ⇒Low Cost
Corresponding to more than Cu-35wt%Sn bronze

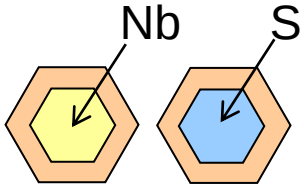
Process of Internal Tin Nb_3Sn wire

Sn rod / Cu tube

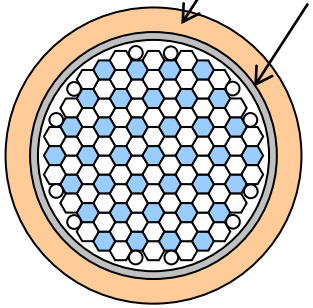
Nb rod / Cu tube



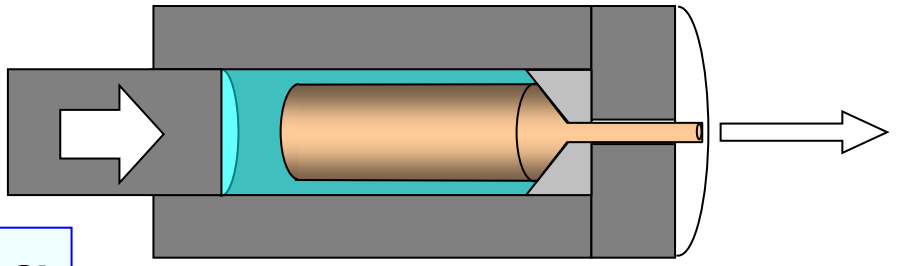
Drawing & Annealing



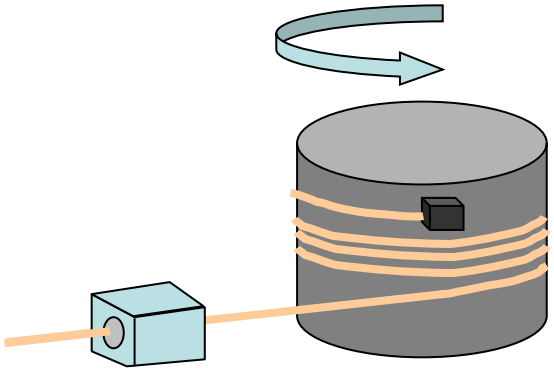
Hexagonal wires Assembling



Hydrostatic Extrusion

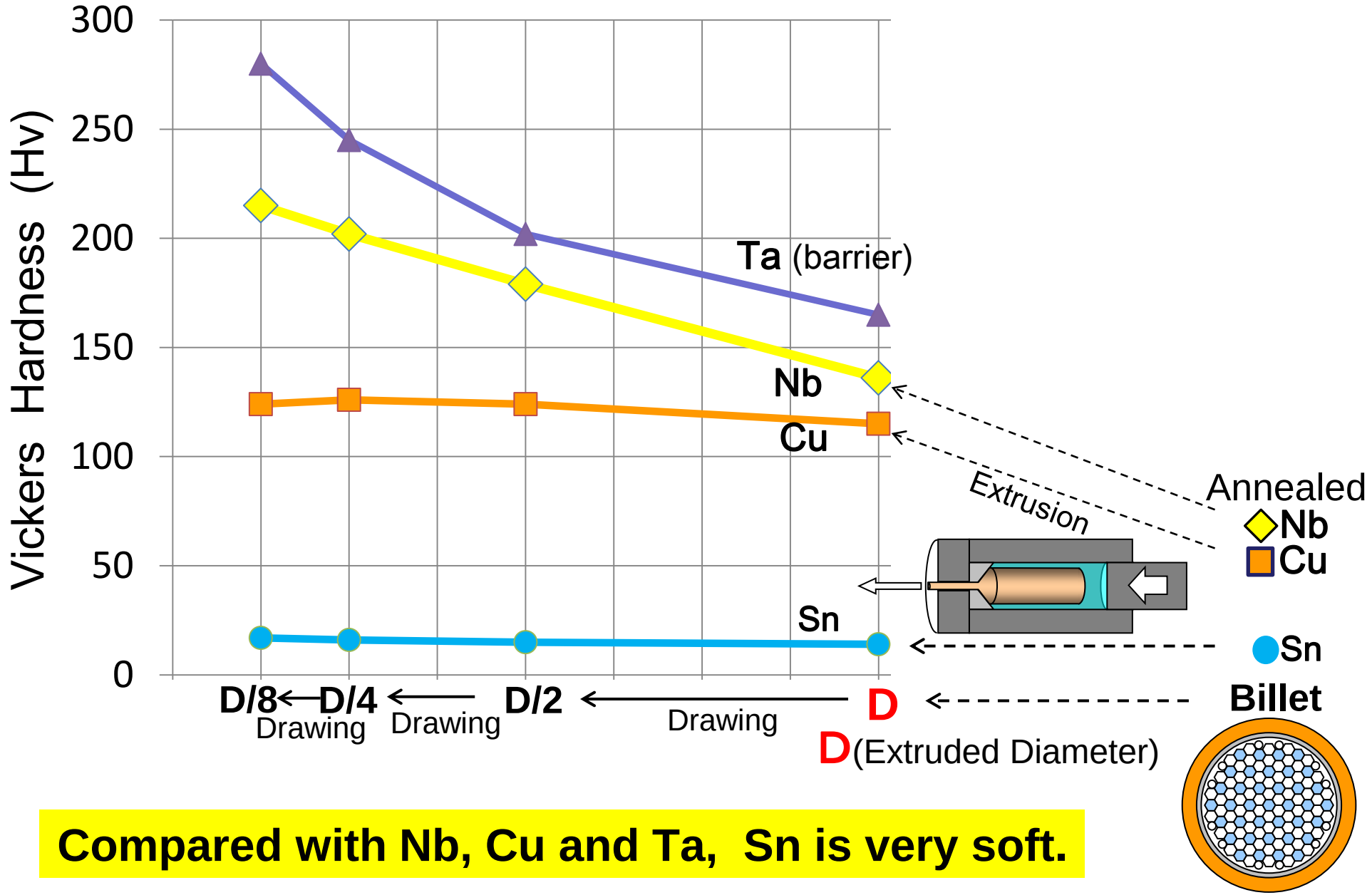


Drawing



Heat-Treatment

Hv of each materials in process



Compared with Nb, Cu and Ta, Sn is very soft.

Optimization of Spacing (1) Flux Jump

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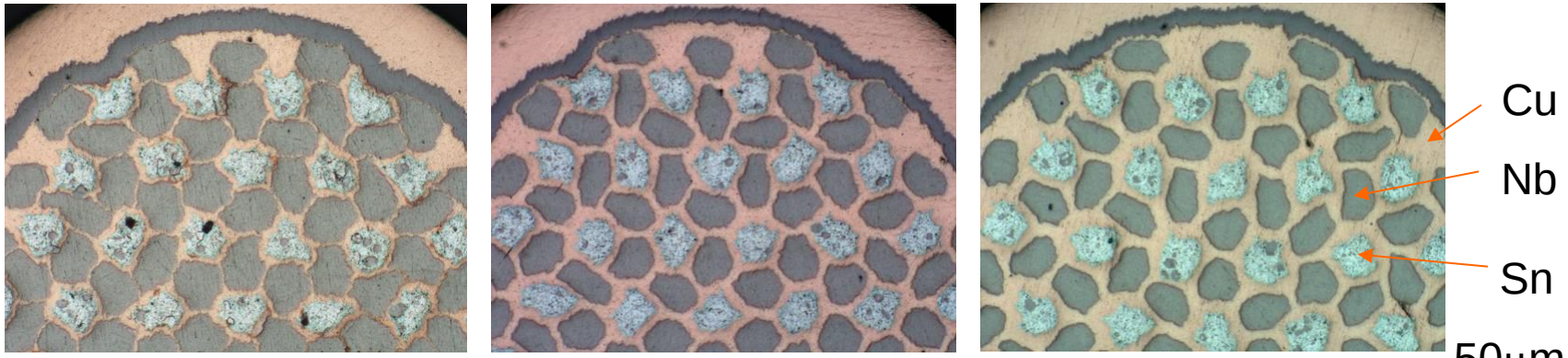
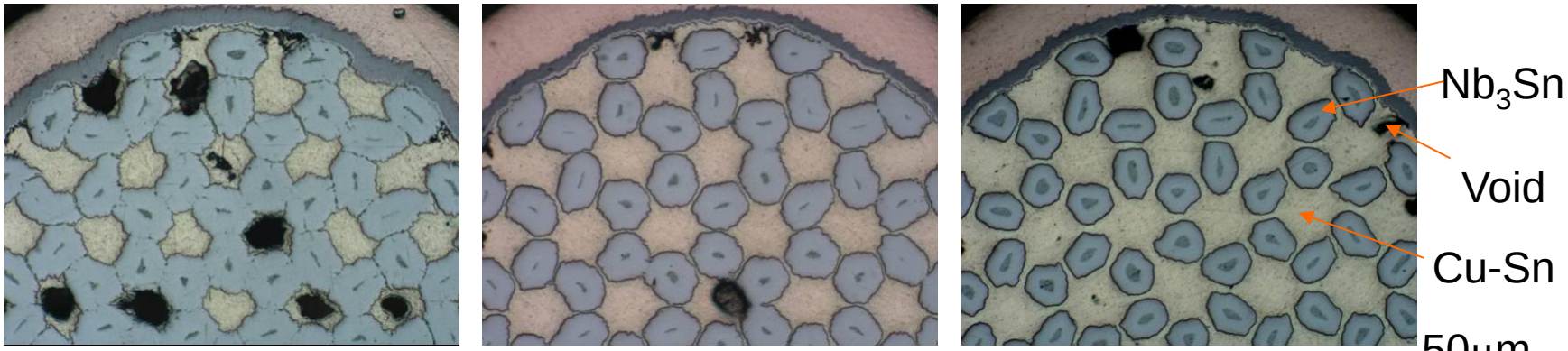
Nb filament spacing Narrow ⟺ Wide



Sample (A) Sample (B) Sample (C)

Fig. Cross-sectional views of the wires before heat-treatment (0.5mm in diameter).

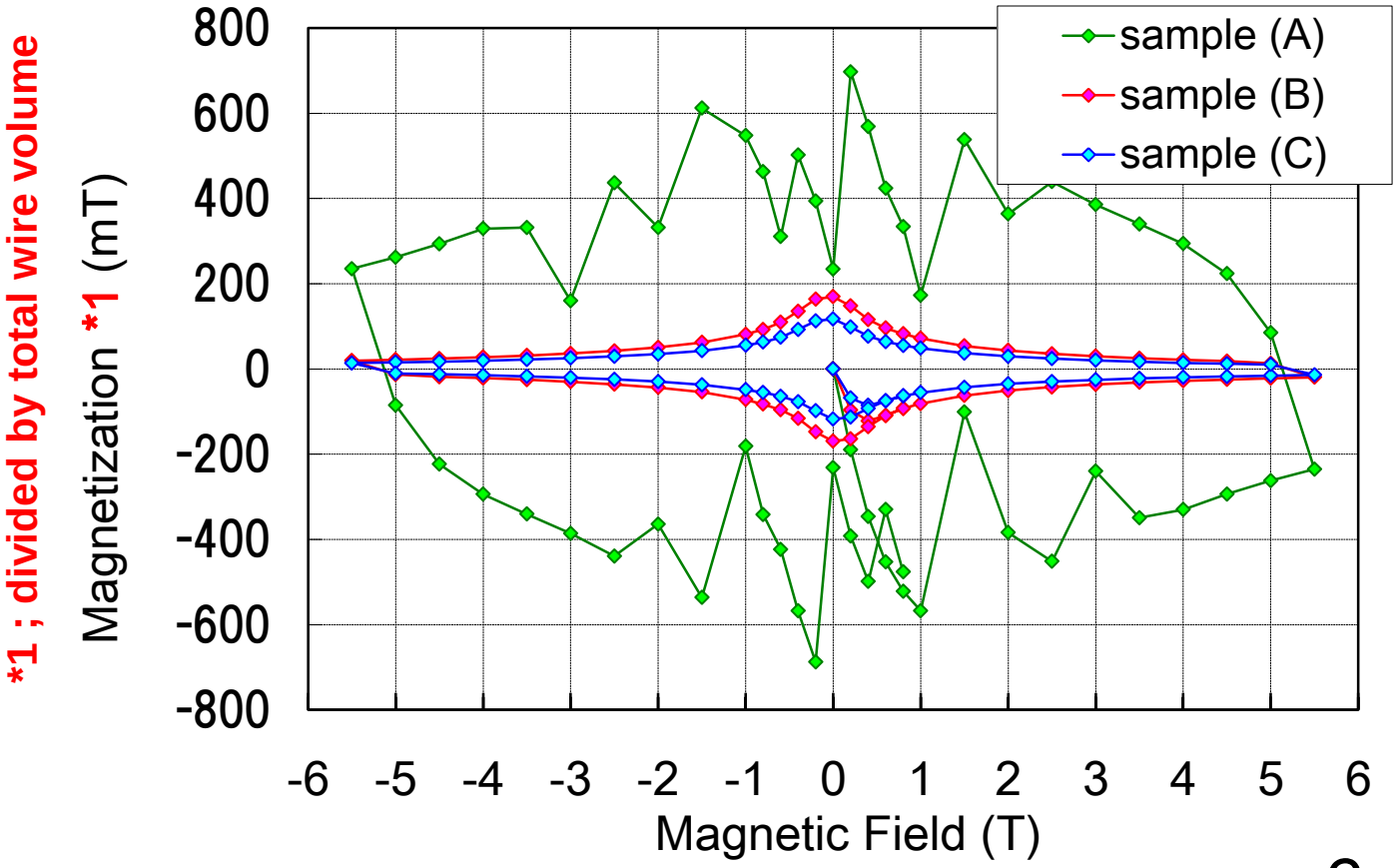
Nb_3Sn filament Connect ⟺ Separate



Sample (A) Sample (B) Sample (C)

Fig. Cross-sectional views of the wires after heat-treatment (0.5mm in diameter).

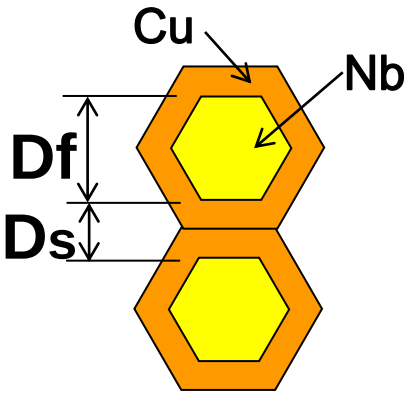
Optimization of Spacing (2)



Df / Ds was optimized.

Df ; Filament diameter

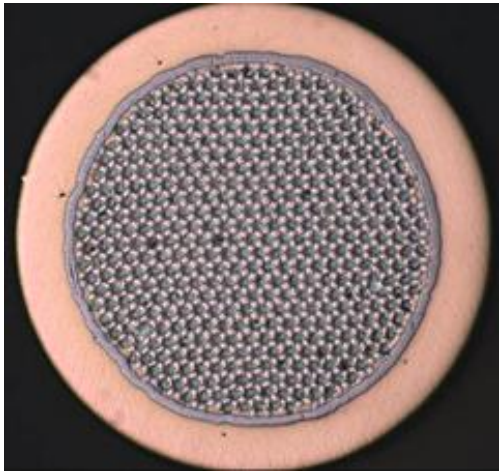
Ds ; Filament spacing



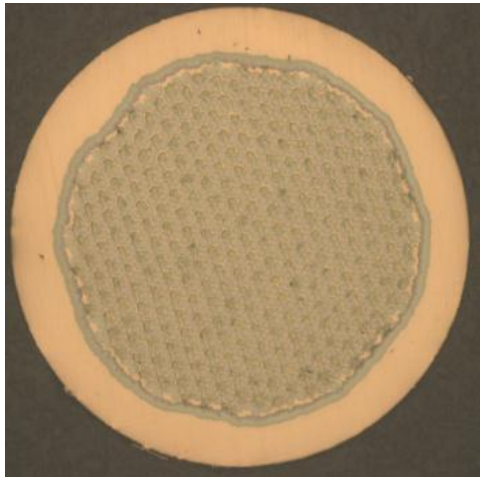
Manufacturing (L=14km class wire @ 1mm dia.)

Four manufacturing size billets are successfully extruded and drawn.

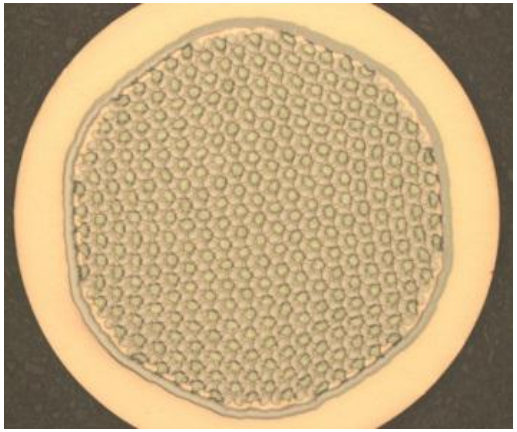
Billet ID No.	**HE5000**(2010)	**HE5143**(2011)	**HE5542**(2012)	**HE6585**(2014)
Number of Nb filament	840	564	564	277
Number of Sn filament	421	283	295	120
Total number	1261	847	859	397
Filament dia. @φ1mm	15 μm	20 μm	20 μm	30 μm
Cu ratio	0.51	0.51	0.51	0.51
Mole ratio (**Nb**/Sn)	**2.53**	**2.72**	**2.40**	**2.89**



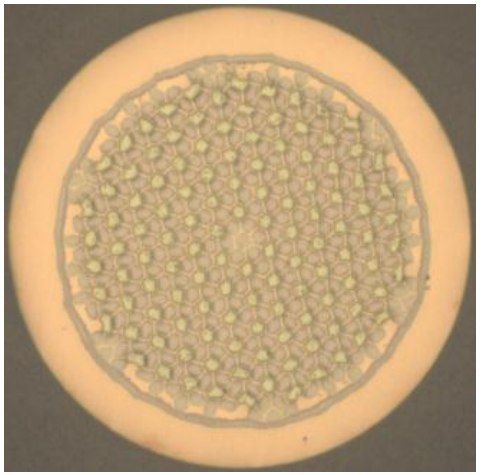
HE5000



HE5143

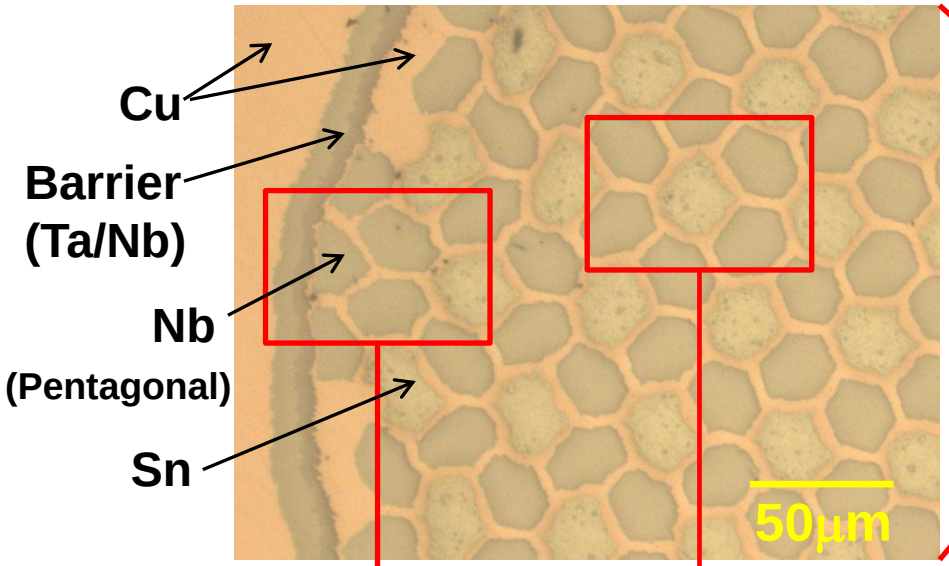


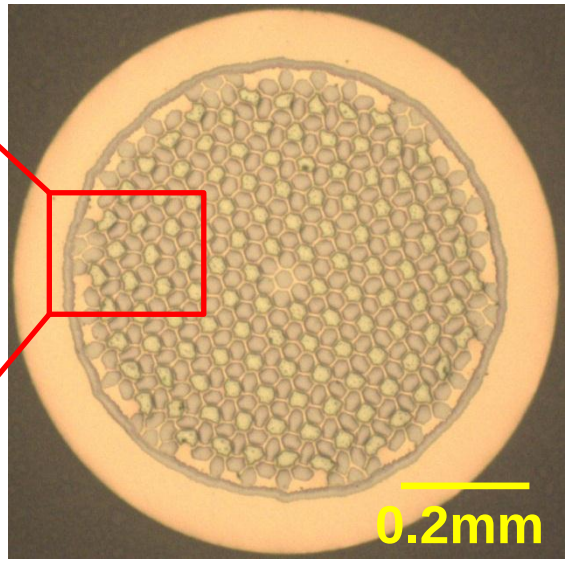
HE5542



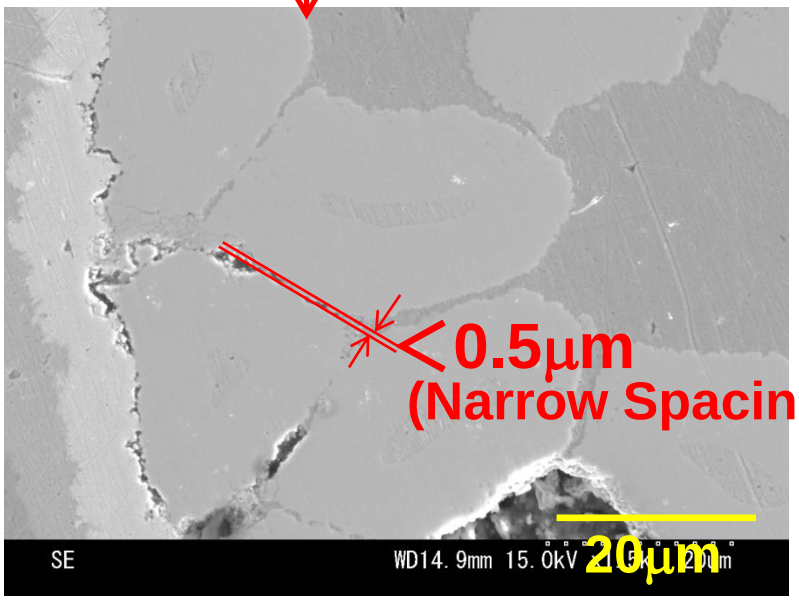
HE6585

Cross section of before & after HT (No.HE6585)

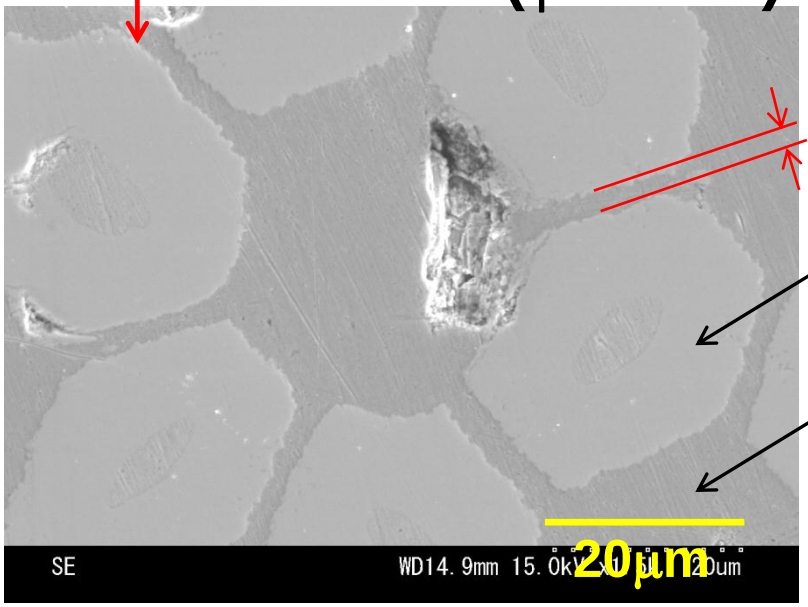




Before HT (ϕ0.8mm)



After HT (1)

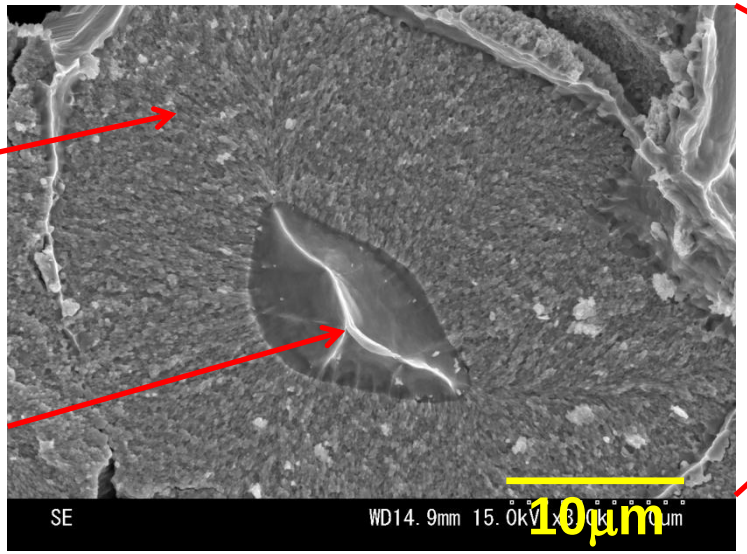


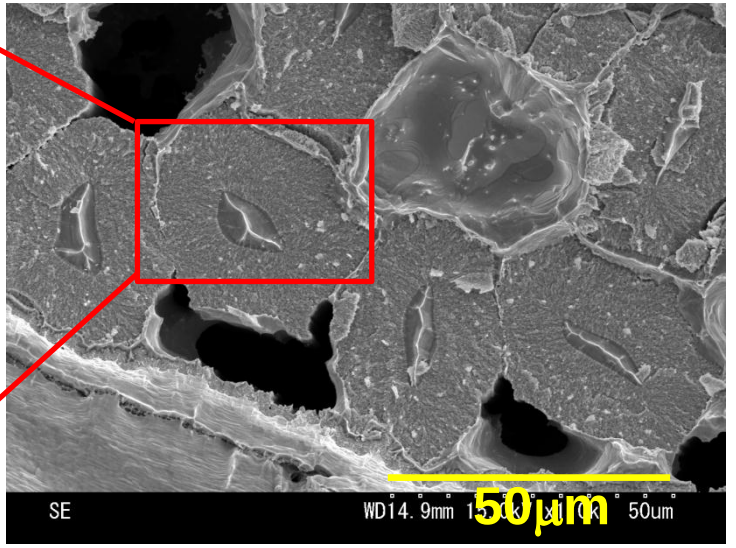
After HT (2)

SEM photograph of after HT (No.HE6585)

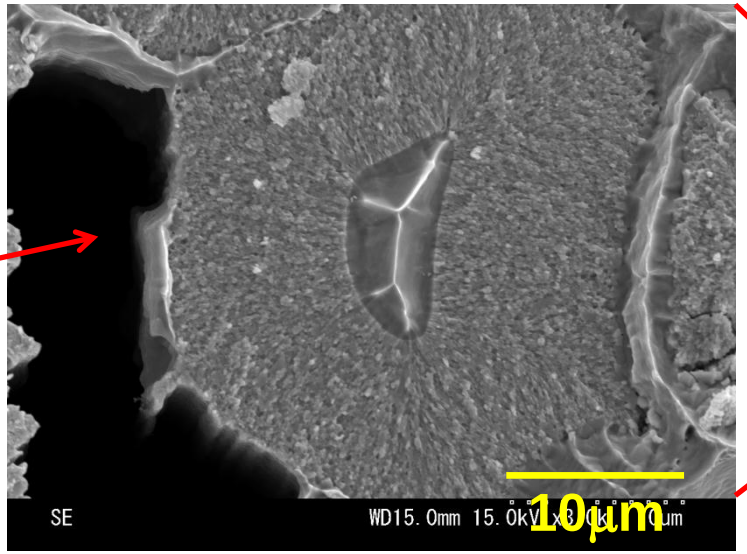
Nb3Sn layer

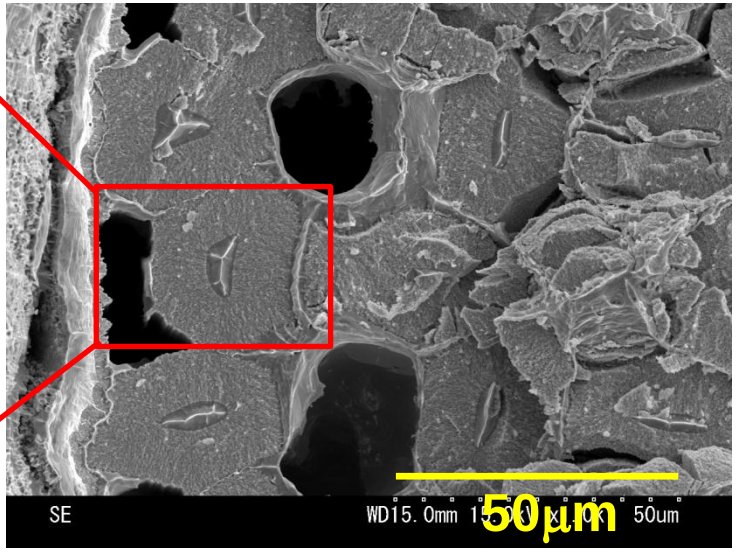
Non react Nb core





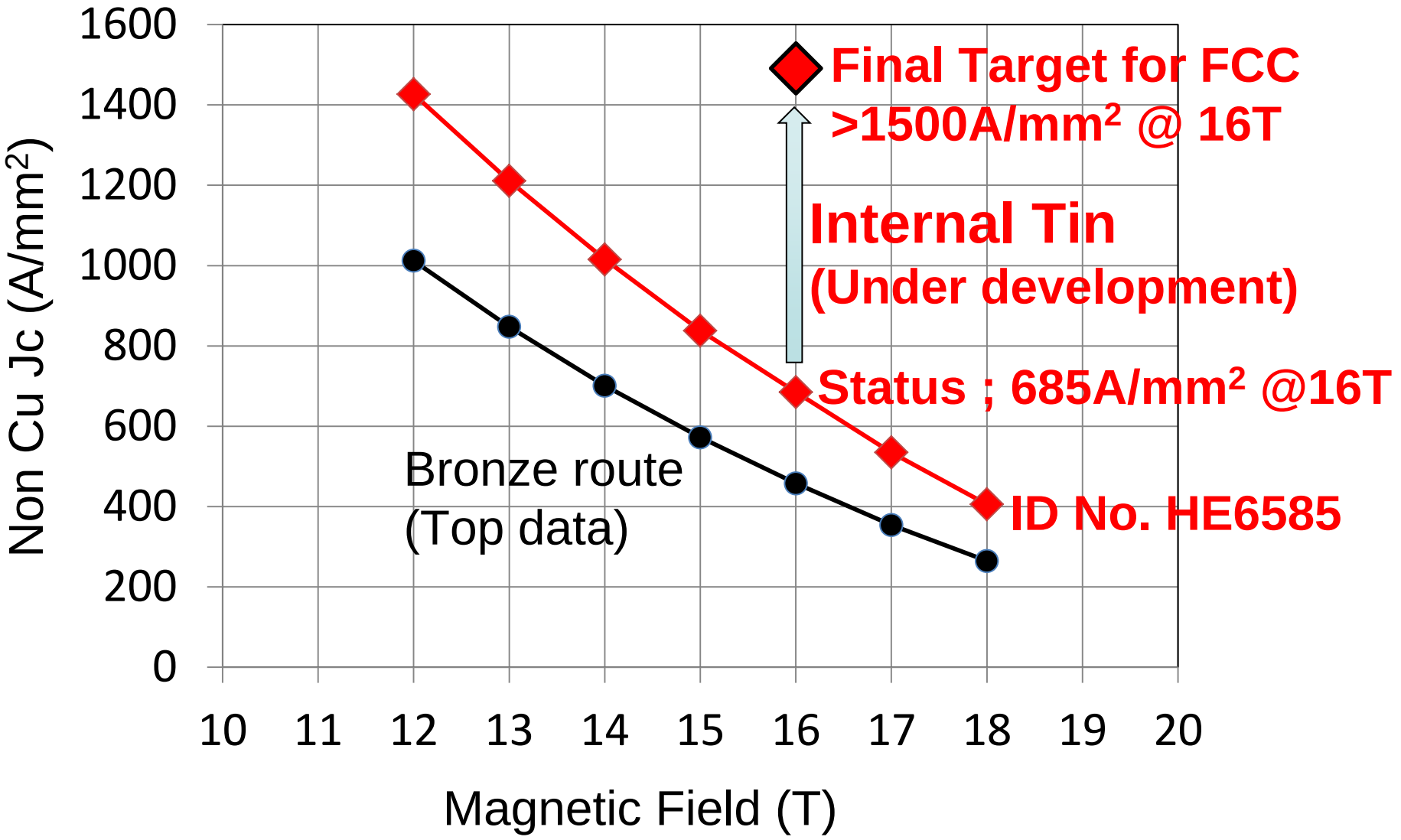
Void



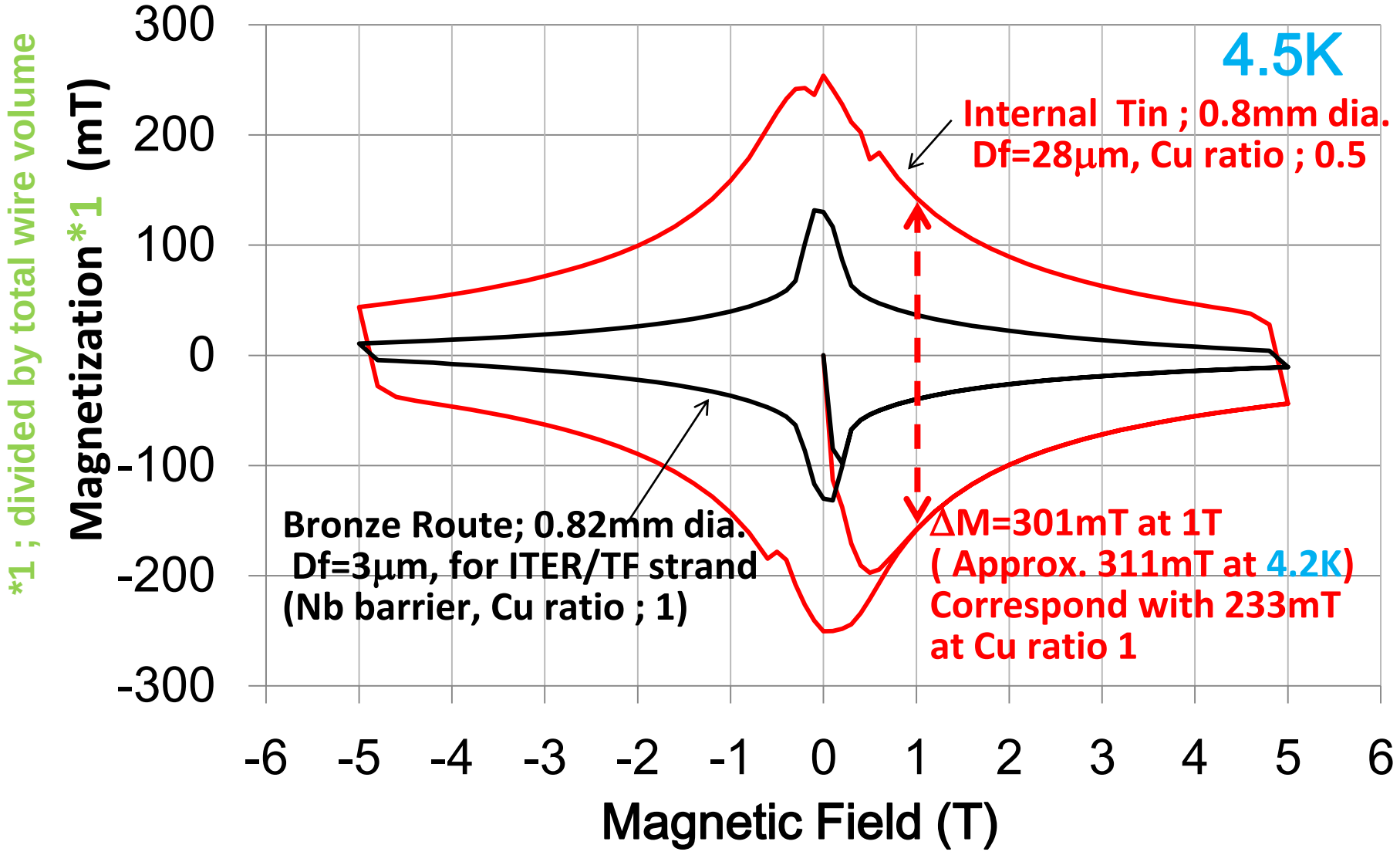


Filament diameter ; 24μm(Before HT) ⇒28～30 μm（After HT)

Non-Cu Jc properties of manufacturing wire



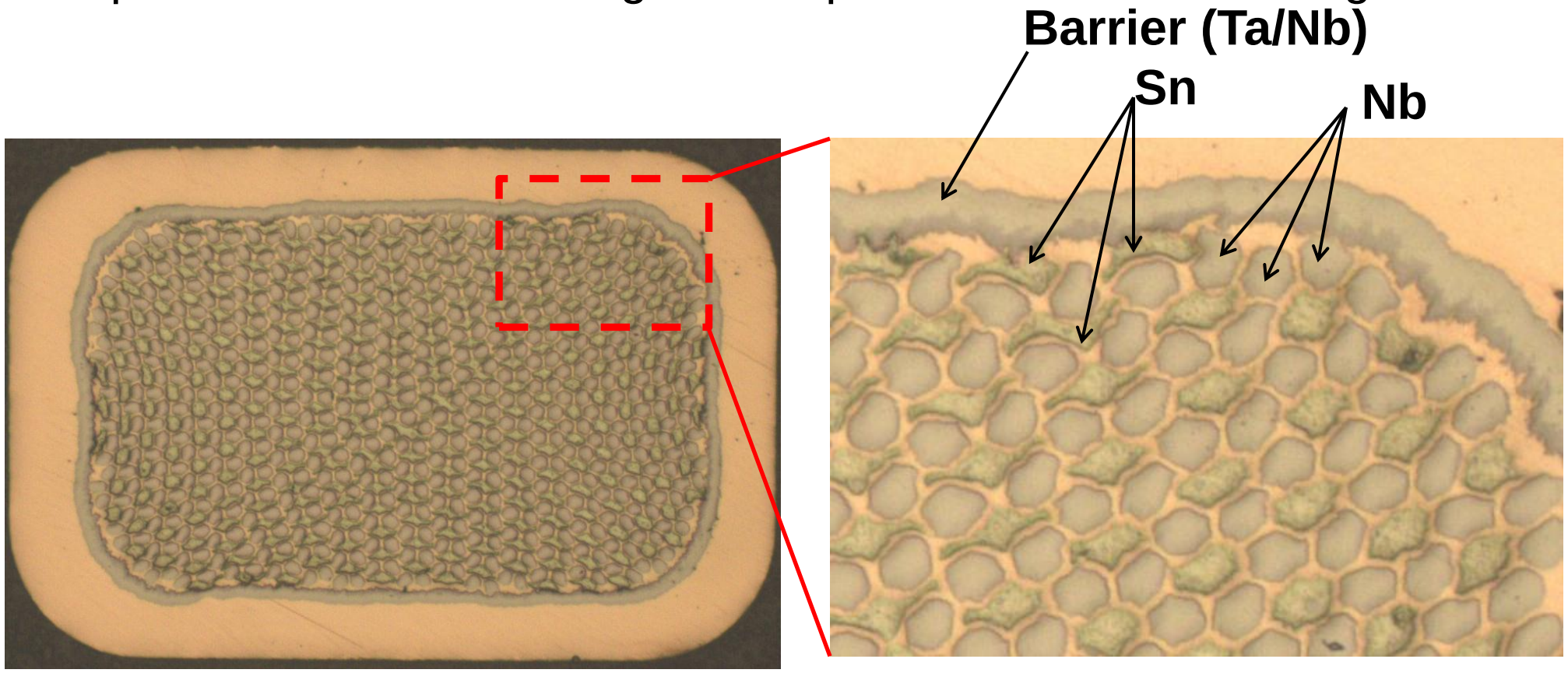
Magnetization



Rectangular Wire

Good barrier shape (no deformation)
High RRR ; ≧250

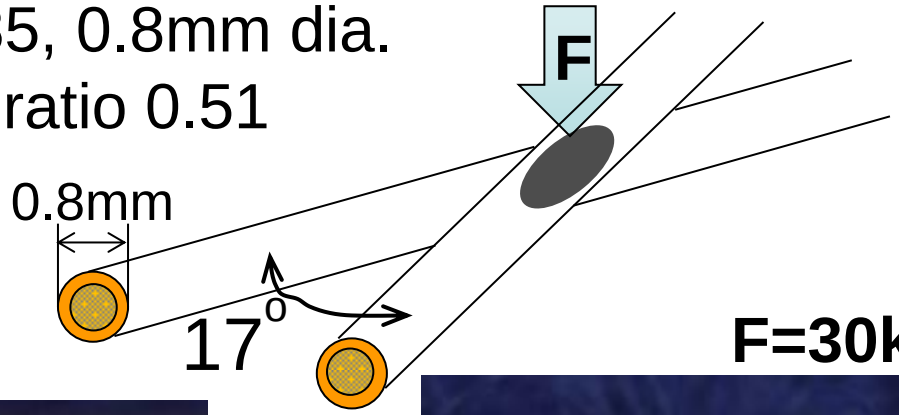
It is possible to work rectangular shape without Ic & RRR degradation.



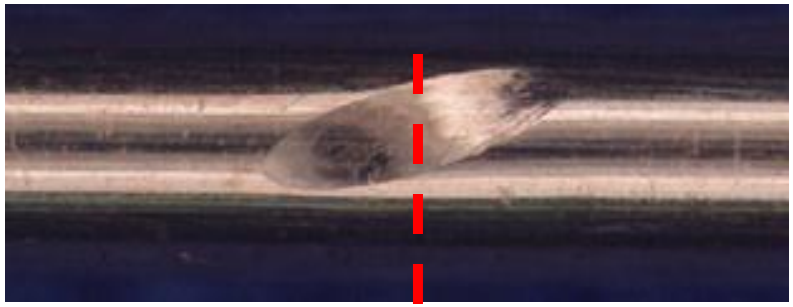
ID No. HE5143, 1.14X1.72mm Ic=504A at 18T (Non-Cu Jc =403A/mm^2), RRR=254

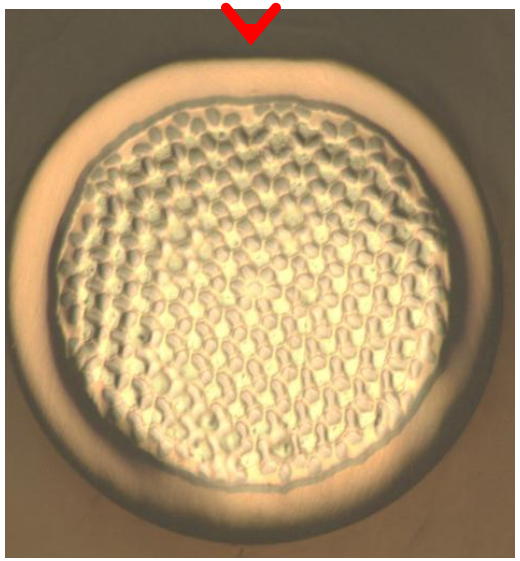
Deformation in Cabling Process

Sample ; ID No. HE6585, 0.8mm dia.
Df=24μm, Cu ratio 0.51

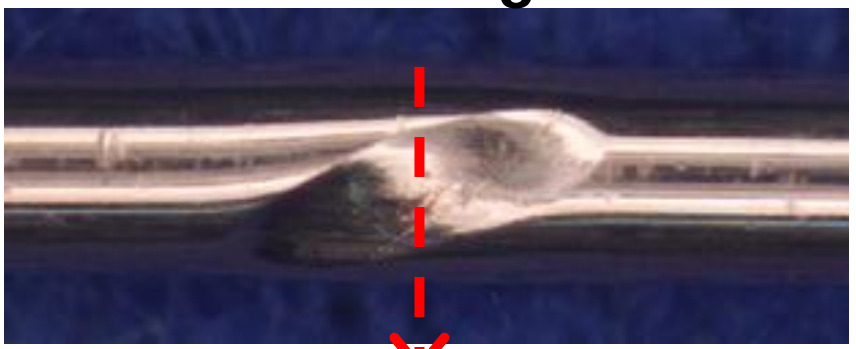


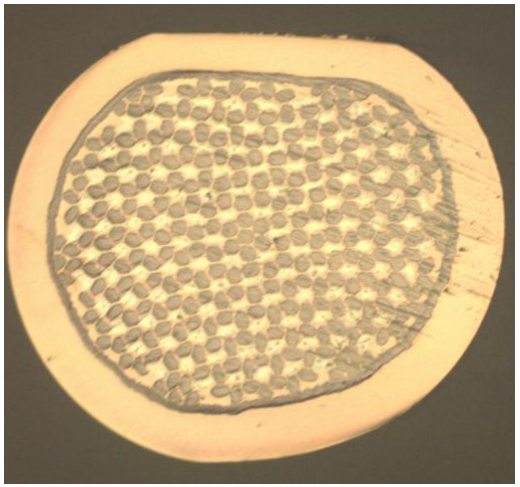
F=15kg





F=30kg





Deformation in Cabling Process (RRR & Ic)

Sample ; ID No. HE6585, 0.8mm dia. Df=28～30μm (after HT) , Cu ratio 0.51

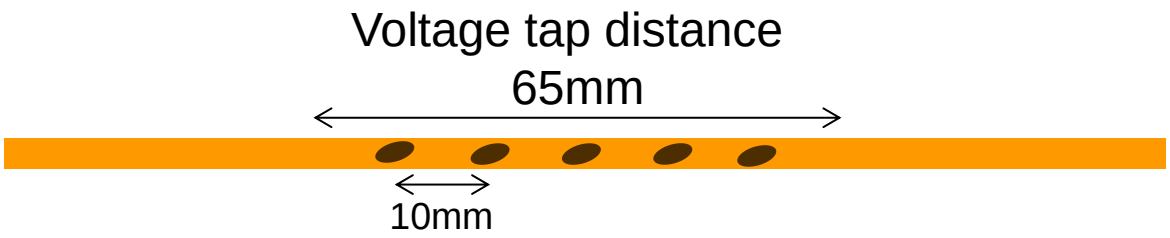
Heat treatment condition ; 210℃x15h + 415℃x15h + (415～700℃)/50h + 700℃x140h

(1) RRR

No Press : RRR=285

Press 15kg ; RRR=287

Press 30kg ; RRR=289



There are five press points between voltage tap.)

(2) Critical Current ; Ic at 16T

No Press ; Ic =210A

Press 30kg ; Ic =211A

(There are fifteen press points between voltage tap (500mm).)

Conclusion

Item	FCC final target	Status
Non Cu Jc at 16T (A/mm^2)	>1500	685
$\mu_0\Delta M$ @ 1T, 4.2K (mT)	<150	233***1**
$\sigma(\mu_0\Delta M)$ @ 1T, 4.2K (%)	<4.5	-----
Deff	<20	28～30 ? ***2**
RRR***3**	>150	>250
Unit Length (km)	>5	>20 (ϕ0.8mm)

***1 : It is divided by total wire volume (in the case of Cu ratio ; 1).**

***2 : Geometrical diameter after HT (approx. 24μm before HT)**

***3 : After wire deformation, RRR is NOT degraded.**

Next stage

(1) High Jc

- **(a) Optimization of ratio of Nb, Sn & Cu inside barrier**
- **(b) Geometrical filament diameter ; < 20μm**
  (Design of cross section of wire)
- **(c) Optimization of heat treatment**

(2) Low magnetization

- **(a) Prevent of completely proximity effect between each Nb_3Sn filament.**

(3) Stability

- **(a) Cu ratio change to 0.8 – 1.0 from 0.5.**
- **(b) Prevent of completely proximity effect**

(4) Cost

- **(a) Scale up of billet size**